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Major eastern wheatbelt soils to characterise soil moisture availability

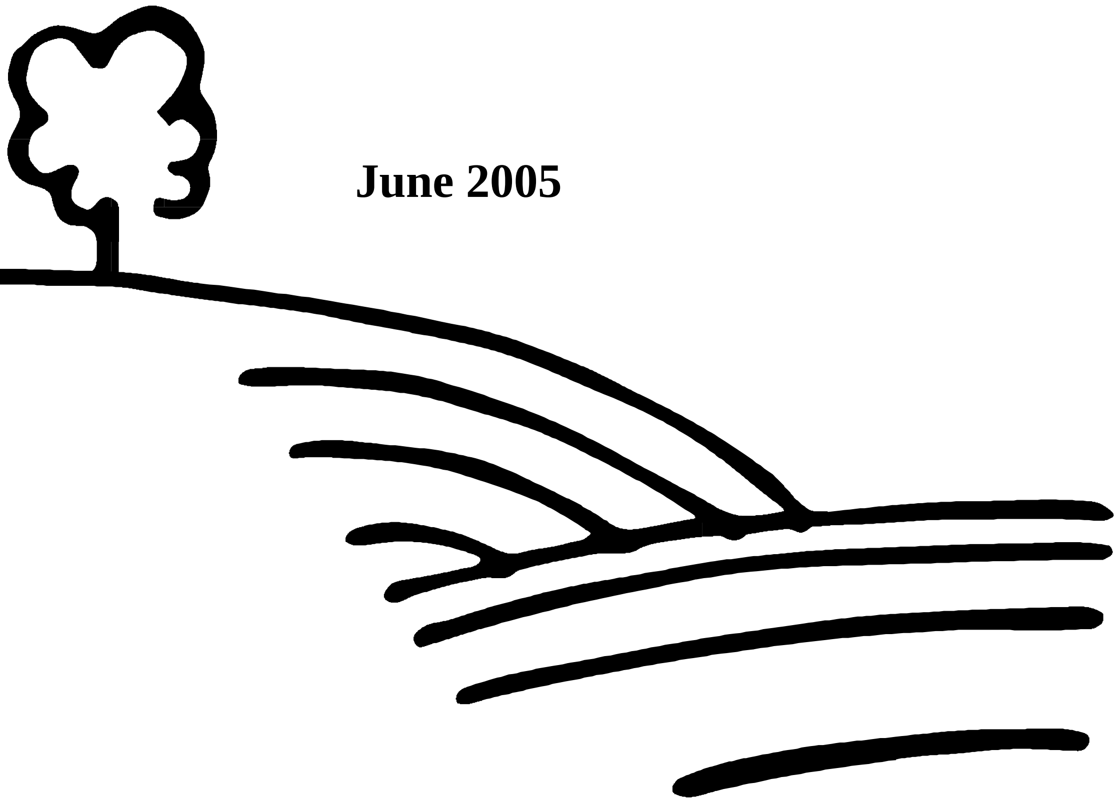
Jeffrey Jon Russell

Department of Agriculture
Government of Western Australia

MAJOR SOILS OF THE EASTERN WHEATBELT TO CHARACTERISE SOIL MOISTURE AVAILABILITY

JJ Russell

June 2005



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Disclaimer

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

Department of Agriculture
Government of Western Australia

Contents

Introduction

The Eastern Wheatbelt of Western Australia is predominantly covered by the Merredin Advisory District. This covers about 3.42 million hectares (Stoneman 1992). A wide variety of soils is present and over past decades a number of publications described these soils for scientific and farming purposes (Bettenay and Hingston 1961; Hingston and Bettenay 1961; Frost 1990; Stoneman 1992). This report does not wish to duplicate such work but to add to information on the soil-water relationships of some soils.

MIDAS is a bio-economic model of mixed crop/livestock farms in WA. It selects farm management strategies which maximise profit subject to resource, technical and environmental constraints (Pannell and Bathgate 1991). The model is strongly based on soil types and rotations. Seven broad soil classes have been recognised for the Eastern Wheatbelt: acid sands, good sandplain soils, gravelly sands, duplex soils, medium-heavy soils, heavy non-friable soils and heavy friable soils. These are designated as S1 to S7.

In 1990 a soil moisture monitoring network was established on the Merredin Research Station (MRS) and some farms. This network has also been expanded through research activities of other officers from the Department of Agriculture who required information on crop water use for specific experiments conducted on the MRS.

Water is one of the major limiting factors to crop production in the Eastern Wheatbelt. Supply is a function of the seasonal rainfall and water stored in the soil prior to seeding. Knowledge about these factors will help forecast potential crop yields which is valuable in crop management decisions concerning areas to sow, fertiliser use and herbicide application.

A knowledge of yield potential for a particular season is very valuable for a grain grower in determining the scale of planting and the levels of inputs for a crop enterprise. In general, the greater the yield potential the greater the proportion of a farm that should be cropped and the greater the likelihood of profitable returns to additional fertiliser and herbicide inputs.

Yield potential cannot be known in absolute terms as it is partly determined by seasonal rainfall. However, because stored soil water and early rains contribute to yield, knowledge of these makes it possible to provide probabilities of yield potential before the season has begun and these can be updated with increasing certainty as it progresses (Cramb *et al.* 1991) as the probability of future rainfall can be derived from past records (see McKeague and Perry 1991).

Of critical importance is the estimation of stored soil moisture. The establishment of the moisture network has allowed for determining a base line on soil water storage. Stored soil water can be measured directly at any point in the season from the moisture network. However there is a need to be able to estimate stored moisture by a computed water balance procedure for it to be of use to grain growers in the region. PYcal is one such program developed by David Tennant that enables this to be done. Presently it is confined mainly to deep sands or red and yellow duplex soils (see Tennant 1993).

A detailed knowledge of the important soil classes of the Merredin region that incorporates physical and chemical properties with a knowledge of the soil water-holding capacities and availability of this water to crop production will be of benefit in determining potential yields. Expanding PYcal to cover a greater number of soils will give it greater versatility. Association with the MIDAS soil classes will enhance tactical decision-making within the MIDAS model.

Methods

Soil pits were excavated at predetermined locations on the MRS and at one farm. These pits were associated with existing experimental sites of the moisture monitoring network established in 1990 or with experimental sites where crop water use measurements were being obtained in 1993. The soils also had to be representative of the MIDAS soil classes. Reference to Stoneman (1992) was considered when selecting sites. Pits were dug to 2 m. Additional deeper soil samples were gathered from hand augered samples later in the season.

Each pit was characterised visually for colour using a Munsell Chart (1990) and hand texturing (McDonald *et al.* 1994). Soil samples were collected for laboratory analysis of particle size and chemical properties. These were taken at 10 cm intervals for about the first half metre then at 20 cm intervals. Bulk density samples were obtained using steel cores of 55 mm diameter and 40 mm deep. These were pushed into a prepared soil surface on the face of this pit. They were taken horizontally to the pit and at 20 cm intervals to match the depth intervals used for soil moisture measurements. Unfortunately before some pits were sampled for bulk density, rain filled the bottoms with water. The pits were later pumped out and left to dry before taking these lower samples.

Particle size distribution was determined according to a modified pipette method. A 100 g sample of sieved and oven dried soil was dispersed over night in a 0.5% Calgon solution.

Field moisture was determined gravimetrically from hand augered soil samples. These samples were taken about 2 cm either side of the set depth interval weighed and dried at 110°C for 72 hours. Sampling was done in August when the soil was at maximum moisture capacity for the season. The samples were collected from around the pit from an area that had minimal plant cover. The area had been sprayed with a non-selective herbicide a few weeks after being dug.

Soil pH was determined in a 1:5 water and 1:5 $CaCl_2$ solution. Total soluble salts (TSS) are determined from soil electrical conductivity (EC) measurements in a 1:5 soil/water solution. More detailed laboratory analysis of soil chemical characteristics was determined according to Loveday (1974).

Saturated hydraulic conductivity (Ksat) rates were measured for at least 3 depth intervals for each pit. The technique developed by Talsma and Hallam (1980) using a constant head well permeameter was followed. A minimum of three measurements were recorded for each depth interval.

Total volumetric water content profiles were determined from neutron moisture meter measurements using a Campbell Pacific Hydroprobe 503. These were obtained from the associated experimental site near the pit, so they represent the moisture content underneath a crop or pasture. All soil types had readings taken in 1993. This season was very wet, receiving 278 mm from April to October. The 1994 season was a direct contrast to 1993 when only 158 mm was received. As a result water content profiles are given for this year to contrast the difference. However, some measurements in 1994 could not be taken at all sites.

Results

Eight different soils from seven Midas soil classes are described over following pages, covering soil profile descriptions, classification, physical and chemical properties, and graphing of volumetric water content.

Local name: **Acid sandplain, wodjil soil**
Relevant MIDAS soil class: **S1**

Location: Eastern side of paddock T3 of Merredin Research Station, south of gravel pit

Soil profile description

0-12 cm: Very dark grayish brown clayey sand

12-45 cm: Dark yellowish brown, coarse sandy loam

45-190 cm: Yellowish brown, coarse sandy loam.

90 cm: Some small ferruginous nodules

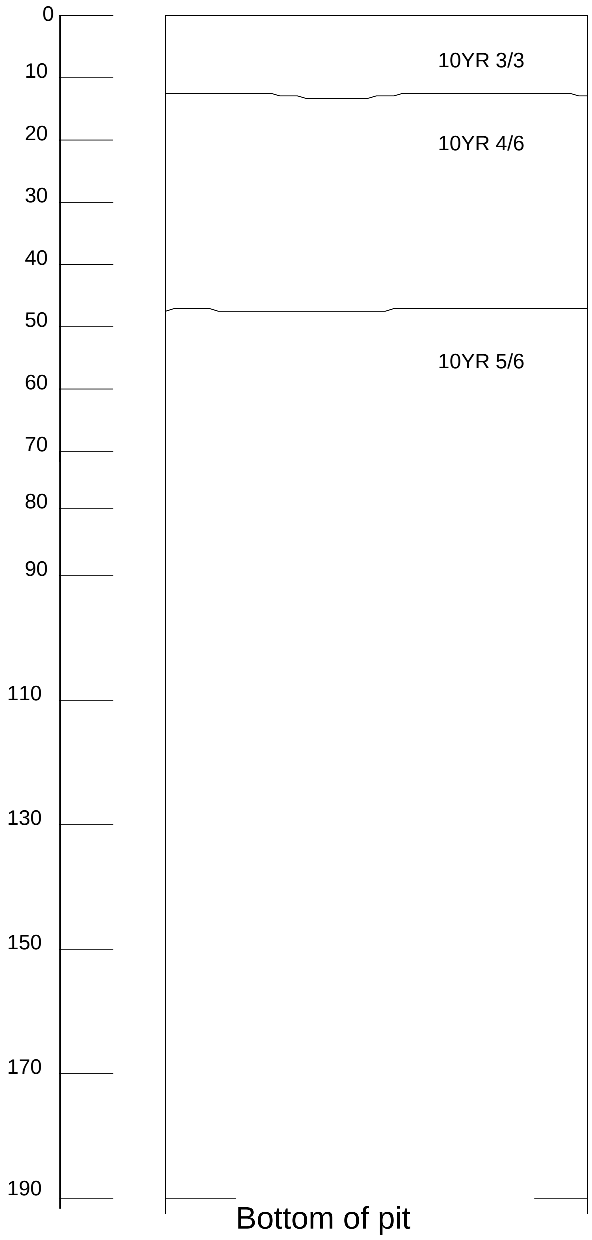

Figure 1. Soil profile description of an acid sandy soil of Merredin region

Location:	Merredin Research Station	
Topography	slope to NW, 3%	
Parent material	sand	
Profile drainage	well drained	
External drainage	well drained	
Land use	cropping	
Soil classification	Northcote (1979)	Ucl.42
	Isbell (1993)	Regolithic Chernic Tenosol
	Stace *et al*. (1968)	Siliceous Sand
	FAD (1989)	Luvic Arensol
	USDA (1992)	Agric Ustic Quartzipsamment

Horizon	**Depth (cm)**	**Description**
Ap	0-10	Brown (10YR 5/3, dry), very dark greyish brown (10YR 3/2, moist), whole coloured; clayey fine to coarse sand; apedal; dry, dry, loose consistence; pH 5.0; EC 0 mS/m; sand fabric; abundant fine roots; clear boundary to
Bw1	10-100	Yellow (10YR 7/8, dry), brownish yellow (10YR 6/8, moist); whole coloured; clayey fine to coarse sand; apedal, massive; dry, firm consistence, hardsetting between 10 and 70 cm; pH 4.5; EC 0 mS/m; at 100 cm depth some soft and hard iron segregations; abundant fine roots; clear boundary to
Bw2	100-180	Yellow (10YR 7/8, dry), yellowish brown (10YR 6/6, moist), whole coloured; fine to coarse sandy loam; apedal, massive; dry, loose consistence; pH 5.5; EC 5 mS/m; abundant roots.

Table 1. Physical and chemical properties of acid sandy soil (S1), described in Figure 1

	Physical properties							Chemical properties		
Depth (cm)	Bulk density g/cm^3	Moisture %	Particle size %			Gravel %	Field moisture %	pH_w	pH_{Ca}	TSS %
			Clay	Silt	Sand					
0			8.8	3.6	87.5	0.0	9.4	5.7	4.7	0.01
10	1.52	8.5	15.6	2.8	81.7	0.04	8.3	4.8	4.0	0.01
20			16.4	2.7	80.9	0.06	8.3	4.5	3.9	0.01
30	1.55	8.0	17.3	3.0	74.7	0.2	8.5	4.8	4.3	0.02
40			17.7	3.4	78.9	0.2		4.1	3.9	0.02
50	1.50	6.8	17.5	3.8	78.7	0.1	8.2	4.3	4.0	0.02
60			17.2	3.2	75.8	0.2		4.2	3.8	0.02
70	1.52	5.3	17.0	4.0	79.0	0.2	8.4	4.3	4.0	0.01
80			18.8	3.4	77.8	0.3		3.7	3.6	0.01
90	1.39	4.8	18.5	4.0	77.5	0.3	8.3	4.0	3.7	0.01
110	1.54	6.0	18.7	3.7	77.6	0.3	8.3	4.5	4.0	0.01
130	1.50	5.2	16.5	4.9	78.6	0.1	7.8	4.2	3.8	0.01
150	1.54	6.5	17.4	5.4	77.2	0.3	7.2	3.6	3.9	0.06
170	1.58	8.4	18.1	5.2	77.3	0.3	7.0	4.9	4.9	0.12
190	1.49	8.3	19.8	5.1	75.1	0.5	6.2	5.0	4.9	0.10
210							5.2			
230			15.3	4.8	79.9	0.2	5.3	5.6	5.3	0.02
250			13.8	4.2	82.0	0.4	5.3	5.5	5.3	0.02
270			12.7	4.0	83.3	3.2	5.3	5.9	5.5	0.02
290							5.6			

Table 2. Chemical characteristics of sandplain soil (S1) described in Figure 1

Depth cm	Satn. %	ECe mS/m	Soluble cations mg/L				SARe
			Na	K	Ca	Mg	
0	21.2	19	18.5	9	1.9	0.7	3
20	22.2	39	20	4	7.4	2.0	2
50	22.9	28	9	3	4.4	1.6	1
90	24.8	20	7.5	3	1.8	0.7	1
130	24.9	19	7	2	1.5	1.0	1

Depth cm	Exchangeable cations me/100 g				CEC	% Exchangeable cations			
	Na	K	Ca	Mg		Na	K	Ca	Mg
0	0.11	0.15	0.95	0.18	3.3	3	5	29	5
20	0.07	0.05	0.42	0.08	2.6	3	2	16	3
50	0.03	0.03	0.30	0.06	2.1	1	1	14	3
90	0.03	0.03	0.15	0.11	2.1	1	1	7	5
130	0.03	0.03	0.20	0.33	2.1	1	1	10	16

Table 3. Saturated hydraulic conductivity rates at three depth intervals for acid sandy soil (S1)

Depth	Minimum rate m/s	Maximum rate m/s	Mean rate m/s
Topsoil 2.5-17 cm	2.61×10^{-5}	5.03×10^{-5}	4.30×10^{-5}
Subsoil 27.5-44 cm	1.64×10^{-5}	3.54×10^{-5}	2.80×10^{-5}
Subsoil 78.5-94 cm	2.35×10^{-5}	4.30×10^{-5}	3.73×10^{-5}

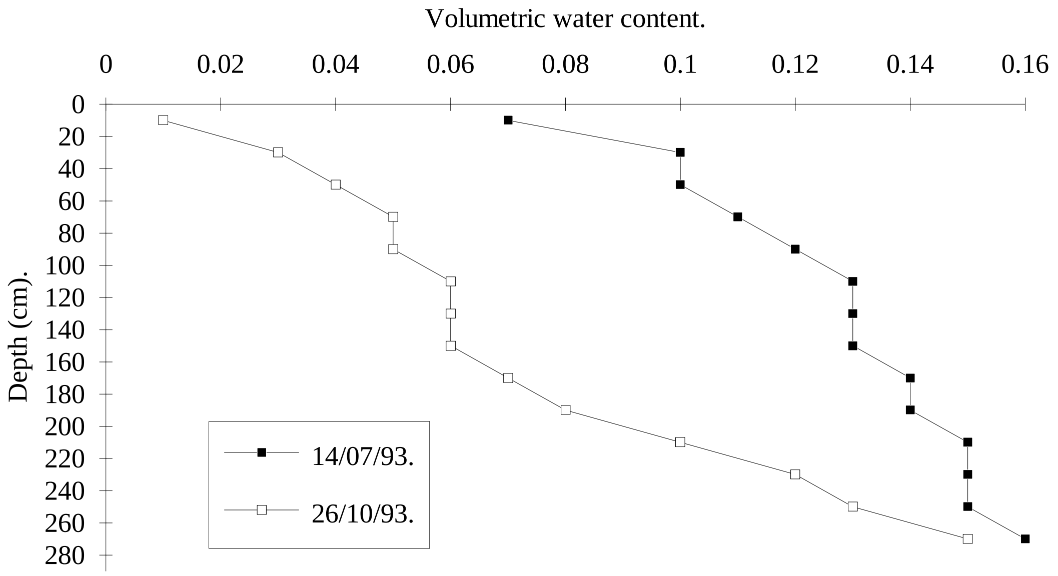

Figure 2. Total volumetric water content (cm^3 cm^{-3}) with depth in an acid sand (S1); 26/10/93 was driest in the season; 14/07/93 was wettest recorded capacity for the year

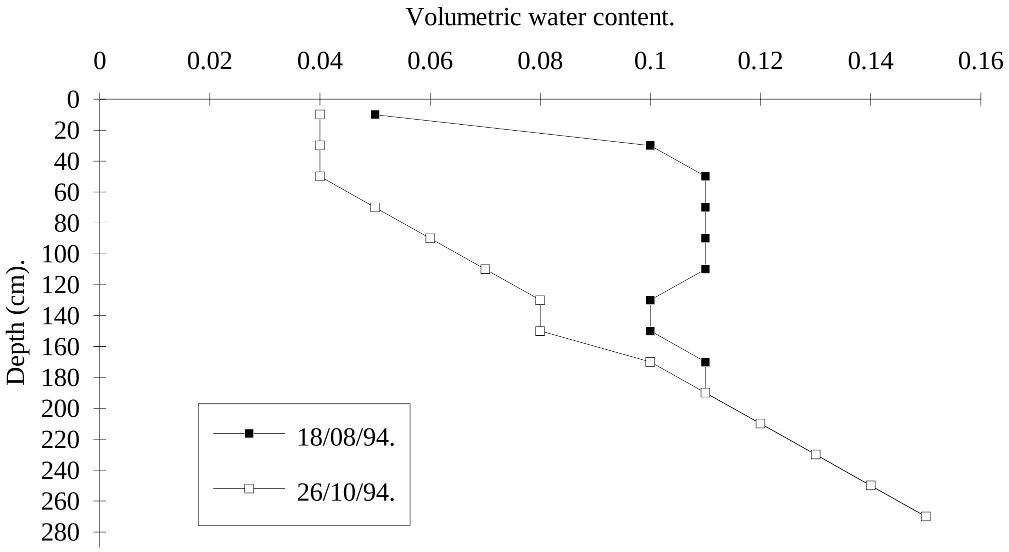

Figure 3. Total volumetric water content (cm^3 cm^{-3}) with depth in an acid sand (S1); 26/10/94 was driest in the season; 18/08/94 was wettest recorded capacity for the year

Local name: **Yellow sandplain**
Relevant MIDAS soil class: **S2**

Location: Eastern fenceline of paddock 8DW of Merredin Research Station

Soil profile description

0-15 cm: Very dark greyish brown coarse loamy sand

15-70 cm: Yellowish brown coarse sandy loam

70-155 cm: Yellowish red mottle (45%) Yellow coarse sandy loam (55%)

155-190 cm: Yellowish brown, light sandy clay loam

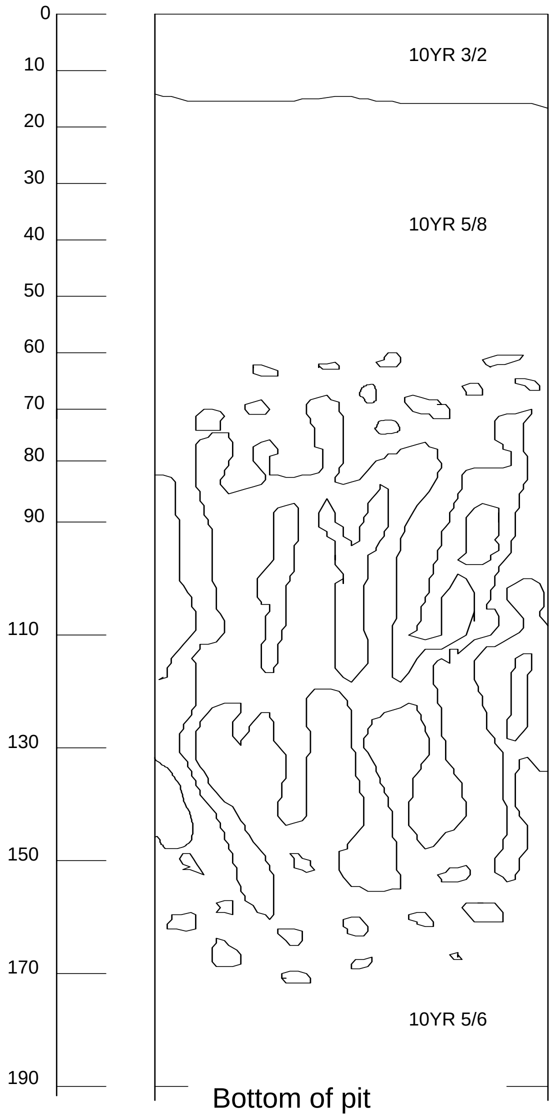

Figure 4. Profile description of yellow sandplain soil; a typical S2 soil would show more uniformity with depth

Location	Merredin Research Station	
Topography	slope to S, 2%	
Parent material	sand	
Profile drainage	well drained	
External drainage	well drained	
Land use	cropping	
Soil classification	Northcote (1979)	Ucl.42
	Isbell (1993)	Regolithic Chernic Tenosol
	Stace *et al.* (1968)	Siliceous Sand
	FAD (1989)	Luvic Arensol
	USDA (1992)	Agric Quartzipsamment

Horizon	**Depth (cm)**	**Description**
Ap	0-15	Greyish brown (10YR 5/3, dry), dark brown (10YR 3/3, moist), whole coloured; humic, clayey fine to coarse sand; apedal, massive, layered with thin clayey bands (5 cm apart); dry, firm consistence, hardsetting; pH 4.5; clay dispersive; sandy fabric; frequent roots; clear boundary to
Bw1	15-50	Yellow (10YR 7/6, dry) dark brown (10YR 3/3, moist); whole coloured; clayey fine to coarse sand; layered with clayey bands 2 cm apart; dry, firm consistence; pH 6.0; clay dispersive; cracks to 150 cm depth; iron segregations, rough faced gravel and quartz grains in nests and throughout; rare fine roots; abrupt boundary to
Bw2	50-150	Reddish yellow (7.5YR 6/6, dry), strong brown (7.5YR 5/6, moist, 70%), yellow (10YR 7/6 moist), light yellowish brown (10YR 6/6, moist, 30%), mottled; fine to coarse sandy loam; dry, very firm especially from 120 cm depth; pH 7.0; dispersive after remoulding; massive; dry, hard consistence; pH 7.0; rare roots.

Table 4. Physical and chemical properties of yellow sandplain soil (S2), described in Figure 4

	Physical properties							Chemical properties		
Depth (cm)	Bulk density g/cm^3	Moisture %	Particle size %			Gravel %	Field moisture %	pH_w	pH_{Ca}	TSS %
			Clay	Silt	Sand					
0			9.1	3.6	87.3	0.1	7.1	6.1	4.9	0.02
10	1.59	7.6	10.8	2.4	86.8	0.1	8.0	5.8	4.5	0.01
20			16.6	2.3	81.1	0.2	8.5	5.2	4.4	0.01
30	1.58	7.7	18.2	2.8	79.1	0.2	8.2	5.3	4.4	0.01
40			17.2	2.6	81.3	0.4		5.0	4.3	0.01
50	1.58	7.9	17.7	3.4	78.8	0.5	8.5	4.9	4.3	0.01
60			17.6	3.5	78.9	1.6		4.4	4.1	0.01
70	1.74	8.3	22.2	5.5	72.2	8.8	8.6	4.8	4.3	0.01
80										
90	1.71	8.4	23.5	7.4	69.1	7.7	8.7	5.3	4.9	0.01
110	1.72	8.4	20.3	8.9	70.8	2.3	8.9	5.8	5.4	0.01
130	1.69	9.1	20.4	8.4	71.3	3.6	9.6	5.8	5.6	0.01
150	1.68	9.6	23.3	7.8	68.9	1.7	10.1	6.5	5.9	0.01
170	1.61	10.6	21.9	7.1	70.9	3.9	10.6	7.0	6.0	0.01
190							12.1			
210							13.6			
230			13.8	7.0	79.2	28.3	12.4	8.4	7.1	0.05
250			12.2	5.6	82.2	53.8	15.1	8.8	7.4	0.04
270							15.1			
290										

230-250 cm samples were very wet

Table 5. Chemical characteristics of yellow sandplain soil (S2) described in Figure 4

Depth cm	Satn. %	ECe mS/m	Soluble cations mg/L				SARe
			Na	K	Ca	Mg	
0	29.7	31	11	38	4.7	1.4	1
20	21.1	18	9	13	1.5	0.7	1
50	21.6	22	11.5	3	1.9	0.6	2
90	31.2	24	15	4	3.0	1.3	2
130	29.9	25	19	2	1.7	1.1	3

Depth cm	Exchangeable cations me/100 g				CEC	% Exchangeable cations			
	Na	K	Ca	Mg		Na	K	Ca	Mg
0	0.03	0.31	1.59	0.38	3.6	1	9	44	11
20	0.03	0.25	1.00	0.33	3.1	1	8	32	11
50	0.03	0.08	0.67	0.22	2.2	1	4	30	10
90	0.07	0.10	1.35	0.96	3.4	2	3	40	28
130	0.13	0.05	0.89	1.39	3.2	4	2	28	43

Table 6. Saturated hydraulic conductivity rates at three depth intervals for yellow sandplain soil (S2)

Depth	Minimum rate m/s	Maximum rate m/s	Mean rate m/s
Topsoil 2.5-17 cm	1.92×10^{-5}	5.21×10^{-5}	3.14×10^{-5}
Subsoil 27.5-45 cm	1.62×10^{-5}	2.96×10^{-5}	2.25×10^{-5}
Subsoil 74.5-90 cm	1.06×10^{-5}	1.31×10^{-5}	1.16×10^{-5}

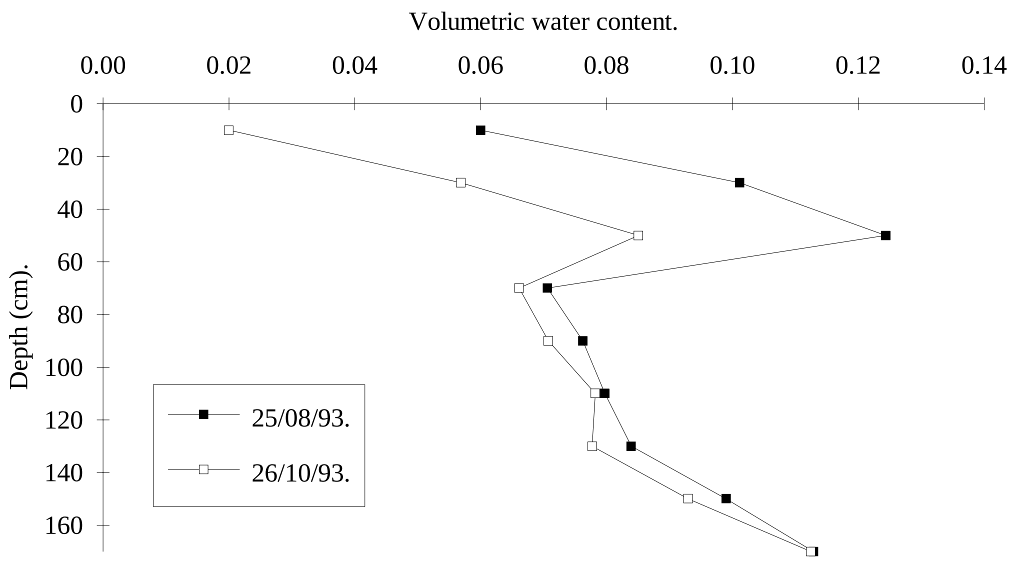

Figure 5. Total volumetric water content (cm^3 cm^{-3}) with depth in sandplain soil (S2); 26/10/93 was driest in season; 25/08/93 was wettest recorded capacity for the year

Local name: **Gravelly sand, sand over gravel**
Relevant MIDAS soil class: **S3**

Location: Paddock 9C of the Merredin Research Station

Soil profile description

0-12 cm: Very dark greyish brown coarse sandy loam

12-45 cm: Yellowish brown light sandy clay loam

Ironstone nodules

45-70 cm: Yellowish brown light sandy clay loam

Ironstone nodules increase with depth

70 cm: Cemented ironstone

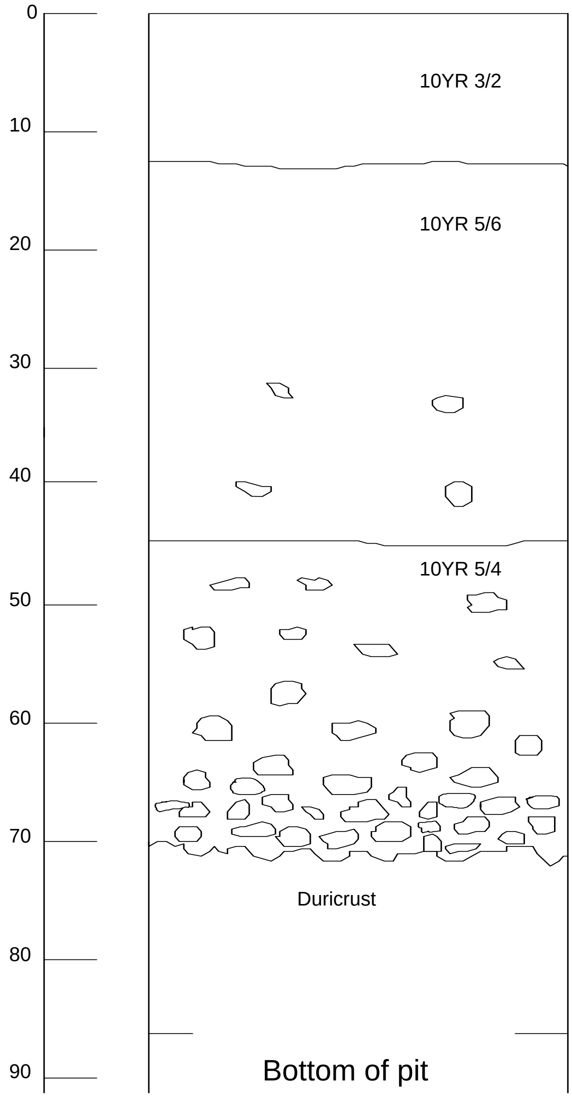

Figure 6. Soil profile description of gravelly sand of Merredin region

Location	Merredin Research Station	
Topography	slope to S, 2%	
Parent material	Colluvial ferruginous gravel and sand	
Profile drainage	Highly permeable	
External drainage	Poorly drained	
Land use	Pasture	
Soil classification	Northcote (1979)	Gn1.11
	Isbell (1993)	Leptic Regosol
	Stace *et al.* (1968)	Siliceous Sand
	FAD (1989)	Dystric Leptosol
	USDA (1992)	Lithic Haplumbrept

Horizon	**Depth (cm)**	**Description**
Ap	0-13	Brown (10YR 4/3, dry), very dark greyish brown (10YR 3/2, moist), whole coloured; clayey fine to coarse sand; apedal, massive; dry, firm consistence, hardsetting; pH 4.5; sandy fabric; clay dispersive after remoulding; abundant roots; clear boundary to
Bw	13-20	Yellow (10YR 7/6 dry), brownish yellow (10YR 6/8, moist), whole coloured; fine to coarse sandy loam; massive, apedal; dry, firm consistence, cemented; pH 5.0; sandy fabric; clay dispersive after remoulding; abundant roots; clear boundary to
C	20-40	Yellow (10YR 8/6 dry), brownish yellow (10YR 6/8, moist, 90%), weak red (10R 4/4, dry and moist, 10% cut gravels), mottled; clayey fine to coarse sandy gravel, gravel 70%; massive, apedal; dry, firm; pH 5.5, sandy fabric; frequent roots; clear boundary to
Cm	40-60+	Yellow (10YR 8/6, dry), brownish yellow (10YR 6/8, moist), weak red (10R 4/4, dry and moist), and white (10YR 8/2 dry and moist), layered; clayey gravel, gravel >70%; layered with sandy clay as thin bands between partly sorted gravel layers; apedal, cemented duricrust; clay dispersive; pH 6.0.

Table 7. Physical and chemical properties of gravelly sand (S3), described in Figure 6

	Physical properties							Chemical properties		
Depth (cm)	Bulk density g/cm^3	Moisture %	Particle size %			Gravel %	Field moisture %	pH_w	pH_{Ca}	TSS %
			Clay	Silt	Sand					
0	1.30	10.9	15.1	4.6	80.3	0.6	10.5	5.1	4.1	0.01
10	1.55	9.2	17.0	3.8	79.3	0.6	9.7	4.2	3.6	0.01
20	1.49	9.5	21.4	3.9	74.8	0.8	11.6	4.4	3.8	0.01
30	1.45	9.6	23.6	4.4	72.1	2.4	12.4	5.0	4.4	0.01
40	1.45	9.4	22.4	6.0	71.6	4.9	12.8	5.6	5.1	0.01
50	1.47	8.1	18.8	7.8	73.5	13.0	10.6	5.2	5.0	0.02
60			24.1	6.3	69.6	70.5	9.4	5.4	4.9	0.01
70			27.2	5.4	67.4	76.0	9.3	5.5	4.9	0.02
80										

Bulk density below 50 cm could not be done because of gravel content

Table 8. Chemical characteristics of gravelly sand (S3) described in Figure 6

Depth cm	Satn. %	ECe mS/m	Soluble cations mg/L Na	K	Ca	Mg	SARe
0	19.5	27	10	13	5.1	1.7	1
20	23.6	22	7	6	2.8	0.9	1
50	29.3	33	24	4	8.3	2.6	2
70	28.8	48	45	4	6.1	3.7	4

Depth	Exchangeable cations me/100 g				CEC	% Exchangeable cations			
cm	Na	K	Ca	Mg		Na	K	Ca	Mg
0	0.03	0.17	0.95	0.27	3.7	1	5	26	7
20	0.05	0.15	0.72	0.20	3.0	2	5	24	7
50	0.08	0.10	1.11	0.42	2.6	3	4	43	16
70	0.14	0.10	0.89	0.72	2.9	5	3	31	25

Table 9. Saturated hydraulic conductivity rates at four depth intervals on gravelly sand (S3)

Depth	Minimum rate m/s	Maximum rate m/s	Mean rate m/s
Topsoil 1.5-16 cm	1.44×10^{-5}	3.42×10^{-5}	2.25×10^{-5}
Subsoil 12.5-26 cm	2.43×10^{-5}	4.05×10^{-5}	3.32×10^{-5}
Subsoil 29.5-46 cm	1.57×10^{-5}	2.1×10^{-5}	1.88×10^{-5}
Subsoil* 54.5-70 cm Just above duricrust	1.11×10^{-5}	4.15×10^{-5}	2.56×10^{-5}

* Duricrust is not assumed to be impermeable to water flow

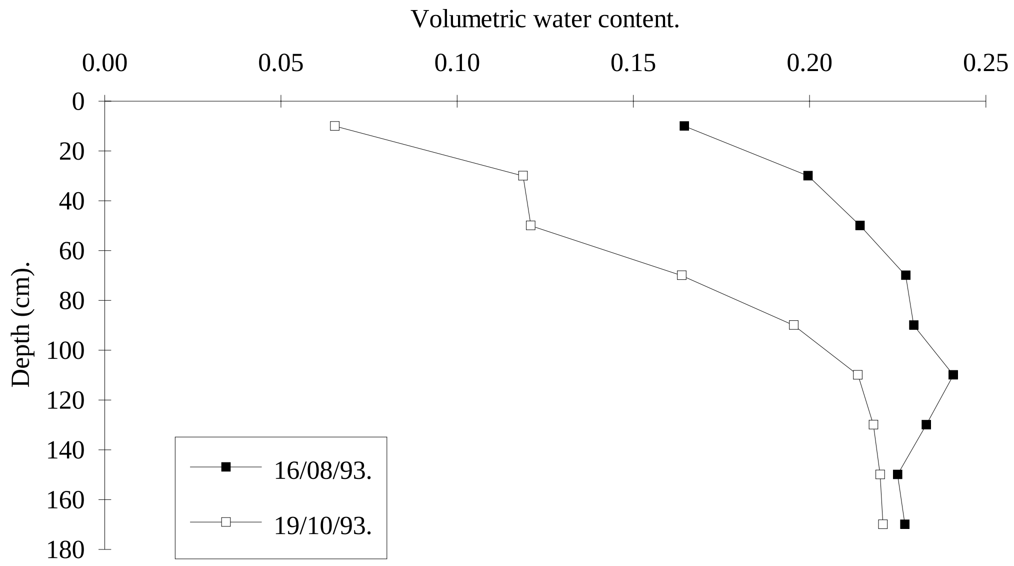

Figure 7. Total volumetric water content (cm^3 cm^{-3}) with depth in a gravelly sand (S3); 19/10/93 was the driest reading obtained in the season (however, the soil could have dried further after this time); 16/08/93 was the wettest recorded capacity

Local name: **Duplex**
Relevant MIDAS soil class: **S4**

Location: South-east of paddock B on the CSIRO lease block

Soil profile description

0-8 cm: Dark brown loamy sand

8-15 cm: Brown coarse clayey sand

15-28 cm: Pale brown coarse loamy sand

28-32 cm: Light brownish gray coarse loamy sand

32-silcrete: Light brownish gray coarse sandy clay loam

Silcrete: Between 40 and 70 cm. Varies in thickness

Silcrete-108 cm: Light olive-brown coarse light sandy clay loam

110-130 cm: Light olive-brown sandy loam

130-170 cm: Light olive-brown sandy clay

Light mottles (1%)

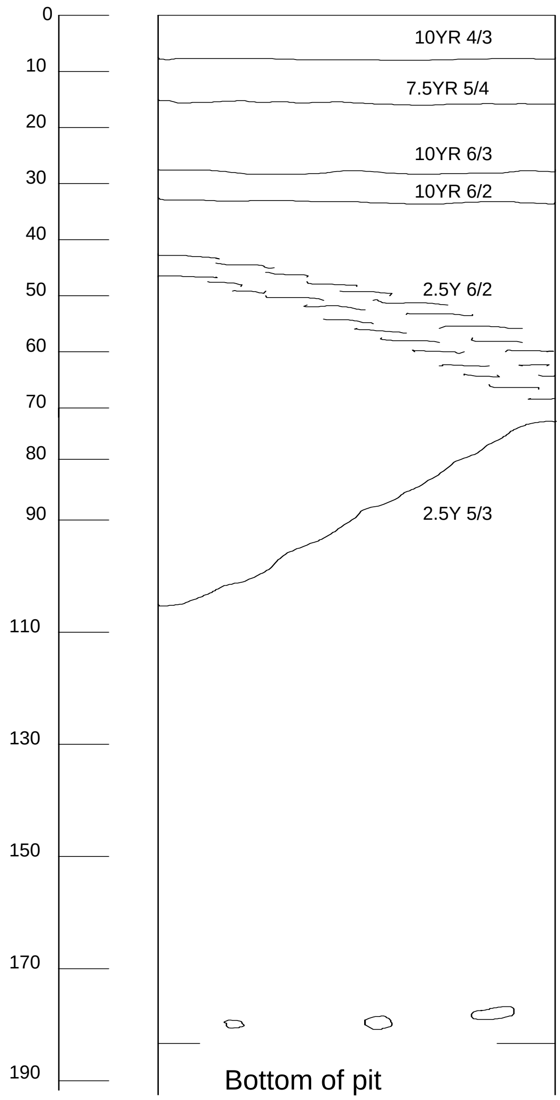

Figure 8. Profile description of a duplex (sand over clay) soil

Location	Merredin Research Station	
Topography	slope to SW, <0.5%	
Parent material	colluvial deposits	
Profile drainage	slowly permeable	
External drainage	poorly drained	
Land use	cropping	
Soil classification	Northcote (1979)	Uc5.13
	Isbell (1993)	Subnatric Yellow Sodosol
	Stace *et al.* (1968)	Intergrade between Alluvial Soil and Soloth
	FAD (1989)	Dystric Leptosol
	USDA (1992)	Typic Fragiochrept

Horizon	**Depth (cm)**	**Description**
Ap	0-15	Light brown (7.5YR 6/4, dry), dark brown (7.5YR 4/4, moist), whole coloured; clayey medium to coarse sand; apedal, massive; moist, loose consistence; pH 6.0; EC 0 mS/m; clay dispersive after remoulding; sandy fabric; abundant fine roots; clear boundary to
Bm21	15-25	Yellowish red (5YR 5/8, dry), yellowish red (5YR 5/6, moist); whole coloured; clayey medium to coarse sand; apedal, massive; dry, very firm, cemented; pH 6.0; EC 0 mS/m; clay dispersive after remoulding; layered through plowing; abundant fine roots; clear boundary to
Bmg2	25-55	Yellow (10YR 7/6 dry), very pale brown (10YR 7/4, moist), whole coloured; clayey medium to coarse sand; apedal, massive; dry, very firm, strongly cemented; pH 6.5; EC 5 mS/m; clay dispersive after remoulding; sandy fabric; abundant fine roots; clear boundary to
2Eb/Bmg	55-70	White (10YR 8/1, dry), light grey (10YR 7/2, moist), whole coloured; clayey coarse sand; large columns, massive**; dry, tough, strongly cemented; pH 7.0; EC 5 mS/m; clay dispersive; sandy fabric; rare roots; gradual boundary to
2Bg2	70-95	White (2.5Y 8/2, dry), yellow (2.5Y 7/4, moist), whole coloured; coarse sandy loam; medium blocky grading to fine blocky and plate structure at 95 cm depth; dry, firm; pH 5.5; EC 15 mS/m: clay dispersive; smooth fabric; large (20 cm in diameter) water worn coarse sandy conglomerates; rare roots; gradual boundary to
3Bk2	95-140	Light yellowish brown (2.5Y 6/4, dry), light yellowish brown (10YR 6/4 moist), whole coloured; fine to coarse sandy clay loam; medium blocky to fine blocky occasionally plate; dry, loose; pH 8.5; EC 0 mS/m; rough fabric; lime nodules (5 cm in diameter, <5%, with depth increasing to 10%), lime in fine earth; at 140 cm depth coarse sandy layer; rare roots.

** cementation of white silica as seen often in creekbeds forming thin crusts glazing over very coarse columnar structure of the underlying soil

Table 10. Physical and chemical properties of duplex soil (S4), described in Figure 8

Depth (cm)	Physical properties: Bulk density g/cm^3	Moisture %	Particle size %: Clay	Silt	Sand	Gravel %	Field moisture %	Chemical properties: pH_w	pH_{Ca}	TSS %
0			4.7	4.8	90.5	2.5	13.2	6.8	5.7	0.01
10	1.57	7.0	5.5	4.3	90.2	3.4	8.3	5.9	4.7	0.01
20			8.1	3.7	88.2	3.3	8.2	6.5	5.2	0.01
30	1.66	8.6	7.5	3.7	88.8	5.3	9.3	7.7	6.4	*
40			4.6	4.0	91.4	4.6	14.8	8.4	6.9	*
50	1.71	7.0	11.9	10.8	77.2	6.4	10.8	7.8	6.2	0.02
60										
70	1.52	14.2	8.5	13.1	78.4	2.5	14.7	6.1	5.2	0.16
80							19.4			
90	1.72	8.8	8.8	12.1	79.1	7.8	17.5	9.0	7.4	0.05
110	1.68	9.6	12.7	13.3	74.0	7.9	9.3	9.4	7.8	0.05
130	1.47	20.0	14.4	18.2	67.4	17.3		9.5	7.8	0.05
150#	1.39	27.1	18.7	30.0	51.3	0.6		9.3	8.0	0.1
170#	1.34	30.1	19.4	32.8	47.8	1.5		9.3	8.0	0.1

samples taken after pit was pumped out   Silcrete layer was at 45-60 cm   Silcrete varied at depth   * very small

Table 11. Chemical characteristics of duplex soil (S4) described in Figure 8

Depth cm	Satn. %	ECe mS/m	Soluble cations mg/L Na	K	Ca	Mg	SARe
0	22.6	39	35	23	8.6	3.9	2
20	21.0	18	19	6	3.7	3.3	2
50	25.4	72	135	6	7.9	6.4	9
110	37.4	141	260	6	10.9	4.9	16
130	42.5	122	220	6	5.3	2.8	19

Depth	Exchangeable cations me/100 g				CEC	% Exchangeable cations			
cm	Na	K	Ca	Mg		Na	K	Ca	Mg
0	0.06	0.33	2.05	0.67	3.9	2	8	53	17
20	0.07	0.08	1.50	0.49	3.1	2	3	48	16
50	1.59	0.25	1.58	1.50	5.7	28	4	28	26
110	4.65	0.79	2.90	5.50	14.7	32	5	20	37
130	3.68	0.79	3.23	4.76	13.1	28	6	25	36

Table 12. Saturated hydraulic conductivity rates at three depth intervals of duplex soil (S4). It is thought that the silcrete layer is about 60-65 cm from the surface and predominantly impermeable

Depth	Minimum rate m/s	Maximum rate m/s	Mean rate m/s
Topsoil 1.5-15 cm	7.34×10^{-6}	5.57×10^{-5}	3.44×10^{-5}
Subsoil 27.5-41 cm	1.88×10^{-6}	1.09×10^{-5}	5.48×10^{-6}
Subsoil 76.5-91 cm (Below silcrete)	4.55×10^{-6}	5.95×10^{-6}	5.34×10^{-6}

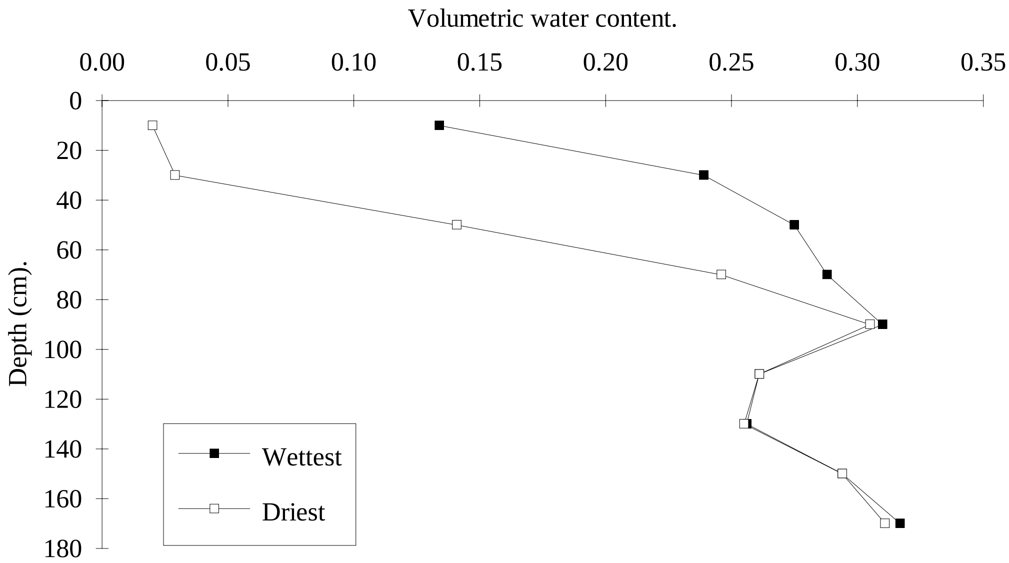

Figure 9. Total volumetric water content (cm^3 cm^{-3}) with depth in a duplex (S4) soil; these were wettest and driest results for the 1993 season

Local name: **Sandy salmon gum, hillside soil, medium land**
Relevant MIDAS soil class: **S5**

Location: Property of R. Robartson, on south-west corner of 88ME83

Soil profile description

0-12 cm: Dark reddish brown sandy loam

12-50 cm: Dark reddish brown sandy clay loam

50-70 cm: Dark brown sandy clay

70-90 cm: Brown sandy clay with mottles

90-170 cm: Yellowish red sandy clay loam

170-190 cm: Brown sandy clay

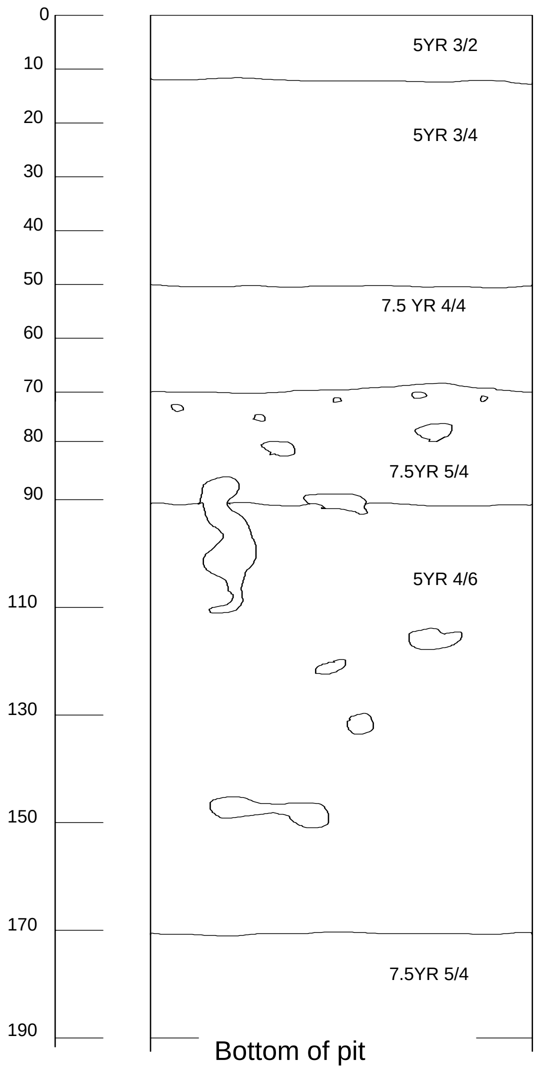

Figure 10. Profile description of medium-heavy soil type

Location	R. Robartson 88ME83	
Topography	long slope to NW, 1%	
Parent material	colluvial and aeolian deposits	
Profile drainage	slowly permeable	
External drainage	poorly drained	
Land use	cropping	
Soil classification	Northcote (1979)	Dy3.53
	Isbell (1993)	Hypermetric Yellow Sodosol
	Stace *et al.* (1968)	Solodic Soil
	FAD (1989)	Gleyic Solonetz
	USDA (1992)	Aquic Durochrept

Horizon	**Depth (cm)**	**Description**
Ap	0-8	Brown (7.5YR 5/4, dry), brown (7.5YR 4/4, moist), whole coloured; humic, coarse sandy loam; apedal, massive; dry, tough consistence, hardsetting; pH 5.5; EC 10 mS/m; clay dispersive; sandy fabric; gully and tunnel erosion; frequent fine roots; abundant sand grit; clear boundary to
Bm1	8-25	Yellowish red (5YR 5/6, dry and moist), whole coloured; coarse sandy clay loam; apedal, massive; dry, tough, cemented; pH 7.5; EC 15 mS/m; clay dispersive; rearrest; cracks to 85 cm with lime and clay skins; clear boundary to
Bmt2	25-55	Yellowish red (5YR 5/6, dry and moist), whole coloured; coarse sandy clay; massive to fine polyhedral; dry, tough consistence; pH 8.5, EC15 mS/m; rough and smooth fabric; clay dispersive; lime in nests and along root channels; rare fine roots; frequent quartz grit; clear boundary to
Btk2	55-105	Yellowish red (5YR 5/6, dry and moist), whole coloured; coarse sandy clay loam; massive to medium blocky; dry, firm consistence; pH 8.5, EC 16 mS/m; rough and smooth fabric; clay dispersive; lime in nests and along root channels; rare fine roots; frequent quartz grit; clear boundary to
2Btk	105-125+	Yellowish red (5YR 5/6, dry and moist, 30%), light grey (10YR 7/2, dry), pale brown (10YR 6/3, moist, 70%) mottled; fine sandy clay loam; prismatic parting to medium blocky peds; dry, firm consistence; pH 9.5, EC 65 mS/m; smooth fabric; clay dispersive; lime in fine earth and in nests and along root channels; rare fine roots.

Table 13. Physical and chemical properties of medium-heavy soil (S5) at Robartsons

Depth (cm)	Physical properties							Chemical properties		
	Bulk density g/cm^3	Moisture %	Particle size %			Gravel %	Field moisture %	pH_w	pH_{Ca}	TSS %
			Clay	Silt	Sand					
0			14.0	7.4	78.6	0.3	10.6	5.5	4.7	0.03
10	1.71	10.1	19.9	5.5	74.6	0.2	17.6	7.1	6.4	0.01
20			13.7	5.8	82.3	0.3	12.4	8.4	7.6	0.01
30	1.65	7.8	15.5	6.7	77.8	6.0	15.5	8.2	7.4	0.02
40			20.9	6.0	73.0	16.6		8.6	7.5	0.02
50	1.71	11.9	30.7	4.6	64.5	5.6	14.0	8.7	7.4	0.01
60			35.4	4.6	60.0	4.5		8.5	7.2	0.02
70	1.63	16.0	32.9	8.5	58.5	5.6	15.7	8.9	7.7	0.04
80										
90	1.68	12.9	29.3	8.6	62.1	7.7	13.2	9.4	8.0	0.09
110	1.76	9.0	24.7	8.0	67.2	0.9	9.6	8.6	7.6	0.12
130	1.73	14.0	31.0	12.0	56.9	0.3	13.4	8.8	7.4	0.12
150	1.62	13.1	36.5	7.7	54.2	0.3	16.6	6.0	5.0	0.11
170	1.57	21.7	34.1	3.6	62.4	5.0	14.2	5.5	4.5	0.15
190							14.3			
200			40.1	3.2	56.7	1.3	11.8	5.0	4.0	0.19
230							14.5			
250							15.6			
270							15.2			

170 measured after pit was pumped out

Table 14. Chemical characteristics of medium-heavy soil (S5) described in Figure 10

Depth	Satn.	ECe	Soluble cations mg/L				SARe
cm	%	mS/m	Na	K	Ca	Mg	
0	23.5	79	52.5	46	16	6.9	3
20	28.7	29	25	5	8.5	2.7	2
50	43.3	32	46	5	2.8	1.9	5
90	49.9	103	175	4	5.2	1.9	19
130	46.1	377	640	12	8.9	14.6	31

Depth	Exchangeable cations me/100 g				CEC	% Exchangeable cations			
cm	Na	K	Ca	Mg		Na	K	Ca	Mg
0	0.19	0.43	3.19	1.39	7.0	3	6	46	20
20	0.10	0.05	4.06*	0.89	5.1	2	1	80*	17
50	1.14	0.14	6.40*	4.92	12.6	9	1	51*	39
90	3.49	0.35	2.19*	6.57	12.6	28	3	17*	52
130	4.02	0.31	1.89	5.45	13.1	31	2	14	42

Table 15. Saturated hydraulic conductivity rates at four depth intervals of medium-heavy (S5) soil

Depth	Minimum rate m/s	Maximum rate m/s	Mean rate m/s
Topsoil 2.5-17 cm	1.06×10^{-5}	1.37×10^{-5}	1.24×10^{-5}
Subsoil * 27.5-43 cm	2.1×10^{-6}	1.97×10^{-5}	8.18×10^{-6}
Subsoil 57.5-72 cm	5.06×10^{-7}	3.69×10^{-6}	2.54×10^{-6}
Subsoil 77.5-93 cm	5.31×10^{-7}	5.06×10^{-6}	2.07×10^{-6}

* Equation 2 Talsma and Hallam (1980).

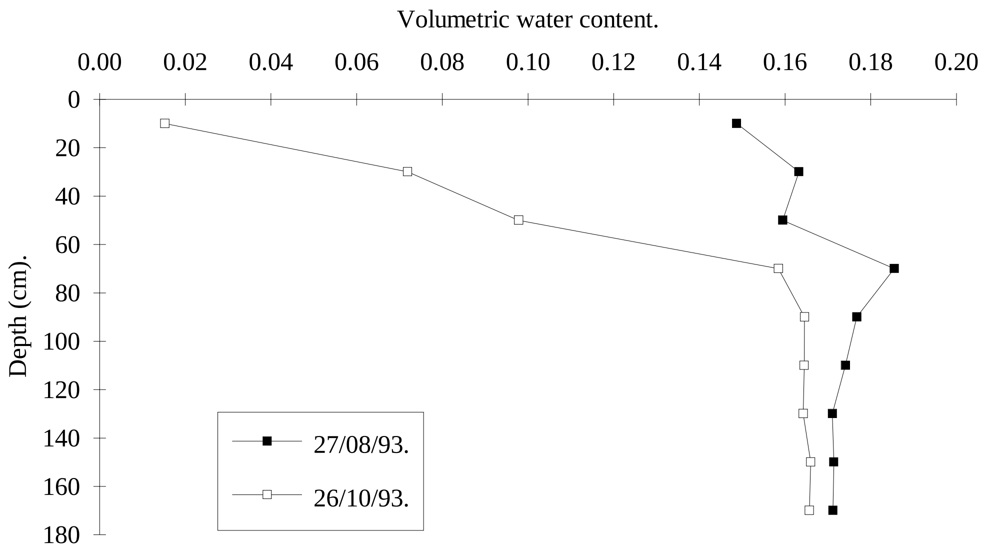

Figure 11. Volumetric water content ($cm^3\ cm^{-3}$) with depth in a medium-heavy (S5) soil; 26/10/93 was the driest reading in the season; 27/08/93 was the wettest recorded capacity

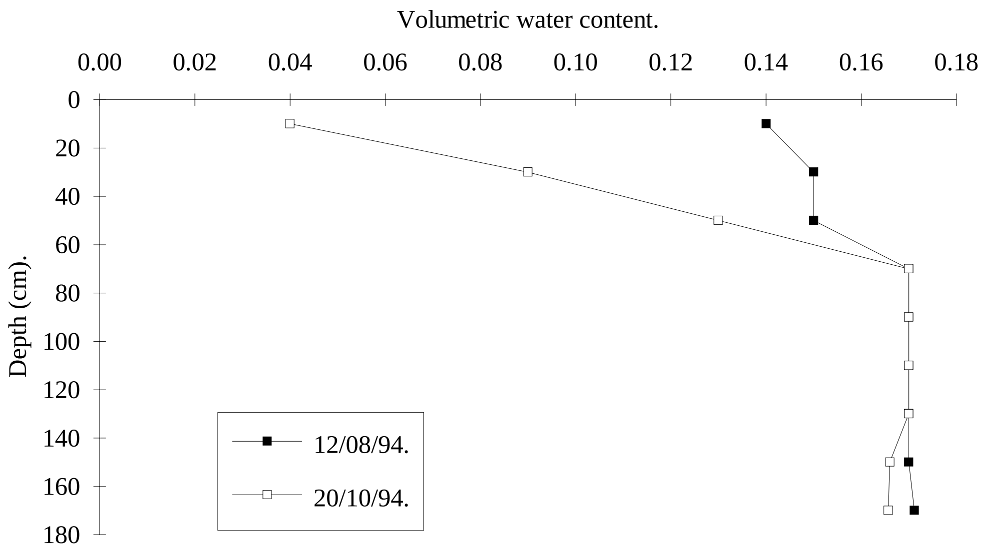

Figure 12. Volumetric water content ($cm^3\ cm^{-3}$) with depth in a medium-heavy (S5) soil; 20/10/94 was the driest reading in the season; 12/08/94 was the wettest recorded capacity

Local name: **Sandy salmon gum, medium-heavy land**
Relevant MIDAS soil class: **S5**

Location: North-east corner of paddock 9A3 on the Merredin Research Station

Soil profile description

0-8 cm: Dark brown clayey sand

8-50 cm: Dark red sandy loam

50-108 cm: Brown sandy clay

Calcite flecks

108-155 cm: Brown sandy clay

155-190 cm: Brown sandy clay.

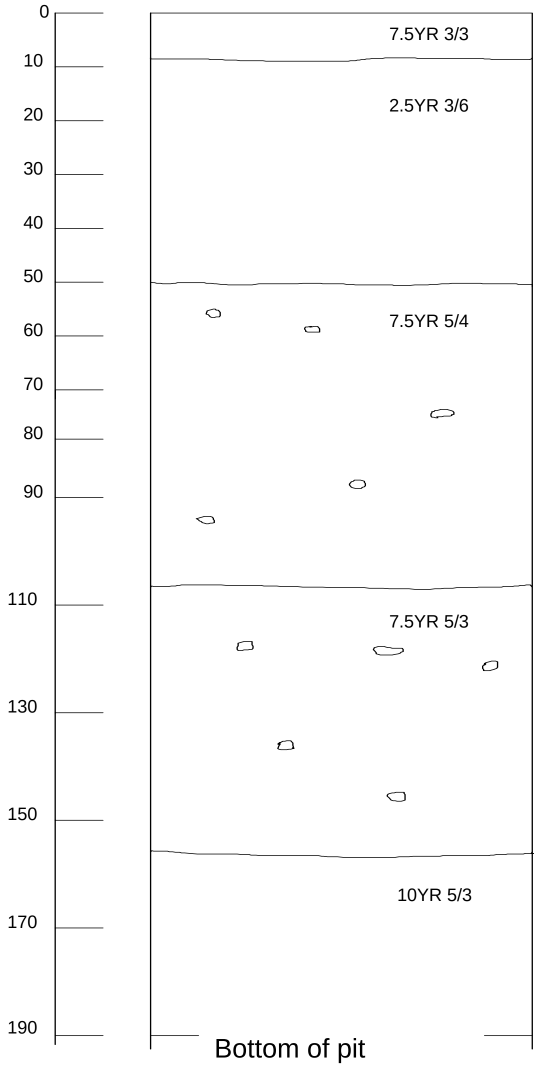

Figure 13. Profile description of medium-heavy soil

Location	Merredin Research Station	
Topography	Slope to S 2%	
Parent material	alluvial sediments and aeolian deposits	
Profile drainage	slowly permeable	
External drainage	poorly drained	
Land use	pasture	
Soil classification	Northcote (1979)	Dy2.13
	Isbell (1993)	Sodic Hypocalcic Yellow Chromosol
	Stace *et al.* (1968)	Solodic Soil
	FAD (1989)	Dystric Leptosol
	USDA (1992)	Arenic Eutrocrept

Horizon	Depth (cm)	Description
Ap	0-5	Light brown (7.5YR 6/4, dry) dark brown (7.5YR 3/2, moist), whole coloured; weakly humose, clayey fine to medium sand; massive, apedal; dry, firm, hardsetting; pH 6.0; clay dispersive after remoulding; sandy fabric; abundant roots; abundant coarse white sand grains; clear boundary to
Bw	5-25	Reddish yellow (5YR 6/6 dry), light red (2.5YR 6/6, moist), whole coloured; clayey fine to coarse sand; massive, apedal; dry, firm, hard setting; pH 6.5; clay dispersive after remoulding; sand fabric; frequent fine roots; abundant white coarse sand grains; clear boundary to
B21t	25-45	Reddish yellow (5YR 6/6, dry and moist), whole coloured; coarse sandy clay loam, subplastic increasing to sandy medium clay; medium to fine blocky grading into massive structure, dry, tough to hard consistence; smooth fabric, grading to rough fabric; sporadic ironstone gravel and abundant quartz grains; pH 8.5; clay dispersive after remoulding; rare fine roots; clear boundary to
B22t	45-100	Reddish yellow (7.5YR 6/6, dry), reddish yellow (5YR 6/6, moist), whole coloured; gritty medium clay; massive to coarse rocky, occasionally plate; dry, tough consistence; rough fabric; pH 9.0; sporadic lime segregation in fine earth; rare roots; clear boundary to
2B2gt	100-120+	Very pale brown (10YR 7/4, dry), pale brown (10YR 6/3, moist 50%), reddish yellow (7.5YR 6/6, dry) reddish yellow (5YR 6/6, moist, 50%) mottled; fine sandy medium clay; massive to coarse blocky; dry, tough consistence; smooth and rough fabric; pH 9.5; sporadic lime segregation in fine earth; rare roots.

Table 16. Physical and chemical soil properties of medium-heavy soil (S5) shown in Figure 13

Depth (cm)	Physical properties					Chemical properties		
	Particle size %			Gravel %	Field moisture %	pH_w	pH_{Ca}	TSS %
	Clay	Silt	Sand					
0	10.8	4.4	84.4	0.4	19.0	6.4	5.4	0.02
10	23.4	4.8	71.8	0.7	12.3	7.9	6.5	0.02
20	30.5	4.2	65.2	2.0	10.6	8.2	6.7	0.03
30	34.5	4.4	61.0	0.8	15.0	8.5	7.0	0.02
40	38.1	4.8	57.1	1.4				0.02
50	40.8	5.7	53.4	1.4	15.0	8.7	7.3	0.02
60								
70	35.4	5.6	59.0	10.1	15.1	9.0	7.7	0.04
80								
90	31.8	4.9	63.3	6.8	11.6	9.2	7.9	0.07
110	37.6	9.4	53.0	1.5	11.0	9.2	7.9	0.09
130	32.4	7.4	60.2	2.5	9.0	9.1	7.9	0.09
150	30.8	4.4	64.8	1.3	8.8	9.4	7.8	
170	35.0	3.3	61.7	2.2	10.2	8.7	7.5	0.10
190					13.0			

Table 17. Chemical characteristics of medium-heavy soil (S5) described in Figure 13

Depth cm	Satn. %	ECe mS/m	Soluble cations mg/L				SARe
			Na	K	Ca	Mg	
0	28.1	33	15.5	20	2.7	1.8	2
20	48.8	37	59	5	4.0	2.4	6
50	47.8	39	66	4	8.6	4.0	5
90	48.1	87	160	4	3.7	2.3	16
130	47.6	240	420	11	3.9	5.1	33

Depth cm	Exchangeable cations me/100 g				CEC	% Exchangeable cations			
	Na	K	Ca	Mg		Na	K	Ca	Mg
0	0.20	0.22	1.31*	3.87	5.6	4	4	23*	69
20	1.07	0.66	3.13*	7.14	12.0	9	5	26*	60
50	1.68	0.53	4.29*	8.20	14.7	11	4	29*	56
90	2.91	0.33	2.72*	6.24	12.2	24	3	22*	51
130	3.98	0.19	0.41*	7.22	11.8	34	2	3*	61

Table 18. Saturated hydraulic conductivity rates at three depth intervals for the medium sandy salmon gum soil shown in Figure 13

Depth	Minimum rate m/s	Maximum rate m/s	Mean rate m/s
Topsoil 2.5-17 cm	1.23×10^{-5}	1.9×10^{-5}	1.64×10^{-5}
Subsoil * 10.5-25 cm	1.07×10^{-6}	7.3×10^{-6}	3.47×10^{-6}
Subsoil 37.5-54 cm	1.44×10^{-6}	4.2×10^{-6}	2.8×10^{-6}

* Equation 2 of Talsma and Hallam (1980)

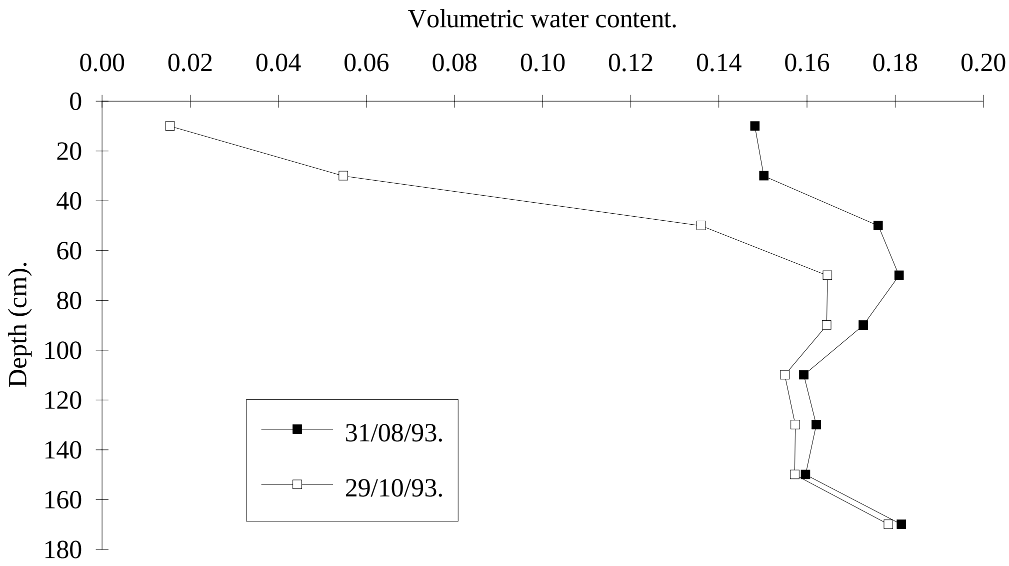

Figure 14. Total volumetric water content (cm^3 cm^{-3}) with depth in a medium-heavy (S5) soil; 29/10/93 was the driest reading obtained in the season; 31/08/93 was the wettest recorded capacity

Local name: **Heavy land, salmon gum, gimlet**
Relevant MIDAS soil class: **S6**

Location: South-west corner of paddock 3C3 of Merredin Research Station

Soil profile description

0-10 cm: Dark brown sandy clay loam

10-50 cm: Dark brown light medium clay

Reddish yellow fragments

50-170 cm: Dark brown medium clay with pink mottles

170 cm: Manganese oxide layer

Mosaic of clay, yellowish red, sandy clay

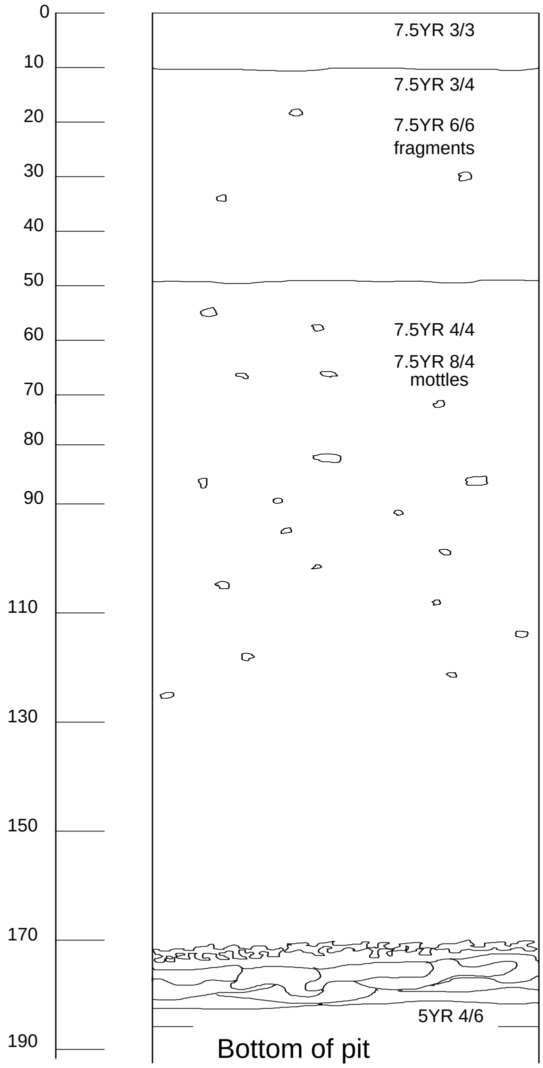

Figure 15. Profile description of heavy red-brown soil of Merredin Region

Location	Merredin Research Station	
Topography	slope to NE, <0.5%	
Parent material	colluvial deposits	
Profile drainage	slowly permeable	
External drainage	poorly drained	
Land use	cropping	
Soil classification:	Northcote (1979)	Dy2.133
	Isbell (1993)	Hypercalcic Yellow Chromosol
	Stace *et al.* (1968)	Solodic Soil
	FAD (1989)	Luvic Calcisol
	USDA (1992)	Typic Eutrochrept

Horizon	**Depth (cm)**	**Description**
Ap	0-8	Light reddish brown (5YR 6/4, dry), reddish brown (5YR 4/3, moist), whole coloured; weakly humic clay loam; cloddy; cracking (to 80 cm depth); dry, firm consistence, hardsetting, pH 7.5; EC 15 mS/m; sandy fabric; some lime in fine earth; dispersive clay; abundant roots; clear boundary to
Bt21	8-40	Yellowish red (5YR 5/6, dry and moist), whole coloured; silty light clay; coarse blocky; dry, tough; pH 9.5; EC 110 mS/m; rough fabric; 30% lime segregations, coarse quartz grit; frequent roots; gradual boundary to
Btk2	40-80	Reddish yellow (5YR 6/6, dry), yellowish red (5YR 5/6, moist), whole coloured; gritty light clay; medium blocky; dry, tough consistence; pH 9.5; EC 40 mS/m; rough and occasionally smooth fabric; 10% lime segregations; frequent roots; gradual boundary to
2Bt2	80-160+	Reddish yellowish (5YR 6/6, dry), yellowish red (5YR 5/6, moist), whole coloured; weak gritty medium clay; prismatic structure breaking into medium blocky peds; dry, firm; smooth; pH 9.5; EC 15 mS/m; lime segregations; frequent roots.

Table 19. Physical and chemical properties of Merredin heavy land red-brown soil (S6) described in Figure 15

Depth (cm)	Physical properties							Chemical properties		
	Bulk density g/cm^3	Moisture %	Particle size %			Gravel %	Field moisture %	pH_w	pH_{Ca}	TSS %
			Clay	Silt	Sand					
0			28.3	14.6	57.1	0.3		6.8	6.2	0.02
10	1.31	23.8	46.0	16.7	37.4	1.1	20.0	8.6	7.6	0.03
20			43.3	19.7	37.0	4.6	25.6	8.7	7.8	0.03
30	1.25	25.2	45.6	18.3	36.1	10.8	23.8	9.4	8.2	0.05
40			44.2	18.7	37.1	7.1	23.4	9.3	8.1	0.07
50	1.37	22.1	46.1	16.5	37.3	4.5	19.8	9.7	8.3	0.09
60			47.6	14.5	37.9	3.4	22.9	9.7	8.3	0.11
70	1.44	19.6	46.5	14.2	39.4	4.1		9.8	8.4	0.11
80							22.5	9.1	8.3	0.14
90	1.46	16.9	43.8	12.1	44.0	10.8		9.7	8.4	0.10
110	1.51	13.7	47.9	10.7	41.4	9.0	21.2	9.8	8.6	0.12
130	1.72	15.2	52.6	10.1	37.3	13.2	19.2	9.6	8.4	0.14
150	1.54	21.4	53.5	9.9	36.6	1.2	19.8	9.3	8.1	0.15
170	1.58	19.3	43.3	15.5	41.3	0.4		8.4	7.1	0.14

Table 20. Chemical characteristics of red-brown heavy soil (S6) described in Figure 15

Depth cm	Satn. %	ECe mS/m	Soluble cations mg/L Na	K	Ca	Mg	SARe
0	42.5	67	36.5	40	33.6	17.2	1
20	60.0	41	49.5	8	11.9	4.9	3
50	59.7	61	120	6	5.3	2.2	11
90	67.7	88	175	6	3.0	2.0	19
130	64.7	236	420	10	6.2	3.9	33

Depth	Exchangeable cations me/100 g				CEC	% Exchangeable cations			
cm	Na	K	Ca	Mg		Na	K	Ca	Mg
0	0.23	1.64	8.17	3.64	14.9	2	11	55	24
20	0.89	0.78	4.76	10.18	23.8	4	3	20	43
50	3.71	0.91	0.87	11.01	16.5	22	6	5*	67
90	5.15	1.09	-	-	15.3	34	7	-	-
130	5.30	1.46	1.36*	8.28	16.4	32	9	8*	50

* Results are by difference

Table 21. Saturated hydraulic conductivity rates at three depth intervals on Merredin red-brown heavy soil (S6)

Depth	Minimum rate m/s	Maximum rate m/s	Mean rate m/s
Topsoil 2.5-18 cm	7.84×10^{-7}	5.06×10^{-6}	2.74×10^{-6}
Subsoil 11.5-30 cm	1.59×10^{-6}	1.19×10^{-5}	6.84×10^{-6}
Subsoil 52.5-68 cm	2.02×10^{-7}	1.77×10^{-5}	4.73×10^{-6} (4.05×10^{-7})

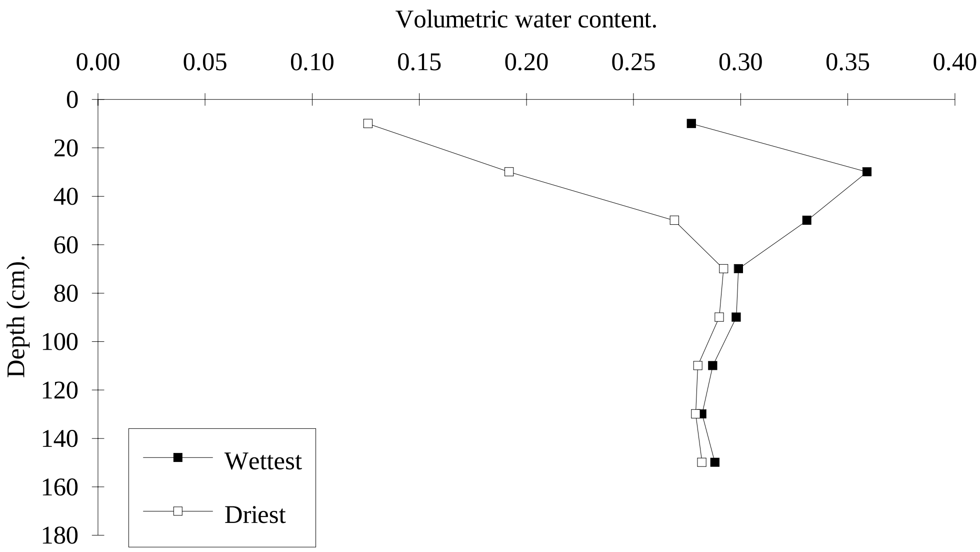

Figure 16. Total volumetric water content ($cm^3\ cm^{-3}$) with depth in a heavy (S6) soil; these were the wettest and driest results for 1993 season

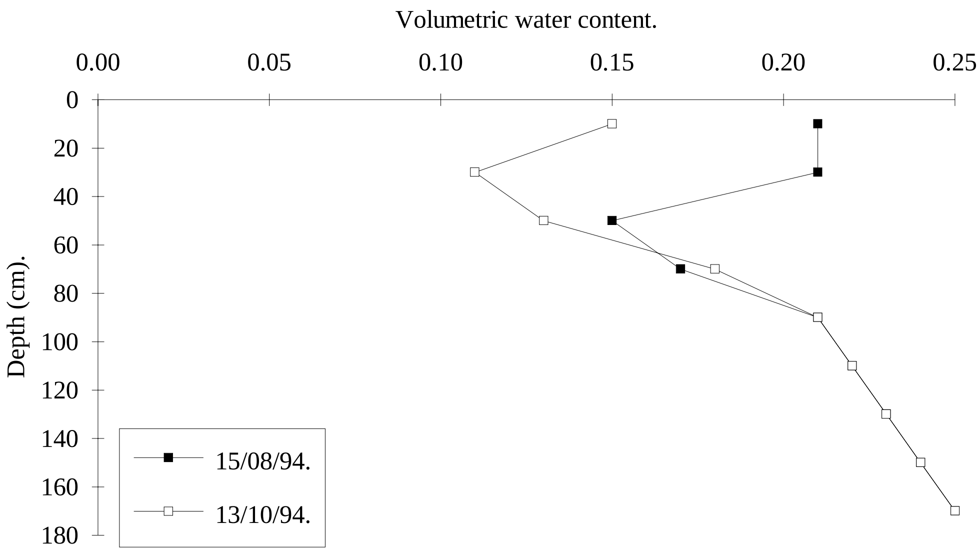

Figure 17. Total volumetric water content ($cm^3\ cm^{-3}$) with depth in a Merredin heavy (S6) soil; 13/10/94 was the driest reading obtained in the season; 15/08/94 was the wettest recorded capacity

Local name: **Heavy land (friable), salmon gum, gimlet**
Relevant MIDAS soil class: **S7**

Location: North-west corner of paddock 5A on Merredin Research Station

Soil profile description

0-12 cm: Dark reddish brown sandy clay loam

12-50 cm: Red medium clay

50-170 cm: Light brown medium clay with pink mottles

165-170 cm: Manganese oxide layer

170-190 cm: Mosaic of clays

Yellowish red medium clay with pink mottles

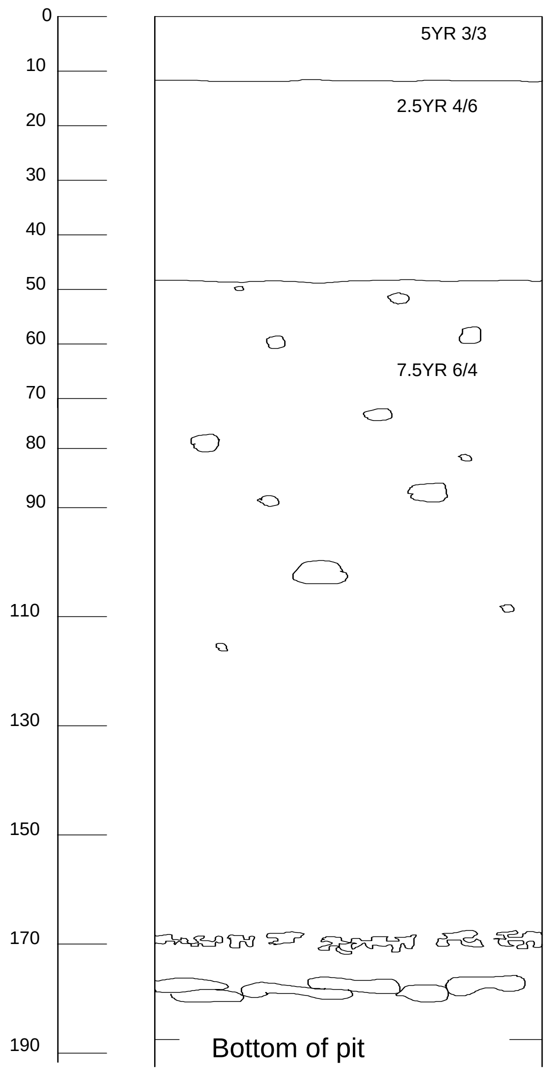

Figure 18. Profile description of friable red-brown heavy soil of Merredin region

Location	Merredin Research Station	
Topography	plain, flat	
Parent material	colluvial and aeolian deposits	
Profile drainage	slowly permeable, when cracked open fast penetration	
External drainage	poorly drained	
Land use:	cropping	
Soil classification	Northcote (1979)	Gn4.13
	Isbell (1993)	Sodic Calcic Red Chromosol
	Stace *et al.* (1968)	Solarised Solonetz
	FAD (1989)	Luvic Calcisol
	USDA (1992)	Vertic Eutrochrept

Horizon	**Depth (cm)**	**Description**
Ap	0-10	Reddish yellow (5YR 6/6, dry), red (2.5YR 4/6, moist), whole coloured; weakly humose, fine sandy clay loam; cloddy, hardsetting; dry, tough consistence; pH 8.0; EC 5 mS/m, rough fabric; clay dispersive; lime in the fine earth and as rounded nodules; abundant roots; cracking surface; clear boundary to
Bt21	10-35	Red (2.5YR 5/6, dry), red (2.5YR 4/8, moist), whole coloured; fine sandy clay; prismatic to coarse blocky parting to fine polyedral ped; dry, firm; no lime; mainly rough fabric at some prisms clay skins; pH 8.0; EC15 mS/m; clay strongly dispersive; cracking to 100 cm depth; frequent fine roots; clear boundary to
Bk22	35-115	Reddish yellow (5YR 6/6, dry), yellowish red (5YR 5/6, moist), whole coloured; gritty light medium clay; medium to fine blocky; dry, firm consistence; rough fabric; pH 8.5; EC 15 mS/m, lime in fine earth and as nodules, which are mainly orientated along root channels, frequent fine roots; gradual boundary to
Bk23	115-160+	Reddish yellow (5YR 6/6, dry), yellowish red (5YR 5/6, moist), whole coloured; gritty light medium clay; fine polyhedral massive; dry, firm consistence; rough fabric; pH 9.0: EC 1309 mS/m; lime in fine earth and as nodules, which are mainly orientated along root channels and concentrated in nests; frequent fine roots.

Table 22. Physical and chemical properties of friable heavy land red-brown soil (S7) shown in Figure 18

	Physical properties								Chemical properties		
Depth (cm)	Bulk density g/cm^3	Moisture %	Particle size %			Gravel %	Field moisture %	pH_w	pH_{Ca}	TSS %
			Clay	Silt	Sand					
0			17.9	9.1	73.0	0.3	17.8	6.3	5.6	0.02
10	1.38	19.6	48.2	10.9	41.7	0.1	13.8	8.0	6.7	0.01
20			46.6	12.6	40.8	0.1		8.5	7.4	0.02
30	1.30	18.9	39.9	16.1	44.0	14.1	21.2	8.7	7.9	0.04
40			40.1	16.2	43.7	18.6	16.3	8.8	7.9	0.04
50	1.39	12.5	40.5	12.9	46.6	24.7	15.6	9.2	8.0	0.06
60							12.7			
70	1.34	10.5	41.8	10.1	48.1	15.0	15.7	9.3	8.1	0.09
80							13.9			
90			41.8	9.2	49.0	8.4	14.3	9.4	8.1	0.10
110			42.8	9.3	47.9	7.8	14.7	9.4	8.2	0.12
130	1.64	18.0	41.2	10.8	48.0	11.1	16.0	9.3	8.2	0.16
150	1.71	15.7	45.7	10.4	43.9	8.6	15.8	8.9	8.2	0.37
170	1.57	21.7	49.2	9.2	41.5	1.9	15.4	9.2	8.1	0.20
190							15.8			

130-170 cm measured later in season

Table 23. Chemical characteristics of friable red-brown soil (S7) described in Figure 18

Depth cm	Satn. %	ECe mS/m	Soluble cations mg/L				SARe
			Na	K	Ca	Mg	
0	36.7	71	38.5	27	46.3	21.7	1
20	58.2	61	52	4	23.5	9.0	2
50	55.6	115	180	4	15.7	5.6	10
90	55.7	114	210	5	4.2	1.8	22
130	49.6	343	590	14	16.9	15.8	25

Depth	Exchangeable cations me/100 g				CEC	% Exchangeable cations			
cm	Na	K	Ca	Mg		Na	K	Ca	Mg
0	0.13	1.20	5.22*	3.55	10.1	1	12	52*	35
20	0.80	0.04	2.43	6.87	21.4	4	<1	11	32
50	2.25	0.22	7.36*	7.37	17.2	13	1	43*	43
90	4.12	0.98	0.25*	8.05	13.4	31	7	2*	60
130	3.53	0.85	0.00*	7.42	11.8	30	7	0*	63

* Results are by difference

Table 24. Saturated hydraulic conductivity rates at three depth intervals on red-brown friable heavy soil

Depth	Minimum rate m/s	Maximum rate m/s	Mean rate m/s
Topsoil 0-18 cm	1.01×10^{-6}	7.6×10^{-6}	3.32×10^{-6}
Subsoil 12.5-26 cm	4.43×10^{-7}	3.54×10^{-6}	1.75×10^{-6}
Subsoil 47.5-62 cm	9.61×10^{-7}	2.53×10^{-6}	5.51×10^{-6}

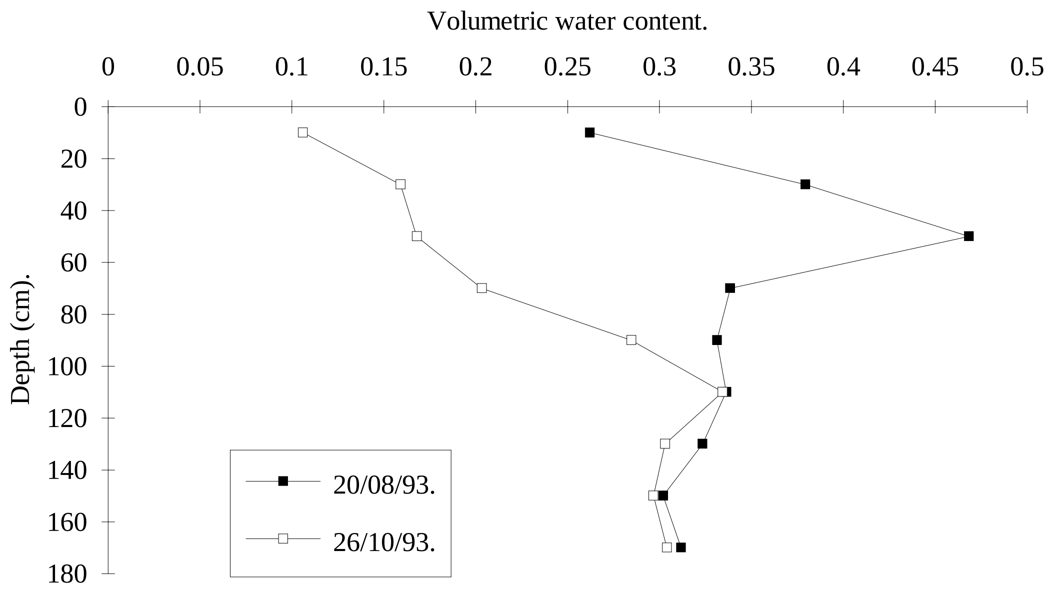

Figure 19. Total volumetric water content (cm^3 cm^{-3}) with depth in friable Merredin heavy (S7) soil; 26/10/93 was the driest reading in the season; 20/08/93 was the wettest recorded capacity

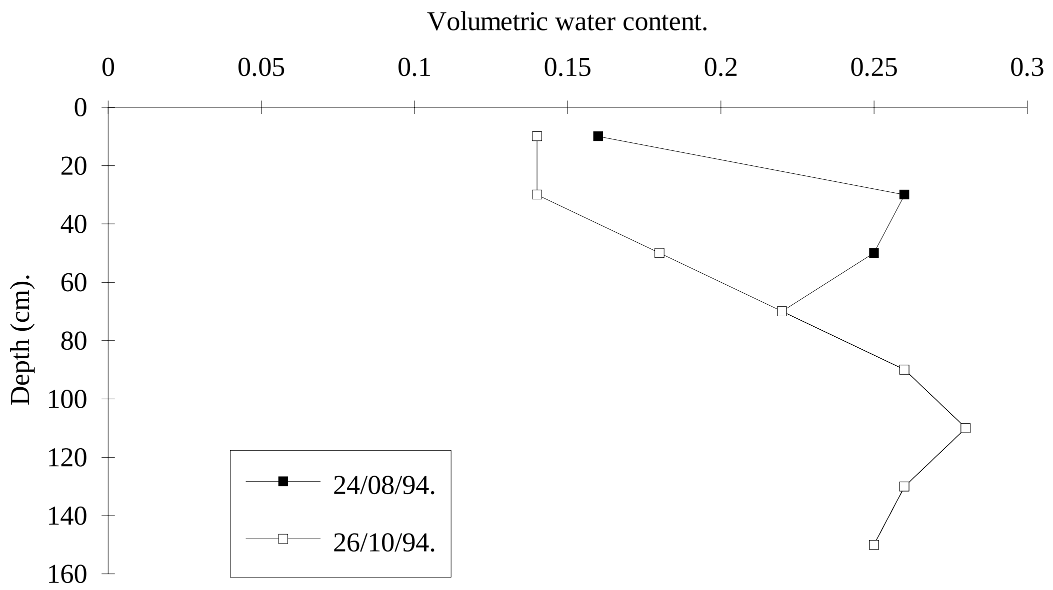

Figure 20. Total volumetric water content (cm^3 cm^{-3}) with depth in a friable Merredin heavy (S7) soil; 26/10/94 was the driest reading in the season; 24/08/94 was the wettest recorded capacity

Discussion

The basic characteristics of each of the MIDAS soil classes can be found in the soils described here and other publications. There will always be variation among soils in each class. Reference to Stoneman (1991) indicates this. The good sandplain (S2, Figure 3) and duplex (S4, Figure 7) soils also display this variation. The sandplain soil is not uniform for its total depth with a mottle zone commencing at 70 cm. The duplex soil is very complex having the silcrete layer that varies in thickness and at depth. Likewise, gravelly sands (S3) are known to vary in depth to duricrust or in the depth of sand over the gravel horizon.

Bulk density at the lower depths of the S4 to S7 soils are less than those immediately above them. The moisture content of these samples were much greater and reflect the effect of untimely rain that flooded the pits. For purposes of analysis it might be best to ignore these values or substitute values similar to those found at 130 cm. Root penetration on these soils below this depth in most years is likely to be small.

Hydraulic conductivity

Conductivity is the ability of the soil to transmit water and so has an impact on plant available water. The rate of movement of water through soil is of great importance in many aspects of agriculture. Two important aspects are the entry of water into the soil and the movement to plant roots. The Ksat measurements determined on the different soils fall within the limits of $3x10^{-4}$ m/s to $1x10^{-7}$ m/s given by Talsma and Hallam (1980). Ksat on the S1, S2 and S3 soils shows a consistency with depth. In the main the faster rates were those of the S1 soil. Water movement is greatest through these soils, so it is likely that in some years water will go below the root zone and not be available for crop use. This is likely to have happened in 1993 (Figure 2).

The effect of higher clay content on conductivity can be seen in the S4, S5, S6 and S7 soils. This is noticed most in the subsoil measurements. These have Ksat rates about 10 times less than the sandy soils and there is a distinct reduction in rate between the topsoil and subsoil measurements.

Plant available water - Crop models

Accurately evaluating the available soil water reservoir is vital to developing optimum management for rainfall crop production in marginally dry areas (Ritchie 1981). The physical properties of the soils described in this report can be used in the model formulae developed by Ritchie and Crum (1989) who outlined the minimum data requirements needed for such work. Estimates can be made from these laboratory measured soil properties to determine the upper and lower limits of soil moisture from which an estimate of available moisture can be determined. While caution is required in its application, comparison to the readings obtained from the soil water network can be used to directly verify the accuracy of these estimations. Once this has been done it will then allow for wider application to similar soils within the region and for incorporation in the MIDAS model.

Special account may be required for deep soils such as the acid sand (S1), more typical sand plain (S2) soils and possibly gravelly sands (S3). Ritchie (1981) identified two problems with defining the upper and lower limits of soil water: water flow into and out of the root zone and incomplete extraction at lower boundaries due to sparse root density. Ritchie and Crum (1989) suggest that below about 1.3 m there is incomplete extraction of available water. Indeed the moisture profile of the acid sand (Figure 2) suggests that both problems occurred in 1993.

It has also been found that some annual crops have the ability to extract moisture at greater depths (Ratliff *et al.* 1983) whereas at the surface most water is extracted regardless of the crop. Measurements taken through the soil moisture network comparing different crop and pasture species on similar soils should help to give accurate field measurement for soil water balance modelling to overcome this problem.

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References

Bettenay, E and Hingston, FJ (1961). Soils of the Merredin area. CSIRO Soils and Land Use series 41.

Cramb, J, Perry, MW; McKeague, S and Mulcahy, MJ (1991). The environment of Western Australia. In the Wheat Book. Bulletin 4196. Department of Agriculture.

FAO (1989). Soil Map of the World). World Soil Resources Report 60, Rome, reprint, Wageningen, Technical Paper 20.

Hingston, FJ and Bettanay, E (1961). A laboratory examination of the soils of the Merredin area, Western Australia. CSIRO Divisional Report 7/90.

Isbell, RF (1993). A classification system for Australian Soils. Technical Report 2/1993 CSIRO.

Loveday, J (1974). Methods for analysis of irrigated soils. Farnham Royal.

McDonald, RC, Isbell, RF; Speight, JG; Walker, J and Hopkins, MS (1984). Australian soil and land survey: Field Handbook. nkata Press, Melbourne.

McKeague, SH and Perry, MW (1991). Using rainfall deciles to assess seasonal outlooks. Plant Industries.Technical Report 28. Department of Agriculture.

Munsell (1990). Munsell soil colour charts. MacBeth Division of Kollmorgin Instruments Corporation.

Northcote, KH (1979). A Factual Key for the recognition of Australian Soils. Rellim Technical Publications, Adelaide.

Pannell, D and Bathgate, A (1991). MIDAS. Model of an integrated dryland agricultural system. Version EWM91-4. Department of Agriculture.

Ratliff, LF, Ritchie, JT and Cassel, DK (1983). Field-measured limits of soil water availability as related to laboratory measured properties. *Soil Science Society of America Journal* **47:** 770-775.

Ritchie, JT (1981). Soil water availability. *Plant and Soil* **58:** 327-338.

Ritchie, JT and Crum, J (1989). Converting soil survey characterization data into IBSNAT crop model input. *In* Land qualities in space and time (J Bouma and AK Bregt eds). Wageningen, Netherlands.

Stace, HCT, Hubble, GD; Brewer, R; Northcote, KH; Sleeman, JR; Mulcahy, MJ and Hallsworth, EG (1968). Handbook of Australian Soils. Rellim Technical Publications, Glenside.

Stoneman, TC (1992). An introduction to the soils of the Merredin advisory district. Bulletin 4235 Western Australian Department of Agriculture.

Talsma, T and Hallam, PM (1980). Hydraulic conductivity measurements of forested catchments. *Australian Journal of Soil Research* **20:** 139-148.

Tennant, D (1993). Role of potential yield estimates. *In* Australian Grain Vol **3**(4), Western Focus section vi-vii.

USDA (1992). Soil Survey Staff. Keys to Soil Taxonomy. SMSS Technical Monograph 19, Blacksburg.