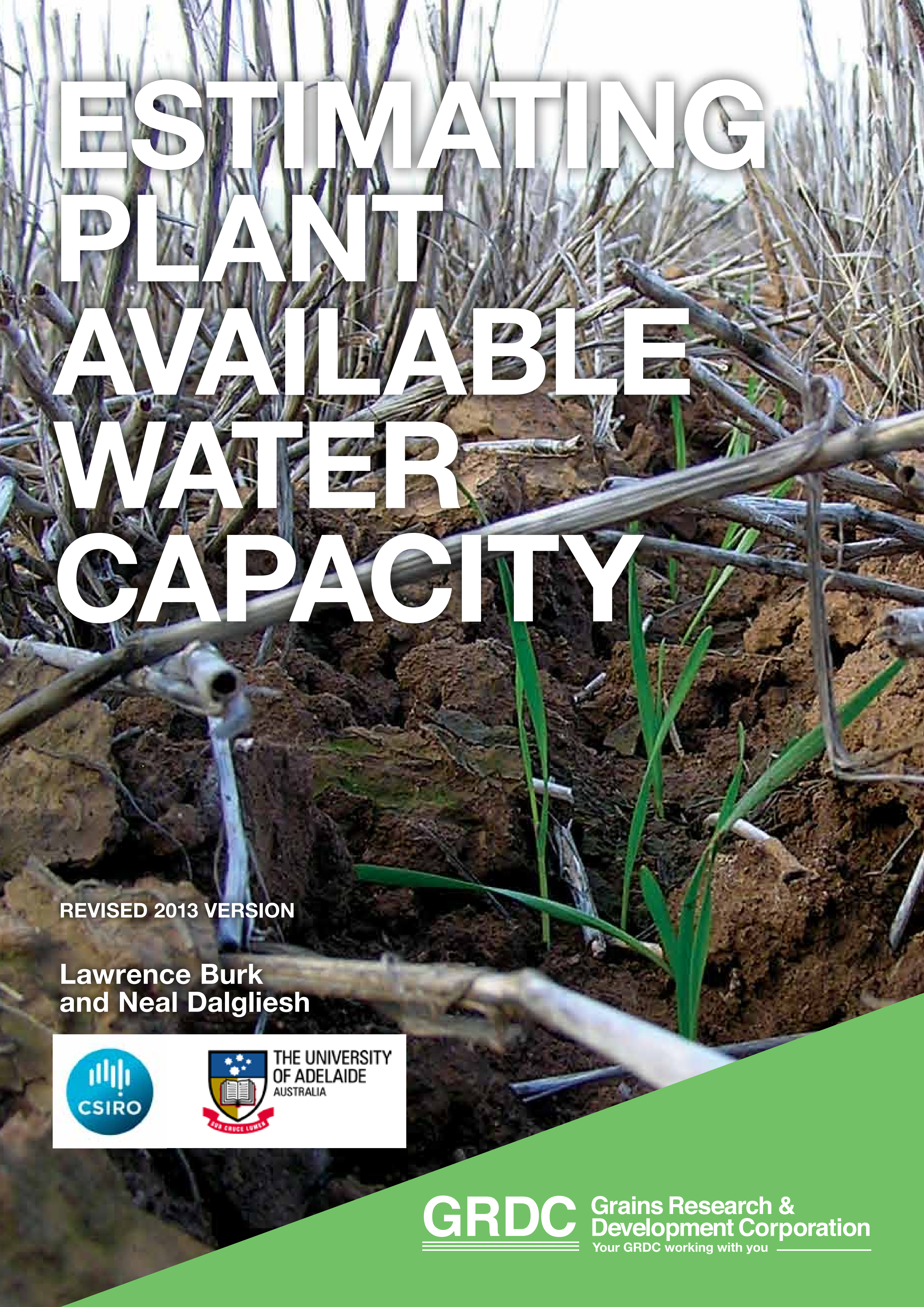

ESTIMATING PLANT AVAILABLE WATER CAPACITY

REVISED 2013 VERSION

Lawrence Burk
and Neal Dalgliesh

CSIRO

THE UNIVERSITY OF ADELAIDE AUSTRALIA

GRDC Grains Research & Development Corporation

Your GRDC working with you

ESTIMATING PLANT AVAILABLE WATER CAPACITY

Authors: Lawrence Burk and Neal Dalgliesh

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OVERVIEW

This manual provides consultants and advisers with practical information, methods and tools for the characterisation of soils for plant available water capacity, with the aim being to ensure improved consistency of measurement and delivery of information to the Australian agricultural sector.

Why characterise soils?

Characterisation provides a way for the grower, 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 farmers' intuitive knowledge ('gut feel'); to develop better rules-of-thumb for managing resources in a more informed way; and 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.

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, known as the soil water 'bucket'. It is different from soil monitoring, which is about measuring the quantity of water in the soil bucket at a certain time.

Information required to characterise a soil for PAWC (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; and
- bulk density (BD) – the density of the soil, which is required to convert measurements of gravimetric water content to volumetric.

As well as measuring soil physical characteristics, collecting soil chemical data can provide information about the potential for subsoil constraints to affect a soil's ability to store water, or the plant's ability to extract water from the soil.

Working together

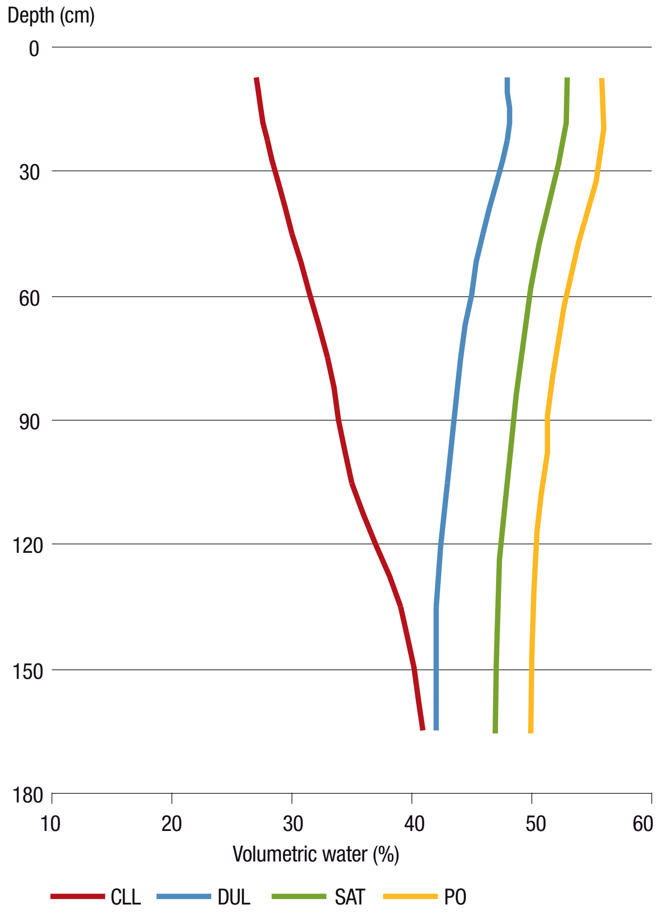
It is recommended that grower groups and/or consultants work together to identify and characterise district/regional soils. State-based regional mapping activities may also be useful for identifying appropriate sites. Where practical it is suggested that groups attempt to locate soil characterisation sites next to existing soil description sites, thus adding value to existing information.

How do you characterise soils?

Soil properties can be determined in a number of ways including:

1. Calculation of PAWC from field measurements of DUL, CLL and BD.
2. Laboratory-based generation of a soil moisture characteristic curve, by placing a soil core

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)



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 report concentrates on the first of these methods.

What data have already been collected?

More than 900 soils have so far been characterised for PAWC. There are a number of ways of checking data availability for your area. The national soil water characteristic database, APSoil, can be downloaded at www.apsim.info/wiki. Data may also be viewed using Google Earth (www.google.com/earth/index.html) with the *.kml file available for download from either the above website or from the ASRIS website (www.asris.csiro.au). Data for individual sites may be downloaded to Excel for personal use. APSoil soil characterisation data and ASRIS-based soil information are also available for use on Apple iPad devices using the application, SoilMapp, which is a free download from the Apple store.

Adding to the database

An aim of GRDC soil projects being managed by CSIRO is to coordinate the ongoing collection and databasing of soil water information and to provide it in the public domain as part of the APSoil database. The authors would like to request that researchers and growers undertaking characterisation activities consider including their data in the publicly available database. Contact details of the authors are provided at the front of this report.

Locating the characterisation site in the landscape

The data must enable the characterisation site to be located in the landscape and should include geo-spatial coordinates, information on land ownership and contact details. However, it should be understood that upon publication in the public domain, any data emanating from the project will be identified by GPS coordinates only, no information relating to property name or land ownership will be published.

Required data:

- year of data collection;
- state;
- region;
- nearest town;
- site location (district, village etc);
- data source (consultant's name, GRDC project, etc);
- GPS coordinates (decimal degrees); and
- GPS datum (preferably WGS84).

Consultants and researchers participating in the CSIRO soil characterisation activity must conform to a specific protocol relating to intellectual property and the landowner's privacy. This includes:

a) notification (in writing) to the land owner about 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, providing the land owner with a copy of the data collected and intended for use in the public domain.

Details and proforma documents may be obtained from the authors (for contact details see page 2).

PART I
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. While there are no easy answers to this challenge it is expected that by combining the local knowledge of growers, consultants and advisers, backed up by spatial tools such as yield and electromagnetic induction (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. Soils are highly variable and characterisation of a 'soil type' for plant available water capacity (PAWC) will only ever be a good estimation 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 growers/consultants;
- likelihood of local logistical support for the activity;
- sufficient land area to enable measurement of drained upper limit (DUL) and crop lower limit (CLL) at the same site;
- a distance of at least two to three tree heights from any tree; and
- opportunity to add to existing data sets.

DUL can be measured either opportunistically or through the establishment of a controlled characterisation site.

Opportunistic

This is the simplest way of determining DUL but 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 (at least 8m x 8m) is identified and the crop or weeds removed by hand or herbicide. The aim is to allow the soil sufficient time to naturally recharge as the season progresses. Where surface run-off reduces the efficiency of water entry, it is suggested that a layer of organic matter (such as hay) be applied to the soil surface to reduce run-off and evaporation and to enhance infiltration.

When it is considered that recharge is complete, the soil is covered with builder's plastic (100 micron) and sealed around the edges (with loose soil) to minimise evaporation and to exclude subsequent rainfall (an area of 4 x 4m or 3 x 3m located in the middle of the area is sufficient). The site should be left to drain before sampling for moisture content.

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 before sampling. Trickle irrigation is an efficient and cheap method of irrigation as the dripper system can be reused a number of times.

Step 2: Sampling for soil chemistry

Note: Sampling for soil chemistry may occur at any time, but is usually undertaken during site installation or at the time of DUL and BD measurement. Do not take samples from within the irrigated area, that is at DUL measurement, in case changes in soil chemical status have occurred as a result of the wetting process. Take samples next to the wetted area.

Core for chemical analysis:

- use a drill rig with 37 or 50-mm diameter tube or a hand-held coring kit. Take three cores per site and bulk samples across layers;
- sample at depth intervals matched with the middle of soil horizons, or use a standard set of increments such as 0–15 centimetres, 15–30cm, 30–60cm, 60–90cm, 90–120cm, 120–150cm and 150–180cm. Use the same interval set for all measurements on a particular site including DUL, BD, CLL and chemistry; and
- dry samples for four to five days at 40°C and analyse for EC, chloride, cations, CEC, pH (H_2O and $CaCl_2$), B, Al, Mn, organic carbon and particle size.

Step 3: Wetting the profile for DUL determination

Establishing the site

- Assuming use of 4-metre-wide builders plastic, dig a 10cm deep trench in a rectangle measuring approximately 3.8 x 4.2m (throw the soil to the outside). This results in a plot area of approximately 16m^2. If using a neutron moisture meter or other soil water monitoring device, locate the access tube centrally within the plot. Heap loose soil around the access tube to a radius of 15–20cm to divert rainfall away from the tube (Photo 1).
- Use a 30m length of drip-tube (for example, DripEze™) 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 4.4m length of 4m wide 100 micron black plastic sheeting and lay across the plot. Bury 10cm 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 it with duct tape (Photo 2).
- Where grazing is likely, or feral animals such as pigs are a problem, erect a fence around the plot.
- Start irrigation of the site, regulating flow rate to ensure that surface ponding does not occur outside the plot area.
- Control weeds in the 2m buffer area around the plot during irrigation 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.

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 'cones' of wetting surrounded by areas of dry. On heavy clays it is suggested that lines be laid approximately 30cm apart, and on lighter textured soils 15-20cm apart, although this should be confirmed for individual soils.

How much water should be applied?

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

Heavy textured soils (for example, 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 about 200 litres of water a week is a good rule of thumb. This can be increased if no surface ponding of water around the characterisation site is observed. Because of the high clay content (and consequently the small pore space) these soils drain very slowly. Expect that it may take three to six months for wetting to a potential rooting depth of 1.8m and one to two months for effective drainage to cease. Because of the slow wetting it is recommended that monitoring be undertaken during this phase, that is, occasional coring or use of a neutron moisture meter or other such device (see below).

On lighter textured soils, time to wet will vary from one 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.

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 about 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 one or two months. Take care to control all weeds and crops within the surrounding buffer area during drainage (2m on all sides is recommended).

1

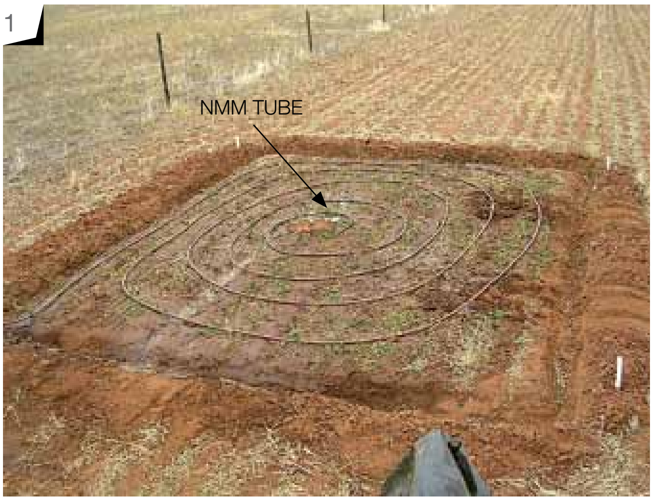


Photo 1: Pond under construction showing the trench, trickle line and neutron moisture meter (NMM) access tube in place.

2

Photo 2: Completed pond showing header tank, in-line filter and wetted area covered in plastic sheet, the edges of which were placed in the trench before back filling with soil.

Monitoring the wetting process

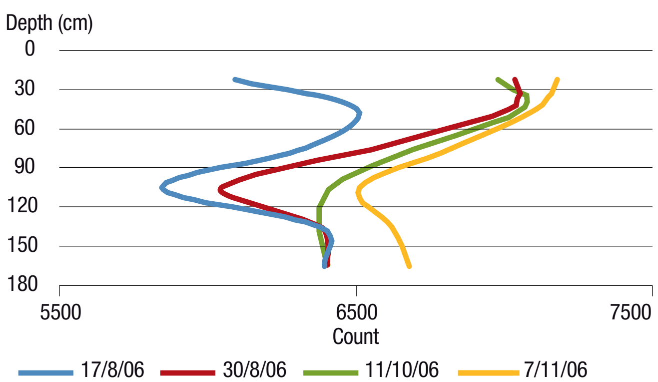
Using an NMM or similar monitoring device: The most convenient way to gauge the progress of wetting is to use a monitoring device such as a neutron moisture meter (NMM). This requires the installation of an access tube in the centre of the characterisation site.

- 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.
- Drill a vertical hole that closely fits the diameter of the access tube using either a hydraulic rig or hand equipment and insert the tube. For rigid soils, pour kaolinite clay slurry into the hole and insert the tube 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 enough was used. The kaolinite should be mixed at a ratio of about 50:50 clay to water (by volume).
- Take moisture readings at regular intervals, recording and graphing the recharge.
- A standing platform (that straddles the plot) is recommended when undertaking readings. This allows the operator to access the tube without compacting the surrounding soil surface.

Figure 2 shows the wetting process, using raw data collected with a neutron moisture meter. Over time, as water is applied, the Count line will move to the right, representing profile recharge as irrigation water moves deeper into the profile. This line will eventually stabilise, indicating that saturation has been reached, then move back to DUL as drainage occurs. Note that the line is generally not linear, indicating differences in soil texture and bulk density through the profile and corresponding change in water holding capacity of the soil.

Coring: Where a neutron moisture meter 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.

FIGURE 2 THE WETTING PROCESS, USING RAW DATA COLLECTED WITH A NMM



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

Materials

- water reservoir (fire-fighting tank, 1000L skip, 200L drum etc);
- poly tap, piping, fittings and filter to join reservoir to irrigation drip-tube;
- drip-tube (embedded dripper type recommended), 13mm diameter and 30m in length, with a plug for one end;
- plastic sheet, black 100 micron, 4.4m length from a 4.0m-wide roll;
- rainwater or other good quality, low salinity water – about 1000 to 4000L depending on soil texture and starting soil moisture content; and
- if using a NMM: an access tube, a rubber stopper, enough kaolinite/water to make around 10L of slurry and duct tape.

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 to make the hole and insert the tube; and
- large bucket and a mixing stick for the slurry.

Maintenance and monitoring of site

- mobile water tank;
- NMM or soil-coring equipment to monitor wetting; and
- datasheet to collect data for use in graphing the progress of soil wetting.

Step 4: Sampling for DUL and BD

Note:
a) this activity should not occur until drainage has ceased;
b) samples for BD can be taken at any time (in rigid soils), but it makes practical sense to sample at DUL so that DUL and BD can be determined together.

Rigid soils

For these soils, where both DUL and BD are to be field measured it is suggested that a process be used that provides information on both parameters using the one sample. Samples are taken for BD at predetermined depths (the middle of each layer) 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 method shown in Figure 3 and Photos 3 to 13 enables intact samples (75mm diameter x 50mm height) to be taken to a depth of 180cm without the need for a pit. Where a pit is preferred, a similar sampling process and tools are used, with a back-hoe replacing the hand auger to access soil at depth. Taking 3 replicates x 7 layers per site (to determine DUL and BD) generally takes about three hours using the auger method, but varies due to soil conditions. BD and DUL can also be done using hydraulically operated systems with large diameter tubes. BD should not be measured using tubes of less than 75mm diameter due to the potential to significantly alter BD through soil compression.

Leave the plastic plot cover in place during sampling to provide a cleaner working environment. Cut holes to access the soil, taking care to avoid cutting the irrigation system (Photos 3 and 4).

- The recommended sampling depth for DUL and BD is 1.5 to 1.8m unless plant rooting depth is restricted by physical or chemical constraints, such as rock or high salinity.
- Record data (Appendix 3, 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 accurately (+/-1mm) and to process samples carefully.
- Sample at depth intervals that match soil horizons or, if

FIGURE 3 SCHEMATIC OF HAND CORING PROCESS

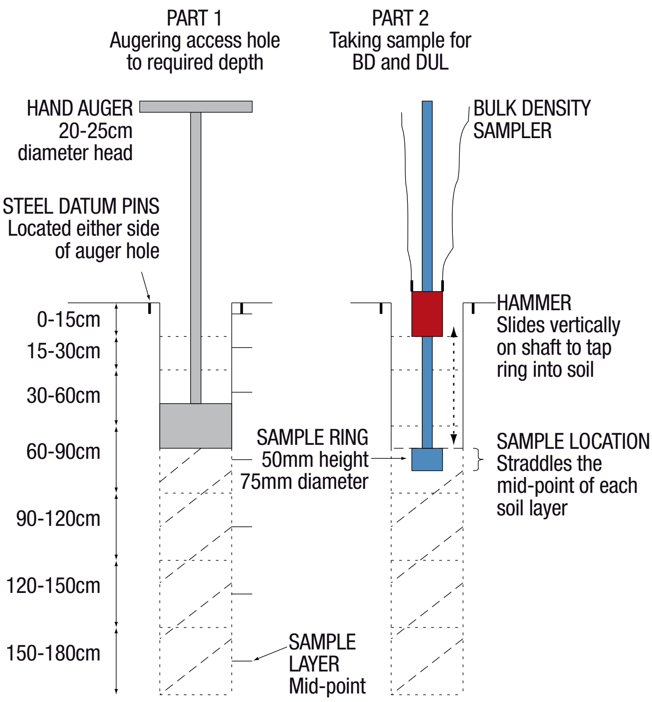


Figure 3: Schematic of hand coring process for BD (and for DUL) where an access hole is augered to the required depth using a 20–25cm diameter hand auger, the base of the hole levelled with an auger levelling head and the sample taken using a sliding hammer sampler. Once a particular sample is taken,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

3

Photo 3: Cut hole in plastic.

4

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

appropriate, a set of standard depth intervals such as: 0–15cm, 15–30cm, 30–60cm, 60–90cm, 90–120cm, 120–150cm and 150–180cm.

- If using the method described by the accompanying photos, work accurately from a surface datum (small bolts or steel rod tapped in flush with the soil surface, Figure 3, Photo 4) and avoid contamination of the sample with loose material from higher levels or from the soil surface.
- Take care when trimming the sample to ensure accurate levelling of soil. Smooth out small imperfections in the surfaces of the sample and if excess soil or small pebbles are removed in the levelling process, replace with a suitable quantity of similar soil or sand.

Shrink/swell soils

The method described above for rigid soils can also be used for shrink/swell soils (such as the vertosols common in northern Australia and parts of the south), but there is also an alternative.

For shrink/swell soils it is possible to measure gravimetric soil water at DUL (using a 37 or 50mm diameter coring tube) and calculate BD, a much easier process than having to sample for BD in the field.

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);
- tare the balance with the dried paper bag and weigh the samples; and
- record the dry soil weight on Datasheet 2 (Appendix 3).

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 with a bag of the same type;
- put each sample into a alfoil or steel labelled tray, ensuring that all of the soil is removed from the bag, and dry them at 105°C; and
- tare the balance with one of the trays and record the dry soil weight.


5

Photo 5: Auger to the first sampling point so that the sample will straddle the mid-point of the first layer. Check depth against datum pins. Lightly oil sampling rings, ensure there is no grit on the outside of the rings, assemble the BD sampler body and take the first sample.


8

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


6

Photo 6: Disassemble the sampler body and carefully remove the sample in its rings, taking care not to damage soil core in the main ring.


9

Photo 9: Slide sample from ring into storage bag. Weigh immediately if using a paper bag for DUL sampling. If using a plastic bag the sample may be weighed on return to base but the bag needs to be well sealed and stored in a cool environment.


7

Photo 7: Remove one of the steel spacer rings and, using a knife, carefully pare back the soil level with the end of the main sampling ring; then repeat the process with the other spacer ring.


10

Photo 10: Augering to the next depth layer.

11


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

12


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

13


Photo 13: Referencing sampling depth. The sampler is placed in the hole and the depth 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.

For rigid soils (and shrink/swell where BD field measured) calculate DUL and BD by:

- using Datasheet 1 (Appendix 3) determine gravimetric soil water per cent and BD for each layer;
- check whether data meets required criteria (SAT-DUL ≥ 5%) and if not met recalculate using same datasheet;
- calculate volumetric soil water content at DUL; and
- graph the volumetric water per cent and bulk density for the profile.

For shrink/swell soils (where DUL measured in field and BD calculated) calculate DUL and BD by:

- using Datasheet 2 (Appendix 3) determine gravimetric soil water per cent for each sample;
- calculate BD using criteria (PO-SAT ≥ 3%; SAT-DUL = 5%);
- calculate volumetric soil water content at DUL; and
- graph the volumetric water percentage and bulk density for the profile.

Note: Datasheets (Appendix 3) may be copied and used for the recording and calculation of DUL and BD. Copies of the datasheet are also available for download at www.apsim.info/wiki/

PART II
CHARACTERISATION FOR CROP LOWER LIMIT (CLL)

Step 5: Identify and establish sites for CLL measurement

Purpose: to identify and establish site for the measurement of CLL. 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 prior to flowering of the crop. 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 to measure DUL before the start of the winter season, over-sow the commercial crop and either use the DUL site for later measurement of CLL, or place drippers (with no plastic cover) in an adjacent area of emerging crop and apply water for the first few weeks of crop growth to ensure recharge of the profile. Take care 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 nearby;
- somewhere that will not interfere with normal farm practice (spraying etc); and
- 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 grower 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. Sometimes it may be possible to set up a site that measures CLL for a range of crops, for example at a field day site.

Determine whether irrigation is necessary (see the note above):

- if summer rains have been followed by good breaking rains there should be no need to irrigate. If not, and unless it is appropriate to use the DUL site, transfer the DUL plot irrigation system to the cropping plot(s) and apply water equivalent to that of good rains.

If irrigation is necessary:

- apply water such that soil moisture content is somewhere between CLL and DUL; and
- do so sparingly since excessive water may prevent the crop from reaching CLL later.

Step 6: Core for soil moisture at anthesis

Purpose: to assist with determination of crop rooting depth and water extraction at maturity.

Coring at anthesis 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, to minimise crop damage, take samples at the previously established sampling depths;
- bag the samples in either paper or plastic bags, depending on the chosen sampling procedure; and
- avoid sampling within at least 75cm of previous coring holes or access tubes if sampling on the old DUL/BD site.

Process samples for gravimetric water:

- process as per Step 4;
- use Datasheet 3 (Appendix 3) to calculate gravimetric and volumetric soil water percentage; and
- graph the results.

Step 7: Erecting rain-exclusion tent at anthesis

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

Erect a rain-exclusion tent over each crop being studied (Photos 14 to 16):

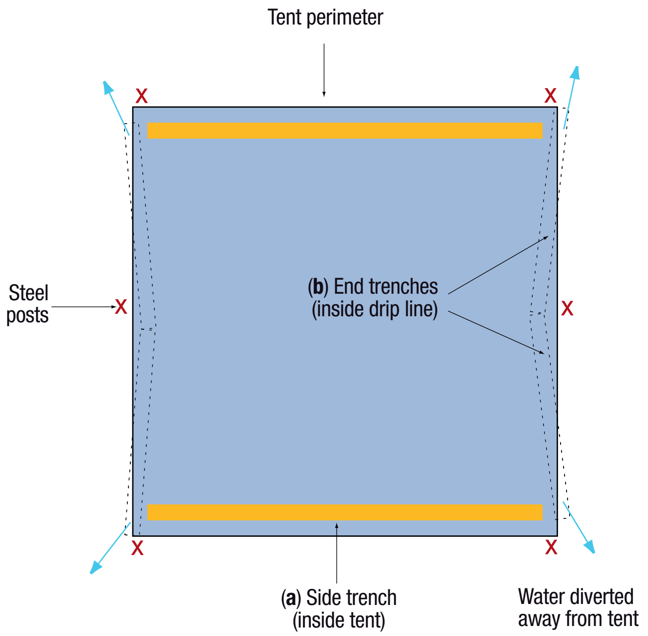
- leave ends open to ensure ventilation;
- use a roof pitch of *at least* 20 degrees to shed water efficiently;
- use long star-pickets driven deep into the soil to prevent roof collapse if the surface soil becomes saturated;
- the length of the cover (7m) allows the ends to be rolled and placed in trenches (Figure 4(a)) dug along the inside of each side of the tent. Backfill the trenches with the roof crest pipe hung a little low. This anchors the tent against strong winds with permanently dry soil and begins to tension the cover;
- finish tensioning the cover by pushing the roof crest pipe up against the plastic (now anchored by soil in the trenches) and tying it in place; and
- dig a trench inside the drip line across the ends of the tent to prevent tent 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 section wired between them. Posts are positioned to support a 3 x 3m 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 pitch on the roof to better shed water.

FIGURE 4 FLOOR PLAN OF THE TENT SHOWING THE LOCATION OF: (a) SIDE TRENCHES TO ANCHOR THE COVER AND (b) END TRENCHES TO CAPTURE AND DIVERT RUN-OFF FROM THE COVER AND OVERLAND FLOW OF RAINWATER



CONSTRUCTING A RAIN-EXCLUSION TENT

Materials:

- six long star-posts
- three 3m lengths of 1" (approx) steel round or box section tubing
- wire to connect frame components
- cover:
  - fabric – Solar Weave, Solar Shield or similar (or clear plastic)
  - dimensions – 3m wide x 7m long finished size
  - two sides have reinforced edge with six eyelets along each side, ends not hemmed
  - eyelet spacing from bottom left-hand corner 2350cm, 2450cm, 3450cm, 3550cm, 4550cm and 4650cm – 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 backfill 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 each end; and
- look for, and note the depth to which, crop roots are present in each core.

Process samples for gravimetric water:

- process as per Step 4 (p10); and
- calculate gravimetric water content using Datasheet 1 or 2 (Appendix 3) 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, unless soil texture changes sharply down the profile (duplex soil), in which case it will be necessary to make some judgement of the values to use based on similar soils in the APSoil database.

PART III

CALCULATION OF PAWC

PAWC can be calculated and graphed using Datasheet 1 (Appendix 3) 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 root zone. The depth of this zone is estimated using both the rooting depth observed during coring and the 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.
- Coring for CLL may extend below the depth of the crop's actual root zone. This may lead to the over estimation of PAWC for the crop being studied, unless depth of root zone was observed and recorded, and water extraction at time of CLL sampling compared with that 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 measurement of CLL (Step 5).

Undertaking this process over a number of cropping seasons, together with insight into the ability of different pastures and crops to extract soil water, helps build a good understanding of the seasonal wetting and drying cycles of the soil. Once the DUL and BD have been measured for a particular soil type, the measurements 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.

APPENDIX 1: IRRIGATION REQUIREMENTS FOR WETTING DUL/BD SITE

The quantity of water required is that which will fully wet the soil to the full depth of crop rooting. It is very difficult to accurately estimate the amount for an uncharacterised soil, but the method below provides a starting point that should minimise the water requirement and the time required to irrigate and drain 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 have been calculated (assuming that rooting depth is 150cm). 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 1 RULE OF THUMB SOIL WATER CAPACITY ESTIMATES (mm WATER/cm SOIL) FOR COMMON SOIL TEXTURE CLASSES

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

Example 1

Assuming that the soil is a heavy clay which holds 1.5mm/cm to 150cm:

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 texture chosen to represent the soil type at the site, so discrepancy 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; and
- wet the soil slowly over time – small quantities of water over a long 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 method for field texturing, a useful skill and a source of information for the soil characterisation database.

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 knead until the ball of soil just fails to stick to your fingers. Then 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 (Table 2). 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; and
- 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 per cent within 5cm of depth, often at about 15cm (these are also called texture-contrast soils); and
- gradational – the texture changes gradually down the profile. Many soils vary from a loamy surface to a clay loam and then to clay.

TABLE 2 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: DATASHEETS

Datasheet 1: Rigid soil-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 (BD) AND DRAINED UPPER LIMIT (DUL)							
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)
		A	B	C	D	E	F	G	H	I	J	K	L
					π x radius^2 x height = π x C^2 x B			((wet – dry) / dry) = (E – F) / F	grav (g/g) x 100 = G x 100	dry Wt / core vol = F / D	grav (g/g) x BD = G x I	grav (%) x BD = H x I	(1 – BD / 2.65) = (1 – I / 2.65)
1	0-15	15	5	3.75	221	450	365	0.233	23.3	1.65	0.385	38.50	0.38
2	15-30	15	5	3.75	221	440	400	0.100	10.0	1.81	0.181	18.12	0.32
3	30-60	30	5	3.75	221	395	370	0.068	6.8	1.68	0.113	11.32	0.37
4	60-90	30	5	3.75	221	387	360	0.075	7.5	1.63	0.122	12.23	0.38

CALCULATION SHEET

						BULK DENSITY (BD) AND DRAINED UPPER LIMIT (DUL)							
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)
		A	B	C	D	E	F	G	H	I	J	K	L
					= π x C^2 x B			= (E – F) / F	= G x 100	= F / D	= G x I	= H x I	= (1 – I / 2.65)
1													
2													
3													
4													
5													
6													
7													

				BD AND DUL – RECALCULATED WHERE SAT - DUL < 5% (COL O)					CROP LOWER LIMIT				PAWC	
	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 weight (g)	CLL gravimetric (%)	CLL volumetric (%)	PAWC per layer (mm)	PAWC profile (mm)
	M PO – 0.03 = L – 0.03	N SAT (mm/mm) x 100 = M x 100	O SAT – DUL = M – J	P (1 – 0.08) / (1 / 2.65 + grav) = (1 – 0.08) / (1 / 2.65 + G)	Q grav x BD = G x P	R grav x BD = H x P	S DUL + 0.05 = Q + 0.05	T SAT (mm / mm) x 100 = S x 100	U	V	W ((wet – dry) / dry) x 100 = (U – V) / V x 100	X grav x BD = W x I	Y (DUL - CLL) x thick / 10 = (K - X) x thick / 10 *	Z = sum Column Y
	0.346	34.61	– 0.04	1.51	0.351	35.11	0.401	40.11	190	180	6	8	40	99
	0.286	28.63	0.11						199	190	5	9	14	
	0.338	33.76	0.22						362	355	2	3	24	
	0.355	35.47	0.23						369	357	3	5	20	

* if Column ‘O’<0.05 = (R - X) x thick / 10

				BD AND DUL – RECALCULATED WHERE SAT - DUL < 5% (COL O)					CROP LOWER LIMIT				PAWC	
	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 weight (g)	CLL gravimetric (%)	CLL volumetric (%)	PAWC per layer (mm)	PAWC profile (mm)
	M = L – 0.03	N = M x 100	O = M – J	P = (1 – 0.08) / (1 / 2.65 + G)	Q = G x P	R = H x P	S = Q + 0.05	T = S x 100	U	V	W = (U – V) / V x 100	X = W x I	Y = (K – X) x A / 10*	Z = sum Column Y

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

EXAMPLE

						BULK DENSITY (BD) AND DRAINED UPPER LIMIT (DUL)							
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 (%)	SAT volumetric (mm/mm)
		A	B	C	D π x radius^2 x height = π x C^2 x B	E	F	G ((wet – dry) / dry) = (E – F) / F	H grav (g/g) x 100 = G x 100	P (1 – 0.08) / (1 / 2.65 + grav) = (1 – 0.08) / (1 / 2.65 + G)	Q grav x BD = G x P	R grav x BD = H x P	S DUL + 0.05 = Q + 0.05
1	0-15	15	5	3.75	221	450	300	0.500	50.0	1.05	0.524	52.43	0.574
2	15-30	15	5	3.75	221	440	301	0.462	46.2	1.10	0.506	50.63	0.556
3	30-60	30	5	3.75	221	395	280	0.411	41.1	1.17	0.479	47.95	0.529
4	60-90	30	5	3.75	221	387	280	0.382	38.2	1.21	0.463	46.29	0.513

CALCULATION SHEET

						BULK DENSITY (BD) AND DRAINED UPPER LIMIT (DUL)							
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 (%)	SAT volumetric (mm/mm)
		A	B	C	D = π x C^2 x B	E	F	G = (E – F) / F	H = G x 100	P = (1 – 0.08) / (1 / 2.65 + G)	Q = G x P	R = H x P	S = Q + 0.05
1													
2													
3													
4													
5													
6													
7													

		CROP LOWER LIMIT				PAWC	
	SAT volumetric (%)	Sample wet wt (g)	Sample dry weight (g)	CLL gravimetric (%)	CLL volumetric (%)	PAWC per layer (mm)	PAWC profile (mm)
	T SAT (mm /mm) x 100 = S x 100	U	V	W ((wet – dry) / dry) x 100 = (U – V) / V x 100	X grav x BD = W x P	Y (DUL – CLL) x thick / 10 = (R – X) x A / 10	Z = sum Column Y
	57.43	190	160	19	20	49	291
	55.63	199	170	17	19	48	
	52.95	362	320	13	15	98	
	51.29	369	330	12	14	96	

		CROP LOWER LIMIT				PAWC	
	SAT volumetric (%)	Sample wet wt (g)	Sample dry weight (g)	CLL gravimetric (%)	CLL volumetric (%)	PAWC per layer (mm)	PAWC profile (mm)
	T = S x 100	U	V	W = (U – V) / V x 100	X = W x P	Y = (R – X) x A / 10	Z = sum Column Y

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 number	Depth range (cm)	Layer thickness (cm)	Bulk density (g / cc)	Sample wet weight (g)	Sample dry weight (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 number	Depth range (cm)	Layer thickness (cm)	Bulk density (g / cc)	Sample wet weight (g)	Sample dry weight (g)	Gravimetric (%)	Volumetric (%)
		A	B	D	E	F = ((D - E) / E) x 100	G = F x B
1							
2							
3							
4							
5							
6							
7							

APPENDIX 4: 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 4630 1400) for about $200 each. While 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: 0.3m) irrigation pipe or similar. Available from irrigation specialists.

■ Plastic sheeting for DUL plot

100 micron black builder's plastic sheeting, 4m 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 915 625.

■ Bulk density sampling kits

All-Turnit Engineering manufacture bulk density sampling kits as shown in this document. Contact Peter Ryan, Mob: 0412 746 061, Ph: 07 4633 0456.

■ Augering heads and handles

Dormer Engineering manufacture a range of augering systems suitable for soil sampling. Ph: 02 6672 1533.

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