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The Tully Rundown Experiment: Site Description and Initial Characterisation

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SUGAR YIELD DECLINE JOINT VENTURE

Cooperative Research Centre for
Sustainable Sugar Production

CSIRO LAND and WATER

TECHNICAL REPORT 5/1999

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SITE DESCRIPTION AND INITIAL CHARACTERISATION

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Cooperative Research Centre for
*S*ustainable *S*ugar *P*roduction

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1. INTRODUCTION

Sugar yield decline within the Queensland sugar industry has been defined as the loss in productive capacity of soils as a result of growing sugarcane as a monoculture. It has been estimated to cost the sugar industry $200 - $400 million per year, and has in the past been largely associated with soil microbiological factors (Magarey 1996). The loss in a soils productive capacity can be expressed schematically as in Fig. 1.1, which can serve as a framework for the research studies being carried out at the Rundown site near Tully in north Queensland. It has been established from previous work that fumigation results in an increased yield of up to 20% (Muchow et al 1994; Magarey and Croft 1995), and this increase in yield (shown as A in Fig. 1.1) can be attributed largely to soil biological (pathological) factors (and maybe some nutritional aspects as a result of the 'flush' of nutrients that usually follows fumigation). If A is attributed to biology, then B (Fig. 1.1) could be attributed to physical and/or chemical factors, and it is clear that all three are involved in the yield decline problem. In reality, crop yield will reflect the overall productive capacity of soils, or 'soil health', which is an expression of a complex interaction between the physical, chemical and biological factors.

The key question then is how (and why) does the productive capacity of soils decrease as a function of time ? Why is it that soil cannot maintain plant production similar to that obtained in its first year of production ? Is there a key measure that can be used to quantify the productive capacity of soil, or is the soil health a product of several key factors that interact in some complex way ? Also, will the key factors which determine soil health be the same in various climatic zones and in various soil types, or will the key factor or combination of factors differ across regions and between soils ? In these sugarcane systems the plant is doing the integrating, and the level of 'soil health' is reflected by the plant through its performance in terms of growth rates, health, and yields. Ideally, there will be an index that we can use to 'quantify' soil health, but at this stage that index is unknown.

In order to address these issues effort needs to be made to address and improve understanding of the soil properties, which are more fundamental than the state variables. We need to measure and quantify the changes in soil properties following introduction of a sugarcane crop to new land, as subtle changes in soil properties with time may be critical to interpretations and subsequent solutions to the yield decline problems. Alternatively, the changes may be abrupt and catastrophic (at least on some soils) and easily identified. There may be no changes in the soil productive capacity with time and this would be an equally valid outcome of the experiment and allow us to say with confidence (at least for the particular climate and soil type being studied) that 'yield decline' is not an issue.

It is also important to note that it may be impossible to determine which are the key soil properties involved in loss of a soils productive capacity by attempting to improve yields through outcome oriented approaches such as introducing crop rotations. We <u>expect</u> yields to improve by introducing a rotation system as it is a well established fact in probably every monoculture system that we know about. However, the chances of identifying the key (critical) changes in soil properties may be difficult using crop rotations, as basically we are approaching the problem from only one direction. The crop rotation starts with the system in its degraded form and does something to it (maybe even just breaking the disease cycle) to obtain improved yields. A difficulty with rotation experiments on old land is that they lack a real control, new land. The Rundown experiment starts with new land and therefore adds to the experimental program by having new land as the control. However, it too is somewhat incomplete as it is not possible to include old land (fully degraded land) within the Rundown experiment as a comparative treatment.

The basic aim of the Rundown experiment then is to analyse changes in soil properties with time in an attempt to establish critical factors which lead to a break down in the soils productive capacity, as expressed by a decline in crop yield. An additional aim is to develop quantitative relationships between the soil biology, soil chemistry and soil physics. In this report we provide a brief outline of the experimental aims, a description of the soils at the Rundown field site, and a summary of the key soil data obtained from measurements carried out at 'time zero' to establish our benchmark for the site. These data will serve as the reference data for all future experiments and enable comparisons to be made over time to determine what, if any, changes occur in soil properties as a result of sugarcane monoculture.

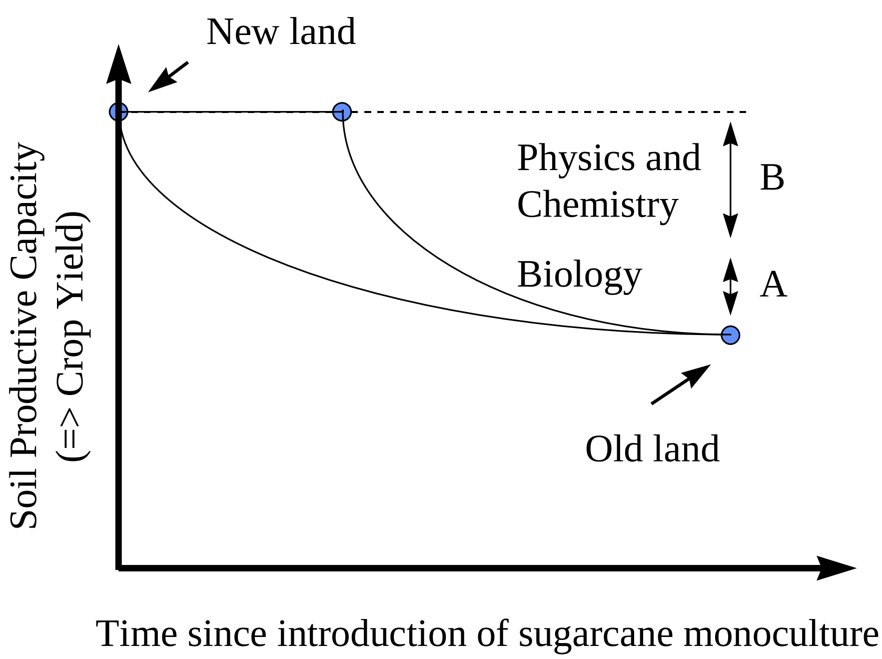


Fig. 1.1 Schematic of changes in soil productive capacity under monoculture systems. 'A' gives the response to fumigation, which is attributed to biological factors, 'B' the response to changes in soil physical and chemical properties, and 'A+B' the overall loss of productive capacity of the soil (ie decline in soil health).

2. THE RUNDOWN EXPERIMENT

2.1 Overview

The key experimental objectives identified when establishing the Rundown field site where to

1. identify changes in soil biophysical (chemical, physical and biological) properties and their influence on sugarcane yield when new land is planted to monoculture sugarcane
2. utilise the resultant information to develop strategies and/or more targeted research to limit the negative impact of changes in soil biophysical properties on crop yield

In pursuing these objectives it was hoped that measurements would quantify changes in and interactions between soil chemical, biological and physical properties as a function of time, and that particular attention would be given to:

- changes in soil biological properties
- changes in soil chemical properties
- changes in soil physical properties (structure) and their impact on the soil water balance
- rates of soil acidification
- changes in plant root development and performance
- changes in sugarcane yield due to changes in the above factors.

The philosophy in establishing the Rundown experiment was to keep a high degree of flexibility within the research program and to accommodate other scientists studies when their input could add value to the overall aim of the Rundown project. The intention is also to apply appropriate models to a) help determine potential yields in order to assist in separating out climatic effects from soil induced effects on crop yield, and b) extrapolate findings in both space and time.

The site chosen for the Rundown experiment is on the Tully Tea Plantation road some 15 km from Tully. As far as we have been able to determine the site was under rainforest until 1962 when it was cleared for tea. Tea proved unsuccessful and was replaced with *Brachiaria humidicola* pasture in 1966. The site has been used for fattening beef cattle since then. We have not been able to determine if and when fertiliser was applied but it seems from the relatively high P and S levels we have measured that superphosphate may have been applied at some stage. We obtained access to the field site in late 1995.

The Rundown experiment consists of a randomised split block design with 14 treatments replicated 3 times (total of 42 plots) (Table 2.1, Fig. 2.1). The plot sizes are roughly 15 m wide (10 rows) by 25 m long, with borders between plots ranging from 5-10 m. The experimental design was set to enable a range of histories to be available at the end of the first plant cycle when the whole site is put back to plant cane (Table 2.1). If the site is maintained as a long term site, treatments 13 and 14 provide opportunity to incorporate new land as the reference into second and third plant cycles. The first sugarcane crop (Q117) was planted in July 1996.

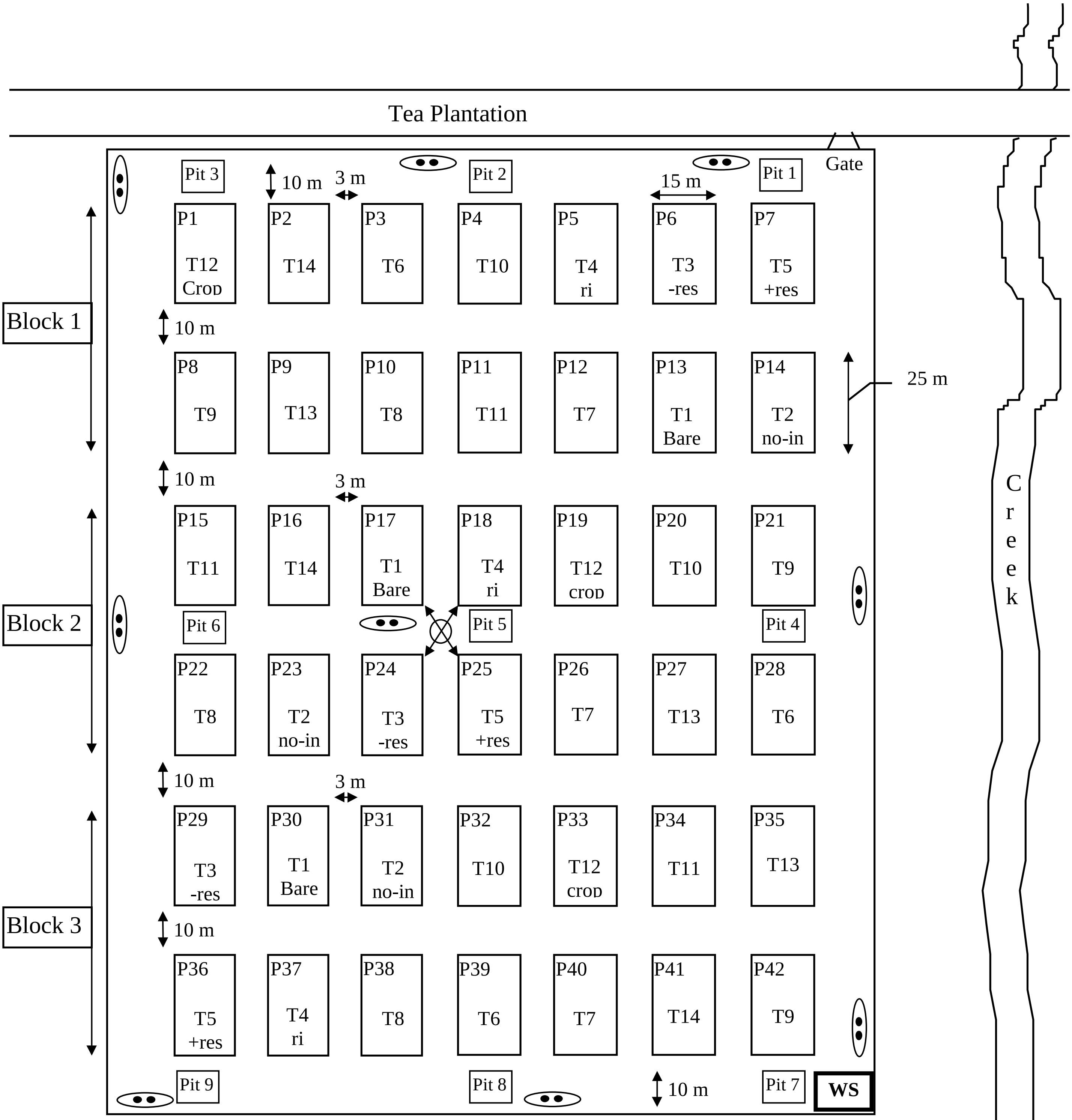
Table 2.1 Experimental treatments and time scale. Key: NL = new land; bare = new land kept bare; crop = crop other than sugarcane; PCa = plant cane; R1..R5 = ratoons with residue retained; -res = green cane harvesting but with trash removed from the plots; +ri = green cane harvesting but with trash incorporated; +noin = trash retained but with no inputs

	YEAR					
	96/97	**97/98**	**98/99**	**99/00**	**00/01**	**01/02**
Treatment						
1	bare	bare	bare	bare	bare	PCa
2	PC+noin	R1+noin	R2+noin	R3+noin	R4+noin	PCa
3	PCa-res	R1-res	R2-res	R3-res	R4-res	PCa
4	PCa+ri	R1+ri	R2+ri	R3+ri	R4+ri	PCa
5	PCa	R1	R2	R3	R4	PCa
6	NL	PCa	R1	R2	R3	PCa
7	NL	NL	Pca	R1	R2	PCa
8	NL	NL	NL	PCa	R1	PCa
9	NL	NL	NL	NL	PCa	PCa
10	NL	NL	NL	NL	NL	PCa
11	NL	NL	NL	NL	NL	NL
12	crop	crop	crop	crop	crop	PCa
13	NL	NL	NL	NL	NL	NL
14	NL	NL	NL	NL	NL	NL

2.2 Site Instrumentation

The site has been instrumented with an automatic weather station to provide a continuous record of rainfall, air temperature, soil temperature, solar irradiation, wind speed, humidity, and potential evapotranspiration calculated using the Penman-Monteith procedure.

Attempts to develop some understanding of the water balance and linkages between soil water and the soil biology and chemistry at the site have been made by instrumenting key treatment plots with tensiometers to monitor soil water suction and TDR (Time Domain Reflectometry) to monitor soil water content. Early experience with ponding and extended periods of saturation at the field site led to the installation of several banks of piezometers to enable measurement of ground water fluctuations and changes in groundwater quality. Suction cups have also been installed in key treatment plots to facilitate analysis of soil water quality and movement of applied nutrients such as nitrates. The above data will help provide insights into changes in the water and nutrient balance at the site and the role they play in controlling dynamics of the soil biota, soil acidification, and changes in crop water use and yield, especially if the site is drained at some stage in the future. Additional details of the site instrumentation are given by Goding et al. (1999).



Notes: P=plots; T=treatments; Pit=time zero soil sampling pit
Plot width 15m; Plot length 25 m; Horizontal borders 10 m; Vertical borders 3 m
WS = Weather Station

Site for detailed instrumentation

Banks of piezometers

Fig. 2.1 Tully Rundown site showing instrumentation and experimental layout (not to scale)

3. SITE AND SOIL DESCRIPTION

The soil at the Rundown site is classified as a dermosolic redoxic hydrosol according to the new Australian Classification (Isbell 1996), is formed on Alluvium, and characterised by a uniform or gradational texture profile, mottled yellow and grey B horizon, and moderate to strong structure throughout. The soil was described using material from soil cores obtained during installation of the banks of piezometers, which are labeled 1 to 9 starting with 1 in the top north-west corner and moving across and down the field to 9 in the bottom right hand corner. Note that this numbering is different for the numbering used for the soil pits. A schematic of the soil profiles at each of the 9 locations showing variations in the soil and depths to soil layers is given in Fig. 3.1.

3.1 General site description

Project : RUNDOWN
Described by : SUZANNE BERTHELSEN
Date : 05/09/96

Elevation : 30 metres
Runoff : slow
Drainage : poorly drained
Locality : Tully Rundown
Latitude 175318 S Longitude 14550

CLASSIFICATION
Principal Profile Form : Gn3.91
Great Soil Group : No suitable group. Affinities with GLEYED PODZOLIC SOIL
New Australian Classification : DERMOSOLIC REDOXIC HYDROSOL
Soil Land Class : Coom
LANDFORM
Relief Modal/Slope Class : level plain <9m <1%
Pattern Type : alluvial plain
Element Type : plain
Slope : <1 %   180 degree Aspect flat
Slope Category : level
GEOLOGY
Substrate Material : unconsolidated substrate material
Geological Reference : Qa
MICRORELIEF
Type of Microrelief : debil-debil
Vertical Interval : 0.2 m
Horizontal Interval : 2 m
Component Sampled : depression
VEGETATION
Tallest Stratum Form : Mid-high closed tussock grassland
Ground Cover Species : BOHUM
SITE DISTURBANCE
Complete clearing, pasture, cultivation at some stage
CONDITION OF SURFACE SOIL WHEN DRY
Hard setting

3.2 Soil profile descriptions

PROFILE NO 1:

LOCATION : PIEZOMETER NEST S1 - RUNDOWN SITE TULLY (NW CORNER)

PROFILE MORPHOLOGY :

HORIZON	DEPTH	DESCRIPTION
AP1	0 to 0.15 m	Brown (10YR5/3); clay loam; strong 2-5mm subangular blocky; dry; abrupt change to-
AP2	0.15 to 0.20 m	Brown (10YR5/3); 20-50% 15-30mm distinct yellowish brown (10YR5/6) mottles; clay loam; weak 5-10mm subangular blocky; moderately moist; abrupt change to-
B21	0.20 to 0.45 m	Yellowish brown (10YR5/6); light clay; strong 5-10mm subangular blocky; moderately moist; gradual change to-
B22	0.45 to 0.65 m	Brownish yellow (10YR6/6); light clay; strong 5-10mm subangular blocky; moderately moist; gradual change to-
B23	0.65 to 1.20 m	Light yellowish brown (10YR6/4); 20-50% 15-30mm distinct red (2.5YR4/8) mottles; medium heavy clay; strong 5-10mm subangular blocky; moderately moist; clear change to-
B24g	1.20 to 1.60 m	Light brownish grey (10YR6/2); 2-10% 5-15mm distinct strong brown (7.5YR5/8) mottles; coarse sandy light clay; strong 10-20mm subangular blocky; moderately moist; 2-10% 6-20mm, subrounded quartz gravel, dispersed; gradual change to-
D1	1.60 to 2.20 m	Light brownish grey (10YR6/2); clayey coarse sand; single grain; wet; 20-50% 6-20mm, subrounded quartz gravel, dispersed; abrupt change to-
D2	2.20 to 2.50 m	Pale red (2.5YR6/2); 10-20% 5-15mm distinct strong brown (7.5YR5/8) mottles; medium clay; strong 10-20mm subangular blocky; moderately moist; clear change to-
D3	2.50 to 3.10 m	Dark yellowish brown (10YR4/5); 2-10% 5-15mm distinct grey (10YR6/1) mottles; medium clay; strong 10-20mm subangular blocky; moderately moist; 10-20% <2mm manganiferous laminae; diffuse change to-
D4	3.10 to 3.60 m	Yellowish brown (10YR5/8); medium clay; strong 10-20mm subangular blocky; moderately moist; gradual change to-
D5	3.60 to 4.00 m	Dark yellowish brown (10YR4/5); loamy fine sand; single grain; wet; 2-10% manganiferous soft segregations; abrupt change to-
D6	4.00 to 4.10 m	Dark yellowish brown (10YR4/6); heavy clay; strong 10-20mm subangular blocky; moderately moist.

PROFILE NO 2:

LOCATION : PIEZOMETER NEST S2 - RUNDOWN SITE TULLY

PROFILE MORPHOLOGY :

HORIZON	DEPTH	DESCRIPTION
AP1	0 to 0.10 m	Brown (10YR5/3); clay loam; strong 2-5mm subangular blocky; clear change to-
B21	0.10 to 0.40 m	Olive yellow (2.5Y6/6); 2-10% <5mm faint olive yellow (2.5Y6/8) mottles; light clay; strong 5-10mm subangular blocky; diffuse change to-
B22	0.40 to 1.10 m	Olive yellow (2.5Y6/6); 10-20% 5-15mm distinct greyish brown (2.5Y5/3) mottles; light medium clay; strong 5-10mm subangular blocky; diffuse change to-
B23	1.10 to 1.60 m	Grey (2.5Y6/1); 10-20% 15-30mm distinct red (2.5YR4/8) mottles; medium heavy clay; strong 5-10mm subangular blocky; <2% manganiferous; diffuse change to-
B24	1.60 to 2.00 m	Light brownish grey (2.5Y6/3); 2-10% 5-15mm distinct strong brown (7.5YR5/8) primary and red (2.5YR4/6) secondary mottles; medium heavy clay; strong 5-10mm subangular blocky; 2-6mm manganiferous laminae; diffuse change to-
B25	2.00 to 2.40 m	Light brownish grey (2.5Y6/3); <2% <5mm distinct strong brown (7.5YR5/8) mottles; medium heavy clay; strong 5-10mm subangular blocky; diffuse change to-
B26	2.40 to 2.60 m	Light brownish grey (2.5Y6/3); strong brown (7.5YR5/8) primary and red (2.5YR4/6) secondary mottles; medium heavy clay; strong 5-10mm subangular blocky; 2-6mm manganiferous laminae; diffuse change to-
D1	2.60 to 2.80 m	Light grey (10YR7/2); clayey coarse sand; single grain; <2% 6-20mm, subrounded quartz gravel, dispersed; manganiferous; abrupt change to-
D2	2.80 to 3.00 m	Light grey (10YR7/2); strong brown (7.5YR5/8) primary and grey (7.5YR6/1) secondary mottles; silty light clay; strong 20-50mm subangular blocky.

PROFILE NO 3:

LOCATION : PIEZOMETER NEST S3 - RUNDOWN SITE TULLY

PROFILE MORPHOLOGY :

HORIZON	DEPTH	DESCRIPTION
AP	0 to 0.10 m	Dark yellowish brown (10YR3/4); clay loam; strong 2-5mm subangular blocky; gradual change to-
B1	0.10 to 0.25 m	Light olive brown (2.5Y5/4); 10-20% 5-15mm distinct strong brown (7.5YR4/6) mottles; light clay; strong 5-10mm subangular blocky; clear change to-
B21	0.25 to 0.60 m	Light olive brown (2.5Y5/6); 2-10% 5-15mm distinct light olive brown (2.5Y5/8) mottles; medium clay; strong 5-10mm subangular blocky; diffuse change to-
B22	0.60 to 0.85 m	Light olive brown (2.5Y5/4); medium clay; strong 5-10mm subangular blocky; diffuse change to-
B23	0.85 to 1.40 m	Light grey (2.5Y7/2); 2-10% 5-15mm distinct red (2.5YR4/6) mottles; medium clay; strong 5-10mm subangular blocky; 2-10% 2-6mm manganiferous soft segregations; gradual change to-
B24g	1.40 to 1.80 m	Light brownish grey (2.5Y6/2); <2% 5-15mm distinct strong brown (7.5YR4/6) mottles; medium heavy clay; strong 5-10mm subangular blocky; diffuse change to-
B25	1.80 to 2.30 m	Light brownish grey (2.5Y6/3); 10-20% 15-30mm prominent strong brown (7.5YR5/8) primary and red (2.5YR4/6) secondary mottles; medium heavy clay; strong 5-10mm subangular blocky; abrupt change to-
D1	2.30 to 2.60 m	Greyish brown (2.5Y5/2); clayey coarse sand; single grain; 2-10% 6-20mm, subrounded quartz gravel, dispersed; abrupt change to-
D2	2.60 to 2.80 m	Light brownish grey (2.5Y6/2); 10-20% 15-30mm prominent strong brown (7.5YR5/8) mottles; fine sandy loam; massive; 2-10% 2-6mm manganiferous laminae; clear change to-
D3	2.80 to 3.00 m	Light grey (2.5Y7/2); 10-20% 15-30mm prominent strong brown (7.5YR5/8) mottles; medium heavy clay; strong 20-50mm subangular blocky; 20-50% 6-20mm manganiferous laminae.

PROFILE NO 4:

LOCATION : PIEZOMETER NEST S4 - RUNDOWN SITE TULLY

PROFILE MORPHOLOGY :

HORIZON	DEPTH	DESCRIPTION
AP	0 to 0.15 m	Brown (10YR5/3); clay loam; strong 2-5mm subangular blocky; clear change to-
B1	0.15 to 0.25 m	Brownish yellow (10YR6/6); 2-10% <5mm prominent strong brown (7.5YR5/8) mottles; light clay; strong 5-10mm subangular blocky; clear change to-
B21	0.25 to 0.60 m	Brownish yellow (10YR6/6); light medium clay; strong 5-10mm subangular blocky; clear change to-
B22	0.60 to 1.05 m	Light yellowish brown (10YR6/4); 2-10% 5-15mm prominent red (2.5YR4/6) mottles; medium clay; strong 5-10mm subangular blocky; clear change to-
D1	1.05 to 1.20 m	Light yellowish brown (10YR6/4); 2-10% 5-15mm prominent strong brown (7.5YR5/8) mottles; sandy light clay; moderate 10-20mm subangular blocky;
D2	1.20 to 1.40 m	Light yellowish brown (10YR6/4); sandy light clay; massive; 2-10% 6-20mm, subrounded quartz gravel, dispersed;
D3	1.40 to 1.50 m	Brown (7.5YR4/4); 2-10% 5-15mm distinct pale brown (10YR6/3) mottles; sandy light clay; massive;
D4	1.50 to 2.10 m	Brown (7.5YR4/4); 2-10% 5-15mm distinct grey (10YR6/1) mottles; light medium clay; strong 5-10mm subangular blocky; 2-10% 2-6mm manganiferous laminae.

PROFILE NO 5:

LOCATION : PIEZOMETER NEST S5 - RUNDOWN SITE TULLY

PROFILE MORPHOLOGY :

HORIZON	DEPTH	DESCRIPTION
AP1	0 to 0.05 m	Brown (10YR5/3); clay loam; strong 2-5mm subangular blocky; clear change to-
AP2	0.05 to 0.10 m	Light yellowish brown (10YR6/4); clay loam; strong 5-10mm subangular blocky; clear change to-
AP3	0.10 to 0.20 m	Light yellowish brown (10YR6/4); 2-10% 5-15mm faint brown (7.5YR4/4) mottles; medium clay; strong 5-10mm subangular blocky; gradual change to-
B21	0.20 to 0.80 m	Brownish yellow (10YR6/6); <2% 5-15mm faint strong brown (7.5YR5/8) mottles; medium clay; strong 5-10mm subangular blocky; gradual change to-
B22	0.80 to 1.50 m	Light grey (10YR7/1); 20-50% 5-15mm distinct strong brown (7.5YR5/8) primary and reddish yellow (7.5YR6/8) secondary mottles; medium clay; strong 5-10mm subangular blocky;
D	1.50 to 2.00 m	Yellowish brown (10YR5/6); 20-50% 15-30mm distinct light grey (10YR7/2) mottles; coarse sandy light clay; massive.

PROFILE NO 6:

LOCATION : PIEZOMETER NEST S6 - RUNDOWN SITE TULLY

PROFILE MORPHOLOGY :

HORIZON	DEPTH	DESCRIPTION
AP1	0 to 0.05 m	Brown (10YR5/3); clay loam; strong 2-5mm subangular blocky; clear change to-
AP2	0.05 to 0.10 m	Brown (10YR5/3); distinct yellowish brown (10YR5/6) mottles; clay loam; strong 5-10mm subangular blocky; clear change to-
AP3	0.10 to 0.20 m	Yellowish brown (10YR5/6); medium heavy clay; strong 5-10mm subangular blocky; gradual change to-
B21	0.20 to 0.40 m	Brownish yellow (10YR6/6); 2-10% <5mm distinct yellowish red (5YR5/8) mottles; medium heavy clay; strong 5-10mm subangular blocky;
B22	0.40 to 0.95 m	Strong brown (7.5YR5/8); 2-10% 5-15mm distinct light brownish grey (2.5Y6/3) mottles; medium heavy clay; strong 5-10mm subangular blocky; <2% 2-6mm manganiferous soft segregations; clear change to-
B23	0.95 to 1.60 m	Strong brown (7.5YR5/8); 10-20% 15-30mm distinct light brownish grey (2.5Y6/2) mottles; sandy light clay; massive; <2% 2-6mm manganiferous soft segregations; clear change to-
D1	1.60 to 1.70 m	Light grey (10YR7/2); sandy clay loam; massive; 10-20% 6-20mm, subrounded quartz gravel; clear change to-
D2	1.70 to 2.10 m	Light reddish brown (2.5YR6/3); 2-10% 15-30mm distinct red (2.5YR4/6) mottles; medium clay; strong 5-10mm subangular blocky.

PROFILE NO 7:

LOCATION : PIEZOMETER NEST S7 - RUNDOWN SITE TULLY

PROFILE MORPHOLOGY :

HORIZON	DEPTH	DESCRIPTION
AP	0 to 0.12 m	Grey (10YR5/1); clay loam; strong 2-5mm subangular blocky;
B21	0.12 to 0.22 m	Light yellowish brown (10YR6/4); <2% <5mm distinct strong brown (7.5YR5/6) mottles; light medium clay; strong 5-10mm subangular blocky;
B22	0.22 to 0.60 m	Brownish yellow (10YR6/6); <2% <5mm distinct yellowish red (5YR5/8) mottles; light medium clay; strong 5-10mm subangular blocky;
B23	0.60 to 1.00 m	Light yellowish brown (10YR6/4); <2% 5-15mm distinct strong brown (7.5YR5/8) primary and red (2.5YR4/6) secondary mottles; light medium clay; strong 5-10mm subangular blocky;
B24	1.00 to 1.90 m	Light reddish brown (2.5YR6/4); 10-20% 5-15mm distinct strong brown (7.5YR5/8) primary and red (2.5YR4/6) secondary mottles; light medium clay; strong 5-10mm subangular blocky;
D	1.90 to 2.20 m	Light brownish grey (2.5Y6/3); 2-10% 5-15mm distinct light red (2.5YR6/8) primary and olive brown (2.5Y4/6) secondary mottles; fine sandy clay loam; moderate 10-20mm subangular blocky.

PROFILE NO 8:

LOCATION : PIEZOMETER NEST S8 - RUNDOWN SITE TULLY

PROFILE MORPHOLOGY :

HORIZON	DEPTH	DESCRIPTION
AP0	0 to 0.10 m	Brown (10YR5/3); clay loam; strong 2-5mm subangular blocky; clear change to-
B21	0.10 to 0.55 m	Brownish yellow (10YR6/8); light medium clay; strong 5-10mm subangular blocky; gradual change to-
B22	0.55 to 1.00 m	Brownish yellow (10YR6/8); 2-10% 5-15mm distinct strong brown (7.5YR5/8) primary and red (2.5YR4/6) secondary mottles; light medium clay; strong 5-10mm subangular blocky; gradual change to-
B23	1.00 to 1.60 m	Brownish yellow (10YR6/8); 2-10% 5-15mm distinct strong brown (7.5YR5/8) primary and red (2.5YR4/6) secondary mottles; light medium clay; strong 5-10mm subangular blocky; gradual change to-
B24	1.60 to 1.80 m	Brownish yellow (10YR6/6); <2% 5-15mm faint strong brown (7.5YR5/8) primary and red (2.5YR4/6) secondary mottles; medium heavy clay; strong 5-10mm subangular blocky; gradual change to-
B25	1.80 to 2.40 m	Light brownish grey (2.5Y6/2); 2-10% 15-30mm distinct red (2.5YR4/6) mottles; medium heavy clay; strong 5-10mm subangular blocky; 2-10% 2-6mm manganiferous laminae; gradual change to-
B26r	2.40 to 2.80 m	Yellowish red (5YR4/6); 20-50% 15-30mm distinct pale red (2.5YR6/2) mottles; medium heavy clay; strong 5-10mm subangular blocky; 10-20% 2-6mm manganiferous laminae.

PROFILE NO 9:

LOCATION : PIEZOMETER NEST S9 - RUNDOWN SITE TULLY

PROFILE MORPHOLOGY :

HORIZON	DEPTH	DESCRIPTION
AP1	0 to 0.14 m	Greyish brown (10YR5/2); clay loam; strong 2-5mm subangular blocky;
B21	0.14 to 0.60 m	Brownish yellow (10YR6/6); <2% <5mm faint brownish yellow (10YR6/8) mottles; light clay; strong 5-10mm subangular blocky;
B22	0.60 to 0.90 m	Light yellowish brown (10YR6/4); 2-10% <5mm distinct brownish yellow (10YR6/8) mottles; light clay; strong 5-10mm subangular blocky;
B23	0.90 to 1.30 m	Very pale brown (10YR7/3); 10-20% 15-30mm distinct brownish yellow (10YR6/8) mottles; light clay; strong 5-10mm subangular blocky; 10-20% manganiferous soft segregations;
D1	1.30 to 1.60 m	Very pale brown (10YR7/3); 10-20% 15-30mm distinct brownish yellow (10YR6/8) mottles; sandy clay loam (heavy); moderate 10-20mm subangular blocky; 2-10% 2-6mm, subrounded quartz gravel; 10-20% manganiferous soft segregations;
D2	1.60 to 2.00 m	Light brownish grey (2.5Y6/2); 10-20% 15-30mm distinct brown (7.5YR4/4) mottles; medium heavy clay; strong 5-10mm subangular blocky; 10-20% manganiferous laminae.

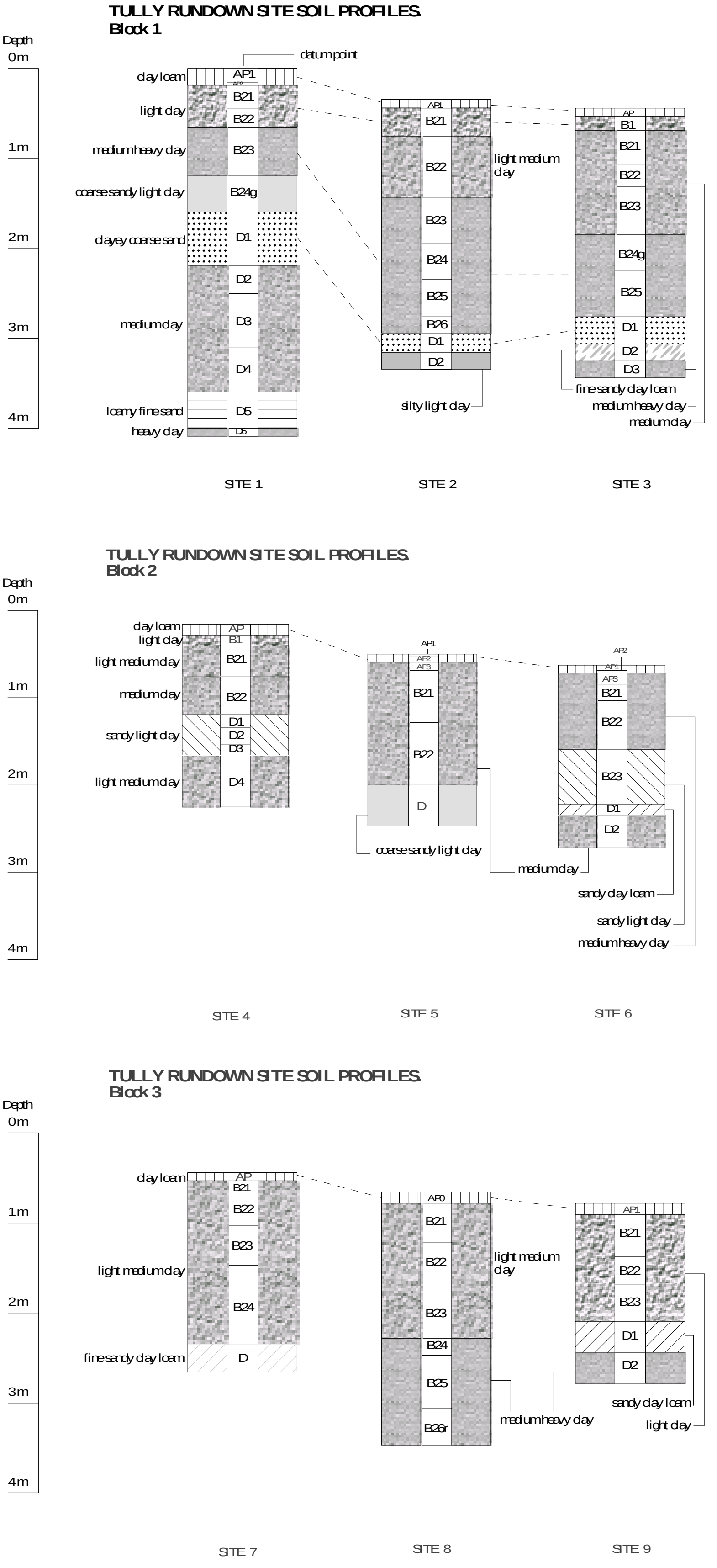


Fig. 3.1 Soil profiles across the Rundown site showing variation in soil and depths to soil layers

4. SOIL PHYSICAL CHARACTERISATION

Soil physical property characterisation involved measurements of soil hydraulic conductivity ($k(\theta)$), soil water retention ($\psi(\theta)$), soil bulk density (ρ_b), particle size distributions (PSD), and soil mineralogy.

Large pits with shelves were dug at 9 locations across the field site (Fig. 2.1) to facilitate collection of soil cores for laboratory analysis and for making field measurements of hydraulic conductivity using the disk permeameter. A brief description of each of the measurements is included below.

Undisturbed soil cores (7.3 cm diameter by 5 cm deep) were collected at 3 depths (10-15, 30-35, 50-55 cm) from each soil pit. These cores were pushed vertically into the soil and then excavated manually to minimise soil disturbance. Plastic caps were placed on each end of the core to contain the soil during transport to the laboratory and during storage prior to the laboratory analyses.

4.1 Hydraulic conductivity

Saturated hydraulic conductivity k_s measurements were made using the falling and/or constant head methods (Klute and Dirksen, 1986) as described by Ford and Bristow (1995). These data are given in Table 4.1.

In situ measurements of unsaturated conductivity were obtained using the disc infiltrometer (Anonymous, 1988). Measurements were made using two different suctions at 3 depths at two of the pits (pit 1 and 9) using the procedures described by Ford and Bristow (1995). The measured data are included in Table 4.2.

4.2 Soil water retention and bulk density

Soil water retention curves where determined on the same soil cores at the completion of the k_s measurements. This was achieved using a ceramic plate with a hanging water column to obtain measurements at suctions of 0, 10, 30, 50 and 100 cm. Once the 100 cm suction measurements were completed four subsamples, each 3 cm in diameter and 1 cm deep, were taken from the core and placed in a separate pressure chamber to obtain measurements at 300, 1000, 3000 and 15000 cm suctions.

The $\psi(\theta)$ data and plots of the 'mean' water retention curves for each depth are given in Table 4.3 to Table 4.11 and Fig. 4.1 to Fig. 4.9. The means are based on the values of the three replicates at each depth, and should be viewed as an illustration of trends. The real information lies in the basic $\psi(\theta)$ data of the individual samples.

Plant available water, defined for our purpose as that water held by the soil between suction's of 300 and 15000 cm is included in the above tables together with the soil bulk density which was calculated for each soil core. Further analysis of these data and procedures for estimating them from more readily available soils data such as particle size distributions is given by Bristow et al. (1999).

4.3 Particle size distributions

Soil from the actual cores used for water retention measurements were used for particle size distribution (PSD) determinations using sieving and the pipette method described by Coventry and Fett (1979). Size classes included gravel (>2 mm), coarse sand (0.2 - 2 mm), fine sand (0.02 - 0.2 mm), silt (0.002 - 0.02 mm) and clay (<0.002 mm). The PSD data are given in Table 4.12. Their use as surrogates for estimating soil water retention properties via pedotransfer functions are discussed by Bristow et al. (1999).

Table 4.1 Saturated hydraulic conductivity Ks (cm/h)

LOCATION	Depth (cm)	K sat (cm/h) Rep 1	Rep 2	Rep 3	Average	Std.dev.
Pit 1	10-15	6.46	1.64	1.49	3.2	2.8
	30-35	27.20	8.20	1.46	12.3	13.3
	50-55	0.42	19.93	41.11	20.5	20.4
Pit 2	10-15	1.23	0.63	1.27	1.0	0.4
	30-35	0.41	0.76	2.52	1.2	1.1
	50-55	96.61	2.58	4.44	34.5	53.8
Pit 3	10-15	63.74	1.63	3.95	23.1	35.2
	30-35	1.97	1.21	0.81	1.3	0.6
	50-55	0.99	2.42	7.72	3.7	3.5
Pit 4	10-15	0.43	0.75	1.18	0.8	0.4
	30-35	37.97	37.19	64.39	46.5	15.5
	50-55	104.47	11.98	142.19	86.2	67.0
Pit 5	10-15	2.13	4.81	6.64	4.5	2.3
	30-35	5.53	99.06	41.32	48.6	47.2
	50-55	2.13	4.81	6.64	4.5	2.3
Pit 6	10-15	3.29	6.89	4.67	5.0	1.8
	30-35	0.18	2.44	1.36	1.3	1.1
	50-55	2.88	1.37	0.69	1.6	1.1
Pit 7	10-15	12.47	2.54	0.80	5.3	6.3
	30-35	0.96	0.75	1.22	1.0	0.2
	50-55	8.27	4.44	23.12	11.9	9.9
Pit 8	10-15	4.47	0.99	5.05	3.5	2.2
	30-35	9.15	1.67	1.79	4.2	4.3
	50-55	35.09	32.79	3.40	23.8	17.7
Pit 9	10-15	8.56	1.63	1.95	4.0	3.9
	30-35	4.09	3.94	1.29	3.1	1.6
	50-55	1.30	19.90	2.34	7.8	10.5

Table 4.2 Disc permeameter data including sorptivity, steady state flow (SSF), hydraulic conductivity (k), macro-capillary length (MCL) and mean pore size (MPS). Bulk density measured at the disc permeameter sites are also included.

Location	Tension (mm)	Depth (cm)	Rep.	Bulk Density (g/cm^3)	Sorptivity (cm/h^5)	SSF (cm/h)	k (cm/h)	MCL (cm)	MPS (cm)
Pit 1	10	10	1	1.22	0.20	0.26	0.25	0.51	0.15
			2	1.26	0.26	0.46	0.44	0.68	0.11
			3	1.25	0.22	0.46	0.43	0.86	0.09
			Mean	1.24	0.23	0.39	0.37	0.68	0.11
			Stdev	0.02	0.03	0.12	0.11	0.17	0.03
		30	1	1.24	0.31	0.78	0.76	0.47	0.16
			2	1.33	0.91	2.46	2.30	1.11	0.07
			3	1.25	0.72	1.46	1.36	1.13	0.07
			Mean	1.27	0.64	1.57	1.47	0.90	0.10
			Stdev	0.05	0.31	0.85	0.78	0.38	0.05
		50	1	1.25	0.47	1.70	1.58	1.24	0.06
			2	1.34	0.31	0.58	0.51	2.18	0.03
			3	1.3	0.43	0.80	0.67	3.11	0.02
			Mean	1.30	0.40	1.03	0.92	2.18	0.04
			Stdev	0.05	0.08	0.59	0.58	0.94	0.02
Pit 1	40	10	1	1.22	0.16	0.21	0.20	0.55	0.14
			2	1.26	0.29	0.38	0.34	1.79	0.04
			3	1.24	0.14	0.15	0.14	0.57	0.13
			Mean	1.24	0.19	0.24	0.23	0.97	0.10
			Stdev	0.02	0.08	0.12	0.10	0.71	0.05
		30	1	1.24	0.37	0.33	0.30	1.75	0.04
			2	1.33	0.37	0.35	0.33	1.32	0.06
			3	1.25	0.35	0.34	0.31	1.45	0.05
			Mean	1.27	0.36	0.34	0.31	1.51	0.05
			Stdev	0.05	0.01	0.01	0.02	0.22	0.01
		50	1	1.25	0.13	0.10	0.08	5.66	0.01
			2	1.34	0.16	0.19	0.16	2.82	0.03
			3	1.3	0.11	0.18	0.16	1.24	0.06
			Mean	1.30	0.14	0.16	0.13	3.24	0.03
			Stdev	0.05	0.03	0.05	0.05	2.24	0.02

Table continued

Location	Tension (mm)	Depth (cm)	Rep.	Bulk Density (g/cm^3)	Sorptivity (cm/h^5)	SSF (cm/h)	k (cm/h)	MCL (cm)	MPS (cm)
Pit 9	10	10	1	1.27	0.29	0.62	0.60	0.49	0.15
			2	1.27	0.32	0.89	0.87	0.42	0.18
			3	1.15	0.23	1.49	1.47	0.22	0.34
			Mean	1.23	0.28	1.00	0.98	0.38	0.22
			Stdev	0.07	0.04	0.44	0.44	0.14	0.10
		30	1	1.36	0.18	0.53	0.49	1.38	0.05
			2	1.32	0.24	1.10	1.06	0.69	0.11
			3	1.34	0.34	0.86	0.76	2.03	0.04
			Mean	1.34	0.25	0.83	0.77	1.37	0.07
			Stdev	0.02	0.08	0.29	0.28	0.67	0.04
		50	1	1.30	0.49	0.83	0.55	8.02	0.01
			2	1.28	0.27	0.62	1.94	*	*
			3	1.36	0.46	1.06	0.90	2.63	0.03
			Mean	1.31	0.41	0.84	1.13	5.33	0.02
			Stdev	0.04	0.12	0.22	0.72	3.82	0.01
Pit 9	40	10	1	1.25	0.28	0.40	0.37	1.27	0.06
			2	1.11	0.28	0.19	0.10	13.01	0.01
			3	1.15	0.16	0.34	0.33	0.36	0.21
			Mean	1.17	0.24	0.31	0.27	4.88	0.09
			Stdev	0.07	0.07	0.11	0.15	7.06	0.10
		30	1	1.36	0.12	0.17	0.16	0.92	0.08
			2	1.32	0.29	0.17	0.08	18.41	0.00
			3	1.34	0.10	0.12	0.11	1.31	0.06
			Mean	1.34	0.17	0.15	0.12	6.88	0.05
			Stdev	0.02	0.10	0.03	0.04	9.99	0.04
		50	1	1.30	0.19	0.22	0.12	12.40	0.01
			2	1.28	0.16	0.19	0.14	5.19	0.01
			3	1.36	0.18	0.24	*	*	*
			Mean	1.31	0.17	0.21	0.13	8.79	0.01
			Stdev	0.04	0.02	0.03	0.01	5.10	0.01

Table 4.3 Soil water retention data for Pit 1

					psi (cm)									PAWC
LOCATION	depth (cm)	Ring #	BD (g/cm^3)	Porosity	1	10	30	50	100	300	1000	3000	15000	.3 - 15 bar
Pit 1	10-15	B92	1.086	0.590	0.519	0.516	0.494	0.467	0.434	0.409	0.310	0.271	0.264	0.145
		B107	1.156	0.564	0.493	0.491	0.489	0.466	0.430	0.383	0.367	0.254	0.260	0.123
		267	1.104	0.583	0.531	0.520	0.516	0.498	0.461	0.385	0.315	0.302	0.271	0.113
	30-35	E11	1.216	0.541	0.495	0.473	0.438	0.418	0.393	0.341	0.351	0.287	0.270	0.070
		252	1.253	0.527	0.498	0.486	0.445	0.423	0.396	0.344	0.338	0.279	0.274	0.069
		1K	1.250	0.528	0.498	0.483	0.456	0.439	0.415	0.375	0.356	0.302	0.290	0.085
	50-55	6X	1.341	0.494	0.482	0.489	0.479	0.471	0.452	0.431	0.418	0.354	0.331	0.100
		B34	1.253	0.527	0.489	0.486	0.467	0.453	0.433	0.410	0.394	0.333	0.316	0.094
		B110	1.224	0.538	0.469	0.471	0.456	0.445	0.424	0.388	0.387	0.324	0.307	0.081
Averages	10-15		1.115	0.579	0.514	0.509	0.500	0.477	0.442	0.392	0.331	0.276	0.265	0.127
	30-35		1.240	0.532	0.497	0.481	0.446	0.427	0.401	0.353	0.348	0.289	0.278	0.075
	50-55		1.273	0.520	0.480	0.482	0.467	0.457	0.436	0.409	0.400	0.337	0.318	0.092

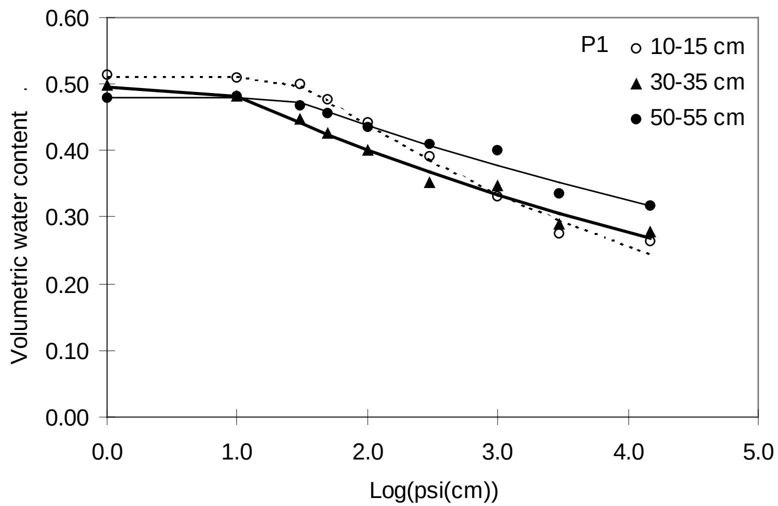


Fig. 4.1 Average water retention for each soil depth in pit 1 (points are measurements, lines are best fit smoothed Brooks-Corey function)

Table 4.4 Soil water retention data for Pit 2

									psi (cm)					PAWC
LOCATION	depth (cm)	Ring #	BD (g/cm^3)	Porosity	1	10	30	50	100	300	1000	3000	15000	.3 - 15 bar
Pit 2	10-15	419	1.325	0.500	0.456	0.450	0.448	0.437	0.412	0.367	0.351	0.290	0.262	0.105
		253	1.283	0.516	0.473	0.467	0.460	0.453	0.425	0.424	0.376	0.305	0.275	0.149
		180Z	1.364	0.485	0.475	0.477	0.471	0.460	0.435	0.355	0.356	0.310	0.288	0.068
	30-35	37A	1.255	0.526	0.463	0.466	0.459	0.448	0.428	0.424	0.367	0.334	0.283	0.141
		14	1.287	0.515	0.486	0.497	0.490	0.480	0.459	0.462	0.405	0.363	0.327	0.134
		211	1.228	0.537	0.503	0.505	0.482	0.465	0.437	0.442	0.365	0.280	0.251	0.191
	50-55	951	1.300	0.509	0.466	0.476	0.466	0.455	0.436	0.449	0.387	0.361	0.311	0.138
		261	1.308	0.506	0.487	0.480	0.467	0.454	0.433	0.459	0.404	0.356	0.307	0.153
		B53	1.314	0.504	0.452	0.460	0.447	0.436	0.419	0.422	0.371	0.328	0.291	0.131
Averages	10-15		1.324	0.500	0.468	0.464	0.460	0.450	0.424	0.382	0.361	0.302	0.275	0.107
	30-35		1.257	0.526	0.484	0.489	0.477	0.464	0.441	0.442	0.379	0.325	0.287	0.155
	50-55		1.307	0.507	0.468	0.472	0.460	0.448	0.429	0.444	0.387	0.349	0.303	0.141

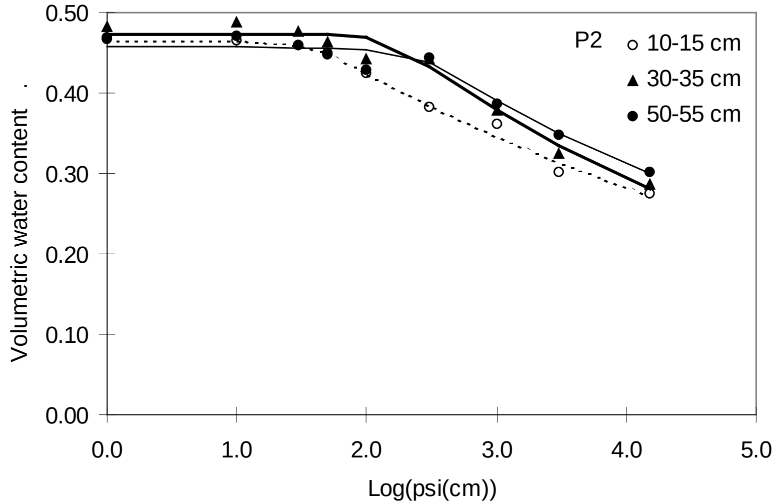


Fig. 4.2 Average water retention for each soil depth in pit 2 (points are measurements, lines are best fit smoothed Brooks-Corey function)

Table 4.5 Soil water retention data for Pit 3

					psi (cm)									PAWC
LOCATION	depth (cm)	Ring #	BD (g/cm^3)	Porosity	1	10	30	50	100	300	1000	3000	15000	.3 - 15 bar
Pit 3	10-15	20A	1.234	0.534	0.463	0.470	0.461	0.441	0.410	0.388	0.328	0.258	0.234	0.154
		9B	1.243	0.531	0.450	0.449	0.450	0.437	0.408	0.438	0.332	0.308	0.250	0.188
		29X	1.354	0.489	0.448	0.448	0.448	0.435	0.408	0.434	0.329	0.340	0.261	0.173
	30-35	6Z	1.562	0.411	0.390	0.396	0.393	0.381	0.366	0.382	0.335	0.304	0.253	0.128
		217	1.548	0.416	0.385	0.393	0.390	0.380	0.367	0.414	0.365	0.317	0.281	0.133
		84X	1.576	0.405	0.418	0.424	0.420	0.413	0.401	0.413	0.375	0.309	0.293	0.120
	50-55	B7	1.536	0.421	0.398	0.406	0.403	0.394	0.363	0.383	0.327	0.295	0.237	0.146
		B69	1.485	0.440	0.406	0.411	0.399	0.387	0.354	0.354	0.310	0.310	0.281	0.074
		B36	1.390	0.476	0.430	0.431	0.405	0.392	0.359	0.413	0.294	0.307	0.252	0.161
Averages	10-15		1.277	0.518	0.453	0.456	0.453	0.438	0.409	0.420	0.330	0.302	0.248	0.172
	30-35		1.562	0.411	0.398	0.405	0.401	0.392	0.378	0.403	0.358	0.310	0.276	0.127
	50-55		1.470	0.445	0.411	0.416	0.402	0.391	0.359	0.383	0.310	0.304	0.256	0.127

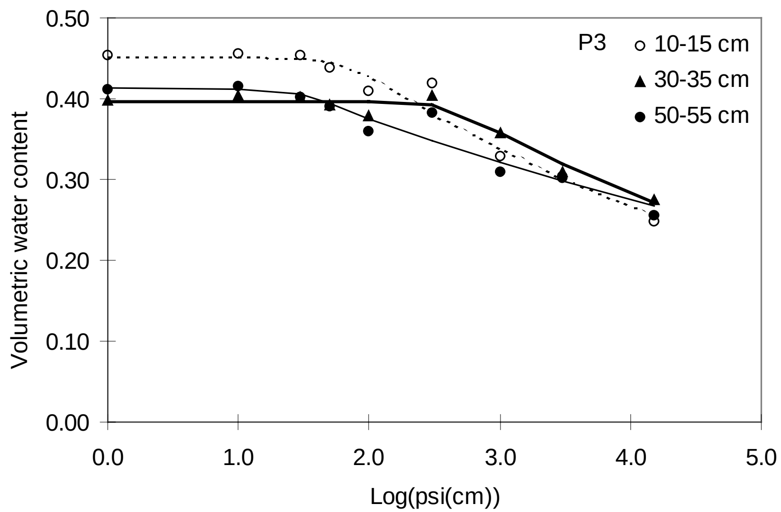


Fig. 4.3 Average water retention for each soil depth in pit 3 (points are measurements, lines are best fit smoothed Brooks-Corey function)

Table 4.6 Soil water retention data for Pit 4

LOCATION	depth (cm)	Ring #	BD (g/cm^3)	Porosity	psi (cm) 1	10	30	50	100	300	1000	3000	15000	PAWC .3 - 15 bar
Pit 4	10-15	41A	1.291	0.513	0.449	0.450	0.457	0.439	0.416	0.400	0.343	0.308	0.262	0.138
		234	1.289	0.513	0.473	0.471	0.476	0.457	0.430	0.415	0.350	0.314	0.270	0.144
		810	1.331	0.498	0.473	0.476	0.480	0.462	0.435	0.403	0.358	0.310	0.270	0.133
	30-35	9	1.227	0.537	0.474	0.462	0.437	0.416	0.392	0.368	0.318	0.279	0.238	0.129
		B82	1.219	0.540	0.466	0.453	0.421	0.402	0.377	0.364	0.305	0.271	0.232	0.132
		B67	1.160	0.562	0.484	0.459	0.413	0.390	0.363	0.338	0.286	0.241	0.215	0.123
	50-55	E42	1.213	0.542	0.508	0.500	0.482	0.469	0.451	0.415	0.363	0.328	0.285	0.130
		963	1.287	0.514	0.489	0.486	0.471	0.458	0.439	0.420	0.366	0.335	0.293	0.127
		B45	1.148	0.567	0.509	0.491	0.458	0.439	0.412	0.387	0.327	0.301	0.257	0.130
Averages	10-15		1.304	0.508	0.465	0.466	0.471	0.453	0.427	0.406	0.350	0.311	0.268	0.138
	30-35		1.202	0.546	0.475	0.458	0.424	0.403	0.377	0.357	0.303	0.264	0.228	0.128
	50-55		1.216	0.541	0.502	0.492	0.470	0.455	0.434	0.407	0.352	0.322	0.279	0.129

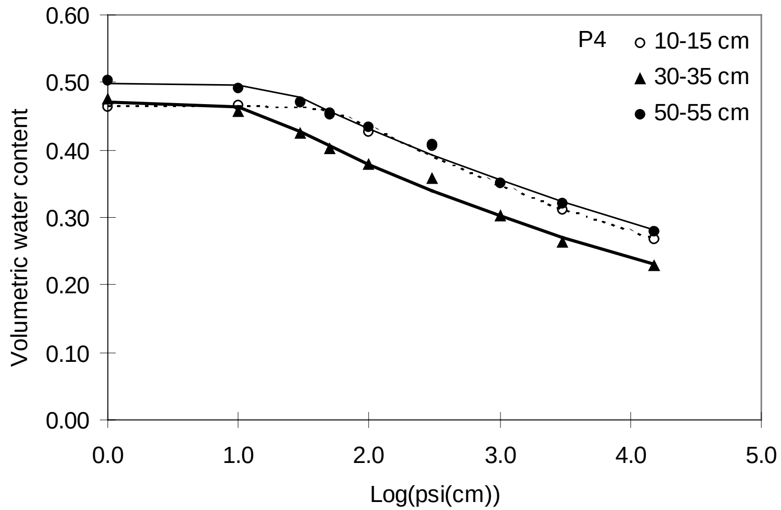


Fig. 4.4 Average water retention for each soil depth in pit 4 (points are measurements, lines are best fit smoothed Brooks-Corey function)

Table 4.7 Soil water retention data for Pit 5

					psi (cm)									PAWC
LOCATION	depth (cm)	Ring #	BD (g/cm^3)	Porosity	1	10	30	50	100	300	1000	3000	15000	.3 - 15 bar
Pit 5	10-15	909	1.285	0.515	0.462	0.466	0.461	0.442	0.437	0.365	0.340	0.290	0.234	0.131
		J19	1.317	0.503	0.467	0.461	0.430	0.413	0.406	0.335	0.263	0.208	0.160	0.175
		25A	1.300	0.509	0.444	0.427	0.381	0.364	0.360	0.261	0.213	0.194	0.164	0.097
	30-35	278	1.256	0.526	0.490	0.486	0.454	0.437	0.433	0.355	0.357	0.290	0.257	0.098
		243	1.300	0.509	0.468	0.468	0.447	0.432	0.427	0.371	0.357	0.301	0.259	0.112
		B54	1.195	0.549	0.469	0.459	0.422	0.405	0.402	0.337	0.312	0.283	0.248	0.089
	50-55	B105	1.267	0.522	0.479	0.481	0.462	0.449	0.429	0.424	0.377	0.341	0.298	0.126
		E64	1.296	0.511	0.488	0.490	0.476	0.465	0.448	0.432	0.384	0.358	0.318	0.114
		E27	1.249	0.529	0.497	0.500	0.489	0.475	0.456	0.446	0.398	0.349	0.307	0.139
Averages	10-15		1.301	0.509	0.457	0.451	0.424	0.406	0.401	0.321	0.272	0.231	0.186	0.135
	30-35		1.250	0.528	0.476	0.471	0.441	0.425	0.420	0.354	0.342	0.291	0.254	0.100
	50-55		1.271	0.520	0.488	0.490	0.476	0.463	0.444	0.434	0.386	0.349	0.308	0.126

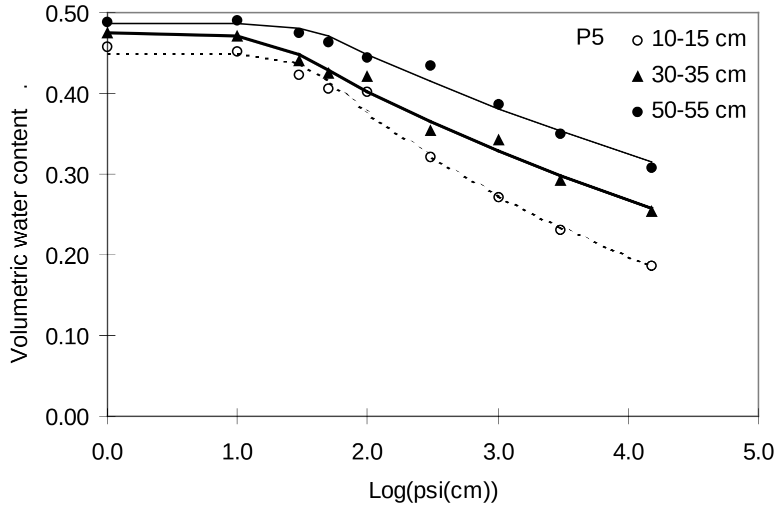


Fig. 4.5 Average water retention for each soil depth in pit 5 (points are measurements, lines are best fit smoothed Brooks-Corey function)

Table 4.8 Soil water retention data for Pit 6

					psi (cm)									PAWC
LOCATION	depth (cm)	Ring #	BD (g/cm^3)	Porosity	1	10	30	50	100	300	1000	3000	15000	.3 - 15 bar
Pit 6	10-15	938	1.388	0.476	0.438	0.440	0.442	0.434	0.431	0.360	0.337	0.295	0.261	0.099
		12X	1.296	0.511	0.475	0.480	0.471	0.451	0.446	0.355	0.354	0.270	0.264	0.092
		25X	1.280	0.517	0.467	0.472	0.458	0.438	0.435	0.332	0.293	0.274	0.245	0.087
	30-35	903	1.528	0.423	0.397	0.401	0.395	0.388	0.373	0.324	0.330	0.298	0.263	0.061
		231	1.497	0.435	0.415	0.419	0.421	0.418	0.397	0.349	0.329	0.306	0.260	0.090
		E24	1.425	0.462	0.425	0.425	0.420	0.408	0.389	0.365	0.336	0.282	0.249	0.116
	50-55	279	1.554	0.414	0.417	0.420	0.415	0.408	0.378	0.376	0.331	0.290	0.258	0.118
		48A	1.398	0.473	0.417	0.423	0.408	0.393	0.359	0.359	0.309	0.268	0.236	0.122
		14B	1.439	0.457	0.448	0.454	0.438	0.425	0.390	0.392	0.350	0.307	0.274	0.118
Averages	10-15		1.321	0.501	0.460	0.464	0.457	0.441	0.437	0.349	0.328	0.280	0.256	0.093
	30-35		1.483	0.440	0.412	0.415	0.412	0.405	0.387	0.346	0.331	0.295	0.257	0.089
	50-55		1.464	0.448	0.427	0.432	0.420	0.409	0.376	0.375	0.330	0.288	0.256	0.119

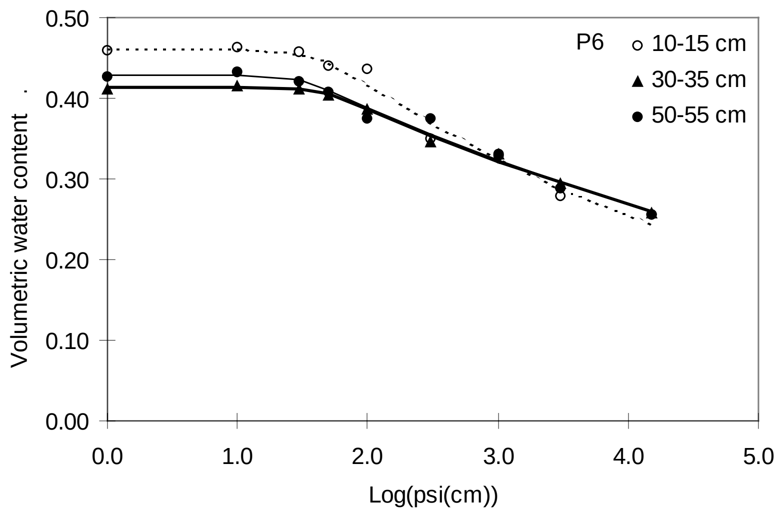


Fig. 4.6 Average water retention for each soil depth in pit 6 (points are measurements, lines are best fit smoothed Brooks-Corey function)

Table 4.9 Soil water retention data for Pit 7

					psi (cm)									PAWC
LOCATION	depth (cm)	Ring #	BD (g/cm^3)	Porosity	1	10	30	50	100	300	1000	3000	15000	.3 - 15 bar
Pit 7	10-15	B19	1.151	0.565	0.517	0.515	0.485	0.459	0.433	0.401	0.340	0.321	0.289	0.112
		15A	1.145	0.568	0.498	0.495	0.497	0.490	0.462	0.414	0.365	0.332	0.306	0.109
		17	1.204	0.546	0.500	0.498	0.499	0.498	0.471	0.426	0.398	0.346	0.318	0.108
	30-35	B31	1.287	0.514	0.480	0.483	0.474	0.464	0.450	0.410	0.403	0.361	0.318	0.093
		221	1.320	0.502	0.493	0.495	0.492	0.485	0.468	0.424	0.403	0.378	0.327	0.097
		E53	1.270	0.521	0.490	0.494	0.483	0.470	0.452	0.414	0.389	0.348	0.305	0.108
	50-55	B108	1.185	0.553	0.501	0.506	0.493	0.479	0.458	0.389	0.392	0.353	0.305	0.084
		820	1.231	0.535	0.524	0.527	0.520	0.507	0.486	0.426	0.412	0.366	0.322	0.104
		E40	1.236	0.534	0.508	0.509	0.497	0.487	0.469	0.414	0.398	0.351	0.320	0.094
Averages	10-15		1.167	0.560	0.505	0.502	0.494	0.482	0.455	0.414	0.368	0.333	0.304	0.110
	30-35		1.292	0.512	0.488	0.491	0.483	0.473	0.456	0.416	0.398	0.362	0.317	0.099
	50-55		1.217	0.541	0.511	0.514	0.503	0.491	0.471	0.410	0.400	0.356	0.316	0.094

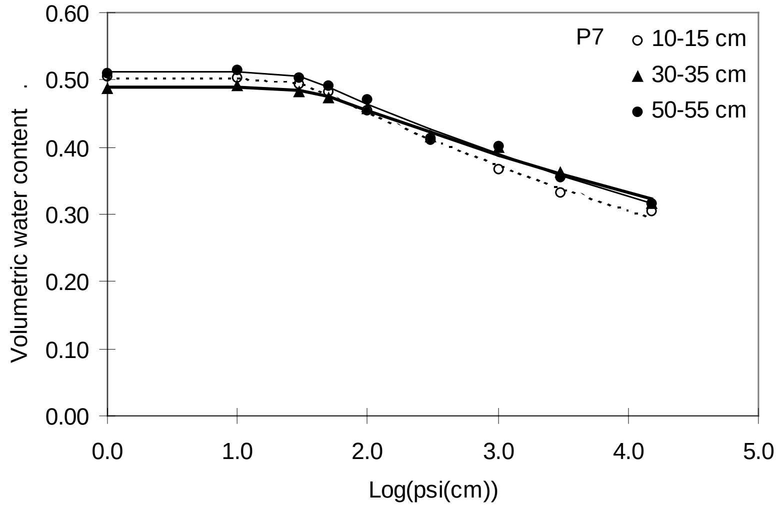


Fig. 4.7 Average water retention for each soil depth in pit 7 (points are measurements, lines are best fit smoothed Brooks-Corey function)

Table 4.10   Soil water retention data for Pit 8

					psi (cm)									PAWC
LOCATION	depth (cm)	Ring #	BD (g/cm^3)	Porosity	1	10	30	50	100	300	1000	3000	15000	.3 - 15 bar
Pit 8	10-15	B28	1.223	0.538	0.497	0.497	0.486	0.466	0.439	0.427	0.378	0.334	0.294	0.132
		B85	1.296	0.511	0.457	0.459	0.460	0.446	0.424	0.395	0.374	0.340	0.287	0.108
		B27	1.219	0.540	0.482	0.483	0.472	0.453	0.426	0.371	0.352	0.318	0.286	0.085
	30-35	B4	1.225	0.538	0.511	0.502	0.482	0.465	0.441	0.398	0.376	0.354	0.310	0.088
		255	1.118	0.578	0.449	0.449	0.446	0.436	0.409	0.366	0.347	0.317	0.279	0.087
		B75	1.231	0.535	0.490	0.490	0.482	0.463	0.440	0.403	0.347	0.346	0.304	0.099
	50-55	B40	1.090	0.589	0.526	0.494	0.441	0.417	0.392	0.371	0.331	0.323	0.269	0.102
		1	1.221	0.539	0.503	0.498	0.478	0.460	0.438	0.387	0.376	0.349	0.297	0.090
		17B	1.325	0.500	0.499	0.503	0.489	0.474	0.450	0.424	0.410	0.355	0.317	0.107
Averages	10-15		1.246	0.530	0.478	0.480	0.473	0.455	0.430	0.398	0.368	0.331	0.289	0.108
	30-35		1.191	0.550	0.483	0.481	0.470	0.455	0.430	0.389	0.357	0.339	0.298	0.091
	50-55		1.212	0.543	0.510	0.498	0.469	0.450	0.427	0.394	0.372	0.343	0.294	0.100

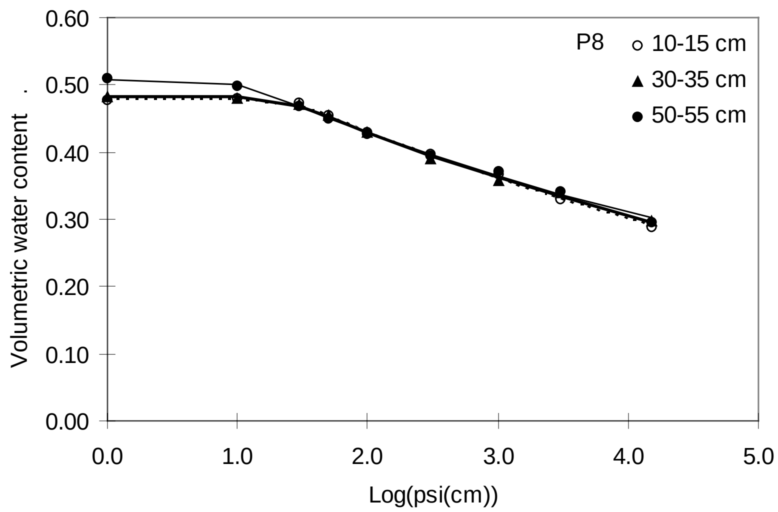


Fig. 4.8 Average water retention for each soil depth in pit 8 (points are measurements, lines are best fit smoothed Brooks-Corey function)

Table 4.11 Soil water retention data for Pit 9

LOCATION	depth (cm)	Ring #	BD (g/cm^3)	Porosity	psi (cm) 1	10	30	50	100	300	1000	3000	15000	PAWC .3 - 15 bar
Pit 9	10-15	B83	1.146	0.567	0.485	0.491	0.467	0.441	0.411	0.405	0.348	0.313	0.273	0.133
		11	1.273	0.520	0.471	0.474	0.469	0.454	0.425	0.408	0.359	0.352	0.294	0.114
		B79	1.263	0.524	0.454	0.459	0.452	0.437	0.412	0.396	0.364	0.337	0.287	0.109
	30-35	210	1.354	0.489	0.453	0.460	0.451	0.436	0.414	0.380	0.348	0.331	0.292	0.089
		78X	1.310	0.506	0.482	0.471	0.449	0.431	0.405	0.376	0.357	0.338	0.302	0.074
		6	1.312	0.505	0.469	0.471	0.462	0.442	0.419	0.391	0.372	0.338	0.296	0.095
	50-55	255	1.491	0.438	0.515	0.525	0.521	0.509	0.485	0.442	0.419	0.414	0.350	0.092
		B103	1.287	0.514	0.459	0.463	0.449	0.436	0.413	0.390	0.381	0.327	0.277	0.112
		3	1.301	0.509	0.476	0.483	0.473	0.461	0.439	0.404	0.398	0.354	0.318	0.086
Averages	10-15		1.227	0.537	0.470	0.475	0.463	0.444	0.416	0.403	0.357	0.334	0.285	0.119
	30-35		1.325	0.500	0.468	0.467	0.454	0.436	0.413	0.383	0.359	0.336	0.297	0.086
	50-55		1.360	0.487	0.483	0.490	0.481	0.469	0.446	0.412	0.399	0.365	0.315	0.097

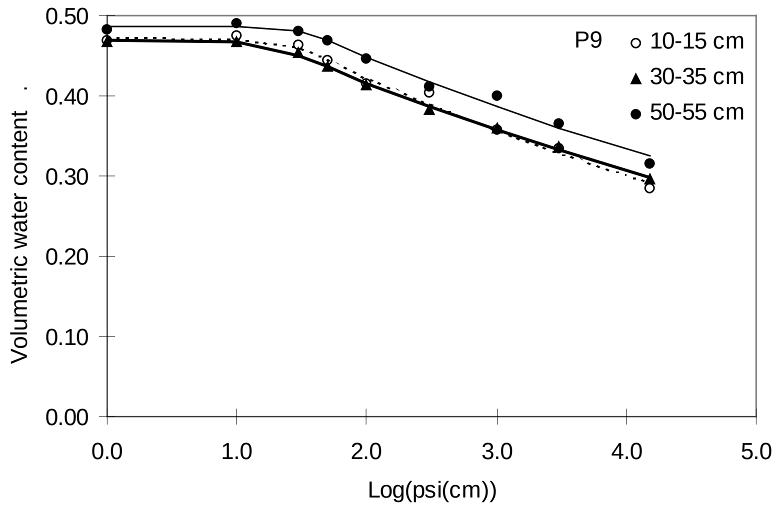


Fig. 4.9 Average water retention for each soil depth in pit 9 (points are measurements, lines are best fit smoothed Brooks-Corey function)

Table 4.12 Fitted parameters for the smoothed Brooks-Corey soil water retention function and particle size distributions. Here θ_s is saturated water content, ψ_e is air entry potential, and b is the soil b-value.

LOCATION	depth (cm)		$\psi(\theta)$				PSD		
		θ_s	ψ_e	b	>2mm	c.sand	f.sand	silt	clay
Pit 1	10-15	0.518	21.2	8.66	0.08	0.17	0.25	0.31	0.27
		0.494	31.4	8.90	0.01	0.14	0.26	0.20	0.40
		0.527	27.5	8.36	0.01	0.21	0.25	0.41	0.13
	30-35	0.496	5.6	12.57	0.05	0.24	0.25	0.50	0.01
		0.499	7.0	11.64	0.08	0.17	0.19	0.38	0.26
		0.495	9.8	13.02	0.01	0.10	0.23	0.13	0.54
	50-55	0.483	44.0	15.62	0.00	0.04	0.25	0.39	0.32
		0.488	16.4	15.63	0.00	0.04	0.30	0.09	0.57
		0.471	20.4	15.27	0.00	0.05	0.31	0.04	0.59
Averages	10-15	0.513	26.5	8.63	0.030	0.174	0.252	0.308	0.266
	30-35	0.497	6.9	12.47	0.047	0.169	0.226	0.336	0.269
	50-55	0.481	23.5	15.71	0.001	0.044	0.289	0.173	0.494
Pit 2	10-15	0.453	35.0	10.98	0.00	0.08	0.37	0.24	0.30
		0.466	58.3	10.76	0.02	0.09	0.33	0.31	0.27
		0.477	26.6	11.52	0.01	0.08	0.31	0.18	0.42
	30-35	0.461	60.0	12.01	0.00	0.05	0.30	0.14	0.51
		0.484	139.1	11.44	0.01	0.04	0.27	0.20	0.49
		0.494	51.8	8.51	0.01	0.06	0.26	0.30	0.38
	50-55	0.461	187.3	11.01	0.01	0.12	0.31	0.11	0.45
		0.466	253.9	9.58	0.04	0.11	0.24	0.19	0.46
		0.444	149.4	10.56	0.00	0.10	0.27	0.37	0.27
Averages	10-15	0.466	34.5	11.33	0.011	0.087	0.338	0.244	0.331
	30-35	0.474	129.8	9.09	0.005	0.047	0.277	0.214	0.462
	50-55	0.457	194.0	10.37	0.019	0.110	0.275	0.224	0.392
Pit 3	10-15	0.465	40.9	8.42	0.04	0.16	0.25	0.50	0.09
		0.441	209.0	7.19	0.04	0.12	0.25	0.31	0.32
		0.439	193.4	8.50	0.10	0.16	0.27	0.16	0.41
	30-35	0.386	276.9	9.55	0.10	0.15	0.16	0.45	0.23
		0.388	522.2	9.92	0.05	0.19	0.22	0.24	0.34
		0.416	265.3	10.40	0.03	0.16	0.29	0.22	0.33
	50-55	0.394	228.4	8.40	0.02	0.26	0.21	0.30	0.23
		0.409	15.0	17.85	0.04	0.21	0.21	0.23	0.35
		0.431	15.9	14.09	0.09	0.20	0.20	0.18	0.42
Averages	10-15	0.453	59.5	9.68	0.056	0.148	0.258	0.322	0.273
	30-35	0.397	352.8	9.83	0.062	0.169	0.226	0.304	0.302
	50-55	0.413	24.8	14.62	0.048	0.224	0.205	0.236	0.334

Table continued

LOCATION	depth (cm)		ψ(θ)				PSD		
		θ_s	ψ_e	b	>2mm	c.sand	f.sand	silt	clay
Pit 4	10-15	0.451	54.0	10.67	0.05	0.18	0.23	0.34	0.25
		0.473	46.1	10.47	0.01	0.09	0.23	0.24	0.44
		0.477	44.2	10.31	0.01	0.08	0.25	0.17	0.50
	30-35	0.470	15.2	10.48	0.01	0.09	0.22	0.26	0.43
		0.462	12.3	10.64	0.01	0.17	0.25	0.31	0.27
		0.484	6.7	9.44	0.04	0.14	0.22	0.33	0.31
	50-55	0.503	24.8	11.49	0.01	0.13	0.23	0.35	0.28
		0.486	27.4	12.83	0.00	0.08	0.15	0.30	0.47
		0.505	11.0	10.88	0.01	0.11	0.19	0.24	0.47
Averages	10-15	0.467	47.7	10.49	0.023	0.117	0.236	0.251	0.396
	30-35	0.471	10.9	10.17	0.019	0.134	0.228	0.302	0.336
	50-55	0.499	17.6	11.88	0.006	0.106	0.189	0.296	0.408
Pit 5	10-15	0.461	56.0	8.47	0.01	0.11	0.21	0.13	0.55
		0.449	53.5	5.43	0.02	0.21	0.20	0.23	0.37
		0.439	14.2	6.59	0.06	0.30	0.17	0.21	0.32
	30-35	0.490	15.8	10.81	0.08	0.44	0.14	0.15	0.27
		0.466	26.2	11.38	0.00	0.16	0.18	0.25	0.41
		0.468	10.6	11.31	0.04	0.14	0.20	0.24	0.42
	50-55	0.479	23.8	14.63	0.00	0.15	0.19	0.25	0.41
		0.488	28.8	15.11	0.01	0.09	0.20	0.27	0.44
		0.494	49.3	12.55	0.01	0.08	0.21	0.30	0.41
Averages	10-15	0.451	28.5	7.10	0.029	0.203	0.193	0.191	0.412
	30-35	0.475	15.6	11.26	0.042	0.245	0.175	0.215	0.365
	50-55	0.488	30.2	14.25	0.006	0.107	0.200	0.275	0.418
Pit 6	10-15	0.440	62.1	10.01	0.01	0.07	0.19	0.27	0.47
		0.477	35.4	9.29	0.01	0.17	0.19	0.23	0.41
		0.470	29.0	8.58	0.00	0.26	0.18	0.21	0.36
	30-35	0.399	29.7	15.30	0.02	0.29	0.16	0.20	0.35
		0.420	46.3	12.28	0.00	0.27	0.15	0.19	0.38
		0.423	46.5	11.16	0.05	0.29	0.15	0.18	0.37
	50-55	0.418	43.0	12.43	0.02	0.23	0.17	0.21	0.39
		0.420	24.7	11.47	0.03	0.23	0.19	0.21	0.38
		0.451	22.1	13.58	0.03	0.26	0.15	0.19	0.40
Averages	10-15	0.461	39.4	9.29	0.006	0.169	0.186	0.235	0.410
	30-35	0.414	40.2	12.74	0.021	0.286	0.156	0.192	0.366
	50-55	0.430	27.9	12.55	0.030	0.238	0.171	0.200	0.391

Table continued

LOCATION	depth (cm)	θ_s	$\psi(\theta)$ ψ_e	b	>2mm	c.sand	PSD f.sand	silt	clay
Pit 7	10-15	0.518	13.1	11.48	0.02	0.20	0.16	0.27	0.37
		0.499	38.7	11.28	0.00	0.11	0.18	0.30	0.42
		0.501	47.2	12.23	0.00	0.06	0.17	0.33	0.44
	30-35	0.481	32.2	15.71	0.00	0.04	0.18	0.32	0.46
		0.495	40.4	14.93	0.00	0.03	0.15	0.32	0.50
		0.491	30.7	13.45	0.00	0.04	0.15	0.31	0.50
	50-55	0.504	23.6	13.06	0.00	0.03	0.14	0.31	0.51
		0.526	31.8	12.63	0.00	0.03	0.14	0.33	0.50
		0.508	28.3	13.32	0.00	0.02	0.14	0.38	0.45
Averages	10-15	0.504	28.8	11.80	0.005	0.124	0.169	0.298	0.409
	30-35	0.489	34.8	14.61	0.001	0.040	0.160	0.315	0.486
	50-55	0.513	27.8	13.00	0.000	0.029	0.140	0.342	0.489
Pit 8	10-15	0.497	25.6	12.60	0.00	0.04	0.16	0.31	0.49
		0.459	38.7	13.75	0.00	0.03	0.18	0.34	0.46
		0.484	20.6	12.01	0.00	0.03	0.15	0.34	0.48
	30-35	0.509	12.6	14.39	0.00	0.03	0.19	0.33	0.45
		0.450	29.0	12.99	0.00	0.02	0.22	0.32	0.44
		0.491	22.4	13.06	0.00	0.09	0.21	0.27	0.43
	50-55	0.527	3.3	12.72	0.00	0.03	0.21	0.30	0.46
		0.502	14.3	13.69	0.00	0.01	0.06	0.77	0.15
		0.501	23.7	14.86	0.00	0.02	0.18	0.31	0.48
Averages	10-15	0.480	26.1	12.84	0.000	0.032	0.163	0.329	0.476
	30-35	0.483	20.2	13.51	0.000	0.047	0.208	0.305	0.440
	50-55	0.508	9.2	14.15	0.001	0.022	0.151	0.461	0.366
Pit 9	10-15	0.489	16.9	11.93	0.00	0.04	0.18	0.30	0.48
		0.474	27.8	14.03	0.00	0.09	0.19	0.27	0.45
		0.457	28.4	14.51	0.00	0.07	0.18	0.36	0.39
	30-35	0.457	24.3	14.27	0.00	0.08	0.22	0.25	0.45
		0.481	7.5	16.26	0.00	0.07	0.21	0.26	0.46
		0.471	20.9	14.81	0.00	0.07	0.21	0.26	0.46
	50-55	0.522	30.1	16.46	0.00	0.03	0.18	0.31	0.47
		0.460	27.3	13.93	0.00	0.08	0.23	0.26	0.43
		0.480	26.1	16.03	0.00	0.06	0.21	0.28	0.46
Averages	10-15	0.473	23.0	13.45	0.000	0.066	0.184	0.309	0.441
	30-35	0.468	16.8	15.05	0.000	0.073	0.214	0.257	0.455
	50-55	0.487	27.9	15.44	0.001	0.056	0.206	0.284	0.454

5. SOIL CHEMICAL CHARACTERISATION

5.1 Soil sampling

Four plots in each block of the trial were randomly selected for sampling before imposition of the treatments. A randomly located cluster of 3 soil cores (50 mm diameter by 2.3 m deep) were taken in each plot. The cores making up each cluster were taken within 1.0 m of each other. The top 0-50 cm of each soil core was sectioned into 10 cm increments, with the rest of the core being sectioned into 20 cm increments. The soil from each of the 3 cores which made up a cluster was bulked on a depth increment basis. Thus, for each depth increment, we ended up with 1 bulk sample per sampled plot, 4 bulk samples per block and 12 bulk samples for the whole trial site. This sampling strategy was used to account for both long and short range spatial variation in measured soil properties (Bramley and White 1991).

The soil samples were returned to the laboratory where they were air-dried in a shadehouse at ambient temperature, sieved (<2 mm) and then stored frozen (-15 ºC) prior to analysis.

5.2 Chemical analysis

Soil chemical analyses were carried out using the methods described by Rayment and Higginson (1992), except for boron for which the methods of Spouncer *et al.* (1992) were used. Analyses included

- pH in water (pH_w) and 0.01 *M* $CaCl_2$ (pH_{Ca}) at a soil:solution ratio of 1:5
- organic carbon (%C) by Heanes wet oxidation
- total Kjeldahl nitrogen (%N)
- phosphate-extractable sulphur (S)
- acid-extractable phosphorus (BSES-P; Kerr and Von Stieglitz 1938)
- exchangeable cations (Ca, Mg, K and Na), cation exchange capacity (CEC) and anion exchange capacity (AEC) by compulsive exchange (Gillman and Sumpter 1986a)
- exchange acidity (H+Al) by extraction with 1 *M* KCl
- DTPA-extractable Fe, Cu, Mn and Zn
- citrate-dithionate extractable Fe and Al
- 0.01 *M* $CaCl_2$-extractable B (Spouncer *et al.*, 1992)
- EC which was determined simultaneously with pH_w

5.3 Soil pH, cations and charge characteristics

The site can be considered to be moderately acidic (Fig. 5.1), with a pH profile similar to that of other sites in the Tully district which were described during the paired sites phase of the yield decline joint venture (Bramley *et al.*, 1996). In contrast, the site has a high organic matter content compared to typical values for soils under sugarcane and C:N ratio's in the topsoil that favour a healthy microbial biomass (Fig. 5.1).

In keeping with the low pH profile, the level of exchangeable Ca is low (Fig. 5.2) and would be considered deficient with respect to sugarcane production (Calcino 1994). This, in combination with the soil pH, suggests that sugarcane, and especially other crops less tolerant of low pH, would benefit from the application of lime. In contrast the Mg status is adequate for sugarcane, and can be considered quite high in the surface soil (Fig. 5.2). K status in the surface layers is similarly adequate for sugarcane growth, but becomes increasingly deficient with depth (Fig. 5.1). The exchangeable sodium percentage does not suggest any likelihood of a sodicity problem.

The CEC (Fig. 5.3) is typical for sugarcane soils in the Tully district (Bramley *et al.*, 1996; Gillman and Sumpter, 1986b). However, the increasingly significant AEC with depth suggests that, consistent with other soils of the wet tropics, this soil has some pH-dependent charge (Gillman and Sumpter, 1986b). Amelioration of the low pH through application of lime could therefore have a beneficial effect on CEC. The exchange acidity is high relative to overall CEC, especially below about 15 cm. Again, sugarcane should benefit from lime application, and it may be essential for production of some other crops.

The very high exchangeable aluminium status, relative to the CEC and overall exchange acidity (Fig. 5.4), suggests that Al toxicity is likely to affect some crops grown at this site. Sugarcane, however, is thought to be tolerant of Al (Calcino, 1994), although Bramley *et al.* (1996) considered it unlikely that an Al profile such as that shown in Fig. 5.4 was optimal for cane production.

5.4 Other nutrients

Soil P in the surface horizon (Fig. 5.5) is adequate for cane production (Calcino, 1994) but becomes increasingly deficient at depths greater than about 10 cm. Sulphur levels appear to be quite good and probably reflect (a) the high rainfall experienced at the site; and (b) a much lower rate of application of P fertilizers (typically DAP) at this site prior to the establishment of the trial than would typically be applied to land under sugarcane. In contrast, the status of both zinc and copper is low (Fig. 5.6) and a remedial application of both trace elements would probably be of benefit for sugarcane production (Calcino, 1994).

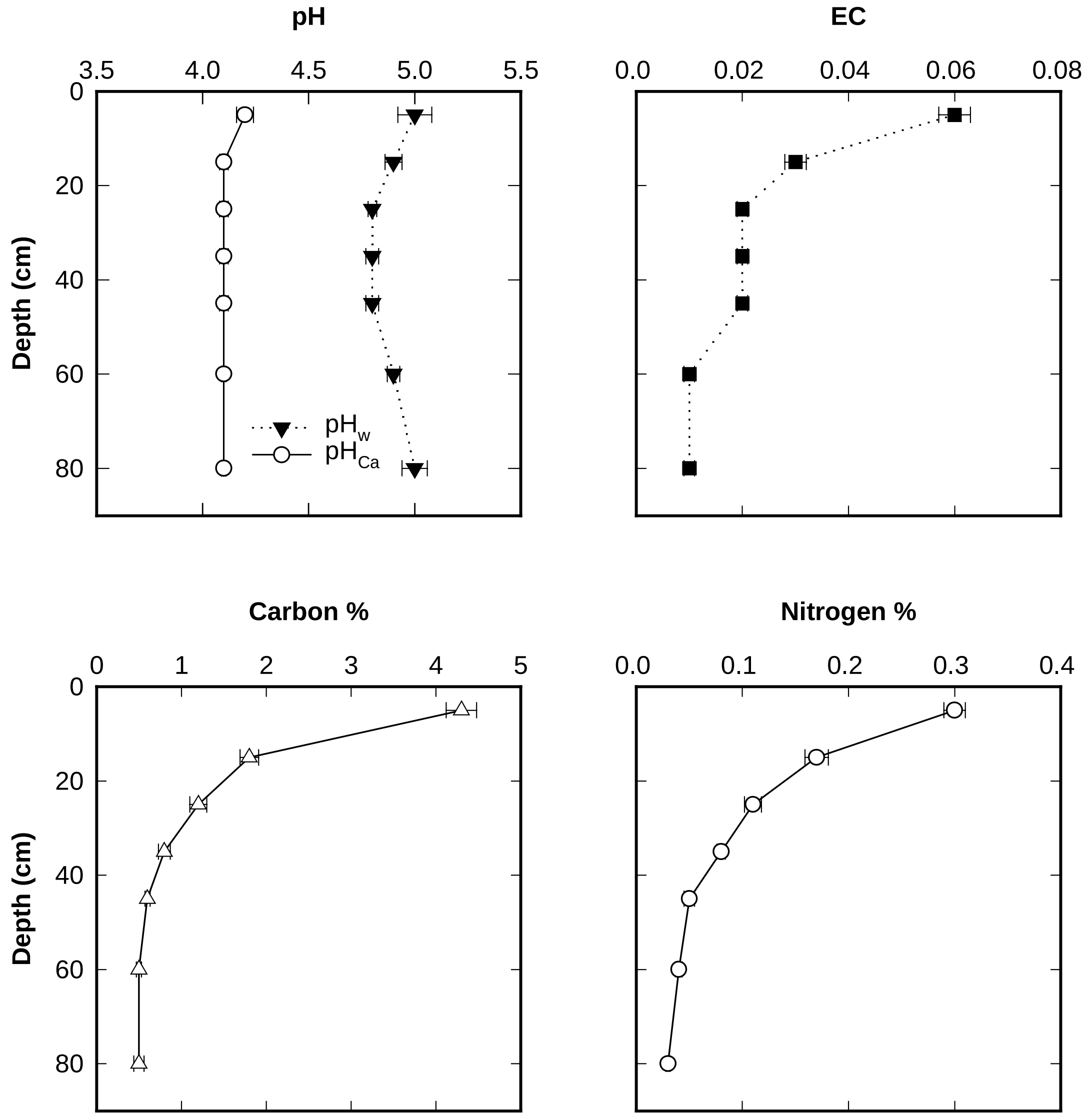


Fig. 5.1 Soil pH, EC, carbon and nitrogen status of the Tully Rundown site prior to imposition of treatments. The error bars denote standard error of the mean.

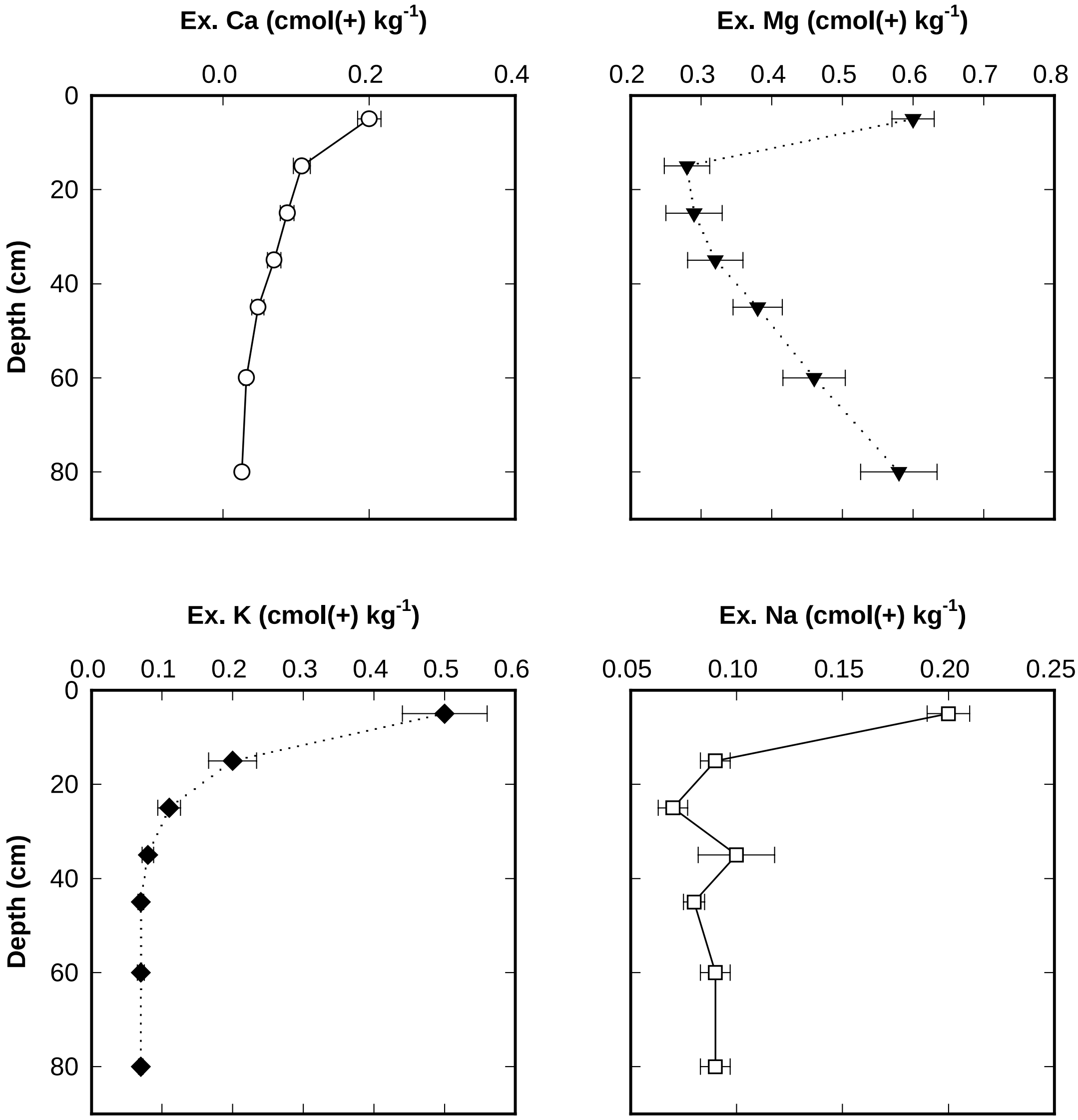


Fig. 5.2 Exchangeable cations in the Tully Rundown site prior to imposition of treatments. The error bars denote standard error of the mean.

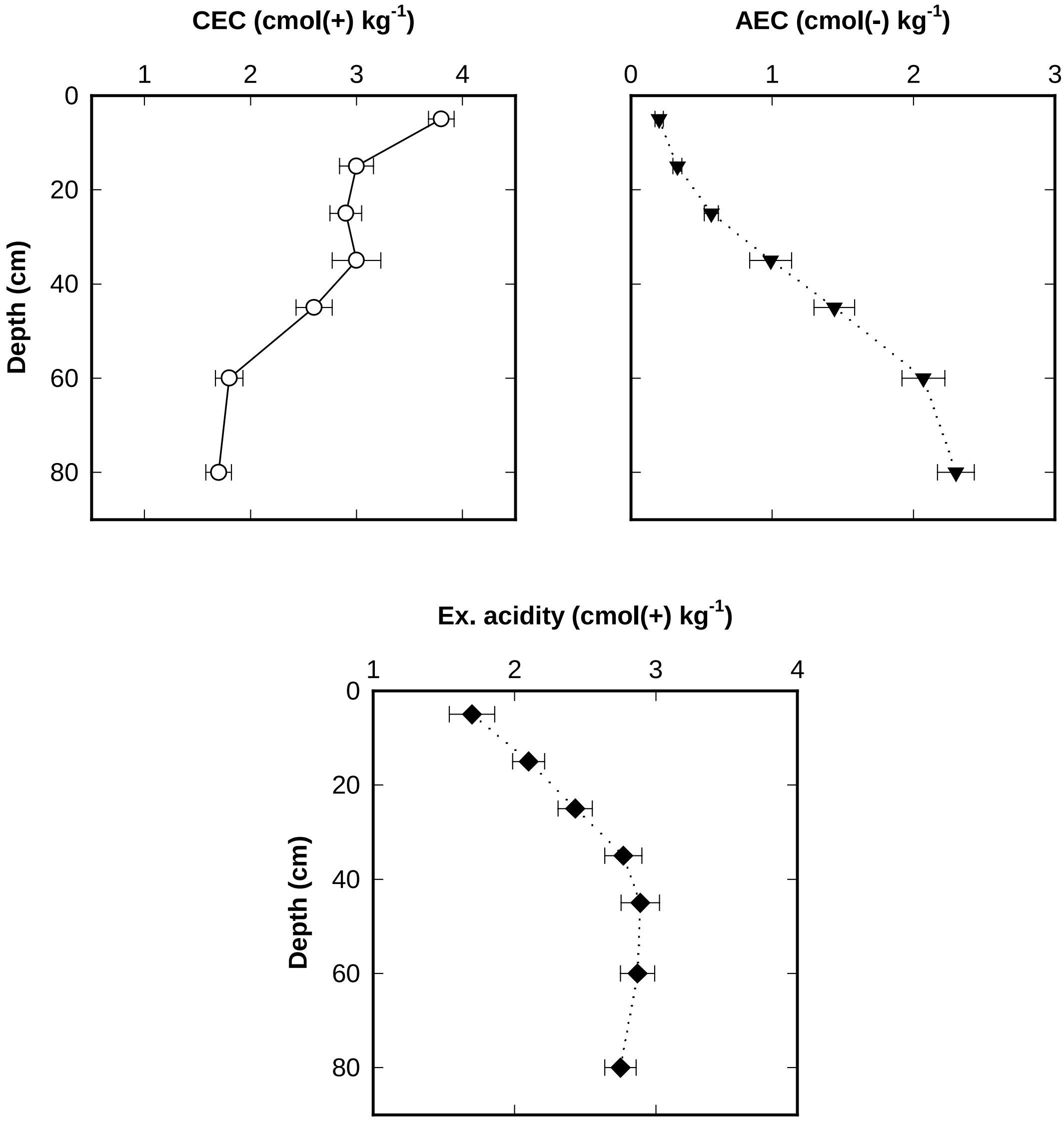


Fig. 5.3 Charge characteristics of the Tully Rundown site prior to imposition of treatments. The error bars denote standard error of the mean.

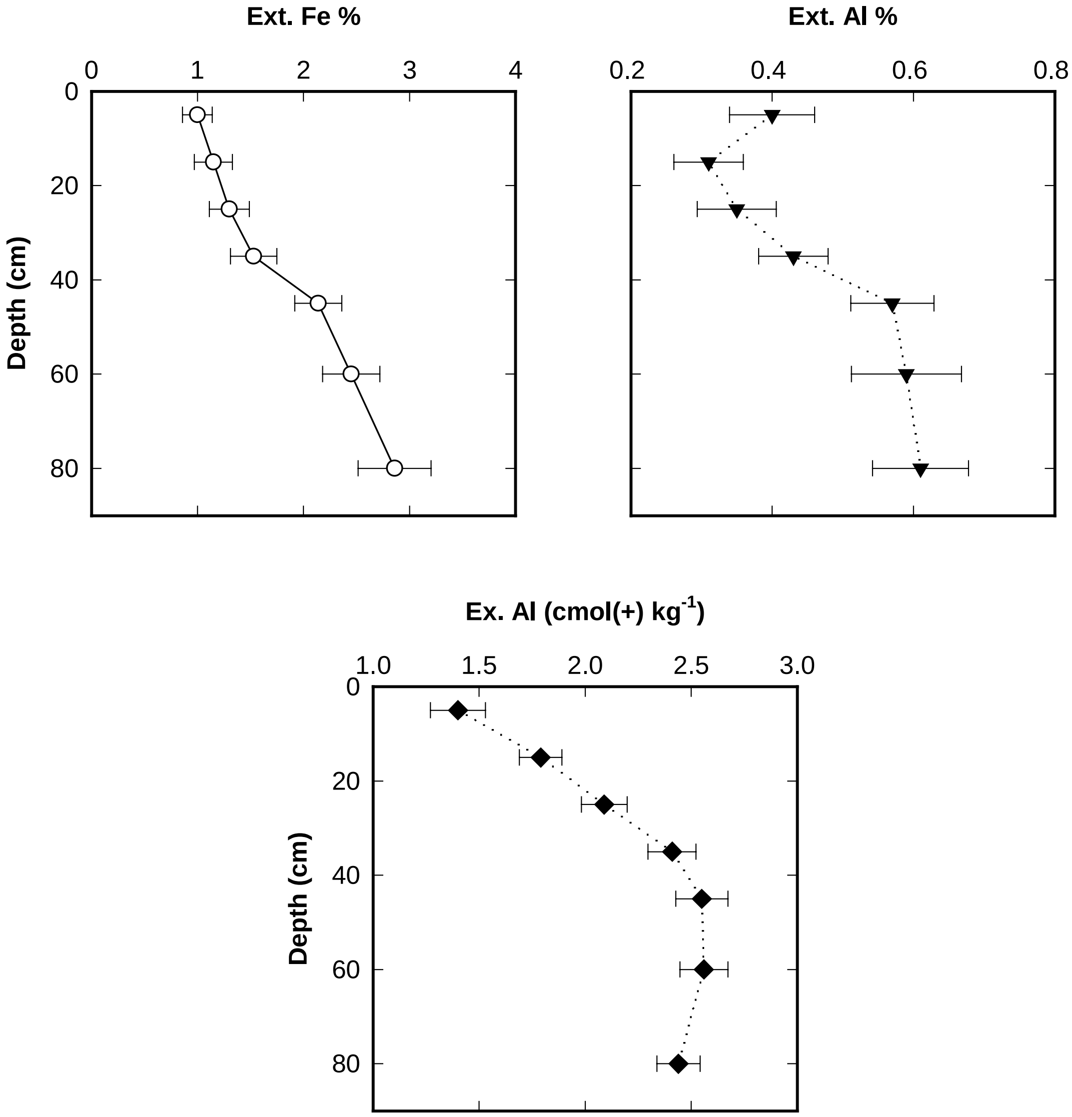


Fig. 5.4 Levels of reactive oxides and exchangeable aluminium in the Tully Rundown site prior to imposition of treatments. The error bars denote standard error of the mean.

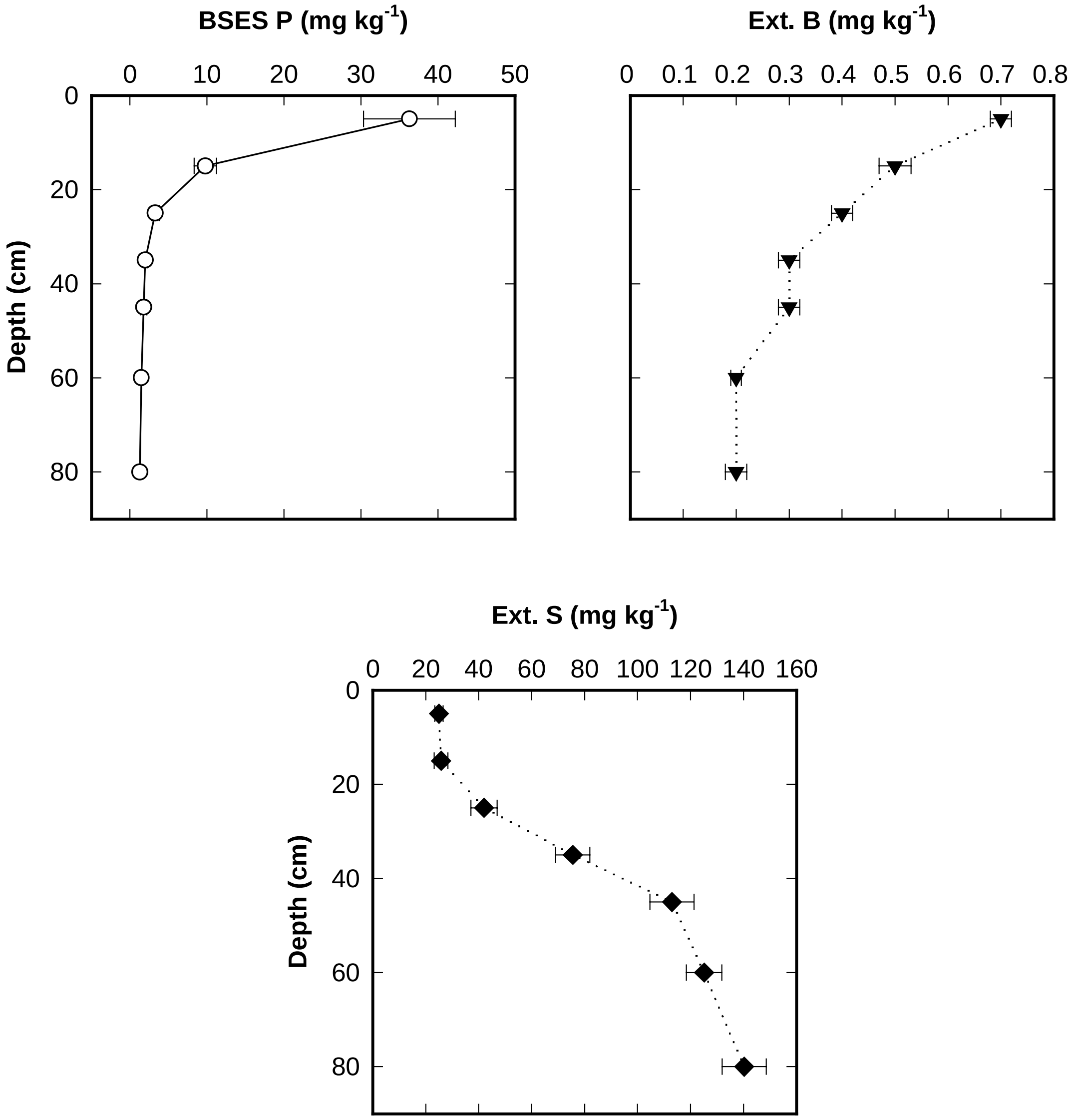


Fig. 5.5 Phosphorus, boron and sulphur status of the Tully Rundown site prior to imposition of treatments. The error bars denote standard error of the mean.

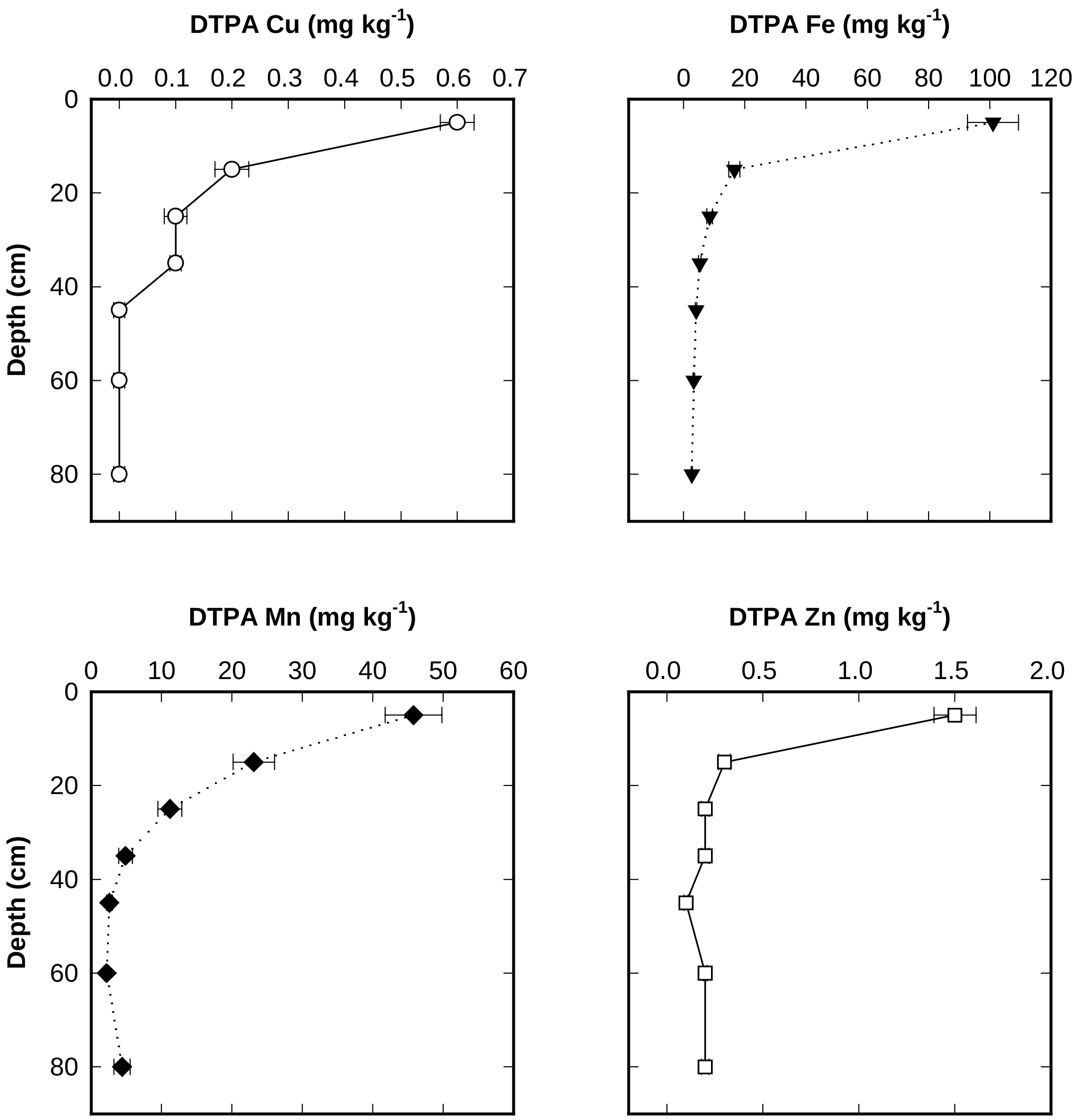


Fig. 5.6 Trace element status of the Tully Rundown site prior to imposition of treatments. The error bars denote standard error of the mean.

6. SOIL BIOLOGICAL CHARACTERISATION

The soil biology at the site has been characterised in terms of the soil microbial biomass carbon. Five soil cores (150 mm depth x 25 mm diameter), taken from within a 300 mm diameter circle, were bulked to give a single sample. Five of these bulked soil samples were collected from random locations within each of the treatment plots.

All soil samples were passed through a 2 mm sieve, adjusted to 40% water holding capacity and incubated at 4°C for seven days prior to analysis. Microbial biomass carbon was measured using the method of Amato and Ladd (1988), whereby a soil sample is fumigated under one atmosphere of chloroform for 10 days, followed by extraction of the fumigated soil with 2M KCl and reaction of the extract with ninhydrin. A factor of 21 is used to convert the ninhydrin-reactive N (biomass N) to biomass carbon.

Results from the ‘time zero’ measurements and a few subsequent samplings are given in Table 6.1. The time zero readings in April 96 were carried out prior to implementation of the treatments so reflect the pasture system at that stage. Changes in pasture treatments 6 and 14 with time show seasonal changes in microbial biomass, and are used as the reference against which the other treatments are compared. Details of this work are given by Holt and Mayer (1998).

Table 6.1 Microbial biomass (μg C g soil^{-1})

Treatment	Apr-96	Sep-96	N0v-96	Apr-97	Aug-97
1 - bare	241	513	517	585	714
2 - cane no input	252	366	453	535	758
3 - cane no residue	246	262	472	564	615
4- cane residue incorporated	245	209	534	580	764
5 - cane + residue	279	406	579	693	949
6 - pasture			762	1192	1464
14 - pasture			857	1410	1516
Confidence intervals					
1 - bare	28	46	91	120	49
2 - cane no input	22	76	64	106	45
3 - cane no residue	65	97	133	31	156
4- cane residue incorporated	71	126	22	37	211
5 - cane + residue	33	110	37	142	144
6 - pasture			84	284	305
14 - pasture			30	205	155

7. ACKNOWLEDGMENTS

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