ESTIMATING PLANT AVAILABLE WATER CAPACITY

A METHODOLOGY

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ACKNOWLEDGEMENTS

This manual was produced as part of the GRDC Project *Training growers to manage soil water (2006-2009).* Production of an earlier manual, upon which this manual is based was undertaken by the CRC Plant-based Management of Dryland Salinity

Recognition by the following people of the value of stored soil moisture and its impact on crop production in southern farming systems provided the catalyst for the writing of this manual. We thank them for their interest, advice and support.

Bill Bellotti, University of Adelaide, Roseworthy, SA.
Mick Faulkner, Agrilink Agricultural Consultants, Watervale, SA .
Peter Hooper, Allan Mayfield Consulting, Clare, SA.
Bill Long, Ag Consulting, Ardrossan, SA.
David Maschmedt, Dept. of Water, Land and Biodiversity Conservation, Adelaide, SA.

PUBLICATION DATA

Citation: Burk, L. and Dalgliesh, N. (2008). Estimating plant available water capacity-a methodology. 40 pp. Canberra: CSIRO Sustainable Ecosystems.

ISBN 0977517004

Version 1.1

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OVERVIEW

The GRDC Project *Training growers to manage soil water* involves research organisations, consultants and farmers across five Australian states (New South Wales, Victoria, Tasmania, South Australia and Western Australia) in training activities associated with the management of soil water and in the characterisation of soils for Plant Available Water Capacity (PAWC). This document provides practitioners with practical information, methodologies and tools for the characterisation of PAWC with the aim of ensuring consistency across regions. This document should be seen as 'living', with modifications made in the light of experience and advances in technologies.

Why characterise soils?

Characterisation provides the means for the farmer, consultant or researcher to gain a better understanding of the size of the soil 'bucket' in which the water resources required to grow a particular crop are stored. This information can be used in a number of ways: to add to the intuitive knowledge of farmers operating within their agricultural system; as a means of developing better rules of thumb to enable management of resources in a more informed way; or as a critical basic input to simulation modelling using tools such as APSIM and Yield Prophet®, which allow exploration of crop management issues in real time and at little cost (Carberry et al 2002; Keating et al 2003).

What is soil characterisation?

Soil characterisation is the determination of the PAWC of the soil at a particular point in the landscape. Generally the site is selected to represent a much broader section of the landscape that is considered as either being of a similar 'soil type' or representing associations of soils with similar characteristics. Characterisation is about defining the ability of a soil to hold water for the use of a particular crop and should not be confused with soil monitoring, which is about measuring the quantity of water in the soil 'bucket' at a particular point in time.

Information required to characterise a soil for PAWC are (Figure 1):

- Drained upper limit (DUL) or field capacity – the amount of water a soil can hold against gravity
- Crop lower limit (CLL) – the amount of water remaining after a particular crop has extracted all the water available to it from the soil
- Bulk density (BD) – the density of the soil, required to convert measurements of gravimetric water content to volumetric

In addition to the measurement of soil physical characteristics it is recommended that soil chemical information be collected to inform on the potential for sub-soil constraints to impact a soil's ability to store water or the plant's ability to extract water from the soil.

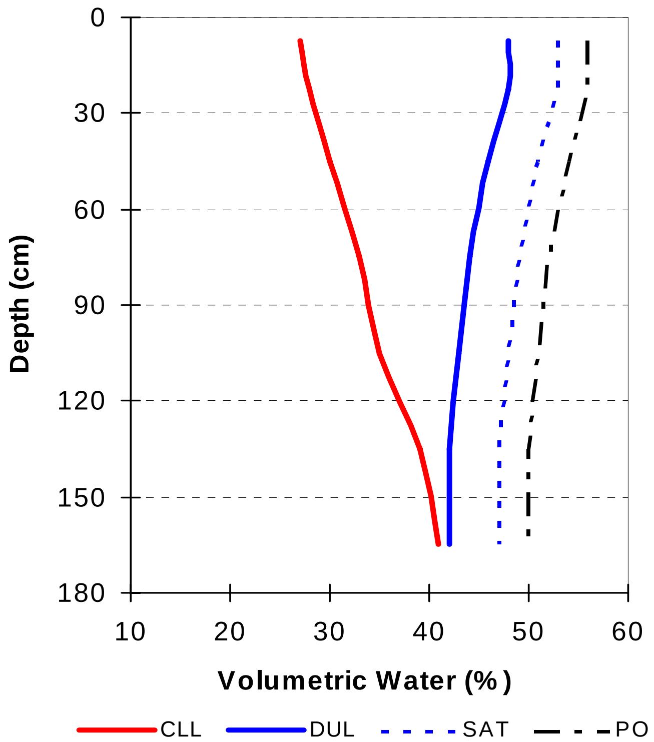

Figure 1: A typical storage profile for a heavy-textured soil showing the potential water storage of the soil, PAWC, as defined by the drained upper limit (DUL), crop lower limit (CLL), saturation (SAT) and total porosity (PO).

Working together

It is recommended that grower groups and/or consultants work together to identify and characterise district/regional soils of importance to agricultural production. Undertaking soil characterisation as a group activity improves resource use efficiency and reduces the potential for duplication. The GRDC project is able to provide assistance to farmer groups and consultants wishing to identify appropriate sites. State based regional mapping activities may also be useful in identifying appropriate sites. Where practical, it is suggested that groups attempt to locate soil characterisation sites adjacent to existing soil description sites, thus adding value to existing information.

How is soil characterisation done?

There are a number of ways that soil properties can be determined, these include:

1. Calculation of PAWC from field measurements of DUL, CLL and BD
2. Laboratory based generation of a soil moisture characteristic curve, done by placing a soil core under constant moisture potentials that equate to DUL (-1.0m) and Lower Limit (-150m)
3. Estimation of PAWC based on knowledge of the water holding capacity of particular soil textural classes that form the horizons of the soil in question

This document currently concentrates on the first of these methodologies.

What data have already been collected?

To date over 500 soils have been characterised for PAWC nationally. There are a number of ways of checking data availability for your area. APSoil is the national database of soil water characteristics (Dalgliesh et al 2006) and is available for download at http://www.apsim.info. Data may also be accessed on-line through the Australian Soil Resource Information System (ASRIS) web site at http://www.asris.csiro.au/index_ie.html (Johnston et al 2003; McKenzie et al 2005) or viewed spatially using Google Earth (http://earth.google.com) with individual site data available for download. The Google Earth data file (*.kml) is available for download from the ASRIS and APSIM web sites.

Adding to the database

A major component of the GRDC project *Training growers to manage soil water* is to coordinate the on-going collection and storage of soil water information in the APSoil database. Consequently the authors would like to request that researchers and farmers undertaking characterisation activities consider including their data in the publicly accessible database. Contact details of the authors are provided at the front of this document.

Locating the characterisation site in the landscape

Data that enable location of the characterisation site in the landscape is essential. These data should include geo-spatial co-ordinates, information on land ownership and contact details to facilitate communication. It should be understood however, that on publication in the public domain, any data emanating from the project *Training growers to manage soil water* will only be identified by GPS co-ordinates. No information relating to property name or land ownership will be divulged.

Required data:

- Year of data collection
- State
- Region
- Nearest town
- Site location (district, village etc)
- Data source (Consultants name, GRDC project etc)
- GPS co-ordinates (decimal degrees)
- GPS Datum (preferably WGS84)

It is a requirement of those consultants and researchers participating in CSIRO soil characterisation activity to conform to a specific protocol relating to intellectual property and the privacy of the landowner. This includes a) notification (in writing) to the land owner of the research to be undertaken on the property, explaining the conditions under which CSIRO employees and their collaborators will enter the property, and seeking permission to enter and undertake the work, and b) at the completion of the activity, the provision to the land owner of a letter and copy of the data which have been collected and intended for publication in the public domain. Details and proforma documents may be obtained from the authors.

PART 1: CHARACTERISATION FOR DRAINED UPPER LIMIT (DUL) AND BULK DENSITY (BD)

STEP 1: SITE SELECTION

Sites should be selected to represent the agriculturally important soils of an area. Selecting a representative site can be difficult, particularly in areas with high spatial variability. Whilst there are no easy answers to this challenge it is expected that by combining the local knowledge of farmers, consultants and advisers, backed up by spatial tools such as yield and EM maps, and the support of soils experts, that the problem of soil and site identification can be minimised. In many cases this may mean that it is necessary to characterise a number of sites within a landscape to represent the inherent variability. It should also be recognised that soils are highly variable and that characterisation of a 'soil type' for PAWC will only ever be a good estimation of PAWC for the particular point and, if the site was selected carefully, a reasonable estimation of the soil that surrounds it.

Select characterisation sites according to the following criteria:

- The soil is of regional importance or of particular interest to a group of farmers/consultants
- Likelihood of local logistical support for the activity
- Sufficient land area to enable measurement of DUL and CLL at the same site
- A distance of at least 2-3 tree heights from any tree
- Opportunity to add to existing data sets

Drained Upper Limit (DUL) can be measured either opportunistically or through the establishment of a controlled characterisation site.

Opportunistic:

Whilst this is the simplest means of determining DUL it is reliant on the vagaries of the season to ensure that the profile is fully wet (to maximum rooting depth) prior to measurement. A small area of the representative soil (6m x 6m) is identified and weeds and crop controlled (by hand weeding or herbicide). The aim is to allow the soil sufficient time to naturally recharge as the season progresses. When it is considered that recharge is complete, the soil is covered with builders plastic (100 micron) which is sealed around the edges (with loose soil) to minimise evaporation and to exclude subsequent rainfall (an area of 4 x 4 or 3 x 3 m located in the middle of the area is sufficient). The site should be left to drain before sampling for moisture content. Where surface runoff reduces the efficiency of water entry, it is suggested that a layer of organic matter be applied to the soil surface (a bale of hay) to reduce runoff and evaporation and enhance infiltration.

Controlled:

The establishment of a soil characterisation site (Photos 1 and 2) allows for the controlled application of water and provides confidence that the soil has been fully recharged prior to sampling. Whilst the soil can be wet using a number of methods, trickle irrigation has proven to be efficient and cheap, the dripper system being capable of reuse a number of times.

STEP 2: SAMPLING FOR SOIL CHEMISTRY

Purpose: to determine soil chemical characteristics that may impact on PAWC

> ***Note:*** *Sampling for soil chemistry may be done at any time but is usually undertaken during site installation or at the time of DUL and BD measurement. It is not recommended that samples be taken from within the wetted area (at measurement of DUL) in case changes in soil chemical status have occurred as a result of the wetting process. Samples should be taken adjacent to the wetted area.*

- Core for chemical analysis:
  - Use a drill rig with 37or 50mm diameter tube or a hand held coring kit (see Appendix 3). It is suggested that 2-3 cores be taken per site with samples bulked across layers.
  - Sample at depth intervals matched with the middle of soil horizons, or use a standard set of increments such as 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm. Note that the same interval set should be used for all measurements on a particular site including DUL, BD, CLL and chemistry.
  - Dry samples for 4-5 days at 40°C and analyse for EC, chloride, cations, CEC, pH (H_2O & $CaCl_2$), B, Al, Mn, organic carbon and particle size.

STEP 3: WETTING THE PROFILE FOR DUL DETERMINATION

Purpose: to wet the soil profile in preparation for measurement of DUL

Establishing the site

- Assuming use of 4.0 m wide rolled plastic sheeting, dig a 10 cm deep trench measuring approx. 3.8 x 4.2 m (throw the soil to the outside). This results in a plot area of approximately 16 m^2. If a Neutron Moisture Meter (NMM) or similar soil water monitoring device is to be used, the access tube should be located centrally within the plot. Loose soil should be heaped around the access tube to a radius of 15 or 20 cm to ensure that rain falling on the plastic sheet will be diverted away from the tube (Photo 1).
- Use a 30 m length of drip-tube (eg DripEze™, see Appendix 3) capable of providing equal water delivery from all emitters along its length, even at low pressure. Plug one end of the drip-tube, pin this end to the ground near the plot centre and then arrange the drip-tube in a coil across the plot area (Photo 1).

- Connect a water reservoir via tap and filter to the drip-tube, fill the reservoir and check operation of the dripper system.
- Cut a 4.4 m length of 4.0 m wide heavy-gauge (100micron) black plastic sheeting and lay across the plot. Bury 10 cm of each edge in the trench. If an access tube for monitoring is present, cut a small cross, force the tube through the cut plastic and seal with duct tape (Photo 2).
- Where grazing is likely or feral animals such as pigs a problem, erect a fence around the plot.
- Commence wetting of the site, regulating flow rate to ensure that surface ponding does not occur outside the plot area.
- Ensure that weeds are controlled in the 2 m buffer area around the plastic during wetting and drainage.
- When it is estimated (or determined through monitoring) that the wetting front has reached full crop rooting depth, turn off the water and leave the plot to drain.

Photo 1: Pond under construction showing the trench, trickle line and NMM access tube in place

Photo 2: Completed pond showing header tank, in-line filter and wet-up area covered in plastic sheet. The edges of the sheet have been placed in the trench before back filling with soil.

Note: *Care should be taken, particularly in sandy textured soils, to ensure that the concentric rings of dripper line are laid sufficiently close to each other to ensure consistent wetting across the whole area. Where lines are too widely spaced it is possible to have areas that are sufficiently wet interspersed with areas which are still dry. It is suggested on heavy clays that lines be laid approximately 30 cm apart and on lighter textured soils 15-20 cm apart, although this should be confirmed for individual soils.*

How much water should be applied?

Rate of application and the required amount of non-saline water to reach DUL will depend on the texture of the soil and estimated depth of rooting.

Heavy textured soils: Heavy textured soils (eg black and grey Vertosols) hold large quantities of water and wet and drain very slowly, so a 'softly softly' approach to wetting is recommended. Applying around 200 L of water per week is a good rule of thumb. This can be increased if no surface ponding of water is observed around the characterisation site. Because of the high clay content (and consequently small pore size) these soils drain very slowly. Expect that it may take 3-6 months for wetting to a potential rooting depth of 1.8 m and 1-2 months for effective drainage to cease. Because of the slow wetting it is recommended that monitoring be undertaken during this phase, either occasional coring or the use of an NMM or other such device (see below).

Lighter textured soils: Time to wet will vary from 1 day for deep sands to several weeks for medium textured soils such as the loams and clay loams. Higher rates of water application are possible on these soils with rates of several hundred litres per day reported. Application rate should be reduced if surface ponding of water is observed on the soil surface outside of the characterisation area.

Whilst the above water quantities may seem high, considering the area of soil to be wet, remember that water will also move laterally, potentially wetting a much larger area than the actual 4 x 4 m characterisation site. It is also possible that the presence of macro-pores or cracks may result in preferential flow of water through the profile and the loss of water below the root zone during the wetting phase.

How long will it take for the soil to drain?

Time will vary with soil texture. Deep sands will drain in a couple of days, medium textured soils in approximately two weeks and heavy clays over a number of months, although drainage rates in heavy clays are so low that, practically speaking, soils can be sampled after 1-2 months. Take care to control all weeds and crops from within the 2 m buffer area during drainage.

WHAT EQUIPMENT IS NEEDED TO SET UP A BD/DUL CHARACTERISATION SITE?

Materials:

- Water reservoir (fire fighting tank, 1000 L skip, 200 L drum etc)
- Poly tap, piping, fittings and filter to join reservoir to irrigation drip-tube
- Drip-tube (embedded dripper type recommended), 13 mm diameter, 30 m in length, with a plug in one end
- Plastic sheet, black heavy gauge (100 micron), 4.4 m length from a 4.0 m wide roll
- Rainwater or other good quality water of low-salinity, about 1000-4000 L depending on soil texture and starting soil moisture content
- If using a NMM: an access tube, a rubber stopper, duct tape, sufficient kaolinite/water to make at least 10 L of slurry

Tools:

- Hacksaw
- Knife
- Small half-round file
- Flat and Phillips screwdrivers
- Pliers
- Shovel
- Spanners or other tools required for irrigation system fittings
- If using NMM tubes, a drill rig or soil auger is required to make the hole and insert the tube
- Large bucket and a mixing stick for the slurry

Maintenance and monitoring of site:

- Mobile water tank.
- Neutron Moisture meter or soil coring equipment to monitor wetting

Monitoring the wetting process

Using an NMM or similar electronic device

The most convenient way to gauge the progress of wetting is to use a monitoring device such as the Neutron Moisture Meter (NMM) or a Gopher. This requires the installation of an access tube in the centre of the characterisation site.

- Before installing an access tube, consider whether it will interfere with, be damaged by, or cause damage, during normal land management practices such as spraying or harvesting operations.
- Access tubes are either aluminium (NMM) or PVC (Gopher, etc), up to 3 m long and have an outside diameter of 20-50 mm.
- A vertical hole that closely fits the diameter of the access tube is drilled using either a hydraulic rig or hand equipment and the tube inserted. For rigid soils kaolinite clay slurry should be poured into the hole and the tube inserted before the slurry has time to set. This ensures good hydraulic contact between tube and soil. A little slurry forced out of the hole indicates use of a sufficient quantity. The kaolinite should be mixed at a ratio of around 30-50% clay to water (by volume).
- Take moisture readings at regular intervals and record and graph recharge.
- It is recommended that a standing platform (that straddles the plot) be used when undertaking readings. This allows the operator to access the NMM tube without compacting the wet soil surface.

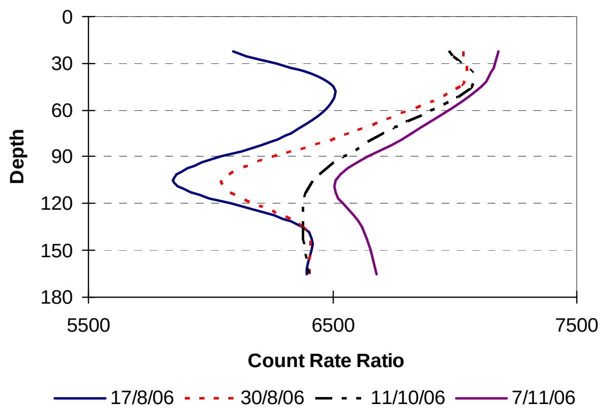

Figure 2, above, demonstrates the wetting process using the raw data collected using an NMM. Over time as water is applied, the ‘Count Rate Ratio’ line will move to the right, representing profile recharge as irrigation water moves deeper into the profile. This line will eventually stabilise, indicating that SAT has been reached (it will then move back to DUL as drainage occurs). Note that the line is generally not linear, indicating differences in soil texture through the profile and corresponding change in water holding capacity of the soil.

Coring

Where an NMM or similar device is not available the use of an auger or corer to check soil wetting prior to DUL sampling is a good practical option. Whilst gravimetric determination of soil water content is preferred, simply removing the core and ‘touching and feeling’ the soil to confirm moisture presence may suffice. Where it is considered that gravimetric sampling is necessary, follow the procedures indicated in *Soil matters* (page 43 & 73) (Dalgliesh and Foale, 1998).

STEP 4: SAMPLING FOR DUL AND BD

Purpose: to sample for soil moisture content at DUL and to determine the BD.

> ***Note:***
> *a) This activity should not occur until drainage has ceased*
> *b) Whilst samples for BD can be taken at any time (in rigid soils) it makes practical sense to sample at DUL so that both DUL and BD can be determined together*
> *c) Assistance in the sampling of DUL and BD may be available through the GRDC project, so please make contact if you require assistance and/or advice*

Rigid Soils

Where DUL is being sampled independent of BD (more likely on shrink/swell soils-see following section) it is necessary only to take standard 37 or 50 mm diameter cores to the required depth and determine gravimetric moisture content for the individual layers. Where both DUL and BD are required to be field measured (more likely on rigid soils) it is suggested that a process be used that provides information on both parameters from the one sample. Samples are taken for BD at pre-determined depths (centred on the middle of each layer increment) from which gravimetric moisture at DUL is also determined. Samples may be collected using a hydraulic driving system, surface based hand augering/coring or from the face of a pit.

The hand coring methodology shown in Figure 3 and Photos 3-13 enables intact samples (75 mm diameter x 50 mm height) to be taken to a depth of 180 cm without the need for a pit. Where a pit is preferred, a similar sampling process and tools are used with a back-hoe providing access to soil at depth. Taking 3 reps x 7 layers per site (to determine DUL and BD) generally takes around 3 hours using the auger method (but varies due to soil conditions). BD and DUL can also be done using a hydraulically operated system and large diameter tubes. It is not recommended that BD be done using tubes of <75 mm diameter due to the potential to compress the samples during coring.

It is recommended that the plastic plot cover be left in place during sampling to provide a cleaner working environment. Holes are cut through the plastic to access the soil, taking care to avoid cutting the irrigation pipe (Photos 3 and 4).

- The recommended sampling depth for DUL and BD is 1.5-1.8 m unless plant rooting depth is restricted by physical or chemical constraints such as rock or high salinity.
- Record data (Appendix 4, datasheet 1-rigid soils). Measure and record dimensions of the sampling ring. Sample volume is critical to BD estimation so it is important to measure ring dimensions often and accurately (+/- 1 mm) and to process samples carefully.
- Sample at depth intervals that match soil horizons, or if appropriate, a set of standard depth intervals such as: 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm.
- If using the method described in the accompanying photos, work accurately from a surface datum (small bolts or steel rod tapped in flush to the soil surface-Figure 3;

Photo 4) and avoid contamination of the sample with loose material falling from higher levels or the soil surface.

- Care should be taken when trimming the sample to ensure accurate levelling of the soil. Small imperfections in the surfaces of the sample should be smoothed out and if excess soil or small pebbles are removed in the levelling process, replaced with a suitable quantity of similar soil or sand.

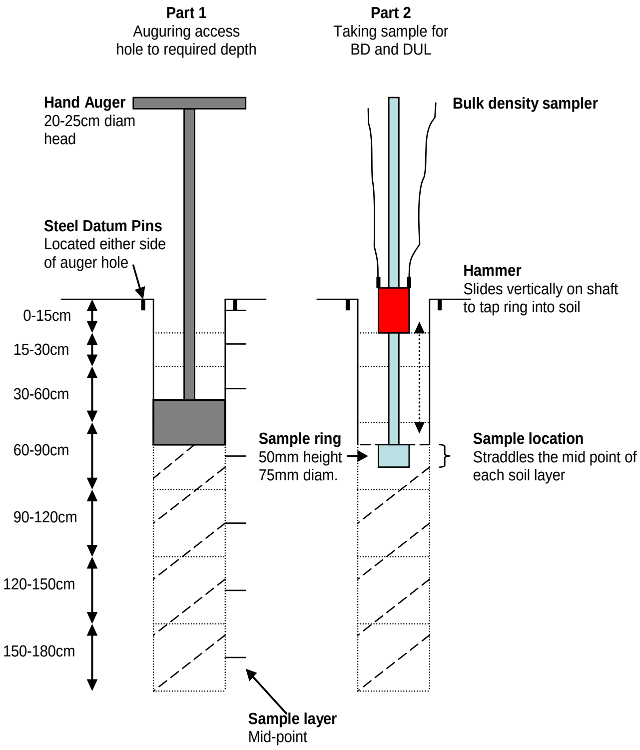

Figure 3: Schematic of hand coring process for BD (and for DUL) where an access hole is augered to the required depth using a 20-25 cm diameter hand auger, the base of the hole levelled with an auger levelling head and the sample taken using a sliding hammer sampler. Once a particular sample has been taken, the process is repeated ie. augering to the next depth layer, levelling the base and sampling. Datum pins located at the soil surface prior to sampling provide a datum for accurate depth measurements.

Photo 3: Cut hole in plastic.

Photo 4: Locate steel datum pins either side of core site.

Photo 5: Dig by hand to the first sampling point (straddling the mid-point of the first layer). Check depth against datum pins. Thoroughly clean and lightly oil the sampling rings. Assemble the BD sampler body and take the first sample.

Photo 6: Disassemble the sampler body and carefully remove sampling rings taking care not to damage the soil core.

Photo 7: Remove the steel spacer rings and, using a knife, carefully pare back the soil, level with the ends of the main sampling ring.

Photo 8: A BD sample ready for bagging. Note the use of the paint scraper as a handy tool on which to hold the coring ring whilst trimming the sample. Two such scrapers are useful when turning the sample over during trimming.

Photo 9: Slide sample from ring into bag. Weigh immediately if using a paper bag for storage (when sampling for DUL). If being stored in a plastic bag the sample may be weighed later but bag needs to be sealed and stored in a cool environment. Samples should be dried at 105^{0}C until at constant weight.

Photo 10: Augering to the next depth layer.

Photo 11: Removing dross and levelling the base of the auger hole in preparation for sampling (using special levelling tool).

Photo 12: Checking the depth of the hole prior to sampling. All measurements are referenced to the datum pins.

Photo 13: Referencing sampling depth. The sampler is placed in the hole and the height of the core sample measured and marked on the shaft of the sampler using the datum pins as reference. The corer is driven into the soil until the mark reaches the line of the datum pins. Driving the sampler past the reference line will result in compaction of the sample within the corer head.

Shrink/swell Soils

Whilst the methodology described above for rigid soils is also often used for soils that exhibit shrink/swell characteristics (such as the Vertosols common in northern Australia and parts of the south), there is an alternative. In rigid soils as the water content changes there is a complimentary change in air filled porosity, whereas in shrink/swell soils, as the soil dries there is a change in the volume of soil aggregates which is more or less equal to the volume of the water lost. The air filled porosity of the aggregates remains the same and the BD changes (Dalgliesh and Foale 1998). Due to the inherently slow drainage of shrink/swell soils there is a problem in defining water content in terms of DUL, SAT etc. To be able to model these soils using the APSIM model requires assumptions about how DUL, SAT and PO are defined which results in the opportunity to calculate BD.

In shrink/swell soils if PO (Total porosity) is calculated from the measured BD, that is $PO_{\% \, Vol} = (1\text{-}BD/2.65) *100$, the difference between this value and volumetric water content of the soil (θ_g x BD) may be too small for the latter to be a sensible estimate of DUL. Research shows a very close relationship between measured BD and gravimetric water content of the wet soil, corresponding to an air-filled porosity of approximately

3% (Gardner 1988; Dalgliesh and Foale 1998). This confirms that the soils are exhibiting shrink/swell behaviour and enables the calculation of BD. BD that corresponds with the soil being absolutely filled with water (zero air-filled porosity) is used as a reference. Values are then selected for (assumed) air-filled porosity at SAT and DUL, and BD at DUL calculated. The assumed values for air-filled porosity which are generally used are 3% at SAT and 5% for SAT-DUL.

The practical outcome for shrink/swell soils is that it is possible to measure gravimetric soil water at DUL (using a 37 or 50 mm diameter coring tube) and calculate BD, a far less onerous process than having to sample for BD in the field as described in the previous section. Table 1 provides an example of the calculations undertaken with the required proforma provided in Appendix 4 (Spreadsheet 2-shrink/swell soils).

Table 1:

Farmer	Layer	Layer Mid-point	Measured Grav	Calculated BD	DUL	SAT
	(cm)	(cm)	(g/g)	(g/cc)	(mm/mm)	(mm/mm)
John Smith	0-15	7.5	0.529	1.01	0.54	0.59
	15-30	22.5	0.507	1.04	0.53	0.58
	30-60	45	0.480	1.07	0.52	0.57
	60-90	75	0.473	1.08	0.51	0.56
	90-120	105	0.420	1.15	0.49	0.54
	120-150	135	0.372	1.23	0.46	0.51
	150-180	165	0.352	1.26	0.44	0.49

Calculations assume:
SAT-DUL = 0.05 and PO-SAT = 0.03
BD = (1-0.08)/(1/2.65+Grav)
DUL = Grav x BD
SAT = DUL+0.05

Table 2 provides an example of the calculations used to confirm that data collected using the rigid soil methodology (where used for rigid or shrink/swell soils) conforms to required criteria (PO-SAT >=3%; SAT-DUL >=5%). Data collected using this methodology are entered and the above criteria confirmed and where necessary re-calculated. The reason that this check is important on rigid soils is that the above criteria are sometimes not met as a result of soil compression during the sampling process. Spreadsheet 1 (Appendix 4-rigid soils) provides the required proforma.

Table 2:

Farmer	Layer	Layer Mid-point	Observed Grav	BD	Calculated DUL	PO	SAT	SAT-DUL	Re-calculated for S/S soils newBD	newDUL	newSAT
	(cm)	(cm)	(g/g)	(g/cc)	(mm/mm)	(mm/mm)	(mm/mm)	(mm/mm)	(g/cc)	(mm/mm)	(mm/mm)
John Smith	0-15	7.5	0.529	1.07	0.567	0.596	0.566	0.00	1.02	0.540	0.590
	15-30	22.5	0.507	1.11	0.565	0.580	0.550	-0.01	1.04	0.530	0.580
	30-60	45	0.480	1.14	0.550	0.568	0.538	-0.01	1.07	0.520	0.570
	60-90	75	0.473	1.18	0.557	0.555	0.525	-0.03	1.08	0.510	0.560
	90-120	105	0.420	1.22	0.511	0.541	0.511	0.00	1.15	0.490	0.540
	120-150	135	0.372	1.32	0.491	0.502	0.472	-0.02	1.23	0.460	0.510
	150-180	165	0.352	1.34	0.470	0.496	0.466	0.00	1.26	0.440	0.490

Calculated where:
DUL = Grav x BD
PO = (1-BD/2.65)
SAT = PO-0.03

Recalculations if measured SAT-DUL<0.05,
assumes SAT-DUL = 0.05 and PO-SAT = 0.03
newBD = (1-0.08)/(1/2.65+Grav)
newDUL = Grav x newBD
newSAT = newDUL+0.05

Processing samples for DUL and BD

- If weighing immediately in-field
  - Place samples in wet-strength paper bags
  - Record wet sample weight after taring the balance with one of the paper bags
  - Dry the samples at 105°C until at constant weight (usually about 48 hours); dry a paper bag with the samples to use as tare.
  - Tare the balance with the dried paper bag and weigh the samples
  - Record the dry soil weight on the data sheet

- If weighing on return to office
  - Place samples in sealed plastic bags and keep cool until return to office
  - Weigh samples after taring the balance for the plastic bag
  - Open the bags and dry the samples at 105°C **after confirming that the bags are able to withstand high temperatures.** If necessary remove samples and dry on trays ensuring that all of the soil is removed from the bag prior to drying.
  - Tare the balance with the plastic bag or tray, weigh samples

- For rigid soils (and shrink/swell where BD field measured): calculate DUL and BD
  - Using Spreadsheet 1 (Appendix 4) determine gravimetric soil water % and BD for each layer.
  - Confirm that data meets required criteria (SAT-DUL >=5%) and if not met recalculate using same spreadsheet
  - Calculate volumetric soil water content at DUL
  - Graph the volumetric water % and bulk density for the profile

- For shrink/swell soils (where DUL measured in field and BD calculated): calculate DUL and BD
  - Using Spreadsheet 2 (Appendix 4) determine gravimetric soil water % for each sample.
  - Calculate BD using criteria (PO-SAT >=3%; SAT-DUL >=5%)
  - Calculate volumetric soil water content at DUL
  - Graph the volumetric water % and bulk density for the profile

Note: Datasheets (Appendix 4) may be copied and used for the recording and calculation of DUL and BD. Copies of the spreadsheet are also available for download at http://www.apsim.info.

PART II – CHARACTERISATION FOR CROP LOWER LIMIT (CLL)

STEP 5: IDENTIFY AND ESTABLISH SITES FOR CLL MEASUREMENT

Purpose: a) to identify and establish site for the measurement of CLL, b) to ensure sufficient initial water in the soil profile for the selected crop to grow to its potential and to extract all available water before it senesces or reaches maturity.

> ***Note:***
> *For successful measurement of CLL it is important that moisture is present to the full depth of potential rooting at some point prior to crop flowering. To ensure that this condition is met it may be necessary to apply water using a drip irrigation system early in crop growth. A suggested method is for DUL to be measured prior to the start of the winter season, the commercial crop over-sown, and either the DUL site used for measurement of CLL, or drippers placed (with no plastic cover) in an adjacent area of emerging crop and water applied for the first few weeks of crop growth to ensure recharge of the profile.*
> *Care should be taken if using the old DUL site to avoid sampling for CLL in previously compacted or disturbed areas.*

- Plot characteristics:
    - Locate CLL plot close to DUL plot, but not so close that lateral seepage occurs between the two plots (if measuring DUL and CLL concurrently). Where the CLL is measured after the DUL, use either the same site (with the provisos mentioned in the note above) or one located close by.
    - Somewhere that will not interfere with normal farm practice (spraying etc).
    - Select crop/s common to the soil type and region. It is common to sample CLL opportunistically, setting up a site in whatever crop the farmer happens to sow after DUL has been measured. Where the opportunity arises it may be possible to set up adjacent sites in two adjoining paddocks and collect CLL on two different crops eg wheat and canola. Sometimes it may be possible to set up a site that measures CLL for a range of crops eg at a field day site.

- Determine whether wetting-up is necessary (see the note above):
    - If summer rains have been followed by good breaking rains there should be no need to wet the plot. If not, transfer the DUL plot irrigation system to the cropping plot/s and apply water equivalent to that of good rains, or if appropriate use the DUL site.

- If wetting-up is necessary:
    - Apply water such that soil moisture content is somewhere between CLL & DUL. Do so sparingly as excessive water may prevent the crop from reaching CLL later.

STEP 6: CORE FOR SOIL MOISTURE-*AT ANTHESIS*

Purpose: to provide a benchmark from which to determine crop rooting depth and water extraction at maturity.

Coring at anthesis (or flowering) provides information on interim soil water status with which the data collected at crop maturity can be compared. Differences in these measurements provide knowledge of rooting depth and extraction patterns within the profile. This minimises the possibility of data misinterpretation, particularly in relation to water extraction at depth. This is useful where seasons have been erratic and it is not known whether the profile has been fully wet to depth during the preceding fallow or summer period. Without this measurement it is possible, when sampling for CLL, to make the mistake that the dry soil at depth was a result of current crop extraction, whereas in fact it was due to extraction by a preceding crop.

Procedure

- Core for soil moisture:
    - Using a hand corer, take samples at the previously established sampling depths.
    - Bag the samples in either paper or plastic bags, depending on the sampling procedure.
    - Avoid sampling within 75 cm of previous coring holes or access tubes when sampling on the old DUL/BD site.

- Process samples for gravimetric water:
    - Process as per *Step 4*.
    - Use Datasheet 3 (Appendix 4) to calculate gravimetric and volumetric soil water %.
    - Graph the results

STEP 7: ERECTING RAIN-EXCLUSION TENT-*AT ANTHESIS*

Purpose: to exclude rain that might otherwise prevent the crop extracting water to CLL.

- Erect a rain-exclusion tent on the crop being studied (Photos 14-16):
    - Install star pickets at the appropriate spacing and attach the lateral steel pipes (Photo 14). Temporarily fix the ridge pipe a little low to allow for later tensioning of the cover. Use long star-pickets driven deep into the soil to prevent roof collapse if the soil becomes saturated.
    - Use a roof pitch of at least 20° to shed water efficiently and leave the ends of the shelter open to ensure ventilation.

- The length of the cover (7 m) allows the ends to be rolled and placed in trenches (Figure 4 (a)) dug along the inside of each side of the tent. Anchor the tent by backfilling the trenches leaving some slack in the tent cover.

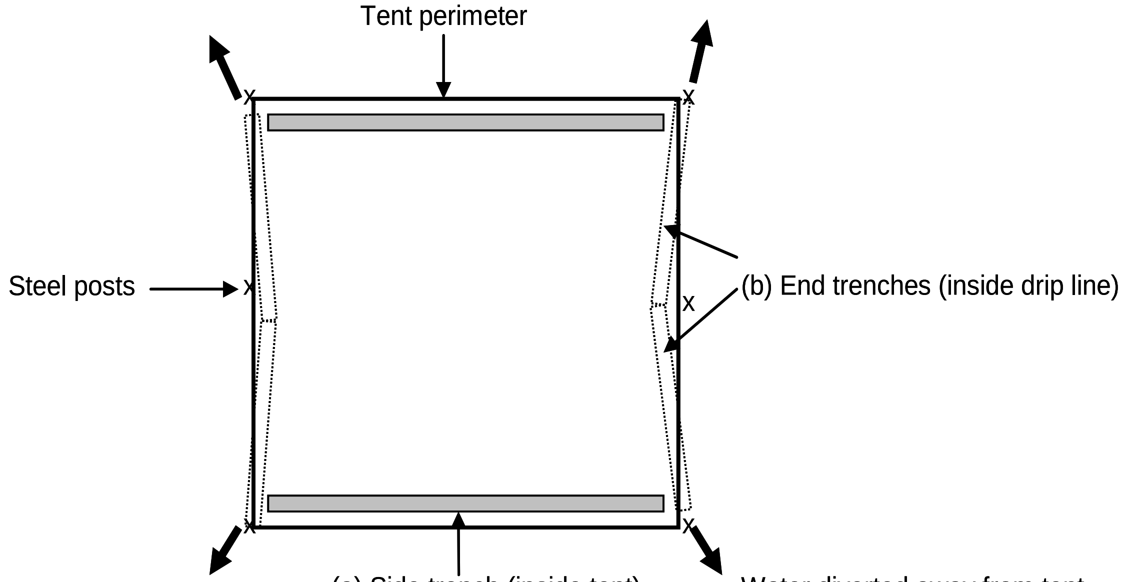

Figure 4: Floor plan of the tent showing (a) location of side trenches for anchoring the tent fly and (b) location of end trenches designed to capture and divert rain and water dripping from the tent fly as well as overland flow.

- Finish tensioning the cover by lifting the ridge pipe into its final position and securing.
- Dig a trench inside the drip line across the ends of the tent to prevent water from run-off or overland flow from entering the tent (Figure 4 (b)).

Photo 14: Rain-exclusion tent frame consists of six star-posts with three pipes or box sections wired between them. Posts are positioned to support a 3 x 3 m tent

Photo 15: Rain-exclusion tent in place. Duct tape on the pipes prevents chaffing. The plastic cover lies between the posts to simplify the attachment of the tubes. At the minimum 20° pitch, the cover must be tight to shed water.

Photo 16: Rain exclusion tent in chickpeas just prior to final sampling for CLL. Note the higher roof pitch to better shed water.

CONSTRUCTING A RAIN-EXCLUSION TENT

Materials:

- Six long star-posts
- Three 3.0m lengths (approx) of 25 mm steel pipe or box section
- Wire to connect frame components
- Cover
    - o Fabric: Solar Weave, Solar shield or similar
    - o Dimensions: 3 x 7 m finished size
    - o Two long sides to have reinforced edges with 6 eyelets along each side.
    - o Cover ends are not hemmed.
    - o Eyelet spacing from bottom left corner: 2350, 2450, 3450, 3550, 4550, 4650 cm. Other side to mirror.
- Duct tape to prevent plastic cover from chaffing on tubing

Tools:

- Mallet or picket driver
- Pick to dig anchor trench
- Shovel to excavate and back-fill the anchor trench
- Pliers
- Measuring tape
- Marker pen
- Stanley knife

STEP 8: CORE FOR CLL-*AT CROP MATURITY*

Purpose: to measure the CLL of a particular crop on a particular soil type

- Remove the rainout shelter:
  - This allows unrestricted access for coring and clears the paddock of tent components ready for harvesting.

- Core for soil moisture:
  - Take three cores at the established sampling depths spaced along the centre-line of the tent and at least 50cm from either end. Bulk samples across layer increments.
  - Look for and note the depth to which crop roots are present in each core (a hand lens is a useful tool).

- Process samples for gravimetric water:
  - Process as per *Step 4*
  - Calculate gravimetric water content using Datasheet 1 or 2 (Appendix 4) to record and calculate CLL

- Graph the results:
  - Graph the CLL data.
  - It is common for some air drying to have occurred in the top two layers of the profile. For this reason it is recommended that values for these layers be changed to equal the value measured in layer three. Where soil texture changes sharply down the profile (duplex soil) it will be necessary to make some judgement on appropriate values based on similar soils in the APSoil database.

PART III – CALCULATION OF PAWC

After data collation the PAWC may be calculated and graphed using Datasheet 1 (Appendix 4) for rigid soils (and shrink/swell where BD was field measured) or Datasheet 2 (for shrink/swell soils where BD was calculated from gravimetric soil moisture). As previously noted, the water availability for a particular crop on a particular soil is calculated as the difference between DUL and CLL within the crop's rooting zone. The depth of this zone is determined using both the rooting depth observations taken during coring and changes in soil water determined at anthesis and crop maturity.

Tips on interpretation of data

- The DUL/CLL lines represent the wet/dry extremes of available soil moisture respectively. The anthesis measurement, normally positioned between CLL and DUL, assists with the interpretation of soil water trends and rooting depth.
- Note that coring for CLL may extend below the depth of the crop's actual rooting zone. This may lead to the over estimation of PAWC for the crop being studied, unless depth of rooting was observed and recorded, and water extraction at time of CLL sampling compared with that measured at anthesis (Step 6) to define the actual depth of the root zone. This should not be an issue if the profile was sufficiently wet prior to the measurement of CLL (Step 5).

Undertaking the process described in this methodology, over a number of cropping seasons, makes it possible to gain a good understanding of the seasonal wetting and drying cycles of the soil, along with insights into the ability of different crops to extract soil water. Once the DUL and BD have been measured for a particular soil type they do not need to be repeated. However, as CLL varies between crop species grown on the same soil, it is recommended that a range of crops be measured as the opportunity arises.

APPENDICES

Appendix 1: Water requirements for wetting-up a DUL/BD site

The required quantity of water is that which will fully wet the soil to depth of crop rooting. It is very difficult to accurately estimate the required amount for an uncharacterised soil, but the method below provides a starting point that should minimise the water and time required for wet-up and drainage of the DUL/BD characterisation plot.

Estimation of water required for a range of soil texture classes

The following rules of thumb are based on data from field characterisation of soils representing a range of texture classes, where the millimetres of available water per centimetre of soil depth has been calculated (assuming that rooting depth is 150cm). More examples of this calculation, for a range of soils from the northern cropping region, are provided on page 57 of *Soil matters* (Dalgliesh and Foale, 1998). It is reasonable to assume that a soil within a texture class intermediate to those provided in Table 3 would also have an intermediate water requirement.

Table 3: Soil water capacity (mm water/cm soil) estimates for a range of soil texture classes

Texture class	Estimated PAWC (mm water/cm soil)
Sand	0.5
Sandy Loam to Clay Loam	0.8-1.2
Heavy Clay	1.5-2.0

Example 1:
Assuming that the soil is a heavy clay which holds 1.5 mm/cm to 150 cm
Soil water capacity factor (mm/cm) = 1.5
Expected rooting depth (cm) = 150
Estimated soil water (mm) = 1.5 x 150
= 225
Estimated soil water (L/m^2) = 225
Estimated water for 16m^2 site (L) = 225 x 16 = 3600
Assume 20% inefficiency in application = 3600 x 120%
Estimate of required water (L) = 4320

Example 2:
Assuming that the soil is a deep sand which holds 0.5mm/cm to 150cm
Soil water capacity factor (mm/cm) = 0.5
Expected rooting depth (cm) = 150
Estimated soil water (mm) = 0.5 x 150
= 75
Estimated soil water (L/m^2) = 75
Estimated water for 16m^2 site (L) = 75 x 16 = 1200
Assume 20% inefficiency in application = 1200 x 120%

Estimate of required water (L) = 1440

Please remember:

- That the assumption inherent in these calculations is that the soil is at lower limit when the water is applied. If the soil already contains available water then the amount required to reach DUL will be less
- That these estimates are based on a judgement about the soil chosen to represent the soil type at the site, differences between this estimate and the actual water requirement may occur.
- Depth of wetting should be confirmed and sufficient drainage time allowed before sampling for DUL.
- Wet the soil slowly over time. Small quantities of water over a longer period provide the best wetting, particularly on heavy clays or sodic soils where entry and movement of water will be slow.

Appendix 2: Determination of soil texture

This section describes a methodology for field texturing, a useful skill and a source of information for the soil characterisation database. These notes are essentially transcribed from Dalgliesh & Foale (1998).

Procedure for describing soil texture

Repeat the following steps for each sampling layer of the soil:

1. Take enough soil to fit into the palm of your hand, removing large stones, twigs, etc.
2. Moisten the soil with water, a little at a time, and kneed until the ball of soil just fails to stick to your fingers. Add slightly more water to get it to the sticky point, which is the Drained Upper Limit (DUL) of the soil.
3. Work the soil in this manner for one to two minutes, relating its behaviour to that described in the Soil Texture Guide overleaf. Inspect the sample to see if sand is visible. If not visible, it may still be felt or heard as the sample is worked.
4. Squeeze and feed the ball out between thumb and forefinger to form a ribbon. Note the maximum length of self-supporting ribbon formed.
5. Use the following notes and the Soil Texture Guide to classify the texture of the soil.

A soil with a high proportion of:

- Sand - *will feel gritty*
- Silt - *will feel silky*
- Clay - *will feel sticky*

Soil texture can change down the soil profile and is described using the following terms:

- Uniform: the texture is the same throughout the profile.
- Duplex: the texture changes by more than 20% within 5 cm of depth, often at around 15 cm. These are also called texture-contrast soils.
- Gradational: the texture changes gradually down the profile. Many soils vary from a loamy surface to a clay loam and then to clay.

SOIL TEXTURE GUIDE					
Ball…	**Ribbon (cm)**	**Feel**	**Texture**	**Acronym**	**Clay (%)**
…will not form	0.5	Single grains of sand stick to fingers.	Sand	S	<10
…just holds together	1.3-2.5	Feels very sandy; visible grains of sand.	Loamy sand	LS	<10
…holds together	2.5	Slightly spongy; fine sand can be felt.	Loamy fine sand	LFS	<10
…holds together	1.3-2.5	Fine sand can be felt.	Fine sandy loam	FSL	15
…holds together	2.5	Spongy, smooth, not gritty or silky.	Loam	L	15-20
…holds together	2.5	Very smooth to silky.	Silt loam	SL	0-25
…holds together strongly	2.5-4.0	Sandy to touch, medium sand grains visible.	Sandy clay loam	SCL	20-30
…holds together	4.0-5.0	Plastic, smooth to manipulate.	Clay loam	CL	30-40
…holds together	5.0-7.5	Plastic, smooth, slight resistance to shearing between thumb and forefinger.	Light clay	LC	35-45
…holds together strongly	>7.5	Plastic, smooth, handles like plasticine; can mould into rods without fracture; moderate shearing resistance.	Medium clay	MC	45-55
…holds together strongly	>7.5	Plastic and smooth, handles like stiff plasticine; can mould into rods without fracture; very firm shearing resistance.	Heavy clay	HC	>55

Appendix 3: Tools and materials

Equipment Suppliers

This list is neither exhaustive nor intended to infer recommendation of particular suppliers.

- **Rain exclusion covers**

Able to be fabricated by any canvas supplier. Covers have been obtained from NJ's Canvas, Toowoomba (Ph: 07 46301400) for approx $140 each. Whilst clear plastic may be used it is not advised due to the potential for the concentration of light and the development of hot spots within the crop canopy which may impact on crop growth.

- **Dripper systems**

DripEze (DDN1320030; non-compensating, 2 L/hr drippers, dripper spacing: 0.3 m) irrigation pipe or similar. Available from irrigation specialists.

- **Plastic sheeting for DUL plot**

100 micron black builder's plastic sheeting, 4 m wide roll - available at most hardware outlets

- **Soil sampling equipment**

Acre Industries manufacture general soil sampling equipment including hand coring kits and sampling tubes. Contact Cliff Edser Mob: 0407 915625

- **Bulk density sampling kits**

All-Turnit Engineering manufacture bulk density sampling kits as shown in this document. Contact Peter Ryan Mob: 0412 746061, Ph: 07 46330456

- **Augering heads and handles**

Dormer Engineering manufacture a range of augering systems suitable for soil sampling. Ph: 02 66721533

Appendix 4: Datasheets

Datasheet 1: <u>Rigid soil</u>-Calculation of DUL, BD, CLL and PAWC

(Note that it will be necessary to duplicate this sheet where more than one rep is being sampled)

EXAMPLE

						BULK DENSITY & DRAINED UPPER LIMIT											BD and DUL-Recalculated where SAT-DUL <5% (Col O)					CROP LOWER LIMIT				PAWC	
Sample No	Depth Range (cm)	Layer thickness (cm)	Sample height (cm)	Tube Radius (cm)	Core Vol (cc)	Sample Wet Wt (g)	Sample Dry Wt (g)	DUL Gravimetric (g/g)	DUL Gravimetric (%)	Bulk Density (g/cc)	DUL Volumetric (mm/mm)	DUL Volumetric (%)	PO Volumetric (mm/mm)	SAT Volumetric (mm/mm)	SAT Volumetric (%)	SAT-DUL (mm/mm)	new BD (g/cc)	new DUL Volumetric (mm/mm)	new DUL Volumetric (%)	new SAT Volumetric (mm/mm)	new SAT Volumetric (%)	Sample Wet Wt (g)	Sample Dry Wt (g)	CLL Gravimetric (%)	CLL Volumetric (%)	PAWC per layer (mm)	PAWC Profile (mm)
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
					πRaidus^2 Height $=\pi C^2 B$			((Wet-Dry)/Dry) =(E-F)/F	Grav(g/g)*100 =G x 100	DrwWt/Core Vol = F/D	Grav(g/g)*BD =G x I	Grav% x BD =H x I	(1-BD/2.65) =(1-I/2.65)	(PO-0.03) =L-0.03	SAT(mm/mm) *100 =M x 100	SAT-DUL =M-J	(1-0.08) /(1/2.65+Grav) =(1-0.8)/(1/2.65 +G)	Grav x BD =G x P	Grav x BD =H x P	DUL + 0.05 =Q + 0.05	SAT (mm/mm)* 100 =S x 100			((Wet-Dry)/Dry)*100 =((U-V) /Vx 100	Grav x BD =W x I	(DUL-CLL)*thick/10 =(J-X) x A/10	=SUM COLUMN Y
1	0-15	15	5	3.75	221	450	365	0.233	23.3	1.65	0.385	38.50	0.38	0.346	34.61	-0.04	1.51	0.351	35.11	0.401	40.11	190	180	6	8	40	99
2	15-30	15	5	3.75	221	440	400	0.100	10.0	1.81	0.181	18.12	0.32	0.286	28.63	0.11						199	190	5	9	14	
3	30-60	30	5	3.75	221	395	370	0.068	6.8	1.68	0.113	11.32	0.37	0.338	33.76	0.22						362	355	2	3	24	
4	60-90	30	5	3.75	221	387	360	0.075	7.5	1.63	0.122	12.23	0.38	0.355	35.47	0.23						369	357	3	5	20	

CALCULATION SHEET

						BULK DENSITY & DRAINED UPPER LIMIT											BD and DUL-Recalculated where SAT-DUL <5% (Col O)					CROP LOWER LIMIT				PAWC	
Sample No	Depth Range (cm)	Layer thickness (cm)	Sample height (cm)	Tube Radius (cm)	Core Vol (cc)	Sample Wet Wt (g)	Sample Dry Wt (g)	DUL Gravimetric (g/g)	DUL Gravimetric (%)	Bulk Density (g/cc)	DUL Volumetric (mm/mm)	DUL Volumetric (%)	PO Volumetric (mm/mm)	SAT Volumetric (mm/mm)	SAT Volumetric (%)	SAT-DUL (mm/mm)	new BD (g/cc)	new DUL Volumetric (mm/mm)	new DUL Volumetric (%)	new SAT Volumetric (mm/mm)	new SAT Volumetric (%)	Sample Wet Wt (g)	Sample Dry Wt (g)	CLL Gravimetric (%)	CLL Volumetric (%)	PAWC per layer (mm)	PAWC Profile (mm)
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
					$=\pi C^2 B$			=(E-F)/F	=G x 100	= F/D	=G x I	=H x I	=(1-I/2.65)	=L-0.03	=M x 100	=M-J	=(1-0.8)/(1/2.65 +G)	=G x P	=H x P	=Q + 0.05	=S x 100			=((U-V) /Vx 100	=W x I	=(J-X) x A/10	=SUM COLUMN Y
1																											
2																											
3																											
4																											
5																											
6																											
7																											

Datasheet 2: <u>Shrink/swell soil</u>-Calculation of DUL, BD (from measured gravimetric moisture at DUL), CLL and PAWC

EXAMPLE

						Drained Upper Limit and Bulk density									Crop Lower Limit				PAWC	
Sample No	Depth Range (cm)	Layer thickness (cm)	Sample height (cm)	Tube Radius (cm)	Core Vol (cc)	Sample Wet Wt (g)	Sample Dry Wt (g)	DUL Gravimetric (g/g)	DUL Gravimetric (%)	BD (g/cc)	DUL Volumetric (mm/mm)	DUL Volumetric (%)	SAT Volumetric (mm/mm)	SAT Volumetric (%)	Sample Wet Wt (g)	Sample Dry Wt (g)	CLL Gravimetric (%)	CLL Volumetric (%)	PAWC per layer (mm)	PAWC Profile (mm)
		A	B	C	D	E	F	G	H	P	Q	R	S	T	U	V	W	X	Y	Z
					πRaidus² Height			((Wet-Dry)/Dry)	Grav(g/g)*100	(1-0.08) /(1/2.65+Grav)	Grav x BD	Grav x BD	DUL + 0.05	SAT (mm/mm)* 100			((Wet-Dry)/Dry)*10	Grav x BD	(DUL-CLL)*thick/10	
					=$\pi C^2 B$			=(E-F)/F	=G x 100	=(1-0.8)/(1/2.65 +G)	=G x P	=H x P	=Q + 0.05	=S x 100			=((U-V) /Vx 100	=W x I	=(J-X) x A/10	=SUM COLUMN Y
1	0-15	15	5	3.75	221	450	300	0.500	50.0	1.05	0.524	52.43	0.574	57.43	190	160	19	20	49	291
2	15-30	15	5	3.75	221	440	301	0.462	46.2	1.10	0.506	50.63	0.556	55.63	199	170	17	19	48	
3	30-60	30	5	3.75	221	395	280	0.411	41.1	1.17	0.479	47.95	0.529	52.95	362	320	13	15	98	
4	60-90	30	5	3.75	221	387	280	0.382	38.2	1.21	0.463	46.29	0.513	51.29	369	330	12	14	96	

CALCULATION SHEET

						Drained Upper Limit and Bulk density									Crop Lower Limit				PAWC	
Sample No	Depth Range (cm)	Layer thickness (cm)	Sample height (cm)	Tube Radius (cm)	Core Vol (cc)	Sample Wet Wt (g)	Sample Dry Wt (g)	DUL Gravimetric (g/g)	DUL Gravimetric (%)	BD (g/cc)	DUL Volumetric (mm/mm)	DUL Volumetric (%)	SAT Volumetric (mm/mm)	SAT Volumetric (%)	Sample Wet Wt (g)	Sample Dry Wt (g)	CLL Gravimetric (%)	CLL Volumetric (%)	PAWC per layer (mm)	PAWC Profile (mm)
		A	B	C	D	E	F	G	H	P	Q	R	S	T	U	V	W	X	Y	Z
					=$\pi C^2 B$			=(E-F)/F	=G x 100	=(1-0.8)/(1/2.65 +G)	=G x P	=H x P	=Q + 0.05	=S x 100			=((U-V) /Vx 100	=W x I	=(J-X) x A/10	=SUM COLUMN Y
1																				
2																				
3																				
4																				
5																				
6																				
7																				

Datasheet 3: For the calculation of gravimetric and volumetric soil water

(Note that it will be necessary to duplicate this sheet where more than one rep is being sampled)

EXAMPLE

				MONITORING DATA			
Sample No	Depth Range (cm)	Layer thickness (cm)	Bulk Density (g/cc)	Sample Wet Wt (g)	Sample Dry Wt (g)	Gravimetric (%)	Volumetric (%)
		A	B	D	E	F *=((D-E)/E) x 100*	G *=F x B*
1	0-15	15	1.20	198	160	24	29
2	15-30	15	1.22	195	150	30	37
3	30-60	30	1.31	347	280	24	31
4	60-90	30	1.35	370	291	27	37

CALCULATION SHEET

				MONITORING DATA			
Sample No	Depth Range (cm)	Layer thickness (cm)	Bulk Density (g/cc)	Sample Wet Wt (g)	Sample Dry Wt (g)	Gravimetric (%)	Volumetric (%)
		A	B	D	E	F *=((D-E)/E) x 100*	G *=F x B*
1							
2							
3							
4							
5							
6							
7							

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