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# Soil water retention determination using the 'Wetlab' facility at CSIRO, Davies Laboratory

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Technical Report **2/97**

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THE 'WETLAB' FACILITY AT CSIRO, DAVIES  
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## Introduction

At the CSIRO Davies Laboratory the facility known as the 'Wetlab' is set up to determine soil water retention curves for soils from saturated conditions to 15 bar suction which is commonly used to estimate 'wilting point'. Suctions ranging from 0 to 100 cm are applied to the soils using ceramic tension plates and hanging water columns. Pressure plate extractors are used for applying higher suction.

The data generated is processed using an Excel worksheet called 'WETLAB.XLT' which calculates the volumetric water contents of the soil at each suction.

The water retention data are analysed routinely using Campbell's equation (Campbell, 1985):

$$\Psi = \Psi_e (\theta/\theta_s)^{-b} \dots\dots\dots (1)$$

- Where:
- $\Psi$  = matric potential
  - $\Psi_e$  = air entry potential
  - $\theta$  = volumetric water content
  - $\theta_s$  = saturation water content
  - $b$  = slope of  $\ln \Psi$  as a function of  $\ln \theta$

This equation can be rewritten as:

$$\Psi = \Psi_e \theta_s^b \theta^{-b}$$

and therefore:

$$\ln \Psi = \ln (\Psi_e \theta_s^b) - b \ln \theta$$

where  $\ln (\Psi_e \theta_s^b)$  is the intercept and  $b$  is the slope of the curve of  $\ln \Psi$  as a function of  $\ln \theta$ . By knowing the values of  $\theta_s$  and  $b$  the intercept  $\ln (\Psi_e \theta_s^b)$  can be used to obtain the air entry potential as:

$$\Psi_e = \frac{\exp(\text{intercept})}{\theta_s^b}$$

This Report summarises the basic equipment used in the Wetlab and explains the processes required to obtain the water retention data. A blank record sheet which is used to collate the raw data and examples of water retention data produced provided in the Appendices.

## **Equipment list**

- Hanging water column ceramic tension plate, tubing and levelling bottle
- Clamps and rods to hold the bottle at various levels
- Distilled water supply
- Filter papers (Whatman, Qualitative, No. 4, 70 mm circle)
- Fine meshed material (140 x 140 mm square)
- Rubber bands
- Broad spatula (at least 80 mm wide)
- Balance (in grams to one decimal place)
- Drying oven

## **Pressure plate extractor measurements**

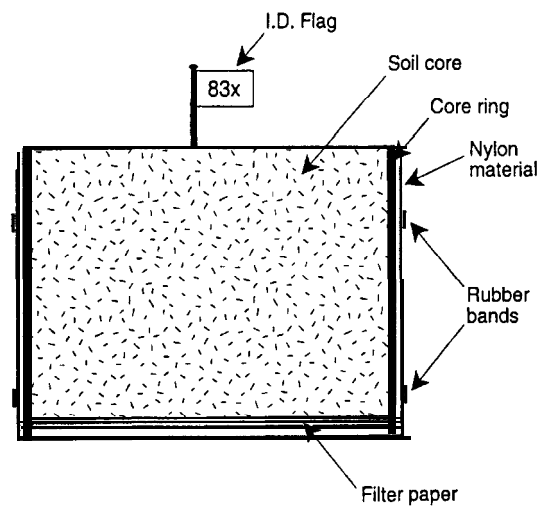
- Three 5 bar pressure plate extractors
- One 15 bar pressure plate extractor
- Assortment of ceramic pressure plates (minimal requirement of two 1 bar plates, one 3 bar plate and one 15 bar plate)
- One burette per pressure plate extractor
- Pressure supply (eg. Industrial Nitrogen cylinders, manifolds, gauges and regulators)
- Small corer, 28 mm diameter, with plunger
- PVC rings, 10 mm deep and 30 mm diameter, labelled with consecutive numbers
- Distilled water supply
- Atomiser spray
- Narrow spatula (about 30 mm wide)
- Small aluminium soil moisture tins with lids (must be light enough to weigh to 3 decimal places)
- Balance (in grams to 3 decimal places)
- Drying oven

## Core preparation

Undisturbed field cores of 73 mm diameter and 50 mm deep are traditionally used in the Wetlab. Other core sizes and other material such as repacked soil and coal tailings have been processed successfully. With this particular core size nine cores can be comfortably placed on most of the tension plates available in the Wetlab. Cores are processed with coring rings remaining around the core to contain the material in its natural state.

It is critical that the lower surface of the core maintain good contact with the ceramic plate throughout the equilibration period. To do this the lower surface is levelled with the ring edge and any depressions are filled with like material. A filter paper is placed on the surface followed by a 140 x 140 mm piece of fine meshed material, secured with a rubber band to the outside of the ring (see Figure 1). Another band is used to keep the material away from the underside of neighbouring cores on the plate. A flag or other type of marker is used to identify each core. This is usually made from some tape and a pin so that the flag can be easily removed when weighing.

The core is then placed onto the ceramic plate making certain that the whole of the lower surface maintains good contact with the ceramic.



**Figure 1. Soil core showing flag, material and filter paper positioning.**

## Tension plate measurements

The tension plates are usually used to determine the moisture content of soils up to 100 cm suction. The plates can hold at least 600 cm suction so greater suctions can be applied if required. Typically suctions of 0, 10, 30, 50 and 100 cm are applied in routine moisture retention determination.

The tension plate needs to be connected via a length of tube to the outlet of a levelling bottle. The whole system from bottle to ceramic must be filled with distilled water and maintained air free (See Figure 2).

The weights of the filter paper and fine meshed material have been determined for each suction and are:

suction	weight
0 cm	3.68 g
10cm	2.93 g
30 cm	2.26 g
50 cm	2.20 g
100 cm	2.05 g
oven dry	1.28 g

An average rubber band weight should be determined for each batch of bands used and added to the above weights. These weights are deducted from the core weight when processing the data.

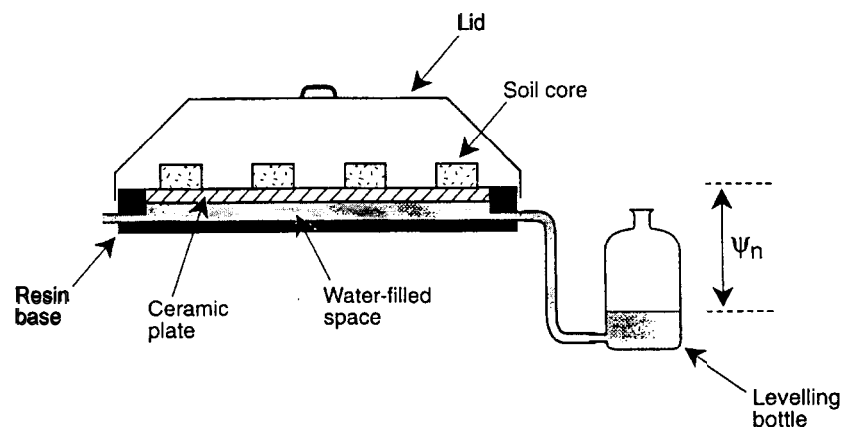


Figure 2. Ceramic tension plate with hanging water column.

Once the cores have been placed on the plate the lid is put in place and a suction applied to the soil via the ceramic by adjusting the height of the hanging water column. As a drying curve is usually determined, the first measure is one of saturation. To obtain this the water level in the bottle is brought to a point just level with the top of the ceramic. This creates free water at surface of the ceramic and hence at the base of the cores. Any excess water will run over the plate edge. The system is left to saturate for at least 24 hours. Measurement is then made by taring the balance with a broad spatula, sliding the core onto the spatula, removing the marker flag, placing core and spatula on the balance and recording the weight. The recorded core weight includes the coring ring, filter paper, nylon material and two rubber bands.

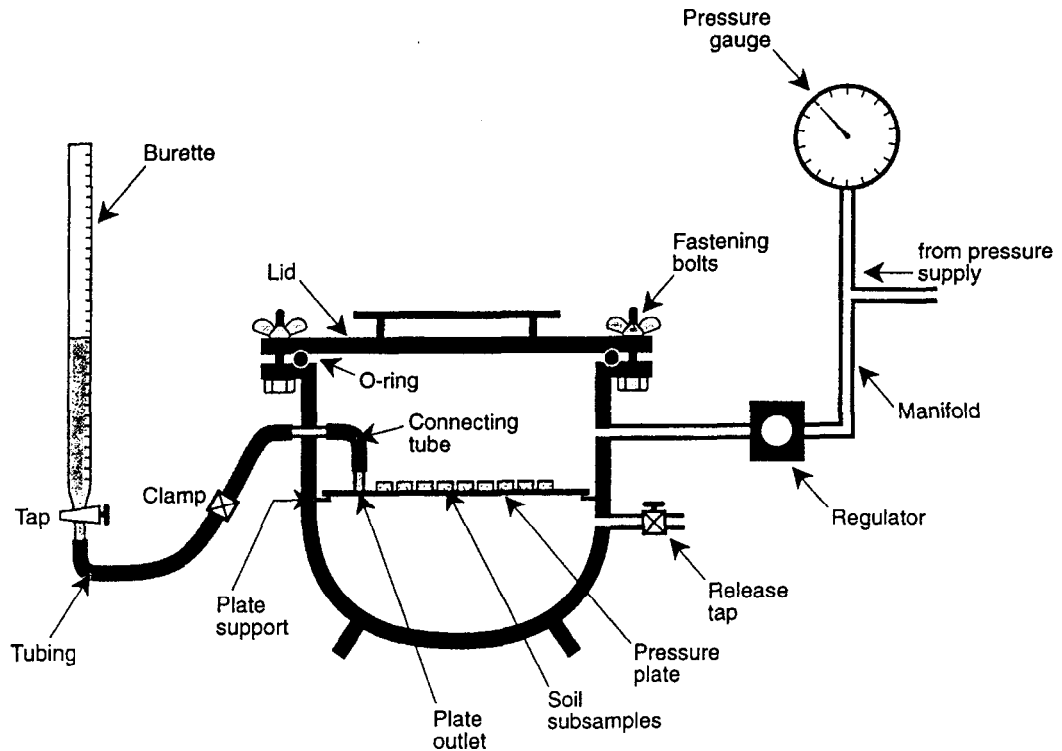
A suction of 10 cm can then be applied to the plate by dropping the bottle so that the water level is 10 cm below the top surface of the ceramic. This is then left to equilibrate for at least one week after which the core is again weighed in the same way as the saturated reading.

The same process is followed for each of the remaining suctions; 30, 50 and 100 cm. The 100 cm readings should only be taken when the pressure plate extractors and ceramic plates are ready for use as the core is sub sampled and reweighed at this stage. The cavity beneath the ceramic should be checked periodically for air bubbles as this is an indication of leakages. Air can leak into the cavity from poor tube connections or from a breakdown in the glue that seals the ceramic to the resin base.

## **Sub sampling and pressure plate extractor measurements**

The pressure plate extractors are used to determine the moisture content of soils under greater suctions than can be applied using the tension plates (see Figure 3). Pressures of 0.3, 1, 3, and 15 bars (equivalent to 300, 1000, 3000 and 15000 cm H<sub>2</sub>O) are usually applied in routine moisture retention determination. As four extractors are available all four measures can be carried out simultaneously. Nitrogen gas is used to supply the required pressure however other sources of pressure generation are suitable.

Pressure plates must be thoroughly saturated before use and are soaked in distilled water overnight prior to use. A tube from the plate outlet extends through the water to the atmosphere to enable air to escape from the cavity between the ceramic and rubber backing as it is wetting up.



**Figure 3. Pressure plate extractor.**

After the soil core weight at 100 cm suction has been recorded the core is placed on the bench and four sub samples extracted using a small corer. Each sub sample is about 10 mm deep and is extruded into a 30 mm diameter by 10 mm high PVC ring using the plunger. The soil core is then reweighed, rubber bands removed, and placed in the oven at 105°C for 24 hours to dry. It is then weighed again.

A record of each PVC ring number is maintained and the sub samples are placed on the appropriate pressure plate. This process continues for each core so that one sub sample from each core is placed on each of the four pressure plates. It is essential to periodically spray the sub samples and ceramic plate surface with distilled water during this stage to maintain a saturated plate.

Good contact of the soil with the pressure plate ceramic is again important, as it was with the tension plates. Sub samples can be saturated and slight pressure applied to the surface to improve contact with the ceramic. Care is needed in exerting pressure on these sub samples, especially on those with less than 0.3 bar pressure applied because of the influence of soil structure on soil water retention at these low pressures. With these sub samples it is advisable to ensure that the lower surface is in

good condition before placing it on the pressure plate. Wetting of these sub samples gently with an atomiser bottle helps improve contact.

The pressure plates are then placed in their respective pressure plate extractors. The plate outlet is connected with a piece of tubing to the pressure plate extractor outlet which extends to the burette. The connecting surfaces of the pressure plate extractor and its lid are wiped with methylated spirit to remove moisture and dust and the lid is secured in position on the pressure plate extractor bowl. The release tap is closed and the regulator turned on gradually until the pressure is just below the desired pressure. Allow a few hours for pressure to equilibrate (gauges often need tapping to obtain a correct reading) and adjust regulator if necessary. It is important that the pressure does not exceed the desired pressure as this could introduce problems with hysteresis. Check for leaking pressure plates by observing regular bubbles rising in the burette. It may be that the plate has not been adequately saturated, has developed a leak or that gas is leaking into the tube which connects the plate to the pressure plate extractor outlet. Check these connections. Transfer sub samples to another prepared pressure plate if necessary.

Pressure is maintained in the pressure plate extractors until the water level in the burette is static. This may take around one week although more time is often required at low pressures. During this time ensure that the water level in the burette is maintained at the same level as the plate inside the extractor so as not to add an extra component of water potential from outside the extractor. Allow a few days of equilibrium before making measurements.

Before releasing the gas from the pressure plate extractors ensure enough moisture tins for all sub samples have been weighed to three decimal places. Once the sub samples have equilibrated the tube from the pressure plate extractor to the burette is clamped tightly and the gas is released gradually using the regulator and the release tap on the chamber. When all the gas has been evacuated the lid is removed. Sub samples are removed quickly, placing each one in a moisture tin and placing the lid on. It is advisable to do all sub samples at once, placing the PVC rings on top of each tin, as the soil will be equilibrating with the atmosphere and either losing or gaining moisture depending on the moisture gradient. Once all sub samples are in the tins they can be weighed and a record made of PVC ring and tin numbers. The PVC rings are no longer needed and can be washed and stored for future use. The moisture tins containing sub samples are then oven dried at 105°C for 24 hours. They are then reweighed.

Pressure plates are washed after use and dried with a coating of sand over the ceramic. This prevents fine airborne particles from lodging in the pores of the ceramic. When dry the sand can be brushed off and the plate stored until required.

## Data processing

An Excel spreadsheet (WETLAB.XLT) has been developed to convert weights obtained and recorded in the laboratory to soil water retention data and to provide plots of the  $\psi(\theta)$  relationship. The spreadsheet is available from the author upon request.

A sheet for recording laboratory data is provided in Appendix A. The data is entered in the same order into the spreadsheet's 'input area' (see Appendix B). The spreadsheet calculates the water retention values, bulk densities, air entry values, slopes,  $R^2$  and has a 'flagging' mechanism for identifying data that does not conform to the expected trend of decreasing water content with increasing suction (see '\*' in the 'data output area' of the spreadsheet). Calculations are carried out using formulas imbedded in the 'ancillary output area' and the 'output area'.

At the end of Appendix B there is an example of a plot of the soil water retention data. The user will need to alter the series details given in the graph to suit their particular data set.

## References

Campbell, G.S. (1985). Soil Physics with Basic Developments in Soil Science 14. Elsevier Science Publishers B.V.

## List of Figures

- Figure 1      Soil core
- Figure 2      Tension plate  
( $\psi_m$  is the distance between the ceramic plate surface and the water surface which equates to the suction being applied at the ceramic plate surface.)
- Figure 3      Pressure plate extractor

## Acknowledgments

This work was supported by CSIRO Division of Land and Water and the Sugar Yield Decline Program.



## APPENDIX B

### DATA INPUT AREA

**DATA INPUT AREA (all weights in g)**

DATA DESCRIPTION: Costanzo New soil, furrow

Ring Height (cm): 5.0

Ring Diameter (cm): 7.3

Volume: 209.3

Filter paper weight at: 0 cm 5.220

10 cm 4.470

30 cm 3.800

50 cm 3.740

100 cm 3.590

oven dry 2.820

Identifier	Depth (cm)	Ring #	Sand wt	0 cm wt	10 cm wt	30 cm wt	50 cm wt	100 cm wt	SS wt	OD SS wt	Ring wt	0.3 bar		
												Tin wt	Soil + tin wt	OD Soil + tin
	0-5	B45		576.9	575.9	575.3	575.1	574.4	517.4	451.2	159.7	23.182	36.767	34.370
		B55		571.4	570.8	570.2	569.3	568.0	514.5	450.0	158.0	22.204	35.217	32.905
		B80		554.0	553.6	553.6	552.9	547.5	491.0	426.7	160.4	21.194	33.830	31.329
	15-20	B44		569.4	569.9	567.7	565.0	558.4	507.4	450.1	161.6	22.319	29.858	28.847
		B51		556.8	556.8	556.0	555.0	549.6	495.1	435.5	157.2	21.216	28.449	27.416
		B54		553.4	553.8	549.2	544.8	538.6	488.6	431.8	157.2	22.065	28.847	27.894
	45-50	B46		583.1	583.0	581.9	578.9	574.2	522.3	460.8	158.8	22.968	36.196	34.033
		B53		575.1	575.3	572.2	568.7	563.3	512.2	455.1	159.3	21.822	34.285	32.291
		B63		568.9	568.6	566.9	564.2	559.5	504.9	445.4	156.5	21.877	35.769	33.412

1 bar			3 bar			15 bar		
Tin wt	Soil + tin wt	OD Soil + tin	Tin wt	Soil + tin wt	OD Soil + tin	Tin wt	Soil + tin wt	OD Soil + tin
22.577	34.890	32.998	22.506	34.306	32.530	22.663	34.913	33.651
21.908	32.141	30.592	23.178	36.428	34.486	22.233	33.977	32.795
22.836	32.633	31.106	22.089	33.559	31.793	22.636	33.296	32.194
23.003	29.293	28.568	22.369	28.686	28.068	36.783	44.670	44.038
22.166	29.712	28.819	22.108	29.664	28.993	37.097	45.120	44.448
21.367	29.249	28.323	22.232	28.794	28.126	37.120	42.430	42.018
23.149	36.737	34.628	22.252	35.557	33.746	21.891	34.459	32.994
22.641	35.288	33.422	22.319	35.397	33.677	22.165	33.287	32.078
22.166	34.083	32.243	22.199	36.093	34.114	22.549	34.882	33.457

## ANCILLARY WORK AREA

0	10	30	50	100	300	1000	3000	15000		
-2.303	2.303	3.401	3.912	4.605	5.704	6.908	8.006	9.616		
ln Theta values										
0	10	30	50	100	300	1000	3000	15000	Slope	Intercept
-0.993	-0.996	-0.995	-0.997	-1.004	-1.072	-1.237	-1.262	-1.695	-9.188	-5.075
-1.014	-1.012	-1.011	-1.023	-1.038	-1.070	-1.262	-1.299	-1.728	-9.005	-5.073
-0.960	-0.956	-0.948	-0.956	-1.023	-1.012	-1.302	-1.317	-1.773	-7.853	-3.558
-1.025	-1.009	-1.029	-1.065	-1.159	-1.417	-1.590	-1.774	-1.993	-6.530	-3.451
-1.030	-1.020	-1.022	-1.034	-1.107	-1.369	-1.585	-1.905	-1.969	-6.023	-2.732
-0.981	-0.966	-1.017	-1.076	-1.164	-1.410	-1.615	-1.776	-2.074	-6.108	-2.918
-0.993	-0.985	-0.991	-1.029	-1.092	-1.142	-1.204	-1.358	-1.535	-12.473	-9.000
-1.020	-1.007	-1.040	-1.087	-1.165	-1.187	-1.283	-1.417	-1.633	-11.493	-8.549
-1.006	-1.000	-1.013	-1.049	-1.113	-1.131	-1.243	-1.338	-1.578	-12.172	-8.844

## DATA OUTPUT AREA

Costanzo New soil, furrow

Depth (cm)	Ring #	B.D. (g/cm <sup>3</sup> )	Available Water	VOLUMETRIC SOIL MOISTURE CONTENTS (m <sup>3</sup> /m <sup>3</sup> ) AT SUCTIONS:										*	PsiE	b	R <sup>2</sup>
				0 cm	10 cm	30 cm	50 cm	100 cm	300 cm	1000 cm	3000 cm	15000 cm					
0-5	B45	1.598	0.159	0.371	0.369	0.370	0.369	0.366	0.342	0.290	0.283	0.184	*	57.06	9.19	0.81	
	B55	1.588	0.165	0.363	0.363	0.364	0.360	0.354	0.343	0.283	0.273	0.178	*	58.09	9.01	0.82	
	B80	1.473	0.194	0.383	0.384	0.388	0.385	0.360	0.363	0.272	0.268	0.170	*	53.67	7.85	0.84	
15-20	B44	1.565	0.106	0.359	0.365	0.357	0.345	0.314	0.242	0.204	0.170	0.136	*	25.64	6.53	0.97	
	B51	1.527	0.115	0.357	0.361	0.360	0.356	0.330	0.254	0.205	0.149	0.140	*	32.15	6.02	0.94	
	B54	1.493	0.119	0.375	0.381	0.362	0.341	0.312	0.244	0.199	0.169	0.126	*	21.60	6.11	0.98	
45-50	B46	1.632	0.104	0.370	0.373	0.371	0.357	0.336	0.319	0.300	0.257	0.215	*	29.70	12.47	0.95	
	B53	1.601	0.110	0.361	0.365	0.354	0.337	0.312	0.305	0.277	0.243	0.195	*	23.84	11.49	0.96	
	B63	1.580	0.116	0.366	0.368	0.363	0.350	0.329	0.323	0.288	0.262	0.206	*	29.95	12.17	0.93	

## SOIL WATER RETENTION PLOT

