



Department of
Agriculture and Food



Research Library

Resource Management Technical Reports

10-2007

Soil survey of the Bettink dairy farm, Riverway Road, Northcliffe

Peter J. Tille
peter.tille@agric.wa.gov.au

Tilwin Westrup
tilwin.westrup@agric.wa.gov.au

Follow this and additional works at: <http://researchlibrary.agric.wa.gov.au/rmtr>



Part of the [Agriculture Commons](#), [Environmental Indicators and Impact Assessment Commons](#), [Environmental Monitoring Commons](#), [Fresh Water Studies Commons](#), [Hydrology Commons](#), [Natural Resources Management and Policy Commons](#), [Soil Science Commons](#), and the [Water Resource Management Commons](#)

Recommended Citation

Tille, P J, and Westrup, T. (2007), *Soil survey of the Bettink dairy farm, Riverway Road, Northcliffe*. Department of Agriculture and Food, Western Australia. Report 324.

This report is brought to you for free and open access by Research Library. It has been accepted for inclusion in Resource Management Technical Reports by an authorized administrator of Research Library. For more information, please contact jennifer.heathcote@agric.wa.gov.au, sandra.papenfus@agric.wa.gov.au.

IMPORTANT DISCLAIMER

This document has been obtained from DAFWA's research library website (researchlibrary.agric.wa.gov.au) which hosts DAFWA's archival research publications. Although reasonable care was taken to make the information in the document accurate at the time it was first published, DAFWA does not make any representations or warranties about its accuracy, reliability, currency, completeness or suitability for any particular purpose. It may be out of date, inaccurate or misleading or conflict with current laws, policies or practices. DAFWA has not reviewed or revised the information before making the document available from its research library website. Before using the information, you should carefully evaluate its accuracy, currency, completeness and relevance for your purposes. We recommend you also search for more recent information on DAFWA's research library website, DAFWA's main website (<https://www.agric.wa.gov.au>) and other appropriate websites and sources.

Information in, or referred to in, documents on DAFWA's research library website is not tailored to the circumstances of individual farms, people or businesses, and does not constitute legal, business, scientific, agricultural or farm management advice. We recommend before making any significant decisions, you obtain advice from appropriate professionals who have taken into account your individual circumstances and objectives.

The Chief Executive Officer of the Department of Agriculture and Food and the State of Western Australia and their employees and agents (collectively and individually referred to below as DAFWA) accept no liability whatsoever, by reason of negligence or otherwise, arising from any use or release of information in, or referred to in, this document, or any error, inaccuracy or omission in the information.



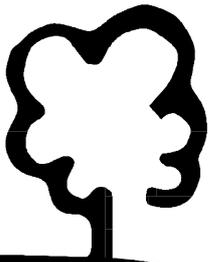
Department of Agriculture and Food
Government of Western Australia



Soil survey of the Bettink dairy farm

Peter Tille and Tilwin Westrup

October 2007



RESOURCE MANAGEMENT
TECHNICAL REPORT 324

Resource Management Technical Report 324

**Soil survey of the Bettink dairy farm
Riverway Road, Northcliffe**

Peter Tille and Tilwin Westrup

October 2007

Disclaimer:

The contents of this report were based on the best available information at the time of the publication. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

© State of Western Australia, 2007



Department of Agriculture and Food
Government of Western Australia



Acknowledgements

Wally and Julie Bettink kindly provided access to their property and shared their knowledge of the farm during this research project.

John Grant and Gina Pemberton from the Department of Agriculture and Food (Albany and Katanning offices respectively) assisted with field work. John Grant and Bill Russell provided farm photographs.

Heather Percy from the Bunbury office helped prepare the soil samples for analyses. Dave Allen from the Chemistry Centre (WA) conducted soil analyses.

Bill Russell and Mike Bolland from the Department of Agriculture and Food in Bunbury undertook technical reviews of the report. Bill also provided information concerning land management practices and issues. Mike provided extensive comments concerning the analysis of laboratory results.

The report was edited by Georgina Wilson. Mark Whitten from the Department of Agriculture and Food in Bunbury assisted with the Glossary.



Julie and Wally Bettink provided generous access to their Northcliffe property for this research study

Summary

A detailed soil survey was completed on Wally and Julie Bettink's property at Northcliffe, Western Australia during 2004. The property covers about 380 ha of which approximately 80% has been cleared and is mostly used for grazing dairy cattle on annual and perennial pastures. A centre pivot system is used to irrigate about 25 ha of pasture.

The Bettinks' property is the DairyCatch monitor farm for the Western Australian Farmers Federation in the Lower South-West Zone. The four main soil types identified on the property were *Loamy gravels*, *Sandy gravels*, *Friable red-brown loamy earths* and *Pale deep sands*. These soils generally have a fair to high capability to support grazing. They would be reasonably representative of the soils found on those dairy farms located on undulating terrain in the Cowaramup to Augusta, Manjimup to Walpole and Burekup to Bridgetown districts.

Over most of the property the main mechanism for nutrient export is likely to be through surface run-off. On the deep sands, leaching of nutrients and transport downslope via through flow is also likely to occur.

Timing of nutrient applications to avoid high run-off events and managing the grazing system to control soil erosion should prove the most effective strategies to minimise nutrient export. Waterways should be fenced and protected by native vegetation.



Dairy cows grazing near centre pivot on the Bettink property

Contents

1. Introduction.....	5
1.1 Property location.....	5
1.2 Climate.....	5
1.3 Geology, geomorphology and topography	6
1.4 Surface hydrology.....	6
1.5 Vegetation and land use.....	6
1.6 Land degradation.....	7
2. Survey methods.....	8
2.1 Previous surveys.....	8
2.2 Survey methodology	10
3. Soil types.....	14
3.1 Friable red-brown loamy earths	14
3.2 Pale deep sands	15
3.3 Loamy gravels.....	16
3.4 Sandy gravels	17
4. Mapping units	18
4.1 Sandy gravel ridges (GRr) – 38.8 ha.....	19
4.2 Red loamy ridges (RBLr) – 35.0 ha	20
4.3 Sandy ridges (DSr) – 36.9 ha	21
4.4 Sandy gravel slopes (GRs) - 37.0 ha.....	22
4.5 Red loamy slopes (RBLs) – 166.1 ha	23
4.6 Sandy slopes (DSs) – 43.9 ha	24
4.7 Drainage lines (DL) – 23.6 ha.....	25
5. Nutrient management.....	26
6. References and bibliography.....	27
Appendix 1. Soil profile descriptions and laboratory analyses.....	28
Friable red-brown loamy earths	29
Pale deep sands	34
Loamy gravels.....	44
Sandy gravels	49
Other profiles.....	57
Appendix 2. Nitrogen and soil acidification.....	61
Appendix 3. Glossary	62

1. Introduction

The survey was conducted as part of the DairyCatch project, the local component of *Dairying for Tomorrow*, the dairy industry's natural resource management program. The survey aimed to:

- provide detailed soil descriptions to add to information associated with the environment in which the dairy industry in Western Australia is located

- collect soil samples at predetermined standard depths from documented farm locations for nutrient analysis

- map soils with similar characteristics based on description and analysis.

This report documents the soils and provides technical detail of the methodology used during soil sampling. Nutrient analysis of soils is still not complete but will be published as an amendment later. The nutrient analysis is of particular interest for areas to be treated with dairy effluent. The sample locations will be documented so that similar samples can be taken in the future and change in nutrient status identified.

This will provide an indication of the benefits in soil fertility and impacts on the environment associated with spreading dairy effluent on-farm in Western Australia.

1.1 Property location

The property is in the Shire of Manjimup in the South West Land Division of Western Australia on the end of Riverway Road, 8 km south-east of the town of Northcliffe. The Gardner River flows along the western boundary, while the southern boundary adjoins State Forest. The coastline of the Southern Ocean is 17 km to the south. The Australian Map Grid coordinates (GDA94) for the centre of the property are 423000 mE and 6161500 mN.

1.2 Climate

The property experiences a moderate Mediterranean climate (Beard 1981) with warm dry summers and cool wet winters. The summers are milder here than elsewhere in the south-west. Cooler temperatures, less evaporation and more summer rain than other dairying areas produce a slightly longer growing season.

The long-term average annual rainfall is approximately 1400 mm, though there has been a significant decrease since the mid-1970s. In an average year, 86% of rain falls between April and October. The average annual evaporation rate is approximately 1100 mm. The growing season at Northcliffe lasts for about nine months, with January, February and part of March being the only time where water availability limits growth potential.

Rainfall for the last two decades of the 20th century was 10 per cent lower than the long-term average (IOCIP 2002). Although winter rainfall decreased by about 15-20 per cent, this decrease was only observed in early winter (May–July) with rainfall actually increasing by a smaller amount in the late winter and spring months of August–October. Another change is that extreme daily rainfall events have become rarer. For example, the chances of a daily rainfall in excess of 30 mm being recorded at Manjimup were more than twice as great in the period between 1930 and 1965 as they were between 1966 and 2001. The decrease in winter rainfall and extreme events has led to a sharp decline in run-off and streamflow. Temperatures have increased gradually over the last 50 years, particularly in winter and autumn.

Mean maximum temperature in Northcliffe for February (usually the hottest month) is approximately 26°C. The coolest month is July when mean minimum temperature is approximately 10°C. Frosts are rare.

1.3 Geology, geomorphology and topography

The Bettink property lies on the edge of the Nornalup Complex in the Albany-Fraser Orogen characterised by crystalline rocks including high grade gneiss and granitic intrusions (Geological Survey of Western Australia 1990). A lateritic mantle has formed on top of the basement rock.

The gneissic geology was mapped by Wilde and Walker (1984), as 'Pnb' and described as layered with a quartz–feldspar–biotite (-garnet) assemblage. The lateritic geology (Czl) is described as being chiefly massive, but includes overlying pisolitic gravel and minor laterised sand. They also noted that the laterite is thinner than north of Pemberton, often without a well-developed pallid zone.

The range in altitude over the property is from 50 to 125 m ASL. The broad lateritic ridge that runs from the north-east to the southern boundary is a major feature. It has two main spurs running east and west and slope gradients on the ridge are mostly 3-5%.

The Gardner River and its tributaries have dissected the lateritic mantle over time, and this has resulted in valleys with narrow drainage channels and moderate sideslopes having gradients of 10-20%.

1.4 Surface hydrology

The Gardner River flows along the western boundary. Minor drainage lines and tributaries dissect the property and flow to the Gardner River.

The catchments for most streams on the property are largely within its boundaries. The main exception is the creek cutting through the western boundary which has its headwaters near Murrillup Road and drains 2,350 hectares upstream.

The property includes several dams, one near the dairy being of particular interest. The centre pivot irrigation area, house and dairy are all within its catchment which lies entirely within the property. The overflow exits the property into State Forest to the south. A data logger has been installed to monitor the outflow.

Water is pumped from the Gardner River to supplement supplies used in the centre pivot. This additional source comprises roughly 30% of the water used for irrigation.

1.5 Vegetation and land use

The property lies within the Warren sub-region of the South-West Botanical Province (Beard 1979). The gravelly ridges were originally dominated by forest and woodland of jarrah (*Eucalyptus marginata*) and marri (*E. calophylla*). Karri (*E. diversicolor*) and forest trees dominated the colluvial valley side-slopes. Peppermints (*Agonis flexulosa*) were often found on deep sandy soils.

About 20% (70 ha) of the property is covered by remnant native vegetation. The farm was first developed in 1951 and supported 50-60 cows for many years. Most clearing was between 1980 and 1996. It now carries about 450 dairy cattle including 200 cows which are milked all year round. These are grazed on around 345 ha of annual and perennial pastures.

Stocking rate is approximately 1.5 head per hectare (roughly equivalent to 13 dse/ha). The southern half of the farm, including the area under the centre pivot, is grazed by milkers, while the remainder is reserved for dry cattle.

Pastures are dominated by subterranean clover (sub-clover, *Trifolium subterraneum* L.), kikuyu (*Pennisetum clandestinum* L.) and annual and Italian ryegrass (*Lolium rigidum* Gaud. and *L. multiflorum* Lam.). Clover dominates the loamy and gravelly soils, with ryegrass showing some persistence problems. Kikuyu makes up about 25% of the pasture and is most common on sands. Yellow serradella (*Ornithopus compressus* Brot.) grows on the sands, and minor amounts of balansa clover (*Trifolium balansa*, classified as *T. michelianum* Savi var. *balansae* (Bioss)) grow in waterlogged drainage depressions.

Soils are tested regularly and a fertiliser program was recommended by a consultant. The soils are deficient in manganese and magnesium (Wally Bettink, pers. comm.). Around 100 kg/ha of Unigraze 51 (9.9% P, 10.9% K, 6.1% S and 15.7% Ca) is spread over the pasture (broadcast or topdressed) twice yearly in April and August.

The area under the centre pivot receives 200 kg of Unigraze 51 plus multiple applications of a custom blend at 50 to 80 kg/ha in December and February, dependent on the results of leaf analysis during these months. The property was limed in 2003 but further liming is not intended as it is felt that this doesn't maintain the nutrient balance.

Hay is cut each year and some is imported from lease blocks on nearby properties. About 400 rolls of silage are made, mostly from pastures cut on sandier soils close to the Gardner River. About 40 ha of oats are grown each winter for fodder.

A centre pivot irrigation system was set up in the south of the property in 1997 and about 25 ha of pasture are irrigated under this system¹. White clover (*T. repens* L.) and perennial ryegrass (*L. perenne* L.) were sown but over time kikuyu invaded and dominated the pasture. Every three to four years the kikuyu has to be sprayed out and other pasture species re-sown. The area under the pivot is split into paddocks to allow rotational grazing. Originally these were wedge-shaped but they have been redesigned to form 16 rectangular paddocks with equal areas of irrigated pasture and a laneway down the middle of the pivot. This has resulted in more even grazing and easier fertiliser application. Some of these paddocks are grazed by milkers, while others are cut for hay.

A series of three effluent ponds in a row is associated with the dairy. Liquid effluent is re-used, being spread via the centre pivot irrigation system. It is stored in the ponds over winter and used for irrigation over summer. Effluent solids are spread on the paddocks in late summer or early autumn. Many of these solids are spread on the sandy soil in the west of the property. There are also several marron ponds.

1.6 Land degradation

Although there is some evidence of landslips and past erosion, the main sign of active erosion was rilling in the compacted wheel tracks on the outside of the centre pivot. There were also some minor rills developing on firebreaks.

Although most soils would have been acid in their natural state, low pH levels are probably due to acidification resulting from establishment of leguminous pastures and application of nitrogenous fertilisers. Subsurface acidification is especially a concern on the sandy soils. Some compaction of loamy topsoils from cattle trampling and machinery traffic seems to have occurred.

¹ Originally 16 ha were irrigated but the area has been expanded by a 50 m extension to the pivot.

2. Survey methods

2.1 Previous surveys

The property lies within the Pimelia Valleys soil-landscape system. This is described in the Department of Agriculture and Food's Map Unit Database (Schoknecht *et al.* 2004) as:

“Undulating terrain with deeply incised valleys, shallow minor valleys and gravelly ridges on deeply weathered mantle and colluvium over metasediments and granitic rocks in the Southern forests between the Donnelly River and Northcliffe. Loamy gravels, friable red/brown loamy earths and brown deep loamy duplexes. Karri-marri-jarrah forest.”

The soil associations were mapped by McArthur and Clifton (1975). They identified an area of Balbarrup association (block laterite on tops of rises and colluvial pisolithic gravel on slopes) on the ridge crest with Pemberton association (dissected lateritic country with steep slopes; podsolc soils on upper slopes and red earths below) on the remainder.

Churchward *et al.* (1988) mapped three units on the property (see Figure 1). The crests and upper slopes of the spurs and ridges were mapped as the *Crowea Subsystem, with gravelly yellow duplex soils* (CRy) on the main ridge and *Crowea Subsystem, with brown gravelly duplex soils and red earths* (CRb) on the eastern spur. The remainder was mapped as major valleys in granitic areas (V2) with red earths and gravelly yellow duplex soils.

Mapping by Churchward *et al.* forms the basis of the following soil-landscape description for the property extracted from DAFWA's Map Unit Database:

Crowea Subsystem, yellow duplex phase (254PvCRy): Broad ridge crests on weathered mantle over gneiss in the Southern Forests between the Donnelly River and Northcliffe. *Loamy gravels and Duplex sandy gravels.* Marri-jarrah-karri forest.

Crowea Subsystem, brown duplex phase (254PvCRb): Broad ridge crests on weathered mantle over gneiss in the Southern Forests between the Donnelly River and Northcliffe. *Loamy gravels, Red deep loamy duplexes and Friable red/brown loamy earths.* Karri-marri-banksia-sheoak forest.

Major Valleys V2 Subsystem (254PvV2): Major valleys 20-40 m deep on colluvium and weathered mantle over gneiss in the Southern Forests between the Donnelly River and Northcliffe. *Loamy gravels, Duplex sandy gravels, Friable red/brown loamy earths and Brown loamy earths.* Marri-jarrah-karri forests.



Figure 1: The Bettink property in relation to mapping by Churchward et al. (1988)

2.2 Survey methodology

The starting point for the survey was the map drawn by land owner Wally Bettink (see Figure 2) which details three soil types:

Yellow gravelly loam over clay through the middle of the property along the ridge

Red-brown gravelly loam over clay on the eastern portion, and

Sand on the western edge of the property.

Soil profiles were examined at 32 sites on cleared land in March and April 2004. Samples were collected for analysis from 17 profiles shown in Figure 3. In addition to the profiles described, a series of site observations of vegetation and surface soil was made across the property.

Site selection was based on the 'free survey' method (Gunn *et al.* 1988), ensuring that profiles of each soil type identified by the land owner and each unit mapped by Churchward *et al.* (1988) were described. Sampling was biased in favour of soils within the dam catchment (upstream from the data logger) and near the centre pivot, as these areas were deemed most likely to provide the most useful information on nutrient management.

A transect of samples was collected across the centre pivot which is used to spread effluent. Two profiles were sampled outside the reach of the pivot where no effluent will be applied. A further two sites were sampled on the margins of the current pivot. These areas are not currently irrigated, but will be when the pivot is extended by 50 metres. Another five samples were collected under the pivot in areas currently being irrigated with effluent.

The soils profiles were examined in pits dug using a shovel to about 40-100 cm, and then hand-augered to 80-100 cm where possible. The presence of stones and very gravelly horizons prevented some profiles from being dug to full depth.

Sites locations were recorded using a Garmin GPS 75 Global Positioning System (GPS) and marked on an aerial photograph. The sites and soil profiles were described using the terminology of McDonald *et al.* (1990). Site details recorded included landform element, slope gradients (measured with a clinometer), surface condition, presence of rock outcrops and native vegetation.

Soil attributes included horizon depth, colour, mottling, field texture, structure and the presence of coarse fragments. Soil colours were described according to standard Munsell color chart notation (Munsell Color Company 1994). Soil pH was tested using an indicator mixed with soil into a paste, and barium sulphate powder (Raupach and Tucker 1959).

Site and soil profile data were then entered into the Department of Agriculture and Food's Soil Profile Database. Soil profiles were classified into WA Soil Groups (Schoknecht 2002).

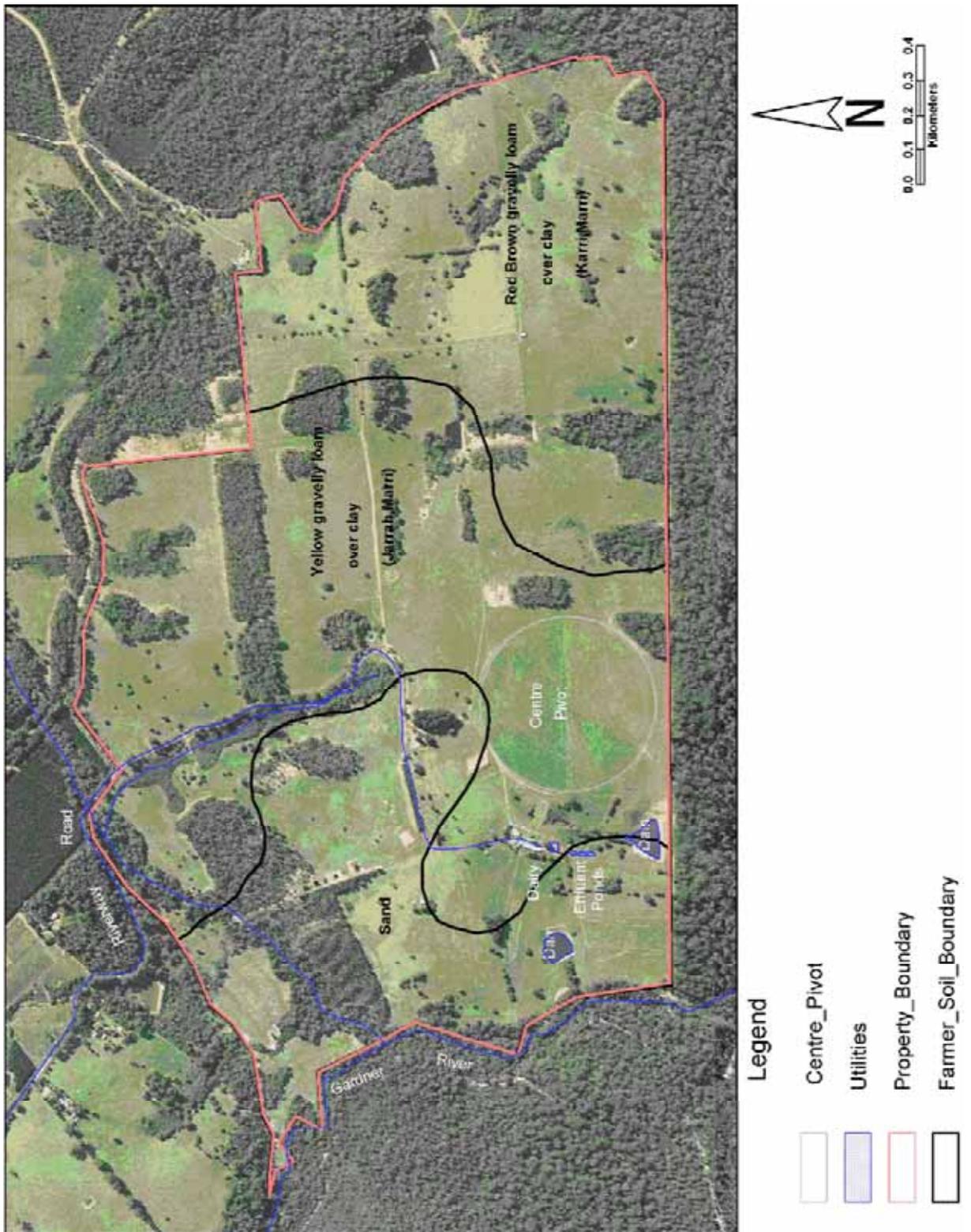


Figure 2: Property soil map drawn by Wally Bettink



Figure 3: Location of soil profiles described

Samples for analysis were collected from standard depths in the top 40 cm of the profile and also where changes in the soil horizons were thought to warrant sampling below this depth. The standard depths are listed below:

Standard sample depth	Comment
0-2 cm	Most often an organic surface crust. Collected from 10-20 locations within 2.5 m radius of the sample hole, using hand-spade.
0-10 cm	Collected using a pogo stick from 20–25 locations within a 2.5 m radius of the sample hole.
10-20 cm	Usually collected from the cleaned wall of a soil pit, otherwise from a soil auger sample.
20-40 cm	Usually collected from the cleaned wall of a soil pit, otherwise from a soil auger sample.
Various	Samples were also collected from horizons in the soil profile which were judged to have the potential to impact on water and nutrient transport of root growth (e.g. coffee rock layers in deep sands, or clay layers in gravel/ loamy duplex soils).

In some instances the standard depth was subsampled to avoid mixing material from different soil horizons. For example, where there was a major soil horizon change at 30 cm, a sample would be taken from 20-30 cm as well as from 30-40 cm. If a major horizon changed at 35 cm, the sample was collected at 20-35 cm only. Samples were oven dried at 40 C, and stored for analysis.

Laboratory analysis was conducted by the Agricultural Chemistry Laboratory at the Chemistry Centre (WA). The samples were processed in two separate batches. The first batch consisted of 57 samples taken from 17 profiles. These were analysed for: air-dry moisture content; pH (1:5 water and 1:5 0.01 M CaCl₂); EC (1:5 water); organic carbon (Walkley and Black 1934, Walkley 1947); total nitrogen and phosphorus; and Colwell-extractable phosphorus and potassium (Colwell 1963). Particle-size analysis (sand, silt and clay fraction only), aluminium (extracted in M CaCl₂), CEC, exchangeable cations and phosphorus retention index were recorded for a further six samples from these profiles along with the previous analyses. A further 15 samples from 0 to 3 cm in depth were sent to Albany for total digestible nutrients (nutrients in OM).

The sites and profile data were used to produce a new soil-landscape map. The main soil types were identified and described. The map unit boundaries were drawn directly into a MicroStation design file using the site data, a rectified colour aerial photograph and a 5 m contour map. The map units incorporate soil types and landforms, as both have a major influence on the movement of nutrients.

3. Soil types

The four main soil types identified were *Friable red-brown loamy earths*, *Pale deep sands*, *Loamy gravels* and *Sandy gravels*. Soil names shown in italics are taken from the Soil Groups of Western Australia (Schoknecht 2002).

3.1 *Friable red-brown loamy earths*

These soils cover about 25% of the property. They have reddish brown loamy topsoils grading into reddish clayey subsoils. They are similar to the loamy gravels but contain less than 20% ironstone gravel. The soil reaction trend is neutral, though slightly acid in places.

A1 horizons are about 10 cm deep, sandy loams to loams with a strong brown to reddish brown colour. They have high organic matter content and a crumb structure, and are usually non-wetting. The pH_{Ca} ranges from 5.4 to 5.7 while Electrical Conductivity or $EC_{(1:5)}$ is 8-18 milliSiemens per metre (mS/m). In the surface mat (typically the top 2 cm), organic carbon was measured in the 4.5-6.6% range, total nitrogen as 0.31-0.48%, total phosphorus as 420-700 mg/kg (with 22-32 mg/kg being extractable) and extractable potassium in the 150-230 mg/kg range.

Over the entire surface 10 cm, organic carbon was measured as 3.2-4.7%, total nitrogen 0.21-0.36%, total phosphorus as 270-520 mg/kg (with 11-16 mg/kg extractable) and extractable potassium in the 79-440 mg/kg range.

A3 horizons extend to about 40 cm, and are red to reddish brown coarse sandy loams to sandy clay loams. This horizon is typically apedal with an earthy fabric, though weak polyhedral peds can occur. There are 2-20% ironstone gravels or granitic fragments. The pH_{Ca} ranges from 5.2 to 6.0 while $EC_{(1:5)}$ is 2-4 mS/m. Organic carbon ranged from 0.5-1.6% with; total nitrogen 0.03-0.10%; total phosphorus 67-190 mg/kg (with 2-3 mg/kg extractable); and extractable potassium in the <10-62 mg/kg range.

B1 horizons extend to a depth of 80 cm and more and are a red or yellowish red sandy clay loam to sandy light clay. This horizon is typically apedal with an earthy fabric, although weak polyhedral peds can occur. There are 0-15% ironstone gravels or granitic fragments.

The pH_{Ca} of the B horizon ranges from 5.6 to 6.6 with $EC_{(1:5)}$ 2-3 mS/m. Organic carbon ranged from 0.3-0.8%; total nitrogen 0.02-0.05%; total phosphorus 55-360 mg/kg (with 2 mg/kg extractable); and extractable potassium in the <10-69 mg/kg range.

Associated soils: There are some similar profiles, but the topsoil is hard and compacted (*Red loamy earths*). In others there is a clear texture contrast between the loamy topsoil and clayey subsoil (*Red* and *Brown deep loamy duplexes*). Some profiles have granitic stones throughout (*Stony soils - with a loamy matrix*). Similar profiles are found in the drainage lines, although these are waterlogged (*Wet soils - with loamy topsoils*).

Five sites matched this soil unit (SCH 099**, 100**, 102*, 109** and 128). See Appendix 1 for profile descriptions and laboratory analyses.

* Chemical analyses available for the A1 horizons only.

** Chemical analyses available for a number of horizons.

3.2 *Pale deep sands*

These soils cover approximately 20% of the property. They are pale coloured sands to at least 80 cm. Topsoils have a dark staining of organic matter, and coffee rock or clayey subsoils may be found at depth. The soil reaction trend is acid to very strongly acid.

The A1 horizons are 10 to 15 cm deep of black, brown or very dark grey, organic sand, loamy sand and sandy loams containing no ironstone gravel. The structure is loose to weak crumb or massive, and has a sandy fabric. This horizon can be strongly non-wetting. The pH_{Ca} ranges from 4.2 to 5.8.

In the surface mat, organic carbon was measured as 4.2-8.3%, total nitrogen in the 0.20-0.52% range, total phosphorus as 140-610 mg/kg (with 19-130 mg/kg extractable); extractable potassium in the 89-670 mg/kg range and $\text{EC}_{(1:5)}$ in the 10 to 28 mS/m range.

Over the entire surface 10 cm, organic carbon was measured as 3.1-6.3%, total nitrogen in the 0.16-0.36% range, total phosphorus as 78-520 mg/kg (with 7-130 mg/kg being extractable), extractable potassium in the 36-360 mg/kg range and $\text{EC}_{(1:5)}$ from 1 to 16 mS/m.

A2 horizons extend to depths of more than 150 cm, and are commonly pale grey to very pale brown sands and loamy sands, with no mottles. This horizon is structureless, loose and variably non-wetting.

The pH_{Ca} of the A2 horizon ranges from 3.3 to 6.8 while the $\text{EC}_{(1:5)}$ is 2-6 mS/m. Organic carbon was measured as 0.2-1.6%, total nitrogen in the 0.02-0.07% range, total phosphorus 46-140 mg/kg (with <2-57 mg/kg being extractable); and extractable potassium 14-94 mg/kg.

The B horizon is variable and found between 90 and 200 cm. It often contains coffee rock and consists of dark brown loamy coarse sand containing 10% ironstone gravel. The pH_{Ca} ranges from 4.5 to 5.1 and organic matter content was 1.5-2.1%. Elsewhere there are brownish grey to brownish yellow fine sands or clayey sands. In some profiles the B horizon is a clay.

Associated soils: Some similar profiles similar exhibit a clear texture contrast between the sandy topsoil and clayey subsoil at about 50 cm (***Grey deep sandy duplexes***). There are also profiles which have a pale sandy topsoil, but with an indurated layer at around 50–80 cm (***Pale shallow sands***). Some have pale loamy sand topsoils which grade to red and brown sands and sandy loams at depth (***Pale sandy earths***).

Ten sites matched this soil unit (SCH 103*, 104**, 105, 106*, 107**, 110**, 135, 136, 137 and 139). See Appendix 1 for profile descriptions and laboratory analyses.

* Chemical analyses available for the A1 horizons only.

** Chemical analyses available for a number of horizons.

3.3 *Loamy gravels*

These soils cover approximately 30% of the property. They are predominantly reddish brown sandy loams grading into clays containing 20-40% ironstone gravel.

A1 horizons are 10-25 cm deep black, brown or reddish brown sandy loams (occasionally loams) with 20-40% ironstone gravel (typically around 25%). They contain high organic matter, and are usually non-wetting. The pH_{Ca} ranges from 5.6 to 6.3 while the $\text{EC}_{(1:5)}$ is 11-37 mS/m.

Organic carbon in the A1 horizon was measured in the 3.4-6.0% range, total nitrogen as 0.21-0.47%, total phosphorus at 190-690 mg/kg (with 10-48 mg/kg extractable) and extractable potassium in the 64-540 mg/kg range.

A3/B1 horizons extend to approximately 40-60 cm and are reddish brown to yellowish red sandy loams to clay loams, with 15-40% ironstone gravel. Structure is polyhedral or subangular blocky. The pH_{Ca} ranges from 5.8 to 6.0 while the $\text{EC}_{(1:5)}$ is 4-8 mS/m. Organic carbon was measured as 0.8-2.9%, total nitrogen in the 0.04-0.17% range, total phosphorus as 76-210 mg/kg (with 2-5 mg/kg being extractable), and extractable potassium 14-88 mg/kg.

B2 horizons were observed as yellowish red and sandy clay loams to medium clays. Gravel content was usually 10-25%. Structure is polyhedral or subangular blocky, and fabric is earthy. At one site the pH_{Ca} was measured at 6.3 with the $\text{EC}_{(1:5)}$ at 2 mS/m. Organic carbon was 0.77% with total nitrogen 0.05%, total phosphorus 91 mg/kg (with 2 mg/kg being extractable), and extractable potassium at 12 mg/kg.

Five sites matched this soil unit (SCH 108*, 126, 130, 131 and 141**). See Appendix 1 for profile descriptions and laboratory analyses.

* Chemical analyses available for the A1 horizons only.

** Chemical analyses available for a number of horizons.

3.4 *Sandy gravels*

These soils cover about 20% of the property. Sandy gravels include three soil groups (**Deep sandy gravels**, **Shallow gravels** and **Duplex sandy gravels**), but these have been combined as they are often difficult to differentiate in the field when examining the profile with a spade and hand auger. They are characterised by sandy topsoils with 20-60% ironstone gravels. Lateritic stones and boulders are often present. The soil reaction trend is slightly acid.

A1 horizons are 5-15 cm deep, brown to very dark grey loamy sands (although the field texture may be a sandy loam due to the presence of organic matter) with 15-40% ironstone gravel. They have high organic matter content, and are usually non-wetting. They have a sandy fabric and are loose, or have a weak crumb structure. The pH_{Ca} ranges from 5.2 to 5.8 while $\text{EC}_{(1:5)}$ is 12-35 mS/m.

In the surface mat (typically the top 2 cm), organic carbon was measured as 4.8-6.5%, total nitrogen as 0.36-0.46%, total phosphorus 490-780 mg/kg (with 49-130 mg/kg extractable) and extractable potassium in the 100-360 mg/kg range.

Over the entire surface 10 cm, organic carbon was measured as 3.5-5.2%, total nitrogen in the 0.21-0.37% range, total phosphorus as 320-530 mg/kg (with 21-110 mg/kg being extractable) and extractable potassium in the 74-330 mg/kg range.

A3 horizons are typically yellowish brown (occasionally reddish brown) loamy sands to clayey sands with 40-60% ironstone gravel. Lateritic stones and boulders are also often present. This horizon has a sandy fabric and is loose to weakly massive.

The pH_{Ca} of the A3 horizon ranges from 4.8 to 5.5 while the $\text{EC}_{(1:5)}$ was 2-7 mS/m. Organic carbon was measured at 0.6-2.0% with total nitrogen in the 0.03-0.09% range; total phosphorus 69-150 mg/kg (2-20 mg/kg being extractable); and extractable potassium in the <10-49 mg/kg range.

Associated soils: The A3 horizon may be more than 80 cm deep (**Deep sandy gravels**). In other situations there is a clear boundary to a clayey subsoil at 50-80 cm (**Duplex sandy gravels**). In many places lateritic stones are present. Elsewhere there is layer of cemented laterite in the top 80 cm which forms a major barrier to root growth (**Shallow gravels** and **Stony soils - with a sandy matrix**).

Eight sites matched this soil unit (SCH 095*, 096**, 097**, 098**, 127, 132, 133 and 140**). See Appendix 1 for profile descriptions and laboratory analyses.

* Chemical analyses available for the A1 horizons only.

** Chemical analyses available for a number of horizons.

4. Mapping units

The soil types found were combined with landscape position to form seven soil-landscape mapping units shown in Figure 4: Sandy gravel ridges (GRr); Red loamy ridges (RBLr); Sandy ridges (DSr); Sandy gravel slopes (GRs); Red loamy slopes (RBLs); Sandy slopes (DSs); and Drainage lines (DL).

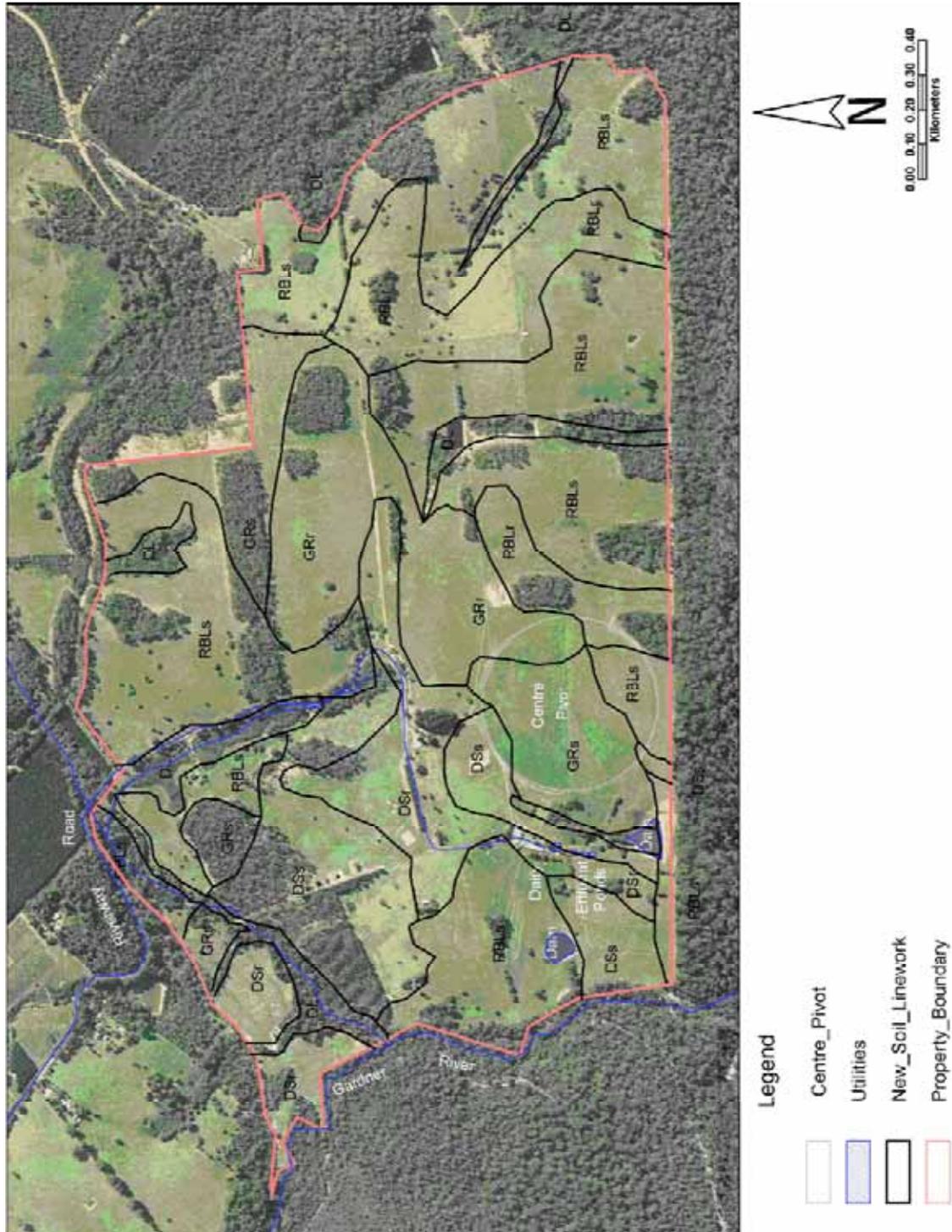


Figure 4: Soil-landscape mapping units for the Bettink property

4.1 *Sandy gravel ridges (GRr) – 38.8 ha*

This unit sits in the centre of the property and represents remnants of a lateritic plateau. It consists of gently inclined upper slopes and ridges having a grade of about 2-7%. The area occurs at elevations of 100-125 m AHD.

The soils are predominantly **Sandy gravels**. Ironstone outcrop and boulders are often present, and many of the profiles would be **Shallow gravels**, although **Deep sandy gravels** also occur. In all profiles examined, a horizon containing at least 20% ferruginous gravel was found in the top 20 cm. The native vegetation is jarrah-marri forest and woodland.

The sandy gravel ridges have a fair to high capability for grazing. They are generally well drained and have fair moisture retention characteristics. Good pasture growth is usually experienced and clover-based pastures do particularly well, although there is a problem in getting the annual ryegrasses to persist.

Topsoil pH is mostly slightly acid (pH_{Ca} 5.0-5.5) but subsurface pH tends to decrease a bit (often to around 5.0) indicating the advisability of liming to minimise the risk of acidification. Whitten *et al.* (2000) suggest that adding sufficient lime to increase pH to at least 5.5 in the top 10 cm of profile should ameliorate any subsurface acidity and prevent it from redeveloping. Salinity levels are very low ($\text{EC}_{(1:5)} < 20$ mS/m) and unlikely to affect pasture growth.

Regular applications of phosphorus are required as these soils with high iron content tend to bind phosphorus, although the problem is not as great as on the red soils discussed below. Extractable phosphorus in the A1 horizon was measured mostly at 4-12% of total P. Total nitrogen in the A1 horizon was around 0.28%, very similar to the nitrogen levels in the *Pale deep sands* and *Red loamy earths*.

There may also be manganese deficiencies. This problem occurs in patches on lateritic soils in the West Dale area and is ameliorated by applying a total of 60 kg/ha manganese sulphate (32% Mn), usually as 30 kg/ha in two successive years (Mike Bolland, pers. comm.). Sulphur and potassium levels are generally reasonable.

Gravel content reduces the moisture-holding capacity of the topsoil of many profiles. Moisture stress is first experienced on the *Shallow gravels* and then the *Deep sandy gravels*. Rooting depth may be restricted on the *Shallow gravels*. The soils are generally well drained though some perching of water above the clayey subsoil may occur. Topsoils are often non-wetting though this is usually a minor problem experienced early in the growing season.

The soils have reasonable nutrient-holding abilities, tending to bind phosphorus due to the iron and aluminium content. Nitrogen is rapidly converted to nitrate which will pass freely through the sandy topsoil but should be held by the clayey substrate². There may be some lateral flow of nutrients above the subsoil (throughflow in the topsoil). Another possible mechanism for nutrient export is through surface run-off and nutrients can be transported attached to soil particles if water erosion is allowed to occur. Being on crest areas not receiving run-on, the risks of erosion are generally not great.

² See Appendix 2 for more details on the fate of nitrogen in the soil.

4.2 *Red loamy ridges (RBLr) – 35.0 ha*

This unit forms the spur running to the east of the main ridge and represents stripped remnants of a lateritic plateau where the underlying granitic rocks have a greater influence on the soils. It consists of gently inclined upper slopes and ridges with a grade of about 2-7%. The area occurs at elevations of 90-120 m AHD.

The soils are predominantly **Loamy gravels**. **Red loamy earths**, **Shallow gravels** and **Deep sandy gravels** may also occur. The native vegetation is marri-karri forest.

The red loamy ridges have high capability for grazing. They are generally well drained, relatively fertile and have fair to good moisture retention characteristics with their loamy topsoils and clayey subsoils. Good pasture growth is usually experienced.

Topsoil pH is mostly slightly acid (pH_{Ca} 5.0-5.5) with a slight increase in subsurface pH.

Regular applications of phosphorus are required as these soils tend to bind phosphorus. Extractable P in the topsoil was mostly 1-5% of total P and, on average, was around half to a third of the amount of extractable P measured in the *Pale deep sands* and *Sandy gravels*. These soils also require nitrogen.

Gravel content reduces the moisture-holding capacity of many topsoils. Moisture stress is first experienced on the *Shallow gravels* and then the *Deep sandy gravels*.

The soils have good nutrient-holding abilities, tending to bind phosphorus due to the high iron and aluminium content while the clayey subsoils limit nitrogen leaching below the clay layer. The main mechanism for nutrient export is likely to be through surface run-off. Broadcast nutrients can be washed downslope before they have become incorporated into the soil and can also be transported on soil particles if water erosion is allowed to occur.

Being on crests not receiving run-on, the risks of erosion are generally not great. However it remains good practice to apply fertiliser at the start of the growing season, about three weeks after pasture emergence. By this time pasture plants would have developed sufficient roots to increase uptake of nutrient elements from soil thereby reducing the proportion of the elements lost in run-off.

4.3 *Sandy ridges (DSr) – 36.9 ha*

This unit forms the spur running to the west of the main ridge. It also includes two low-lying spurs to the west of the creek which flows across the property. It consists of gently inclined mid and upper slopes, and ridges having a grade of about 2-10%. The area occurs at elevations of 65-100 m AHD.

Although the soils are predominantly *Pale deep sands*, also present are *Pale shallow sands*, *Grey deep sandy duplexes* and *Yellow-brown deep sandy duplexes*. The native vegetation appears to have been jarrah-marri woodland with peppermints.

The sandy ridges have poor to fair capability for grazing. They are generally well drained but have poor moisture and nutrient retention. Reasonable to good pasture growth can be achieved on these sands with suitable nutrient application (Mike Bolland, pers. comm.), largely due to the high rainfall.

These soils are naturally acid and pH tends to decrease under grazing systems due to relatively low pH buffering capacities. Many topsoils were strongly to moderately acid (pH_{Ca} 4.2-5.0) with very strongly subsurface pH (as low as 3.3) in some profiles. Liming is strongly recommended. The potential for subsurface acidity to continue to develop should be a concern. This can lead to aluminium toxicity and molybdenum deficiencies are likely to be experienced when pH_{Ca} drops below 4.7. The recommendation is to apply enough lime to the topsoil to maintain pH at 5.5 or greater. Where soils have been allowed to acidify to the extent that pH is around 4, several applications of lime may be required.

These sands require regular nutrient applications. Although phosphorus is mostly retained within the profile, it moves to lower depths with time. Potassium and sulphur are readily leached below rooting depth of pasture in wet years, so in these years fertiliser applications are required to prevent deficiencies that reduce pasture dry matter production.

Because of poor moisture retention, pastures tend not to perform well if there is a late break or an early finish to the growing season. For this reason, early maturing cultivars of sub-clover and annual and Italian ryegrass are more suitable than late maturing varieties. Kikuyu pastures, because they are perennial, seem to persist on these sands by managing to tap into moisture in the clayey substrate.

Soils are generally well drained though some perching of water above the clayey subsoil may occur. They tend to be highly non-wetting and susceptible to wind erosion when left bare.

The sands generally have poor nutrient-holding abilities. Extractable phosphorus in the A2 horizon was relatively high in comparison to the other soils, measured mostly at 15-40% of total phosphorus. Organic matter in the topsoil or iron/organic coffee rock at depth can bind some phosphorus, but nitrogen, because it is mostly present in soil as nitrate, will pass freely through until it reaches a clayey substrate or impermeable hardpan. The topsoils of the *Yellow-brown deep sandy duplexes* should hold phosphorus better than the other sands.

4.4 Sandy gravel slopes (GRs) – 37.0 ha

These occur on slopes below the sandy gravel ridges. They consist of gently inclined upper, mid and lower slopes having a grade of about 5-10%. The unit occurs at elevations of 50-115 m AHD.

There is a variety of colluvial soils with **Deep sandy gravels** and **Duplex sandy gravels** probably most common. There are also some **Yellow-brown deep sandy duplexes**, **Brown deep sands** and **Yellow loamy earths**. The native vegetation is jarrah-marri forest and woodland.

The sandy gravel slopes have a fair to high capability for grazing. They are generally well drained and have fair moisture retention. Good pasture growth is usual and clover-based pastures do particularly well, although there is a problem in getting annual ryegrasses to persist and a need to apply nitrogen and sulphur after each grazing.

Topsoil pH is mostly slightly acid (pH_{Ca} 5.0-5.5) but subsurface pH tends to decrease a bit (often around 5.0). Liming is recommended, with regular liming when pH of the top 10 cm of soil falls below 5.5, to prevent subsurface acidity redeveloping.

Regular applications of phosphorus are required as these soils with high iron and aluminium content tend to bind phosphorus, though the problem is not as great as on the red soils discussed below. Extractable phosphorus in the A1 horizon was measured mostly at 4-12% of the total. Total nitrogen in the A1 horizon was around 0.28%, very similar to the nitrogen levels in the *Pale deep sands* and *Red loamy earths*. There may be manganese deficiencies. Sulphur and potassium levels are generally reasonable.

Gravel content reduces the moisture-holding capacity of many topsoils. Moisture stress is first experienced on the *Deep sandy gravels* and *Brown deep sands*. The soils are generally well drained though some perching of water above the clayey subsoil may occur.

The soils have reasonable nutrient-holding abilities, tending to bind phosphorus due to the high iron and aluminium. Nitrogen is rapidly converted to nitrate in soil which will pass freely through the sandy topsoil but should be held by the clayey substrate. On these slopes there is likely to be some lateral flow of nutrients above the subsoil. Nutrients can also be transported attached to soil particles in run-off if water erosion is allowed to occur.

4.5 *Red loamy slopes (RBLs) – 166.1 ha*

This unit is associated with moderately inclined valley slopes having gradients of 0-20%. It occurs at elevations of 50-100 m AHD. Karri-marri forest and woodland is the main native vegetation.

The soils have mostly developed on freshly weathered bedrock, and granitic outcrops can be seen. The topsoil is often colluvial, containing ironstone gravel from upslope. The dominant soils are **Loamy gravels** and **Friable red-brown loamy earths**. **Red loamy earths**, **Brown deep loamy duplex soils** and **Stony soils** are also present.

The red loamy slopes have high capability for grazing. They are generally well drained, relatively fertile and have good moisture retention with their loamy topsoils and clayey subsoils. Good pasture growth is usual and they tend to do well into the growing season. Topsoil pH is mostly slightly acid (pH_{Ca} 5.0-5.5) with a slight increase in subsurface pH. Salinity levels are low ($\text{EC}_{(1:5)}$ mostly <35 mS/m) and unlikely to affect pasture growth.

Regular applications of phosphorus are required as these soils tend to bind phosphorus. Average extractable phosphorus in the topsoil was mostly 1-5% of total P and around half to a third of the amount of extractable phosphorus measured in the *Pale deep sands* and *Sandy gravels*. These soils also require nitrogen.

The topsoils can become hardsetting in places, especially when compacted by machinery traffic or stock. The *Stony soils* and areas around rock outcrop are often shallow and consequently have poorer moisture retention.

Soils have good nutrient-holding abilities, tending to bind phosphorus due to the high iron and aluminium contents while the clayey subsoils limit nitrogen leaching. The main mechanism for nutrient export is likely to be through surface run-off. Broadcast nutrients can be washed downslope before they have become incorporated into the soil and nutrients can be transported with soil particles if water erosion occurs.

Nutrient export can be minimised through management of surface run-off, maintenance of good ground cover and timing nutrient applications to avoid likely periods of heavy run-off. Special care needs to be taken on slopes steeper than 10%, though the construction of earthworks to control erosion is unlikely to be necessary. It is recommended to apply fertiliser at the start of the growing season, about three weeks after pasture emergence. By this time pasture plants would have developed sufficient roots to increase uptake of nutrient elements from soil thereby reducing the proportion of the elements lost in run-off.

4.6 Sandy slopes (DSs) – 43.9 ha

This unit occurs in the western half of the property. It consists of gently to moderately inclined mid-slopes and upper slopes having gradients of about 5-20%. It occurs at elevations of 65-100 m AHD.

The soils are predominantly **Pale deep sands** but **Grey deep sandy duplexes** and **Pale sandy earths** are also present. The native vegetation appears to have been jarrah-marri woodland with peppermints.

The sandy soils have a poor to fair capability for grazing. They are generally well drained but have poor moisture and nutrient retention. Reasonable to good pasture can be achieved with suitable nutrient application, largely due to the high rainfall.

Soils are naturally acid and pH tends to decrease under grazing. Many topsoils were strongly to moderately acid (pH_{Ca} 4.2-5.0) with very strongly subsurface pH (as low as 3.3) in some profiles. Liming is strongly recommended with regular liming when pH of the top 10 cm falls below 5.5 to prevent subsurface acidity redeveloping. This can lead to aluminium toxicity, and molybdenum deficiencies are likely when pH_{Ca} drops below 4.7.

These sands require regular nutrient applications, especially of potassium and sulphur. Pre-growing season soil tests do not provide a reliable indication of pasture needs during the following growing season. Much depends on rainfall which cannot be accurately predicted. In wet years these nutrients can be leached below the reach of the pasture roots. Subsurface waterlogging can also restrict the ability of plant roots to take up K and S.

Because of the poor moisture retention, pastures tend not to perform well if there is a late break or an early finish to the growing season. For this reason, early maturing cultivars of sub-clover are more suitable than late varieties. Kikuyu pastures seem to persist when they manage to tap into moisture in the clayey substrate. The soils are generally well drained though some perching of water above the clayey subsoil may occur. They tend to be highly non-wetting and susceptible to wind erosion when bare.

The sands generally have poor nutrient-holding abilities. Extractable phosphorus in the A2 horizon was relatively high compared with the other soils, measured mostly at 15-40% of the total. Organic matter in the topsoil or iron/organic coffee rock at depth can bind some phosphorus but nitrogen will pass through freely until it reaches a clayey substrate or impermeable hardpan. Through-flow in the pale sandy subsurface above the low permeability subsoil is likely to be a major avenue of nutrient export.

4.7 Drainage lines (DL) – 23.6 ha

This unit is associated with valley floors and drainage lines in low-lying areas between 50 and 70 m AHD. The soils are a mixture of colluvium and alluvial deposits, and the site examined was **Red loamy earth (wet)**. This area is waterlogged for extended periods, and most remains vegetated with karri, marri forest and woodland, with occasional Warren River cedar.

These soils can support pastures such as balansa clover and kikuyu but nitrate-N, potassium and sulphate-S cannot be accessed by plant roots in waterlogged soil because the roots are not active in saturated conditions. Roots can be seen growing above the surface where the whole soil profile is regularly saturated.

In such cases, fertiliser needs to be applied to the saturated soil for these roots to take up nitrogen, potassium and sulphur³ but the presence of running water in streams means that the risk of nutrient export is very high (even though the soil profile may have good nutrient-holding abilities). These areas are best fenced off to prevent stock access and to maintain the native vegetation.

³ Current research is investigating if the same is true for phosphorus (Mile Bolland, pers. comm.)

5. Nutrient management

The following practices are likely to minimise the risk of nutrient export from this and similar properties:

Fencing off waterways and maintaining vegetation along streamlines;

Grazing management that ensures maintenance of ground cover throughout the year to reduce the risk of run-off and erosion;

Reducing the risk of erosion by ensuring that where possible fence lines and firebreaks do not run directly downslope;

Keeping laneways to ridge lines where possible and, where they need to run downslope, installing cut-off drains to spread run-off and nutrients across grassed paddocks;

Installing a spreader bank below the centre pivot may reduce gully erosion and nutrient transport caused by surface water concentrating in the pivot wheel rut;

Where possible, not siting areas where stock congregate (e.g. feeding areas, stockyards, holding pens) on the *Pale deep sands*; and

Timing the broadscale spreading of fertiliser or manure on paddocks to minimise risk of nutrient loss.

The timing of nutrient applications is important. Farm managers should avoid spreading effluent or fertilisers on waterlogged areas or the *Pale deep sands* when pasture is not growing actively, due to the high risk of nutrient leaching. Care should also be taken to ensure that nutrients are not sitting on the ground surface during heavy rainfall events that are likely to generate run-off (such as summer thunder storms, at the break of season when soils are still non-wetting or when soil profiles are already saturated).

Liquid effluent should not be applied from the centre pivot just prior to, during, or following heavy rainfall events (especially in winter). A good practice is to apply fertiliser and/or effluent three weeks after pasture emergence when pasture plants have developed sufficient roots to take up the nutrient elements applied or mineralised from soil organic matter.



Centre pivot used to irrigate and spread effluent

6. References and bibliography

- Beard JS (1979) Phytogeographic regions. *In Western Landscapes*, J Gentilli (ed). University of Western Australia Press, Nedlands.
- Beard JS (1981) Vegetation survey of Western Australia, 1:1,000,000 Series. Sheet 7 – Swan. University of Western Australia Press, Nedlands.
- Churchward HM, McArthur WM, Sewell PL, Bartle GA (1988) Landforms and soils of the south coast and hinterland, Western Australia - Northcliffe to Manypeaks. CSIRO Division of Water Resources Divisional Report No. 88/1.
- Colwell JD (1963) The estimation of phosphorus fertiliser requirements in wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3**: 190-198.
- Geological Survey of Western Australia (1990) 'Geology and mineral resources of Western Australia'. Western Australian Geological Survey, Memoir 3.
- Gunn RH, Beattie JA, Reid RE, van de Graff RHM (1988) Australian soil and land survey handbook: guidelines for conducting surveys. Inkata Press, Melbourne.
- IOCIP (2002) Climate variability and change in south west Western Australia. Indian Ocean Climate Initiative Panel, Department of Environment, Perth.
- McArthur WM, Clifton AL (1975) Forestry and agriculture in relation to soils in the Pemberton area of Western Australia. CSIRO Soils and Land Use Series No. 54.
- McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1990) Australian Soil and Land Survey Field Handbook. Inkata Press, Melbourne and Sydney.
- Munsell Color Company (1994) Munsell Soil Color Charts. Macbeth Division of Kollmorgan Instruments Corporation, New Windsor, NY.
- Raupach M, Tucker BM (1959) The field determination of soil reaction. *Journal of Australian Institute Agricultural Science* **25**: 129-33.
- Schoknecht N (2002) Soil groups of Western Australia: A simple guide to the main soils of Western Australia, 3rd edn. Resource Management Technical Report 246. Department of Agriculture.
- Schoknecht N, Tille PJ, Purdie B (2004) Soil-landscape mapping in south-western Australia – Overview of methodology and outputs. Resource Management Technical Report 280, Department of Agriculture.
- Walkley A (1947) A critical examination of a rapid method for determining organic carbon in soils – effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science* **63**: 251-64.
- Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29-38.
- Whitten MG, Wong MTF, Rate AW (2000) Amelioration of subsurface acidity in the south west of Western Australia: downward movement and mass balance of surface-incorporated lime after 1-15 years. *Australian Journal of Soil Research* **38**: 711-728.
- Wilde SA, Walker IW (1984) Pemberton-Irwin Inlet, Western Australia. 1:250,000 Series Explanatory Notes. Geology Survey of Western Australia.

Appendix 1 – Soil profile descriptions and laboratory analyses

Descriptions are provided of the 32 profiles examined. The profiles are grouped into the four main soil types described previously, with descriptions of other profiles not matching these groups presented last. Within each main soil type, profiles are listed in chronological order.

Results of the laboratory analysis for the 17 profiles sampled are provided with relevant descriptions. Of these, data are provided for a number of horizons for 11 profiles, while for six profiles only the A1 horizon was analysed.



Loamy gravel



Pale deep sand



Friable red-brown loamy earth



Sandy gravel

***Examples of the varied soil types
found on the Bettink property***

Friable red-brown loamy earths

Profile: SCH 0099

WA Soil Group: Red loamy earth (neutral subsoil)

Australian Soil Classification: Haplic Eutrophic Red Kandosol

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20, 20-40 and 60-80 cm

Location: GDA94 Zone 50 – 422966 mE, 6160727 mN

Outside of southern edge of proposed centre pivot extension, just off boundary fence

Site description:

<i>Landform:</i>	Mid-slope (with gradient of 12%) on undulating low hills
<i>Disturbance:</i>	Extensive clearing for pasture
<i>Surrounding vegetation:</i>	Karri forest with a bit of marri
<i>Rock outcrop:</i>	No rock outcrop
<i>Surface coarse fragments:</i>	Few (5%) ironstone medium gravels
<i>Surface condition:</i>	Hardsetting

Soil Profile Description – SCH 0099

<i>Horizon</i>	<i>Depth (cm)</i>	<i>Description</i>
A1	0-10	Dark reddish brown (5YR 3/3 moist) loam; no mottles; dry soil; apedal, massive structure; 10% coarse fragments; pH 5 (soil paste).
A3	10-20	Reddish brown (5YR 5/4 moist) clay loam; no mottles; moderately moist soil; pedal, weak, subangular blocky structure; rough-ped fabric; 15% coarse fragments; pH 5.5 (soil paste).
B11	20-40	Yellowish red (5YR 5/6 moist) light clay; no mottles; moist soil; 20% subrounded and subangular ferruginous ironstone; pH 6 (soil paste).
B12	40-60	Yellowish red (5YR 5/6 moist) light clay; no mottles; moist soil; 15% subrounded and subangular ferruginous ironstone; pH 6 (soil paste).
B2	60-80+	Reddish brown (5YR 4/4 moist) light medium clay; no mottles; moist soil; 5% coarse fragments.

Laboratory analyses – SCH 0099

<i>Depth (cm)</i>	<i>% Coarse frags</i>	<i>EC (1:5) mS/m</i>	<i>pH (H₂O)</i>	<i>pH (CaCl₂)</i>	<i>Al (CaCl₂) mg/kg</i>	<i>OrgC (W/B) %</i>	<i>N (total) %</i>	<i>P (total) mg/kg</i>	<i>P (HCO₃) mg/kg</i>	<i>K (HCO₃) mg/kg</i>
0-2	12	17	6.1	5.5		6.60	0.482	490	22	230
0-10	15	8	6.3	5.5		3.71	0.236	300	11	140
10-20	27	3	6.7	5.8		1.61	0.102	190	2	34
20-40	20	2	6.9	6.0		0.83	0.048	170	2	37
60-80		3	6.9	6.1		0.47	0.026	360	2	69

<i>Depth (cm)</i>	<i>P (PRI) mL/g</i>	<i>CEC (NH₄Cl) me%</i>	<i>Ca (exch) me%</i>	<i>Mg (exch) me%</i>	<i>Na (exch) me%</i>	<i>K (exch) me%</i>	<i>Al (exch) me%</i>	<i>Mn (exch) me%</i>	<i>Sand %</i>	<i>Silt %</i>	<i>Clay %</i>
20-40	760	4	3.13	0.92	0.15	0.13			64.5	9.5	26

Profile: SCH 0100**WA Soil Group:** Friable red/brown loamy earth (neutral subsoil)**Australian Soil Classification:** Haplic Mesotrophic Red Kandosol

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20, 20-40 and 60-80 cm

Location: GDA94 Zone 50 – 422971 mE, 6160741 mN

On inside of the southern edge of proposed centre pivot extension, 25 m from boundary fence

Site description:*Landform:* Mid-slope (with gradient of 12%) on undulating low hills*Disturbance:* Extensive clearing for pasture*Surrounding vegetation:* Karri forest with a bit of marri*Rock outcrop:* No rock outcrop*Surface coarse fragments:* Few (5%) ironstone medium gravels*Surface condition:* Soft, almost loose**Soil Profile Description – SCH 0100**

<i>Horizon</i>	<i>Depth (cm)</i>	<i>Description</i>
A1	0-10	Dark reddish brown (5YR 3/2 moist) sandy loam; no mottles; dry soil; pedal, moderate, crumb structure; rough-ped fabric; 15% subrounded ferruginous ironstone medium gravels; strongly water repellent; pH 5 (soil paste); clear boundary to:
A3c	10-20	Reddish brown (5YR 4/4 moist) coarse sandy loam (coarse sand is mostly fine ironstone gravel nodules); no mottles; dry soil; apedal, massive structure; earthy fabric; 10% subrounded and rounded ferruginous ironstone medium gravels; water repellent; pH 5.5 (soil paste); gradual boundary to:
B1c	20-50	Yellowish red (5YR 5/6 moist) coarse sandy clay loam (coarse sand is mostly fine ironstone gravel nodules); no mottles; moderately moist soil; apedal, massive structure; earthy fabric; 15% subrounded and rounded ferruginous ironstone medium gravels; pH 6 (soil paste); gradual boundary to:
B2tc	50-80+	Red (2.5YR 4/6 moist) sandy light clay; no mottles; moist soil; 10% ferruginous ironstone fine gravels; pH 6.5 (soil paste).

Laboratory analyses – SCH 0100

<i>Depth (cm)</i>	<i>% Coarse frags</i>	<i>EC (1:5) mS/m</i>	<i>pH (H₂O)</i>	<i>pH (CaCl₂)</i>	<i>Al (CaCl₂) mg/kg</i>	<i>OrgC (W/B) %</i>	<i>N (total) %</i>	<i>P (total) mg/kg</i>	<i>P (HCO₃) mg/kg</i>	<i>K (HCO₃) mg/kg</i>
0-10	14	14	6.4	5.5		4.72	0.36	430	16	440
10-20	19	4	6.8	5.8		1.52	0.101	130	3	57
20-40	25	3	7.0	6.2		0.75	0.047	76	2	44
60-80	7	3	7.4	6.6		0.38	0.024	88	2	56
60-80		3	6.9	6.1		0.47	0.026	360	2	69

<i>Depth (cm)</i>	<i>P (PRI) mL/g</i>	<i>CEC (NH₄Cl) me%</i>	<i>Ca (exch) me%</i>	<i>Mg (exch) me%</i>	<i>Na (exch) me%</i>	<i>K (exch) me%</i>	<i>Al (exch) me%</i>	<i>Mn (exch) me%</i>	<i>Sand %</i>	<i>Silt %</i>	<i>Clay %</i>
60-80	810	2	1.8	0.74	0.11	0.18			68.5	8.5	23

Profile: SCH 0102**WA Soil Group:** Friable red/brown loamy earth (neutral subsoil)**Australian Soil Classification:** Haplic Red Kandosol

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20, 20-40 and 80-100 cm

Location: GDA94 Zone 50 – 422200 mE, 6161296 mN**Site description:***Landform:* Mid-slope (with gradient of 13%) on undulating low hills*Disturbance:* Extensive clearing for pasture*Rock outcrop:* Very slightly rocky. Gneiss scattered across slope; 2 m away rock was struck at 25 cm*Surface condition:* Loose to soft**Soil Profile Description – SCH 0102**

Horizon	Depth (cm)	Description
A1	0-10	Reddish brown (2.5YR 4/3 moist) sandy loam; no mottles; dry soil; pedal, moderate, crumb structure; rough-ped fabric; 5% coarse fragments; water repellent; pH 5.5 (soil paste); clear boundary to:
A31	10-20	Red (2.5YR 4/6 moist) sandy loam; no mottles; dry soil; apedal, massive structure; earthy fabric; few; pH 6 (soil paste); gradual boundary to:
A32	20-40	Dark red (2.5YR 3/6 moist) sandy clay loam; no mottles; dry soil; apedal, massive structure; earthy fabric; 2% gneiss fragments; pH 6 (soil paste); gradual boundary to:
B1	40-60	Red (2.5YR 4/8 moist) sandy clay loam; moderately moist soil; apedal, massive structure; earthy fabric; diffuse boundary to:
B2	60-100+	Red (2.5YR 4/8 moist) sandy clay loam; moist soil; 20% gneiss fragments. Contains large rotten tree roots at 60-80 cm.

Laboratory analyses – SCH 0102

Depth (cm)	% Coarse frags	EC (1:5) mS/m	pH (H₂O)	pH (CaCl₂)	Al (CaCl₂) mg/kg	OrgC (W/B) %	N (total) %	P (total) mg/kg	P (HCO₃) mg/kg	K (HCO₃) mg/kg
0-2	6	18	6.3	5.7		5.18	0.431	700	23	150
0-10	8	13	6.0	5.4		3.77	0.298	520	16	79

Profile: SCH 0109**WA Soil Group:** Brown deep loamy duplex (neutral subsoil)**Australian Soil Classification:** Subnatric Mesotrophic Yellow Sodosol

Described by Peter Tille on 1-Apr-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 15-25, 25-40 and 60-80 cm

Location: GDA94 Zone 50 – 422988 mE, 6161017 mN

Close to middle of the centre pivot

Site description:

Landform: Mid-slope (with gradient of 7%) on undulating low hills. Gradient upslope is 10% and 5% downslope

Disturbance: Extensive clearing for pasture

Rock outcrop: No rock outcrop

Surface coarse fragments: None

Surface condition: Soft

Soil Profile Description – SCH 0109

Horizon	Depth (cm)	Description
A1	0-15	Very dark brown (7.5YR 2.5/2 moist) sandy loam; no mottles; apedal, moderate, crumb structure; 5% ferruginous ironstone fine gravels; non-water repellent; pH 5.5 (soil paste).
A31	15-25	Strong brown (7.5YR 5/8 moist) clayey sand; no mottles; apedal, massive structure; sandy to earthy fabric; 10% ferruginous ironstone medium gravels; non-water repellent; pH 5.75 (soil paste).
A32	25-60	Strong brown (7.5YR 5/6 moist) medium sandy loam; no mottles; 25% subrounded ferruginous ironstone medium gravels; non-water repellent; pH 6 (soil paste).
B2t	60-80+	Reddish yellow (7.5YR 6/8 moist) sandy clay; non-water repellent; pH 6 (soil paste).

Laboratory analyses – SCH 0109

Depth (cm)	% Coarse frags	EC (1:5) mS/m	pH (H₂O)	pH (CaCl₂)	Al (CaCl₂) mg/kg	OrgC (W/B) %	N (total) %	P (total) mg/kg	P (HCO₃) mg/kg	K (HCO₃) mg/kg
0-2	0	14	6.4	5.5		4.46	0.305	420	32	170
0-10	17	12	6.3	5.4		3.22	0.214	270	14	100
15-25	20	4	6.2	5.2		0.91	0.047	78	2	<10
25-40	41	2	6.3	5.3		0.48	0.028	67	<2	62
60-80	12	2	6.5	5.6		0.31	0.019	55	2	<10

Depth (cm)	P (PRI) mL/g	CEC (NH₄Cl) me%	Ca (exch) me%	Mg (exch) me%	Na (exch) me%	K (exch) me%	Al (exch) me%	Mn (exch) me%	Sand %	Silt %	Clay %
60-80	77	<1	0.74	0.43	0.09	0.05			74	6	20

Profile: SCH 0128**WA Soil Group:** Wet soil (loamy duplex)**Australian Soil Classification:** Chromosolic Hydrosol

Described by Peter Tille on 29-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 423552 mE, 6162281 mN

Water seeping on surface 3 m downslope

Site description:*Landform:* Foothlope (gradient 3%) of open depression (vale) on undulating low hills*Disturbance:* Extensive clearing for pasture*Surrounding vegetation:* Peppermints, ti-trees, karri, bracken and rushes*Rock outcrop:* No rock outcrop*Surface coarse fragments:* None*Surface condition:* Soft**Soil Profile Description – SCH 0128**

<i>Horizon</i>	<i>Depth (cm)</i>	<i>Description</i>
A1	0-10	Dark brown fine sandy loam; wet soil; no coarse fragments.
B	10-30+	Brown light clay; wet soil; no coarse fragments. Soil too claggy to auger further.

Pale deep sands

Profile: SCH 0103

WA Soil Group: Pale deep sand

Australian Soil Classification: Possibly an Aeric Podsol (depending on the nature of horizons below 100 cm)

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20, 20-40 and 70-90 cm

Location: GDA94 Zone 50 – 422599 mE, 6161570 mN

Site description:

<i>Landform:</i>	Mid-slope (with gradient of 10%) on undulating low hills. Profile situated in slight concavity
<i>Disturbance:</i>	Extensive clearing for pasture. Surface extensively disturbed by cow hooves. Manure has been spread upslope but not on this site
<i>Surrounding vegetation:</i>	Peppermints
<i>Rock outcrop:</i>	No rock outcrop
<i>Surface coarse fragments:</i>	None
<i>Surface condition:</i>	Water repellent; loose

Soil Profile Description – SCH 0103

<i>Horizon</i>	<i>Depth (cm)</i>	<i>Description</i>
A11	0-2	Black (10YR 2/1 moist) loamy medium sand; no mottles; loose dry consistence; apedal, single grain structure; sandy fabric; no coarse fragments; strongly water repellent; disturbed by cattle hooves, appears white on surface; abrupt boundary to:
A12	2-12	Black (10YR 2/1 moist) loamy medium sand; no mottles; weak dry consistence; apedal, massive to weak, crumb structure; sandy fabric; no coarse fragments; strongly water repellent; pH 4.75 (soil paste).
A21	12-20	Dark grey (10YR 4/1 moist) medium sand; no mottles; weak dry consistence; apedal, massive structure; sandy fabric; no coarse fragments; water repellent; pH 4.75 (soil paste).
A22	20-70	Grey (10YR 5/1 moist) medium sand; no mottles; apedal; sandy fabric; no coarse fragments; pH 4.75 (soil paste).
B1	70-100+	Brown (10YR 5/3 moist) medium sand; apedal; sandy fabric.

Laboratory analyses – SCH 0103

<i>Depth (cm)</i>	<i>% Coarse frags</i>	<i>EC (1:5) mS/m</i>	<i>pH (H₂O)</i>	<i>pH (CaCl₂)</i>	<i>Al (CaCl₂) mg/kg</i>	<i>OrgC (W/B) %</i>	<i>N (total) %</i>	<i>P (total) mg/kg</i>	<i>P (HCO₃) mg/kg</i>	<i>K (HCO₃) mg/kg</i>
0-2	3	10	5.5	4.6		4.15	0.195	140	20	89
0-10	2	6	5.2	4.3		3.74	0.162	78	7	36

Profile: SCH 0104**WA Soil Group:** Grey deep sandy duplex**Australian Soil Classification:** Subnatric Mesotrophic Sodosol

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-15, 15-20, 20-40 and 60-80 cm

Location: GDA94 Zone 50 – 422559 mE, 6160880 mN

Just below the new effluent pit

Site description:*Landform:* Lower slope of undulating low hills*Disturbance:* Extensive clearing for pasture*Surrounding vegetation:* Peppermints*Rock outcrop:* No rock outcrop*Surface coarse fragments:* None**Soil Profile Description – SCH 0104**

Horizon	Depth (cm)	Description
A1	0-10	Very dark grey (10YR 3/1 moist) sandy loam; no mottles; dry soil; weak, crumb to single grain structure; sandy fabric; no coarse fragments; pH 5.75 (soil paste); very high organic matter content; clear boundary to:
?	10-15	White (10YR 8/2 moist) loamy sand; no mottles; dry soil; weak, crumb to single grain structure; sandy fabric; no coarse fragments; pH 7.75 (soil paste); moderate organic matter content; seems to contain ash of some other material; clear boundary to:
A21	15-20	Light grey (10YR 7/1 moist) sand; no mottles; dry soil; apedal, massive structure; sandy fabric; no coarse fragments; pH 6 (soil paste); clear boundary to:
A22	20-50	Light grey (10YR 7/2 moist) loamy sand; dry soil; apedal, massive structure; sandy fabric; no coarse fragments; pH 5.75 (soil paste).
A3	50-70	Light yellowish brown (10YR 6/4 moist) sandy loam; moist soil; apedal, massive structure; 5% coarse fragments.
B2t	70-80+	Sandy clay loam; moist soil.

Laboratory analyses – SCH 0104

Depth (cm)	% Coarse frags	EC (1:5) mS/m	pH (H₂O)	pH (CaCl₂)	Al (CaCl₂) mg/kg	OrgC (W/B) %	N (total) %	P (total) mg/kg	P (HCO₃) mg/kg	K (HCO₃) mg/kg
0-2	1	21	6.6	5.7		4.72	0.417	610	130	480
0-10	3	14	6.9	5.8		3.1	0.289	520	130	360
10-15	4	17	8.3	7.7		0.94	0.086	260	51	260
15-20	3	6	7.5	6.8		0.68	0.048	71	16	94
20-40	1	3	6.4	5.3		0.23	0.019	46	7	83
50-80	13	6	5.9	4.8		0.5	0.035	51	7	190

Depth (cm)	P (PRI) mL/g	CEC (NH₄Cl) me%	Ca (exch) me%	Mg (exch) me%	Na (exch) me%	K (exch) me%	Al (exch) me%	Mn (exch) me%	Sand %	Silt %	Clay %
50-80	110		0.61	0.3	0.14	0.44	0.15	0.02	79.5	5	15.5

Profile: SCH 0105**WA Soil Group:** Pale deep sand**Australian Soil Classification:** Possibly an Aeric Podosol (depending on the nature of horizons below 100 cm)

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 422325 mE, 6160889 mN

Situated in the sandy bull paddock

Site description:*Landform:* Mid-slope on undulating low hills*Disturbance:* Extensive clearing for pasture*Surrounding vegetation:* Peppermints*Rock outcrop:* No rock outcrop*Surface coarse fragments:* None*Surface condition:* Loose**Soil Profile Description – SCH 0105**

Horizon	Depth (cm)	Description
A1	0-10	Black (10YR 2/1 moist) fine sandy loam; no mottles; moist soil; apedal, single grain structure; sandy fabric; no coarse fragments.
A21	10-70	Dark grey (10YR 4/1 moist) fine sand; no mottles; moist soil; apedal, single grain structure; sandy fabric; no coarse fragments.
A22	70-95	Light grey (10YR 7/1 moist) fine sand; no mottles; moist soil; apedal, single grain structure; sandy fabric.
B1	95-100+	Light brownish grey (10YR 6/2 moist) fine sand; many faint light grey (10YR 7/1 moist) mottles; moist soil; apedal; sandy fabric; no coarse fragments.

Profile: SCH 0106**WA Soil Group:** Pale deep sand**Australian Soil Classification:** Aeric Podosol

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20, 20-40 and 70-90 cm

Location: GDA94 Zone 50 – 422500 mE, 6160833 mN**Site description:**

Landform: Upper slope (with gradient of 9%) on undulating low hills
Disturbance: Extensive clearing for pasture
Surrounding vegetation: Peppermints
Rock outcrop: No rock outcrop
Surface coarse fragments: None
Surface condition: Water repellent; loose

Soil Profile Description – SCH 0106

<i>Horizon</i>	<i>Depth (cm)</i>	<i>Description</i>
A1	0-10	Black (10YR 2/1 moist) loamy sand; no mottles; single grain, weak, crumb structure; sandy fabric; no coarse fragments; water repellent, non-calcareous; pH 4.75 (soil paste); high organic matter content; clear boundary to:
A2	10-20	Brown (10YR 5/3 moist) loamy sand; no mottles; single grain, weak, polyhedral structure; sandy fabric; no coarse fragments; water repellent; pH 5 (soil paste); low organic matter content; gradual boundary to:
B11	20-60	Brownish yellow (10YR 6/6 moist) clayey sand; no mottles; apedal, massive structure; sandy fabric; no coarse fragments; pH 5.25 (soil paste); hard to dig; gradual boundary to:
B12c	60-90+	Brownish yellow (10YR 6/6 moist) clayey sand; 15% subrounded ferruginous ironstone medium gravels; pH 5.75 (soil paste).

Laboratory analyses – SCH 0106

<i>Depth (cm)</i>	<i>% Coarse frags</i>	<i>EC (1:5) mS/m</i>	<i>pH (H₂O)</i>	<i>pH (CaCl₂)</i>	<i>Al (CaCl₂) mg/kg</i>	<i>OrgC (W/B) %</i>	<i>N (total) %</i>	<i>P (total) mg/kg</i>	<i>P (HCO₃) mg/kg</i>	<i>K (HCO₃) mg/kg</i>
0-2	5	28	5.4	4.6		4.5	0.384	490	84	360
0-10	5	16	5.4	4.6		3.36	0.299	410	71	230

Profile: SCH 0107**WA Soil Group:** Pale deep sand**Australian Soil Classification:** Aeric Podosol

Described by Peter Tille on 1-Apr-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20, 20-40 and 60-90 cm

Location: GDA94 Zone 50 – 422966 mE, 6161317 mN**Site description:**

Landform: Mid to upper slope (with gradient of 7.5%) on undulating low hills. Site in a bit of a concavity

Disturbance: Extensive clearing for pasture

Surrounding vegetation: Peppermints

Surface condition: Water repellent; loose

Soil Profile Description – SCH 0107

Horizon	Depth (cm)	Description
A11	0-10	Black (10YR 2/1 moist) loamy medium sand; no mottles; dry soil; weak, crumb to massive, single grain structure; sandy fabric; no coarse fragments; strongly water repellent; pH 5 (soil paste); high organic matter content.
A12	10-20	Very dark grey (10YR 3/1 moist) loamy medium sand; no mottles; dry soil; massive to weak, polyhedral structure; sandy fabric; no coarse fragments; water repellent; pH 4.5 (soil paste); moderate organic matter content.
A2	20-50	Grey (10YR 5/1 moist) sand; no mottles; dry soil; sandy fabric; no coarse fragments; non-water repellent; pH 4.5 (soil paste); low organic matter content; gradual boundary to:
B11	50-60	Very dark greyish brown (10YR 3/2 moist) loamy sand (medium to coarse sand grains); no mottles; dry soil; sandy fabric; water repellent; high organic matter content.
B12	60-90+	Very dark greyish brown (10YR 3/2 moist) loamy sand (medium to coarse sand grains); no mottles; dry soil; massive structure; moderately cemented; water repellent; pH 4.75 (soil paste); high organic matter content; coffee rock, difficult (but not impossible) to auger.

Laboratory analyses – SCH 0107

Depth (cm)	% Coarse frags	EC (1:5) mS/m	pH (H₂O)	pH (CaCl₂)	Al (CaCl₂) mg/kg	OrgC (W/B) %	N (total) %	P (total) mg/kg	P (HCO₃) mg/kg	K (HCO₃) mg/kg
0-2	2	26	6.5	5.7		8.31	0.524	300	19	450
0-10	3	1	5.1	4.2		6.27	0.361	200	17	360
10-20	1	3	5.0	3.6		3.21	0.103	61	2	45
20-40	1	2	4.7	3.3		1.6	0.046	46	<2	24
60-90	5	12	6.0	5.1		1.7	0.065	66	19	12

Profile: SCH 0110**WA Soil Group:** Grey deep sandy duplex (poor subsoil)**Australian Soil Classification:** Dystrorphic Brown Kurosol

Described by Peter Tille on 1-Apr-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20, 20-40, 40-60 and 60-80 cm

Location: GDA94 Zone 50 – 422754 mE, 6161302 mN**Site description:**

Landform: Mid to lower slope (with gradient of 7%) on undulating low hills
Disturbance: Extensive clearing for pasture
Rock outcrop: No rock outcrop
Surface coarse fragments: None
Surface condition: Soft to loose; water repellent. Soil downslope is gravelly

Soil Profile Description – SCH 0110

Horizon	Depth (cm)	Description
A1	0-10	Black (7.5YR 2.5/1 moist) loamy sand (fine to medium sand grains); no mottles; dry soil; no coarse fragments; strongly water repellent; pH 5 (soil paste); very high organic matter content.
A21	10-20	Grey (7.5YR 6/1 moist) loamy sand (fine to medium sand grains); no mottles; dry soil; 1% angular quartz fine gravels; water repellent; pH 4.5 (soil paste).
A22	20-40	Grey (7.5YR 5/1 moist) coarse sandy loam (fine to coarse sand grains); dry soil; 2% subrounded ferruginous ironstone fine gravels and 3% angular siliceous quartz fine gravels; water repellent; pH 4.75 (soil paste).
B11	40-60	Grey (7.5YR 5/1 moist) loamy sand (fine to coarse sand grains); dry soil; apedal, massive structure; sandy fabric; 2% subrounded ferruginous ironstone fine gravels and 2% angular siliceous quartz fine gravels; pH 5.5 (soil paste).
B12	60-80+	Brown (7.5YR 4/4 moist) coarse sandy clay (coarse sand grains); dry soil; massive structure; weakly cemented; pH 5.5 (soil paste); harder to dig.

Laboratory analyses – SCH 0110

Depth (cm)	% Coarse frags	EC (1:5) mS/m	pH (H₂O)	pH (CaCl₂)	Al (CaCl₂) mg/kg	OrgC (W/B) %	N (total) %	P (total) mg/kg	P (HCO₃) mg/kg	K (HCO₃) mg/kg
0-2	1	22	5.8	4.6		6.66	0.494	480	100	670
0-10	2	10	5.3	4.2		5.38	0.306	300	48	220
10-20	1	2	5.1	4.0		1.49	0.073	120	28	26
20-40	6	2	5.0	4.0		1.02	0.047	140	57	14
40-60	2	3	4.9	3.9		1.51	0.081	220	97	23
60-80	1	3	5.0	4.5	12	2.09	0.067	100	5	16

Depth (cm)	P (PRI) mL/g	CEC (NH₄Cl) me%	Ca (exch) me%	Mg (exch) me%	Na (exch) me%	K (exch) me%	Al (exch) me%	Mn (exch) me%	Sand %	Silt %	Clay %
60-80	>1000		0.3	0.06	0.04	0.04	1.14	<0.02	81	5.5	13.5

Profile: SCH 0135**WA Soil Group:** Pale deep sand (poor sand, very deep)**Australian Soil Classification:** Aeric Podosol

Described by Peter Tille on 29-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 423031 mE, 6161725 mN**Site description:**

Landform: Mid to upper slope (with gradient of 12%) on undulating low hills. Slope gradient upslope is 8% and 15% downslope

Disturbance: Extensive clearing for pasture

Surrounding vegetation: *Kingia australis* present downslope

Rock outcrop: No rock outcrop

Surface coarse fragments: None

Surface condition: Loose

Soil Profile Description – SCH 0135

Horizon	Depth (cm)	Description
A1	0-10	Black (10YR 2/1 moist) loamy sand (fine to medium sand grains); no mottles; sandy fabric; no coarse fragments; pH 5.5 (soil paste).
A21	10-70	Dark grey (10YR 4/1 moist) sand (fine to medium sand grains); no mottles; apedal; sandy fabric; no coarse fragments; pH 5.5 (soil paste).
A22	70-190	Light grey (10YR 7/1 moist) sand (fine to medium sand grains); no mottles; apedal; sandy fabric; no coarse fragments; pH 6 (soil paste).
B	190-200+	Very dark brown (10YR 2/2 moist) loamy coarse sand; no mottles; weakly cemented; 10% ferruginous ironstone; pH 4.5 (soil paste); loose coffee rock, easy to dig.

Profile: SCH 0136**WA Soil Group:** Pale shallow sand**Australian Soil Classification:** Aeric Podosol

Described by Peter Tille on 29-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 422917 mE, 6161920 mN**Site description:***Landform:* Crest of ridge spur on undulating low hills*Disturbance:* Extensive clearing for pasture*Surrounding vegetation:* Marri, peppermint, jarrah*Rock outcrop:* No rock outcrop*Surface coarse fragments:* None*Surface condition:* Loose**Soil Profile Description – SCH 0136**

Horizon	Depth (cm)	Description
A1	0-20	Black (10YR 2/1 moist) sand; no mottles; no coarse fragments.
A2	20-60	Grey (10YR 5/1 moist) sand; no mottles; no coarse fragments.
B1	60-65	Very dark brown (10YR 2/3 moist) loamy sand; no mottles; no coarse fragments; loose coffee rock.
B2	65-??	Indurated horizon.
C	??-300	Mottled yellow clay layer exposed in nearby pit.

Profile: SCH 0137**WA Soil Group:** Pale sandy earth**Australian Soil Classification:** may be a Bleached-Orthic Tenosol

Described by Peter Tille on 29-Apr-2004 from a hand-augered profile

No samples taken.

Location: GDA94 Zone 50 – 422357 mE, 6161702 mN**Site description:**

Landform: Mid-slope (with gradient of 21%) on undulating low hills. Gradient upslope is 18% and 25% downslope. Red/brown sand appears just downslope

Disturbance: Extensive clearing for pasture

Surrounding vegetation: Peppermints

Rock outcrop: No rock outcrop

Surface coarse fragments: None

Surface condition: Loose

Soil Profile Description – SCH 0137

Horizon	Depth (cm)	Description
A1	0-20	Dark grey loamy sand; no mottles; no coarse fragments.
A2	20-30	Pale grey sand; no mottles; no coarse fragments.
B1	30-60	Red sand; no mottles; no coarse fragments.
B2	60-75+	Brown sandy loam; no mottles; no coarse fragments.

Profile: SCH 0139**WA Soil Group:** Pale deep sand**Australian Soil Classification:** Insufficient data on subsoil to classify

Described by Peter Tille on 30-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 422318 mE, 6162078 mN**Site description:***Landform:* Lower slope on undulating low hills*Disturbance:* Extensive clearing for pasture*Rock outcrop:* No rock outcrop*Surface coarse fragments:* None*Surface condition:* Water repellent; loose**Soil Profile Description – SCH 0139**

Horizon	Depth (cm)	Description
A11	0-15	Black (10YR 2/1 moist) loamy sand (fine to medium sand grains); no mottles; single grain, weak, crumb structure; sandy fabric; no coarse fragments; water repellent; high organic matter content.
A12	15-40	Very dark grey (10YR 3/1 moist) sand (fine to medium grains); no mottles; apedal, single grain structure; sandy fabric; no coarse fragments; moderate organic matter content.
A2	40-100+	Light brownish grey (10YR 6/2 moist) fine sand; no mottles; sandy fabric; no coarse fragments.

Loamy gravels

Profile: SCH 0108

WA Soil Group: Loamy gravel (neutral subsoil)

Australian Soil Classification: Ferric Yellow Dermosol

Described by Peter Tille on 1-Apr-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20, 20-40 and 40-60 cm

Location: GDA94 Zone 50 – 423542 mE, 6161265 mN

Site description:

Landform: Upper slope (with gradient of 3%) on undulating low hills

Disturbance: Extensive clearing for pasture

Surrounding vegetation: Jarrah, marri, peppermint

Rock outcrop: No rock outcrop

Surface coarse fragments: None

Surface condition: Water repellent; soft

Soil Profile Description – SCH 0108

Horizon	Depth (cm)	Description
A1	0-5	Black (7.5YR 2.5/1 moist) loam; no mottles; pedal, moderate, crumb structure; rough-ped fabric; 20% subrounded and rounded ferruginous ironstone medium and fine gravels; water repellent; pH 5.5 (soil paste); clear boundary to:
A3	5-20	Strong brown (7.5YR 4/5 moist) sandy loam; no mottles; pedal, weak, subangular blocky structure; rough-ped fabric; 15% coarse fragments; non-water repellent; pH 5 (soil paste); gradual boundary to:
B1	20-60	Brown (7.5YR 5/4 moist) sandy clay loam; no mottles; pedal, weak, subangular blocky to massive structure; rough-ped fabric; 15% coarse fragments; non-water repellent; pH 6 (soil paste); clear boundary to:
B2t	60-80+	Reddish yellow (7.5YR 6/8 moist) light medium clay; pedal; 10% coarse fragments; non-water repellent; pH 7 (soil paste); appears to be well structured; getting towards weathered rock.

Laboratory analyses – SCH 0108

Depth (cm)	% Coarse frags	EC (1:5) mS/m	pH (H ₂ O)	pH (CaCl ₂)	Al (CaCl ₂) mg/kg	OrgC (W/B) %	N (total) %	P (total) mg/kg	P (HCO ₃) mg/kg	K (HCO ₃) mg/kg
0-2	7	37	5.6	5.1		4.95	0.355	290	25	160
0-10	15	11	5.7	5.0		3.37	0.214	190	10	64

Profile: SCH 0126**WA Soil Group:** Loamy gravel (acidic subsoil)**Australian Soil Classification:** Ferric Red Kurosol

Described by Peter Tille on 29-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 423153 mE, 6162413 mN**Site description:**

Landform: Mid-slope (with gradient of 12%) on undulating low hills. Upslope gradient is 10% and 14% downslope

Disturbance: Extensive clearing for pasture

Surrounding vegetation: Peppermints

Rock outcrop: No rock outcrop

Surface coarse fragments: Few (5%) ironstone fine gravels

Surface condition: Water repellent; soft

Soil Profile Description – SCH 0126

Horizon	Depth (cm)	Description
A1	0-25	Dark reddish brown (2.5YR 3/3 moist) loamy fine sand; no mottles; moist soil; pedal, moderate, crumb structure; rough-ped fabric; 20% subrounded ferruginous ironstone medium gravels 2-20 mm; pH 5.5 (soil paste); high organic matter content; clear boundary to:
B1	25-50	Reddish brown (2.5YR 4/4 moist) clay loam; no mottles; moist soil; pedal, moderate, subangular blocky structure; rough-ped fabric; 40% subrounded ferruginous ironstone medium gravels 2-25 mm; pH 5.5 (soil paste); gradual boundary to:
B2	50-90+	Red (2.5YR 5/8 moist) light clay; few faint mottles; moist soil; pedal, moderate, subangular blocky structure; rough-ped fabric; 10% subrounded ferruginous ironstone fine gravels 2-10 mm; pH 5 (soil paste).

Profile: SCH 0130**WA Soil Group:** Loamy gravel**Australian Soil Classification:** Insufficient data on subsoil to classify

Described by Peter Tille on 29-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 424237 mE, 6161984 mN**Site description:**

Landform: Mid-slope (with gradient of 12%) on undulating low hills
Disturbance: Extensive clearing for pasture
Surrounding vegetation: Peppermints
Rock outcrop: No rock outcrop
Surface coarse fragments: None
Surface condition: Water repellent; soft

Soil Profile Description – SCH 0130

Horizon	Depth (cm)	Description
A1	0-10	Black (7.5YR 2.5/1 moist) sandy loam (fine to medium sand grains); no mottles; weak, crumb structure; sandy fabric; 5% subrounded and rounded ferruginous ironstone medium gravels 5-10 mm; strongly water repellent; pH 6 (soil paste); high organic matter content.
A31	10-35	Strong brown (7.5YR 4/6 moist) sandy loam (fine to medium sand grains); no mottles; apedal, single grain structure; sandy fabric; 40% subrounded and rounded ferruginous ironstone medium gravels 5-40 mm; water repellent; pH 6 (soil paste).
A32	35-60+	Strong brown (7.5YR 5/6 moist) sandy loam (fine to medium sand grains); apedal, single grain structure; sandy fabric; 30% subrounded and rounded ferruginous ironstone medium gravels; pH 6 (soil paste); too gravelly to auger below 60 cm.

Profile: SCH 0131**WA Soil Group:** Loamy gravel**Australian Soil Classification:** Ferric Brown Kandosol

Described by Peter Tille on 29-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 424621 mE, 6161706 mN**Site description:***Landform:* Mid-slope (with gradient of 17%) on undulating low hills. Gradient upslope is 15% and 20% downslope*Disturbance:* Extensive clearing for pasture. Hummocky, uneven land surface due to either removal tree of stumps or mass movement*Surrounding vegetation:* Marri, karri, peppermints*Rock outcrop:* No rock outcrop*Surface coarse fragments:* 10% ferruginous ironstone medium gravels*Surface condition:* Soft**Soil Profile Description – SCH 0131**

Horizon	Depth (cm)	Description
A1	0-10	Dark reddish brown (5YR 3/2 moist) sandy loam (fine to medium sand grains); no mottles; crumb structure; 40% subrounded ferruginous ironstone medium gravels 2-20 mm; pH 5 (soil paste).
B1	10-40	Yellowish red (5YR 4/6 moist) sandy clay loam (fine to medium sand grains); no mottles; weak, polyhedral structure; 30% subrounded ferruginous ironstone medium gravels 2-30 mm; pH 5.5 (soil paste).
B2	40-65+	Yellowish red (5YR 5/8 moist) light medium clay; massive structure; earthy fabric; 10% ferruginous ironstone medium gravels 2-20 mm; pH 6 (soil paste); stone prevented auger from digging deeper.

Profile: SCH 0141**WA Soil Group:** Loamy gravel (neutral subsoil)**Australian Soil Classification:** Ferric Eutrophic Brown Kandosol

Described by Peter Tille on 30-Apr-2004 from a hand-augered profile

Profile sampled at 0-10, 10-20, 20-40 and 50-70 cm

Location: GDA94 Zone 50 – 423117 mE, 6160917 mN

Just inside the southern extent of centre pivot

Site description:

Landform: Mid-slope (with gradient of 12.5%) on undulating low hills. Gradient upslope is 12% and 11% downslope

Disturbance: Extensive clearing for pasture

Surrounding vegetation: Karri forest with a bit of marri

Rock outcrop: No rock outcrop

Surface condition: Soft

Soil Profile Description – SCH 0141

Horizon	Depth (cm)	Description
A1	0-10	Dark reddish brown (5YR 3/4 moist) sandy loam; no mottles; pedal, crumb structure; rough-ped fabric; 25% subrounded and rounded ferruginous ironstone fine gravels 2-10 mm; non-water repellent; gradual boundary to:
A3	10-20	Reddish brown (5YR 4/4 moist) sandy clay loam; no mottles; pedal, moderate, 10-20 mm, subangular blocky structure; rough-ped fabric; 20% ferruginous ironstone medium gravels 2-15 mm; clear boundary to:
B1	20-50	Yellowish red (5YR 5/8 moist) sandy clay loam; no mottles; pedal, weak, subangular blocky to weak, polyhedral structure; earthy fabric; 25% rounded ferruginous ironstone medium gravels 5-15 mm.
B2	50-95+	Yellowish red (5YR 5/8 moist) sandy clay loam; common faint mottles; pedal, weak, polyhedral structure; earthy fabric; 25% subrounded ferruginous ironstone medium gravels 5-20 mm.

Laboratory analyses – SCH 0141

Depth (cm)	% Coarse frags	EC (1:5) mS/m	pH (H₂O)	pH (CaCl₂)	Al (CaCl₂) mg/kg	OrgC (W/B) %	N (total) %	P (total) mg/kg	P (HCO₃) mg/kg	K (HCO₃) mg/kg
0-10	14	31	6.3	5.7		5.96	0.47	690	48	540
10-20	23	8	6.6	5.8		2.90	0.166	210	5	88
20-40	29	4	6.8	6		0.82	0.043	76	2	14
50-70	32	2	7.1	6.3		0.77	0.054	91	2	12

Depth (cm)	P (PRI) mL/g	CEC- (NH₄Cl) me%	Ca (exch) me%	Mg (exch) me%	Na (exch) me%	K (exch) me%	Al (exch) me%	Mn (exch) me%	Sand %	Silt %	Clay %
10-20	390	9	8.39	0.41	0.22	0.24			80	9.5	10.5

Sandy gravels

Profile: SCH 0095

WA Soil Group: Shallow gravel (sandy matrix)

Australian Soil Classification: Insufficient data on subsoil to classify

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20 cm

Location: GDA94 Zone 50 – 423220 mE, 6161166 mN

On the gravel ridge above centre pivot

Site description:

<i>Landform:</i>	Upper slope (with gradient of 2.5%) on undulating low hills
<i>Disturbance:</i>	Extensive clearing for pasture
<i>Surrounding vegetation:</i>	Marri and jarrah woodland
<i>Rock outcrop:</i>	Very slightly rocky - ironstone very low to the ground and difficult to see
<i>Surface coarse fragments:</i>	Few (10%) ferruginous ironstone gravels
<i>Surface condition:</i>	Water repellent; loose

Soil Profile Description – SCH 0095

<i>Horizon</i>	<i>Depth (cm)</i>	<i>Description</i>
A1	0-10	Brown (7.5YR 4/2 moist) loamy fine sand; no mottles; dry soil; pedal, weak, crumb to single grain structure; sandy fabric; 40% subrounded ferruginous ironstone medium gravels; strongly water repellent; pH 5.5 (soil paste).
B1	10-35	Reddish yellow (7.5YR 6/6 moist) loamy fine sand; no mottles; dry soil; apedal, single grain structure; sandy fabric; 60% subrounded ferruginous ironstone medium gravels 5-40 cm; water repellent; pH 5.5 (soil paste); stopped by large ironstone.

Laboratory analyses – SCH 0095

<i>Depth (cm)</i>	<i>% Coarse frags</i>	<i>EC (1:5) mS/m</i>	<i>pH (H₂O)</i>	<i>pH (CaCl₂)</i>	<i>Al (CaCl₂) mg/kg</i>	<i>OrgC (W/B) %</i>	<i>N (total) %</i>	<i>P (total) mg/kg</i>	<i>P (HCO₃) mg/kg</i>	<i>K (HCO₃) mg/kg</i>
0-2	6	20	5.9	5.4		5.21	0.394	520	61	160
0-10	38	18	5.9	5.4		4.96	0.329	440	43	100

Profile: SCH 0096**WA Soil Group:** Shallow gravel (sandy matrix)**Australian Soil Classification:** Insufficient data on subsoil to classify

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20 and 20-40 cm

Location: GDA94 Zone 50 – 423120 mE, 6161288 mN

Along the rip line outside the northern edge of the proposed centre pivot extension

Site description:*Landform:* Mid-slope (with gradient of 7.5%) on undulating low hills*Disturbance:* Extensive clearing for pasture*Rock outcrop:* No rock outcrop*Surface coarse fragments:* Few (10%) ironstone gravels*Surface condition:* Water repellent**Soil Profile Description – SCH 0096**

<i>Horizon</i>	<i>Depth (cm)</i>	<i>Description</i>
A1	0-5	Sandy loam (fine sand grains); no mottles; dry soil; sandy fabric; strongly water repellent; pH 5 (soil paste).
A31	5-40	Clayey sand (fine to medium sand grains); no mottles; moist soil; single grain structure; sandy fabric; 60% subrounded and subangular ferruginous ironstone gravel and stones 2-100 mm; non-water repellent; pH 5.75 (soil paste).
A32	40-65+	Clayey sand (fine to medium sand grains); no mottles; moist soil; single grain structure; sandy fabric; no coarse fragments subrounded and subangular ferruginous ironstone coarse gravels gravel and stones 2-100 mm; non-water repellent; pH 5.75 (soil paste); stopped by large ironstone.

Laboratory analyses – SCH 0096

<i>Depth (cm)</i>	<i>% Coarse frags</i>	<i>EC (1:5) mS/m</i>	<i>pH (H₂O)</i>	<i>pH (CaCl₂)</i>	<i>Al (CaCl₂) mg/kg</i>	<i>OrgC (W/B) %</i>	<i>N (total) %</i>	<i>P (total) mg/kg</i>	<i>P (HCO₃) mg/kg</i>	<i>K (HCO₃) mg/kg</i>
0-2	13	22	6.0	5.5		6.45	0.462	560	69	220
0-10	37	16	5.9	5.3		5.21	0.368	480	47	88
10-20	53	3	5.8	5.0		0.91	0.054	100	6	<10
20-40	61	2	5.9	5.1		0.56	0.033	70	3	<10

Profile: SCH 0 097**WA Soil Group:** Stony soil (sandy matrix)**Australian Soil Classification:** Insufficient data on subsoil to classify

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20 and 20-40 cm

Location: GDA94 Zone 50 – 423096 mE, 6161242 mN

Within northern proposed centre pivot extension (5 m from edge of existing pivot)

Site description:*Landform:* Mid-slope (with gradient of 7.5%) on undulating low hills*Disturbance:* Extensive clearing for pasture*Rock outcrop:* No rock outcrop*Surface condition:* Water repellent**Soil Profile Description – SCH 0097**

Horizon	Depth (cm)	Description
A1	0-10	Brown (7.5YR 4/2 moist) loamy sand; no mottles; apedal; sandy fabric; 25% subrounded ferruginous ironstone; water repellent; pH 4.5 (soil paste); clear boundary to:
A31	10-20	Reddish yellow (7.5YR 6/6 moist) loamy sand; no mottles; apedal, single grain structure; sandy fabric; 50% subrounded ferruginous ironstone; non-water repellent; pH 5.5 (soil paste) ; gradual boundary to:
A32	20-40+	Reddish yellow (7.5YR 6/6 moist) clayey sand; no mottles; apedal, single grain structure; sandy fabric; 30% subrounded ferruginous ironstone; non-water repellent; pH 5.25 (soil paste); too stony to dig further.

Laboratory analyses – SCH 0097

Depth (cm)	% Coarse frags	EC (1:5) mS/m	pH (H₂O)	pH (CaCl₂)	AI (CaCl₂) mg/kg	OrgC (W/B) %	N (total) %	P (total) mg/kg	P (HCO₃) mg/kg	K (HCO₃) mg/kg
0-2	7	18	5.9	5.4		4.82	0.463	780	130	100
0-10	25	12	5.9	5.3		3.53	0.275	530	66	74
10-20	47	3	6.0	5.1		1.08	0.054	150	20	<10
20-40	38	3	5.9	5.0		1.05	0.058	130	12	10

Profile: SCH 0098**WA Soil Group:** Deep sandy gravel**Australian Soil Classification:** Insufficient data on subsoil to classify

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20 and 20-40 cm

Location: GDA94 Zone 50 – 423055 mE, 6161151 mN

Under the centre pivot (on the northern side)

Site description:*Landform:* Mid-slope (with gradient of 9.5%) on undulating low hills*Disturbance:* Extensive clearing for pasture*Rock outcrop:* No rock outcrop**Soil Profile Description – SCH 0098**

<i>Horizon</i>	<i>Depth (cm)</i>	<i>Description</i>
A1	0-10	Dark reddish brown (5YR 3/3 moist) sandy loam; no mottles; moist soil; pedal, moderate, crumb structure; sandy fabric; 20% subrounded ferruginous ironstone medium gravels 2-30 mm; non-water repellent; pH 5.5 (soil paste); clear boundary to:
A31	10-20	Yellowish red (5YR 5/6 moist) clayey sand; no mottles; moist soil; apedal, single grain structure; sandy fabric; 50% subrounded ferruginous ironstone medium gravels 2-30 mm; non-water repellent; pH 6 (soil paste); gradual boundary to:
A32	20-60+	Yellowish red (5YR 5/6 moist) clayey sand; no mottles; moist soil; apedal, single grain structure; sandy fabric; 50% subrounded ferruginous ironstone medium gravels 2-30 mm; non-water repellent; pH 5.5 (soil paste).

Laboratory analyses – SCH 0098

<i>Depth (cm)</i>	<i>% Coarse frags</i>	<i>EC (1:5) mS/m</i>	<i>pH (H₂O)</i>	<i>pH (CaCl₂)</i>	<i>Al (CaCl₂) mg/kg</i>	<i>OrgC (W/B) %</i>	<i>N (total) %</i>	<i>P (total) mg/kg</i>	<i>P (HCO₃) mg/kg</i>	<i>K (HCO₃) mg/kg</i>
0-2	18	23	6.6	5.8		5.62	0.361	490	49	360
0-10	29	13	6.7	5.8		3.76	0.218	320	21	250
10-20	69	4	6.5	5.5		1.31	0.068	100	2	28
20-40	69	3	6.1	5.0		1.03	0.045	69	2	10

Profile: SCH 0127**WA Soil Group:** Ironstone gravelly soils supergroup**Australian Soil Classification:** Insufficient data on subsoil to classify

Described by Peter Tille on 29-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 423350 mE, 6161927 mN**Site description:**

Landform: Upper slope of hillcrest (with gradient of 6%) on undulating low hills. Gradient upslope is 5% and 7% downslope

Disturbance: Extensive clearing for pasture

Surrounding vegetation: Marri and peppermints

Rock outcrop: Large laterite outcrop nearby

Surface coarse fragments: None

Soil Profile Description – SCH 0127

Horizon	Depth (cm)	Description
A1	0-15	Dark brown (7.5YR 3/2 moist) loamy sand; no mottles; apedal; sandy fabric; 50% subrounded and rounded ferruginous ironstone medium gravels 2-20 mm; pH 5 (soil paste); high organic matter content; clear boundary to:
A31	15-40	Reddish brown (5YR 4/4 moist) loamy sand (fine to medium sand grains); no mottles; apedal, single grain structure; sandy fabric; 50% subrounded and rounded ferruginous ironstone medium gravels 2-20 mm; pH 5.5 (soil paste); gradual boundary to:
A32	40-60+	Reddish yellow (5YR 6/6 moist) clayey sand (fine to medium sand grains); no mottles; apedal, single grain structure; sandy fabric; 60% subrounded and rounded ferruginous ironstone medium gravels 2-20 mm; too gravelly to auger any further.

Profile: SCH 0132**WA Soil Group:** Ironstone gravelly soils supergroup**Australian Soil Classification:** Insufficient data on subsoil to classify

Described by Peter Tille on 29-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 424461 mE, 6161105 mN**Site description:**

Landform: Upper slope of hillcrest (with gradient of 2%) on undulating low hills
Disturbance: Extensive clearing for pasture
Surrounding vegetation: Marri
Rock outcrop: No rock outcrop
Surface coarse fragments: None
Surface condition: Soft

Soil Profile Description – SCH 0132

Horizon	Depth (cm)	Description
A1	0-10	Very dark grey (10YR 3/1 moist) sandy loam (medium sand grains); no mottles; crumb structure; 15% subrounded ferruginous ironstone medium gravels; clear boundary to:
A31	10-50	Dark yellowish brown (10YR 4/6 moist) sandy loam (medium sand grains); no mottles; very weak consistence; apedal, massive, single grain structure; sandy fabric; 40% subrounded ironstone medium gravels 5-30 mm; gradual boundary to:
A32	50-65+	Yellowish brown (10YR 5/6 moist) sandy loam (medium sand grains) – almost a clayey sand; no mottles; 50% ferruginous ironstone medium gravels 5-30 mm; too gravelly to auger below 65 cm.

Profile: SCH 0133**WA Soil Group:** Deep sandy gravel**Australian Soil Classification:** Insufficient data on subsoil to classify

Described by Peter Tille on 29-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 423878 mE, 6161840 mN**Site description:**

Landform: Upper slope of hillcrest (with gradient of 2%) on undulating low hills. Gradient increases to 10% downslope

Disturbance: Extensive clearing for pasture

Surrounding vegetation: Marri, jarrah

Rock outcrop: No rock outcrop

Surface coarse fragments: None

Surface condition: Water repellent; soft

Soil Profile Description – SCH 0133

Horizon	Depth (cm)	Description
A1	0-10	Dark reddish brown (5YR 3/2 moist) fine sandy loam; weak, crumb structure; 40% subrounded ferruginous ironstone; high organic matter content.
A3	10-60	Yellowish red (5YR 5/8 moist) clayey sand; very weak consistence; apedal, single grain to massive structure; sandy fabric; 40% subrounded ferruginous ironstone.
B1	60-80+	Yellowish red (5YR 4/6 moist) sandy loam; very weak consistence; apedal, single grain to massive structure; sandy fabric; 30% subrounded ferruginous ironstone.

Profile: SCH 0140**WA Soil Group:** Ironstone gravelly soils supergroup**Australian Soil Classification:** Insufficient data on subsoil to classify

Described by Peter Tille on 30-Apr-2004 from a hand-augered profile

Profile sampled at 0-10, 10-20 and 20-40 cm

Location: GDA94 Zone 50 – 423232 mE, 6161367 mN

Just inside northern edge of the centre pivot

Site description:*Landform:* Mid-slope (with gradient of 10%) on undulating low hills*Disturbance:* Extensive clearing for pasture*Rock outcrop:* No rock outcrop*Surface condition:* Soft**Soil Profile Description – SCH 0140**

Horizon	Depth (cm)	Description
A1	0-10	Very dark brown (7.5YR 2.5/2 moist) loamy sand (medium sand grains); no mottles; weak, crumb structure; sandy fabric; 25% subrounded and rounded ferruginous ironstone medium gravels 2-35 mm; non-water repellent; pH 4.75 (soil paste); high organic matter content.
A31	10-20	Dark yellowish brown (10YR 4/6 moist) loamy sand (medium sand grains);; no mottles; very weak consistence; apedal, single grain to massive structure; sandy fabric; 50% ferruginous ironstone medium gravels 2-35 mm; pH 4.75 (soil paste); low organic matter content.
A32	20-60+	Yellowish brown (10YR 5/6 moist) clayey sand (medium sand grains); no mottles; apedal; sandy fabric; 40% ferruginous ironstone medium gravels 2-40 mm; pH 4.75 (soil paste); also contains some large stones; too gravelly or stony to dig below 60 cm.

Laboratory analyses – SCH 0140

Depth (cm)	% Coarse frags	EC (1:5) mS/m	pH (H₂O)	pH (CaCl₂)	Al (CaCl₂) mg/kg	OrgC (W/B) %	N (total) %	P (total) mg/kg	P (HCO₃) mg/kg	K (HCO₃) mg/kg
0-10	26	35	5.7	5.2		3.72	0.212	460	110	330
10-20	46	7	5.7	4.8		1.99	0.090	140	9	49
20-40	64	3	6.3	5.1		1.10	0.046	76	4	24

Other profiles

Profile: SCH 0101

WA Soil Group: Brown deep sand

Australian Soil Classification: Orthic Tenosol?

Described by Peter Tille on 31-Mar-2004 from a hand-augered profile

Profile sampled at 0-2, 0-10, 10-20, 20-40, 50-60, 70-80 and 80-100 cm

Location: GDA94 Zone 50 – 422983 mE, 6160902 mN

Under the southern portion of centre pivot - just outside second wheel rut from centre

Site description:

Landform: Mid-slope (with gradient of 10%) on undulating low hills. Profile is just off a slight concavity and may be accumulating sediment

Disturbance: Extensive clearing for pasture

Rock outcrop: No rock outcrop

Surface coarse fragments: None

Surface condition: Soft

Soil Profile Description – SCH 0101

Horizon	Depth (cm)	Description
A1	0-12	Very dark grey (7.5YR 3/1 moist) sandy loam (fine to medium sand grains); no mottles; moist soil; weak, crumb structure; sandy fabric; 2% medium gravels; non-calcareous; pH 6.5 (soil paste); very high organic matter content; clear boundary to:
A31	12-25	Brown (7.5YR 4/4 moist) clayey sand (fine to medium sand grains); no mottles; very weak moist consistence; massive, single grain structure; sandy fabric; 2% medium gravels; non-calcareous; pH 5.5 (soil paste); gradual boundary to:
A32	25-50	Yellowish red (5YR 5/5 moist) clayey sand (fine to medium sand grains); no mottles; very weak moist consistence; massive, single grain structure; sandy fabric; 2% medium gravels; non-calcareous; clear boundary to:
2A1	50-60	Dark reddish brown (5YR 3/2 moist) sandy loam (fine to medium sand grains); no mottles; moist soil; single grain, massive structure; sandy fabric; 5% medium gravels; pH 5.75 (soil paste); high organic matter content; may be buried A horizon; clear boundary to:
2A3	60-80	Strong brown (7.5YR 5/8 moist) clayey sand (fine to medium sand grains); moist soil; sandy fabric; no coarse fragments; pH 6 (soil paste); gradual boundary to:
2B1	80-105+	Yellowish red (5YR 5/8 moist) sandy loam (fine to medium sand grains); moist soil; 25% ferruginous ironstone.

Laboratory analyses – SCH 0101

Depth (cm)	% Coarse frags	EC (1:5) mS/m	pH (H ₂ O)	pH (CaCl ₂)	Al (CaCl ₂) mg/kg	OrgC (W/B) %	N (total) %	P (total) mg/kg	P (HCO ₃) mg/kg	K (HCO ₃) mg/kg
0-2		20	6.0	5.2		5.62	0.431	530	28	520
0-10	7	16	6.6	5.7		3.27	0.230	380	36	280

Profile: SCH 0129**WA Soil Group:** Yellow/brown deep sandy duplex**Australian Soil Classification:** Yellow Chromosol, Kurosol or Sodosol

Described by Peter Tille on 29-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 423737 mE, 6162179 mN**Site description:***Landform:* Mid-slope on undulating low hills*Disturbance:* Extensive clearing for pasture*Surrounding vegetation:* Marri, jarrah, peppermints*Rock outcrop:* No rock outcrop*Surface coarse fragments:* None**Soil Profile Description – SCH 0129**

Horizon	Depth (cm)	Description
A1	0-10	Very dark grey (7.5YR 3/1 moist) sandy loam (fine to medium sand grains); moist soil; massive to weak, crumb structure; sandy fabric; 5% ferruginous ironstone medium gravels 2-20 mm; clear boundary to:
A31	10-25	Strong brown (7.5YR 5/8 moist) clayey sand (fine to medium sand grains); moist soil; apedal, massive structure; sandy fabric; 5% ferruginous ironstone medium gravels 2-20 mm; gradual boundary to:
A32c	25-40	Strong brown (7.5YR 5/8 moist) clayey sand (fine to medium sand grains); apedal, massive structure; sandy fabric; 25% ferruginous ironstone 2-40 mm; clear boundary to:
B2	40+	Yellowish red (5YR 5/8 moist) light medium clay; pedal, moderate, 2-20 mm, subangular blocky structure.

Profile: SCH 0134**WA Soil Group:** Yellow/brown deep sandy duplex**Australian Soil Classification:** Yellow Chromosol, Kurosol or Sodosol

Described by Peter Tille on 29-Apr-2004 from an existing vertical exposure

No samples taken

Location: GDA94 Zone 50 – 423569 mE, 6161694 mN**Site description:**

Landform: Lower slope (with gradient of 5%) on undulating low hills. Almost in a saddle
Disturbance: Extensive clearing for pasture
Surrounding vegetation: Peppermints, marri
Rock outcrop: No rock outcrop
Surface coarse fragments: None
Surface condition: Water repellent

Soil Profile Description – SCH 0134

<i>Horizon</i>	<i>Depth (cm)</i>	<i>Description</i>
A1	0-15	Dark grey (10YR 4/1 moist) sandy loam; no mottles; no coarse fragments; water repellent.
A2	15-50	Brown (10YR 5/3 moist) sandy loam; no mottles; apedal, massive structure; sandy fabric; no coarse fragments; clear boundary to:
B1	50-70	Brownish yellow (10YR 6/6 moist) sandy light clay; faint; 10% ferruginous ironstone.

Profile: SCH 0138**WA Soil Group:** Yellow loamy earth**Australian Soil Classification:** Yellow Kandosol or Dermosol

Described by Peter Tille on 30-Apr-2004 from a hand-augered profile

No samples taken

Location: GDA94 Zone 50 – 422423 mE, 6162163 mN**Site description:***Landform:* Footslope on undulating low hills*Disturbance:* Extensive clearing for pasture*Rock outcrop:* No rock outcrop*Surface coarse fragments:* None*Surface condition:* Soft**Soil Profile Description – SCH 0138**

Horizon	Depth (cm)	Description
A1	0-5	Brown (7.5YR 5/4 moist) sandy loam; apedal, massive structure; high organic matter content.
A3	5-20	Reddish yellow (7.5YR 6/8 moist) sandy loam (medium to coarse sand grains); apedal, massive structure; sandy to earthy fabric.
B1	20-35+	Reddish yellow (7.5YR 6/8 moist) sandy clay loam; few faint mottles.

Appendix 2 – Nitrogen and soil acidification

by Mike Bolland and Richard Morris

In most soils, ammonium ions (NH_4^+) are rapidly converted to nitrate (NO_3^-) plus hydrogen ions (H^+) by soil bacteria. Soil ammonium can come from a number of sources. It can be mineralised from soil organic matter as ammonium ions. Urea (as fertiliser or in cow urine patches) is rapidly hydrolysed to ammonium ions to the soil. Ammonium phosphate fertilisers (DAP, MAP) directly supply ammonium ions. Whether ammonium ions are derived from organic matter or fertiliser, they are rapidly converted in soil to nitrate ions plus hydrogen ions.

Soils contain both positive and negative surface charges but in most soils the magnitude of the negative surface charge is far greater than the magnitude of the positive surface charge. So ammonium ions, which have a positive charge, are retained by soil, unless large amounts are applied. One such example is in cow urine patches, when some ammonium ions will leach because there are too few negative charge sites on the soil surface to retain all of them.

Plants take up nitrogen (N) from soil as either ammonium (NH_4^+) or nitrate ions (NO_3^-). To maintain electrical neutrality either side of the root membrane they must pump out an ion of the **same charge to the one taken up**. So they need to pump out a negative hydroxide (OH^-) ion from the root to the soil for every negative nitrate ion (NO_3^-) taken up from the soil. Conversely they need to pump out a positive hydrogen ion (H^+) from inside the root to the soil for every positive ammonium ion (NH_4^+) taken from the soil into the root. Plants do this by dissociating water in their roots to hydrogen and hydroxide ions.

The positive and negative ions plants take up from soil are called cations (+) and anions (-) respectively. Usually plants take up more cations than anions. The resultant excess positive charge of the cations taken up from the soil is simultaneously matched by the movement of hydrogen ions (also a positive charge) from the root into to soil. This trade is performed by the plant to maintain balance either side of the root membrane. Hydrogen ions (H^+) increase the acidity of the soil so taking up ammonium ions (NH_4^+) from soil results in its acidification.

The conversion of ammonium to nitrate ions in soil is also an acidifying process as it produces hydrogen ions ($2\text{NH}_4^+ + 3\text{O}_2 \rightarrow 2\text{NO}_3^- + 8\text{H}^+$). The uptake of these nitrate ions results in hydroxide ions (OH^-) moving from the root to soil and these combine with the hydrogen ions (H^+) produced when ammonium was converted to nitrate to form water (H_2O). Hence when all converted nitrate ions are taken up by the roots, nitrate uptake is **not** an acidifying process.

However, if the nitrate is leached below the root zone before it is taken up by the plant, the hydrogen ions remaining in the soil increase its acidity. That is, the soil is acidified by the hydrogen ions produced when the ammonium ion was converted to nitrate. Leaching of nitrate ions in soil by rainfall is a major cause of soil acidification since most N in soil is present as nitrate.

Appendix 3 – Glossary

- Acidification:** A form of land degradation where soils become increasingly acidic due to human activities such as applying fertilisers or introducing leguminous pastures.
- AHD:** Abbreviation for Australian Height Datum, the height above sea level (usually in metres) of a land surface.
- A horizon:** Basically the topsoil. The **A1 horizon** is at the soil surface (or just below the surface mat) and has an accumulation of organic matter usually making it darker than the underlying horizon. The **A2 horizon** typically lies below the A1 horizon having less organic matter, sesquioxides and/or clay than the underlying horizons, which are generally darker or brighter in colour than the A2. The **A3 horizon** is a transitional layer with characteristic of the overlying and underlying horizons and is typically similar in colour to the underlying horizon.
- Alluvial deposits:** Unconsolidated materials transported or deposited by running water such as a river or stream; includes gravels, sands, silts, clays and various mixtures of these.
- Apedal:** Describes a soil material that has no structure; i.e. there are no observable peds. Apedal massive soil materials are coherent, separate into fragments when disturbed and may be crushed to ultimate particles. Apedal single-grained soil materials consist of loose, incoherent particles.
- B horizon:** The B horizon is basically the subsoil characterised by a concentration of clay, iron, aluminium and/or organic matter. The **B1 horizon** is a transitional layer which is found underneath the A horizons and over the B2 horizon. The **B2 horizon** is the layer of maximum pedological development (e.g. clay content, structure, colour, iron content).
- Coarse fragments:** All soil particles greater than 2.0 mm in diameter, including gravel, pebbles, cobbles and stones.
- Clay (soil particle):** Fine soil particles <0.002 mm in diameter.
- Clay (soil type):** Soil profiles with a clay texture in the top 3 cm.
- Clay (soil texture):** A fine textured soil material with more than 30% clay-sized particles and less than 25% silt-sized particles.
- Clayey sand (soil texture):** Light textured soil material dominated by sand-sized particles (>75%) and containing 5-10% clay-sized particles that give the sand grains slight coherence and make them sticky when wet; heavier in texture than a loamy sand and lighter than a sandy loam.
- Clay loam (soil texture):** Medium to heavy with textured soil material containing 30-35% clay-sized particles a few sand-sized particles; heavier in texture than a sandy clay loam and lighter in texture than a light clay.
- Coffee rock:** A colloquial term typically used to describe the organic pan found in deep sands. Coffee rock can be weakly to strongly cemented by iron and aluminium. The name comes from the resemblance to instant coffee powder that has been exposed to moisture and then allowed to dry.
- Colluvium:** Unconsolidated, unsorted earth materials deposited on sideslopes and/or at the base of slopes by local run-off (unconcentrated) or mass movement (e.g. direct gravitational action).
- Crumb structure:** Describes structure of a soil material with small (1-5 mm diameter) peds that are soft, porous and more or less rounded. They are typically bonded by organic matter.

- Crystalline rock:** An igneous or metamorphic rock comprising interlocking crystals. Examples include granite or gneiss.
- Duplex (soil type):** A soil with a sudden increase in texture between the topsoil and subsoil, e.g. a sand over a clay.
- Earth (soil type):** A soil profile with a gradual increase in texture between the topsoil and subsoil, e.g. a sand grading into a loam with depth or a loam grading to clay with depth. Soils with a loam texture throughout the profile are also referred to as earths.
- Earthy (fabric):** Describes a soil material that is coherent and characterised by the presence of pores and few if any peds.
- EC:** Abbreviation of electrical conductivity, a measure of the ability of a medium to conduct electricity. EC is used often as a surrogate measure of salinity levels in water or soil as the conductivity of a solution generally increases in proportion with its salt content. There are three types of electrical conductivity measurements made on soils:
- EC_e** measurements are made on saturation extract paste from soil samples
- EC_(1:5)** measurements are made on a solution obtained by mixing one part soil with five parts distilled water
- EC_a** measurements are taken in the field using an electromagnetic induction meter.
- Extractable phosphorus/potassium:** Describes the amount of phosphorus or potassium present in the soil as measured by the Colwell procedure (Colwell 1963). This provides an estimate of the amount of **phosphorus/potassium** available to plants and an indication of the likelihood of improved growth response from the addition of fertilisers.
- Fabric:** Describes the appearance of a soil material under X10 hand lens and includes the presence of peds and the nature of their surfaces (rough or smooth ped fabric), the dominance of sand grains (sandy fabric) and the presence of pores and voids in a soil mass (earthy fabric).
- Ferruginous:** Describes material containing iron oxides. Ferruginous gravel consists of ironstone nodules or concretions, typically associated with the lateritic profile.
- Gneiss:** Banded metamorphic rocks which are generally coarse-grained.
- Grade (slope):** Used to describe the slope of a land surface; land with a low grade is relatively flat while land with a high grade is steep. The grade of a slope can be measured as a percentage fall of the land surface over a set distance. For example, a land surface with a 5% gradient drops 5 metres in elevation over a distance of 100 metres, while a land surface with a 50% gradient is steep, dropping 50 metres over the same distance.
- Gravel:** In the South-West of WA, the term is most commonly used to describe the rounded ironstone (ferruginous) gravel associated with laterite and commonly used as a road base. The correct technical definition relates to coarse mineral particles (rock fragments) in the size range of 2-75 mm diameter.
- Gravels (soil type):** Soil with significant ironstone gravel content (>20%) in the top 15 cm of the profile. Includes the Shallow gravels, Duplex sandy gravels, Deep sandy gravels, and Loamy gravels among the WA Soil Groups (Schoknecht 2002).
- Ground cover:** Any matter that protects the soil surface from erosion. It is usually the same as vegetative cover (i.e. living plants) but can include dead plant matter, stones or gravel.
- Hardpan:** A hard soil layer cemented with organic matter, silica, sesquioxides, gypsum or calcium carbonate or formed by physical compaction of the soil.

- Horizon:** Used to describe individual layers in a soil profile. Each horizon has morphological properties different from those above and below it. Typically, the A horizons make up the topsoil and the B horizons constitute the subsoil. These horizons are further subdivided, for example the A1 horizon is the surface soil which has a darker colour because of the presence of organic matter.
- Impermeable:** Describes the nature of a solid material that will not allow fluids to pass freely. A material described as impermeable will have a saturated hydraulic conductivity of less than 0.02 m/day.
- Indurated:** Describes a material hardened by cementation.
- Lateral flow:** Movement of groundwater in a non-vertical direction (i.e. sideways instead of straight up or down). Lateral groundwater flows are usually more or less parallel to the ground surface (though this is not always so) and will transport dissolved nutrients.
- Laterite:** The term is often a cause of confusion. It sometimes refers only to the iron and aluminium-rich duricrust (cemented gravel and ironstone caprock, sometimes called block laterite). In other cases it is applied to the whole lateritic profile or lateritic mantle (see below). Its formation is a matter of some controversy. It was originally believed to be formed in past tropical climates under the extremes of wet and dry seasons, but there is growing evidence of the role of symbiotic bacteria associated with proteaceous plants (e.g. banksias, dryandras) in the present day formation of lateritic materials.
- Lateritic:** A material or landform associated with ferruginous duricrust (ironstone caprock). **Lateritic stones** are large (6-60 cm) fragments of duricrust while **lateritic plateau** is a relatively flat upland landscape formed a lateritic mantle (see below). A **lateritic ridge** is a narrow crest representing a remnant of an eroded lateritic plateau.
- Lateritic mantle/lateritic profile:** Deeply weathered regolith with lateritic materials. Leaching of the profile removes sodium, potassium, calcium and magnesium ions while iron and aluminium oxides remain to form a hardened or cemented layer. Lateritic mantle can be anywhere between 2 and 50 m thick and consists of a number of horizons. The typical profile comprises sand or gravel on top of a ferruginous duricrust (where the iron oxides have accumulated) overlying a mottled clay and then a 'depleted' white clay (the pallid zone from which leaching has occurred).
- Lateritic ridge:** A ridge crest formed on the **lateritic profile**.
- Leaching:** Describes the washing of nutrients out of a soil layer. The process by which nutrients, chemicals or contaminants are dissolved and carried away by water, or are moved into a lower layer of soil.
- Light clay (soil texture):** Heavy textured soil material containing 35-40% clay-sized particles; heavier in texture than a clay loam and lighter in texture than a medium clay.
- Loam (soil texture):** A medium-textured soil material containing a mix of clay, silt and sand particles (approximately 10-25% clay, 25-50% silt and <50% sand); heavier in texture than a sandy loam and lighter in texture than a sandy clay loam.
- Loamy sand (soil texture):** Light-textured soil material dominated by sand-sized particles (>75%) with slight coherence of the sand grains and around 5% clay-sized particles; heavier in texture than a sand and lighter in texture than a clayey sand.
- Loam (soil type):** Soil profiles with a loam texture in the topsoil.
- Massive (structure):** Refers to a soil layer that appears as a soil mass without structure (i.e. without peds). It is coherent, separates into fragments when disturbed and may be crushed to ultimate particles. It is often very hard (e.g. a tight clay) but can be porous.
- Medium clay (soil texture):** Heavy-textured soil material containing 45-55% clay-sized particles; heavier in texture than a light clay and lighter in texture than a heavy clay.

- Mineralisation:** The change of an element from an organic to an inorganic form by micro-organisms.
- Moisture retention:** The ability of a soil layer to hold water added by rainfall or irrigation. In soils with poor moisture retention such as deep sands, water passes quickly through the profile below the rooting zone. In soils with higher clay or organic matter content, more water is retained in the root zone.
- Moisture stress:** Describes the situation where plants become stressed due to a shortage of available water. This slows growth and eventually can lead to plant death.
- Mottles/Mottling:** Patches or blotches of colour in a soil material that differ from the dominant surrounding soil colour. Mottles are due to the iron in the soil undergoing oxidation-reduction reactions and are usually an indication of intermittent waterlogging.
- Munsell Color Chart:** A booklet of colour charts (similar to those produced by paint companies) used to ensure standard descriptions of soil colours. Colour is described in term of its hue, value and chroma. Hue describes the spectral coloration (e.g. if it is red or yellow), value describes the lightness or darkness, and chroma the intensity. For example 5YR 3/4 describes a soil with a yellowish red colour. It has a hue of 5YR, a value of 3 and a chroma of 4. The descriptive colour name will be adequate for most people identifying soils on their properties. They will not need to bother with the Munsell terminology.
- Neutral subsoil:** Where the subsoil is neither acidic nor alkaline (pH value 6.5-7.5).
- Nitrate:** A form of nitrogen (NO_3^-) capable of being dissolved and held in solution. Because it is soluble, nitrate is highly mobile and available for uptake by plants. Its mobility also means that it can be leached down the profile easily.
- Non-wetting (soil):** Describes material that is water repellent. Non-wetting soils typically have a sandy topsoil with organic compounds that form a wax-like coating on the sand grains. Early in the season, infiltration into non-wetting soils will be very patchy, with many areas of topsoil remaining dry. As the season progresses the non-wetting character is usually slowly overcome.
- Nutrient:** A mineral substance absorbed by plant roots to provide that plant with nourishment.
- Nutrient export:** The removal of nutrients (e.g. from applied fertilisers) from an ecological or agricultural system. Nutrient loss from agricultural systems occurs via the hydrological cycle (transported by water in solution or attached to soil particles) or the by removal of farm produce (e.g. sending milk, meat or grain to markets). Nutrient loss from the soil through leaching and/or erosion is the main consideration in this report.
- Nutrient status:** A measure of the amount of nutrients present in the soils at any given time. It usually refers to plant extractable nutrients rather total nutrients – some of which are present but “locked up” by the soil and therefore unavailable. Results are expressed in terms of mass of nutrients present per given mass of soil such as parts per million (ppm) or milligrams per kilogram (mg/kg).
- Organic carbon:** A measure of the amount of carbon contained in the soil excluding inorganic carbon (e.g. the carbon present in calcium carbonate). Organic carbon is often confused with organic matter, but organic carbon should be seen as a component of organic matter. A conversion factor of 1.72 is commonly used to convert organic carbon to organic matter.

- Organic matter:** Material that includes the residual products of living organisms (remnants of plant and animal tissue, often decomposed). Organic matter comprises carbon and other elements including nitrogen, phosphorus and sulphur. It can be an important component of topsoil, improving fertility, structure and water retention.
- Pallid zone:** White to pink kaolinitic clay formed in the lower part of the lateritic profile.
- Pedal:** Describes a structured soil containing peds (see below).
- Peds:** Natural soil aggregates consisting of soil particles held together by cohesive forces or secondary materials such as iron oxides, silica or organic matter.
- Perching:** Describes the situation when water saturates a soil horizon while the underlying material (typically a clayey subsoil) remains unsaturated due to its low permeability. Perching is usually a temporary or seasonal phenomenon.
- pH:** A measure of how acidic or alkaline a solution or soil is. In technical terms pH is the negative logarithm of the hydrogen ion concentration of a solution. The *p* is shorthand for log and the *H* represents the log of hydrogen ions. The pH scale ranges from 0 to 14, with 0 to 6 being **acidic**, 7 is **neutral** and 8 to 14 is **alkaline**. Most plants grow best when the soil pH is in the range of 5.5 to 8.0.
- pH_{ca}:** pH as measured in a 1:5 solution of soil to 0.01 M calcium chloride. This provides a more accurate method for quantifying soil acidity than pH measured in a 1:5 solution of soil to water (pH_w), especially in soils with a high clay percentage. Generally pH_{ca} is 0.8 units less than pH_w.
- pH buffering capacity:** Is the ability of the soil to resist changes in pH over time. pH buffering capacity generally increases with clay and organic matter content. Sandy soils with low pH buffering capacity are more prone to acidification.
- Polyhedral peds:** Naturally occurring soil aggregates (peds) that have an uneven shape with more than six faces.
- Profile (soil):** A vertical cross-section of soil showing the different layers or horizons sitting on top of each other. A soil profile is seen at a road cutting or back hoe pit.
- Rilling/rills:** Type of erosion that results from the removal of soil by run-off water. Numerous small channels (rills) develop and these are commonly 5-10 cm deep, but can be up to 30 cm. Rills typically form on recently cultivated land, disturbed soils and on overgrazed paddocks during summer storms. Unless managed, rills can quickly turn into large gullies.
- Rough ped fabric:** Describes a structured soil in which the natural soil aggregates (peds) have porous surfaces.
- Run-off:** Water flowing downslope over the ground surface, also known as overland flow. Usually the result of rainfall that has not infiltrated into the soil but can also be generated by irrigation.
- Run-on:** Describes run-off flowing onto a piece of land from upslope.
- Sand (particle):** Coarse soil particles that range in diameter from 0.05-2.0 mm.
- Sand (soil texture):** Light textured soil material dominated by sand-sized particles (>75%) and containing few clay-sized particles (<15%).
- Sand (soil type):** Soil profile with a sandy texture in the top 3 cm.
- Sandy (fabric):** Describes a soil material in which sand grains provide the characteristic appearance of the soil mass.

- Sandy clay (soil texture):** Heavy textured soil material containing 35% or more clay-sized particles and in which sand-sized particles are prominent by sight or touch; heavier in texture than a sandy clay loam.
- Sandy clay loam (soil texture):** Medium textured soil material containing 20-30% clay-sized particles and which is sandy to touch; heavier in texture than a sandy loam and lighter in texture than a sandy clay.
- Sandy light clay (soil texture):** Heavy textured soil material containing 35-40% clay-sized particles; and in which sand-sized particles are prominent by sight or touch; heavier in texture than a sandy clay loam and lighter in texture than a sandy clay.
- Sandy loam (soil texture):** Light to medium textured soil material containing 10-20% clay-sized particles and which is very sandy to touch (but which contains <50% sand-sized particles); heavier in texture than a clayey sand and lighter than a sandy loam clay.
- Silt (particle):** Medium-sized soil particles that range from 0.002 to 0.05 mm diameter.
- Single grained:** Describes an apedal soil material consisting of loose, incoherent particles, such as beach sand.
- Soil reaction trend:** The change in pH with depth down a profile. Where the topsoil pH_w is less than 7.0 and the subsoil pH_w is less than 6.5 the soil is said to have an acid reaction trend. Where the topsoil pH_w is between 5.0 and 8.0 and the subsoil is between 6.5 and 8.0 the soil is said to have a neutral reaction trend.
- Stripped:** Refers to the state of a soil profile or landscape when a significant amount of surface material has been removed by erosion. With landscapes, the stripping has often taken place over millions of years.
- Structure (soil):** Describes the way soil particles are arranged within the profile. In a structured soil they are arranged into aggregates or peds. These soils have voids and air spaces around the peds which allow the flow of water and penetration of roots. Well structured soils are usually more stable and less prone to erosion than poorly structured soils. Soils without structure are defined as being either single-grained, like a loose sand, or massive.
- Substrate:** Earth materials underlying the soil profile that show no pedological development; include rock, sediments and saprolite.
- Subsoil:** The lower part of the soil profile. The lower layer/s are usually higher in clay and lower in organic matter than the upper layers (**topsoil**). The subsoil is usually referred to as the B horizon/s and most typically begins at depths of 30-60 cm.
- Subangular blocky peds:** Cube-shaped, naturally occurring soil aggregates (peds) with six relatively flat, roughly equal faces and partly rounded corners.
- Subsurface:** Describes the soil immediately below the surface layer, typically situated at a depth of around 15-20 cm.
- Surface mat:** Soil surface layer, typically 1-3 cm thick containing more organic matter than the underlying A1 horizon. Often contains significant amounts of un-decomposed plant matter.
- Texture (soil):** A soil material description based on field assessment that describes the relative abundance of sand, silt and clay particles. The texture is determined by the proportion of each particle present along with organic matter. A light soil is composed of mainly coarse particles (sands) while in a heavy soil fine particles (clays) dominate. Loams have a good mix of sand, silt and clay.

Texture contrast: Describes the situation in a soil profile where there is a clear change between a light textured topsoil and heavy textured subsoil. This texture change occurs over a vertical distance of less than 10 cm. Examples are a sand over a sandy clay loam (or clay) and a loam over clay.

Total nitrogen/phosphorus: Describes the total amount of nitrogen or phosphorus present in the soil as measured by laboratory analysis. This includes plant available nitrogen/phosphorus as well as the currently unavailable immobilised and organic forms.

Water repellent: Describes a soil material that repels water when dry (see **Non-wetting**).

Weathered: Describes the state of a material (e.g. rock, bedrock, sediment or colluvium) once it has been subjected to physical disintegration, chemical decomposition or biologically induced changes at or near the Earth's surface. The process of weathering involves essentially no transport of the altered material.

Weathered mantle: Weathered material covering the earth's surface (see **Lateritic mantle**).