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APSoil plant available water capacity (PAWC) characterisation of select Liverpool Plains soils and their landscape context

Kirsten Verburg[1], Brett Cocks[2], Bill Manning[3], George Truman[3], Graeme Schwenke[4]

[1] CSIRO Agriculture and Food, Canberra ACT

[2] CSIRO Agriculture and Food, Toowoomba Qld

[3] NSW North West Local Land Services, Gunnedah NSW

[4] Tamworth Agricultural Institute, NSW Department of Primary Industries, Tamworth NSW

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Important disclaimer

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The research described in this report was undertaken as part of project CSP00170 'Measuring and managing soil water in Australian agriculture'. We thank CSIRO, the Grains Research and Development Corporation (GRDC) and the growers supporting GRDC for their funding.

The new Plant Available Water Capacity (PAWC) characterisations reported in Part IIa of this report were undertaken by CSIRO (Brett Cocks) and NSW North West Local Land Services (NW LLS; Bill Manning and George Truman) in close collaboration with a group of local agronomists, consultants and growers. In-kind funding from these organisations is acknowledged. The local project was supported through funding from the Australian Government's National Landcare Programme. We thank Pete McKenzie (Agricultural Consulting and Extension Services) and Jim Hunt (Hunt Ag Solutions) and local growers (Ed Simson, the Duddy family, Jim Mitchell, Simon Thompson, Rod Grant, Ross Durham, Bart Brady, Andrew Watson, Keith Perrett, James Vince and Anthony Martin) who helped locate, set-up or monitor sites for their invaluable assistance. We acknowledge Ainsleigh Wilson (formerly CSIRO) for her assistance with sample processing.

The Plant Available Water Capacity (PAWC) characterisations reported in Part IIb were undertaken by Graeme Schwenke and colleagues at Tamworth Agricultural Institute, NSW Department of Primary Industries as part of the NSW DPI component of the GRDC funded project SIP08 'Combatting subsoil constraints (DNR00004) and the NSW DPI NANORP project 'Options for reducing nitrous oxide emissions from the NSW dryland grains industry (funded by DAFF, GRDC and NSW DPI). We thank local growers and farm managers Ian Carter, Ian Duncan (dec), David Halliday and others for their assistance.

The analysis of results (Part III) also draws on past PAWC investment by GRDC, CSIRO and other collaborators, notably a number of APSoil PAWC characterisation carried out by Dick Richards and Michael Bange (CSIRO, Narrabri).

Site selection for the new characterisations reported in Part IIa was carried out during a meeting that involved Kirsten Verburg (CSIRO), Bill Manning and Dale Kirby (NW LLS), Sean Murphy (DPI Tamworth), Pete McKenzie, Jim Hunt and Robert Banks (Soil Futures Consulting). It used the soil-landscape mapping by Robert Banks and others to target different parts of the Liverpool Plains and capture different soils, because 'not every Vertosol is the same'. The concept of drawing on soil-landscape information for the analysis in Part III also benefitted from discussions with Mark Glover and Neil McKenzie (both CSIRO), and Brian Murphy (NSW Office Environment & Heritage). Follow-up discussions with Robert Banks were also much appreciated. John Gallant and Jenet Austin (CSIRO) assisted with maps and terrain interpretations.

We thank Neal Dalgliesh (CSIRO) for all his work in developing the field measurement of PAWC as a pragmatic provision of soil information for paddock-specific farmer decision making and simulation, setting up the APSoil database and 'spreading the message' about PAWC and soil water management during previous GRDC funded projects.

Finally we thank the reviewers, Tony Webster (part I), Neil McKenzie and Anthony Ringrose-Voase for their comments and feedback on earlier versions.

Executive summary

Knowledge of the plant available water capacity (PAWC) of soils on their farm can help growers and advisors improve the quality of yield forecasts (consisting of rules of thumb or assisted by tools like Yield Prophet®) used to inform management decisions such as whether to sow or not (i.e. opportunity cropping), timing of sowing (and associated crop type and variety choice) and the input level of resources such as nitrogen fertiliser. Past investments by GRDC, CSIRO and other collaborators helped deliver a database ('APSoil') of 1000+ PAWC characterisations across the country. Between 2014 and 2017 GRDC funded project 'Measuring and managing soil water in Australian agriculture' (CSP00170) contributed a further 250 APSoil PAWC characterisations, ten of which were located in the Liverpool Plains. These were carried out in collaboration with local LLS staff (Gunnedah office) and consultants.

This report documents the results from these characterisations (Part IIa) as well as a number of other new characterisations from other projects (Part IIb) for the benefit of local growers and advisors. It also describes the methodology used to measure PAWC in the field and how to access the existing PAWC data in the APSoil database (Part I). As PAWC characterisations are labour intensive, growers and advisors are often not in the position to do a local field characterisation and will instead rely on the existing APSoil characterisations in the APSoil database to estimate the PAWC of their soils. This comes down to finding a soil with similar properties. Given that the nearest APSoil characterisation may be for a completely different soil, this is not an easy task and one that still challenges researchers as well. The report provides some general guidance for this, but also examines to what extent we can extrapolate or generalise from the combined PAWC characterisations in the Liverpool Plains drawing on available soil-landscape information (Part III). This is still research in progress and the preliminary results reported here are included to provide directions for future research and development.

The fifteen new PAWC characterisations have enhanced the coverage of soil types within the Liverpool Plains considerably. Most of the soil-landscape units (SLUs) used for dryland cropping now have at least one PAWC characterisation, although (as noted in Part III) it is still difficult to determine to what extent this characterisation represents most of the soils that are relevant to cropping in the SLUs and how to predict the variability within them. Subsoil constraints, primarily due to salinity, were found to have a larger effect on variability in PAWC than soil texture or geology differences, although the latter were relevant in explaining the PAWC of soils in some of the SLUs. The fact that in the Liverpool Plains most cropping occurs on Vertosols contributes to the finding that texture was not the main factor responsible for variability in PAWC among the characterised sites. That finding may not extend to other regions where both Vertosols and lighter 'red soils' are cropped. While the use of SLU mapping for selection of characterisation sites and interpretation of results proved worthwhile, more research needs to be carried out to develop methods and tools to capture the within SLU variability in PAWC. This could include terrain analysis and Electromagnetic Induction (EM), or indirectly via yield mapping. The value of the digital mapping contained in the new Soil and Landscape Grid of Australia should also be explored. The increasing availability of regional, state and national soil information on-line opens the way to more soil specific management and digital agriculture, although further research, development and extension is required to make it easily accessible and interpretable by growers and advisors.

Part I Characterising PAWC

Introduction to methodology

Adapted from: Verburg K, Cocks B, Webster T, Whish J (2016) Methods and tools to characterise soils for plant available water capacity. GRDC Advisor Update paper Coonabarabran NSW. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Methods-and-tools-to-characterise-soils-for-plant-available-water-capacity-Coonabarabran

1 Introduction

A key determinant of potential yield in dryland agriculture is the amount of water available to the crop, either from in-season rainfall or stored soil water. In the northern region the contribution of stored soil water to crop productivity for both winter and summer cropping has long been recognized. The amount of stored soil water influences decisions to sow a crop or wait (for the next opportunity or long fallow), timing of sowing (and associated crop type and variety choice) and the input level of resources such as nitrogen fertiliser.

The amount of stored soil water available to a crop – plant available water (PAW) – is affected by pre-season and in-season rainfall, infiltration, evaporation and crop water use. It also strongly depends on a soil's plant available water capacity (PAWC), which is the total amount of water a soil can store and release to different crops. The PAWC, or 'bucket size', depends on the soil's physical and chemical characteristics as well as the crop being grown.

Over the past 20 years, CSIRO in collaboration with state agencies, catchment management organisations, consultants and farmers has characterised more than 1000 sites around Australia for PAWC. These data are publicly available in the 'APSoil' database, which can be accessed in the 'SoilMapp' application for iPad, on the APSoil website and via a Google Earth file (see Section 9 Resources).

A number of farmers and advisers, especially in southern Australia, are using the APSoil PAWC data in conjunction with Yield Prophet® to assist with crop management decisions. Yield Prophet® is a tool that interprets predictions made by the APSIM cropping systems model. It uses the information on PAWC along with information on pre-season soil moisture and mineral nitrogen, agronomic inputs and local climate data to forecast, at any time during the growing season, the possible yield outcomes. Yield Prophet® first simulates soil water and nitrogen dynamics as well as crop growth with the weather conditions experienced to date, and then uses the long term historical weather record to simulate what would have happened from this date onwards in each year of the climate record. The resulting range of expected yield outcomes can be compared with the expected outcomes for alternative management options to inform management decisions. Others use the PAWC data more informally in conjunction with assessments of soil water (soil core, soil water monitoring device or depth of wet soil with a push probe) to estimate the amount of plant available water. Local rules of thumb are then used to inform the management decisions.

The APSoil database provides geo-referenced data, but the PAWC characterisations are for points in the landscape. To estimate PAWC at another point in the landscape, one needs to know the soil at that location and then find a similar soil in the APSoil database. This is not a straight forward process and the subject of ongoing research, but a number of soil and landscape data and information sources are available that can assist. If suitable PAWC data are not found, local measurement of PAWC is required. This will often also provide a more accurate estimate although spatial variability may still be an issue.

Part I of this report describes the measurement of PAWC, including practical tips and pitfalls, and outlines where to find existing information on PAWC. It also discusses the principles behind extrapolation from known soil profiles or 'choosing an APSoil characterisation' (Section 7).

During 2015 and 2016 as part of a GRDC funded project 'Measuring and managing soil water in Australian agriculture' (CSP00170) local LLS staff and consultants teamed up with CSIRO to add an additional 10 characterisations from the Liverpool Plains to the APSoil database. The descriptions of these soils are included in Part IIa of this report. Five other new APSoil characterisations are included in Part IIb.

Part III of this report reflects current research in progress that tries to interpret the PAWC results in a soil-landscape context. It examines to what extent we can extrapolate or generalise from the available PAWC characterisations drawing on available soil-landscape information. The preliminary results reported here will be used to determine future directions for research and development to better support growers and advisors who want to estimate the PAWC of their soil.

2 Plant Available Water Capacity (PAWC)

To characterise a soil's PAWC, or 'bucket size', we need to determine (Figure 1a):

- 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 water content

In addition, soil chemical data are obtained to provide an indication whether subsoil constraints (e.g. salinity, sodicity, boron and aluminium) may affect a soil's ability to store water, or the plant's ability to extract water from the soil.

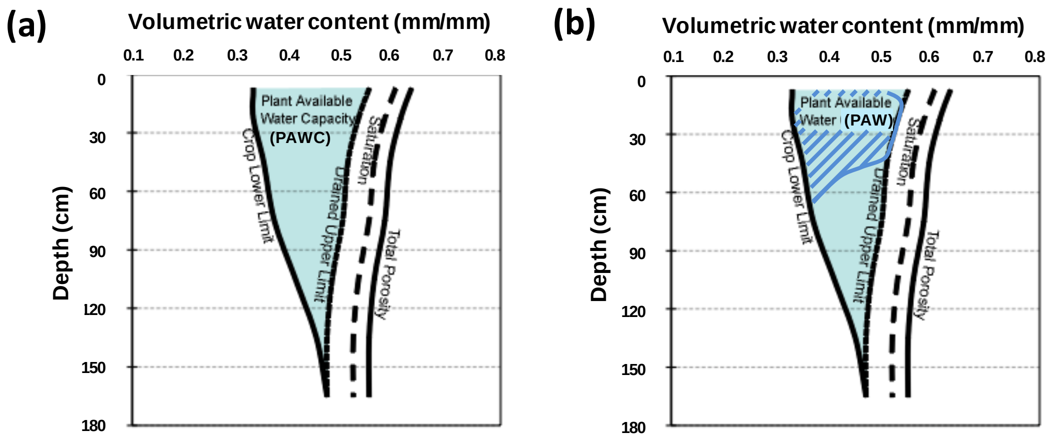


Figure 1. (a) The Plant Available Water Capacity (PAWC) is the total amount of water that a soil can store and release to different crops and is defined by its Drained Upper Limit (DUL) and its crop specific Crop Lower Limit (CLL); (b) Plant Available Water (PAW) represents the volume of water stored within the soil available to the plant at a point in time. It is defined by the difference between the current volumetric soil water content and the CLL.

Source: Verburg et al. (2016) Coonabarabran Update March 2016

Plant Available Water (PAW)

Plant available water is the difference between the CLL and the volumetric soil water content (mm water / mm of soil) (Figure 1b). The latter can be assessed by soil coring (gravimetric moisture which is converted into a volumetric water content using the bulk density of the soil) or the use of soil water monitoring devices (requiring calibration in order to quantitatively report soil water content).

An approximate estimate of PAW can be obtained from knowledge of the PAWC (mm of available water/cm of soil depth down the profile) and the depth of wet soil (push probe or based on a feel of wet and dry limits using an uncalibrated soil water monitoring device).

Knowledge of PAW can inform management decisions and many in the northern region have, formally or informally, adopted this. Several papers at recent GRDC Updates have illustrated the impact of PAW at sowing on crop yield in the context of management decisions (see e.g. Routley 2010, Whish 2014, Dalgliesh 2014 and Fritsch and Wylie 2015).

3 Factors that influence PAWC

An important determinant of the PAWC is the soil's texture. The particle size distribution of sand, silt and clay determines how much water and how tightly it is held. Clay particles are small (< 0.002 mm in size), but collectively have a larger surface area than sand particles (0.02 to 2 millimetres) occupying the same volume. This is important because water is held on the surface of soil particles, resulting in a clay soil having the ability to hold more water than a sand. Because the spaces between the soil particles tend to be smaller in clays than in sands, plant roots have more difficulty accessing these spaces and the more tightly held water. This affects the amount of water a soil can hold against gravity (DUL) as well as how much of the water can be extracted by the crop (CLL).

The effect of texture on PAWC can be seen by comparing some of the APSoil characterisations from the northern region, as illustrated below (Figure 2). The soil's structure, chemistry and mineralogy affect PAWC as well. For example, sodicity may impede internal drainage and constraints such as salinity, sodicity, toxicity from aluminium or boron and extremely high soil density may limit root exploration, sometimes reducing the PAWC bucket significantly. These constraints are often present in the subsoil, and the depth at which they occur greatly influences the PAWC.

The CLL may differ for different crops due to differences in root density, root depth, crop demand and duration of crop growth. Some APSoil characterisations only determined the CLL for a single crop. The CLL for wheat, barley and oats are often considered the same and that of canola can be found to be similar as well, but care needs to be taken with such extrapolations as different tolerances for subsoil constraints can cause variation between crops.

A detailed explanation of the factors influencing PAWC is included in the '*Soil Matters – Monitoring soil water and nutrients in dryland farming'* book (Dalgliesh and Foale, 2005), a pdf of which is available for free online (see Section 9 Resources).

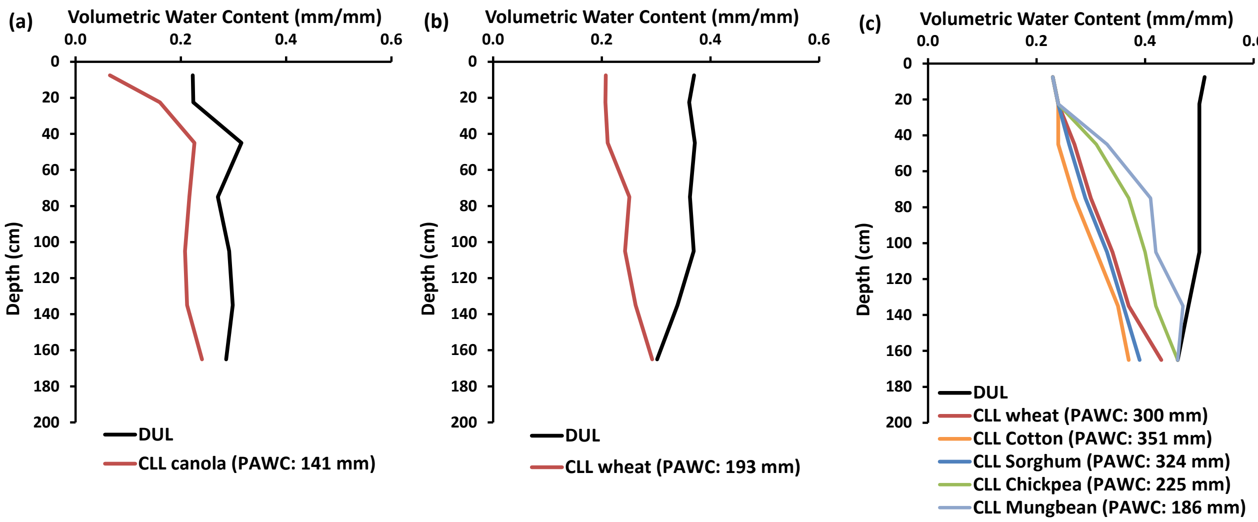


Figure 2. (a) Sandy clay loam (APSoil No683) near Trangie NSW in alluvial sediment formed on a meander plain of the Macquarie River. The higher proportion of sand, particularly in the surface of this soil has resulted in a lower PAWC. (b) Light over medium clay reverting to a sandy clay at depth (APSoil No684) near Trangie NSW in alluvial sediment formed on a back plain of the Macquarie River. The back plains are characterised by large flat areas where finer sediments were deposited from the lower energy flows. These finer sediments produce soils with higher PAWC. (c) Grey-Black Vertosol (APSoil No128) near Spring Ridge NSW on a gently inclined footslope in alluvial fan material of Jurassic Garrawilla volcanics origin. The chart demonstrates how CLL and therefore PAWC is a function of soil and crop.

4 Field measurement of PAWC

Field measurement of DUL, CLL and BD are described in detail in the GRDC PAWC Booklet '*Estimating plant available water capacity*' (Burk and Dalgliesh 2013; see Section 9 Resources). Briefly, to determine the DUL an area of approximately 4 m x 4m is slowly wet up using drip tubing that has been laid out in spiral (see Figure 3 top). The area is covered with plastic to prevent evaporation and after the slow wetting up it is allowed to drain (see GRDC PAWC booklet for indicative rates of wetting up and drainage times). The soil is then sampled for soil moisture and bulk density.

The CLL is measured either opportunistically at the end of a very dry season or in an area protected by a rainout shelter between anthesis/flowering and time of sampling (Figure 3 bottom left). This method assumes the crop will have explored all available soil water to the maximum extent and it accounts for any subsoil constraints that affect the plant's ability to extract water from the soil.

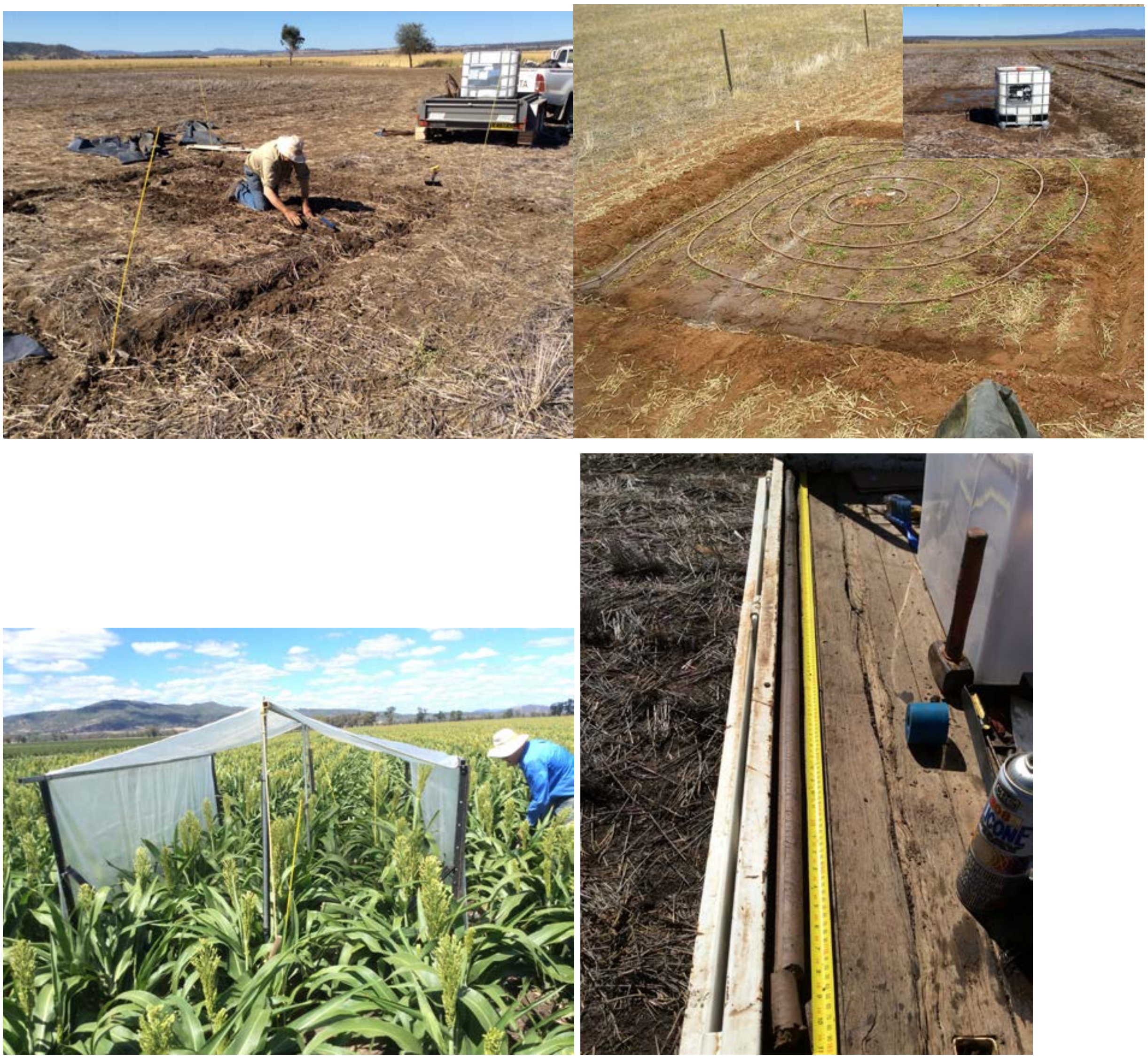


Figure 3. (top left and right) wetting up site for DUL determination; (bottom left) rainout shelter used for CLL determination and (bottom right) soil coring.

Source: Bill Manning, Brett Cocks

Pitfalls and common mischaracterization issues

While the concept of PAWC is simple and the measurement methods for DUL and CLL were developed to be straightforward, not requiring any sophisticated equipment, it is important to consider possible sampling errors. The list below summarises some of the key pitfalls and common mischaracterization issues that we have come across in our collective experience of PAWC characterisations across Australia.

To allow interpretation and use of the data by others, PAWC characterisations should be accompanied by as much extra information as possible, including descriptions of the landscape position, surface condition (e.g. cracking, waterlogging), colour, texture (ideally with a full particle size analysis), Australian Soil Classification (Isbell 1996) and any local classification soil name.

<u>DUL</u>

- Weeds are often seen growing on the side of the plastic cover. It is important that these are strictly controlled throughout the wetting up process until sampling. The crop and all weeds must be removed from a distance away from the plastic to ensure these plants do not 'harvest' water from under the plastic cover.
- In sandy-textured soils the concentric rings of dripper line must be laid sufficiently close to each other to ensure consistent wetting across the whole area.
- Allowing insufficient time for drainage may lead to overestimation of DUL, especially at depth. Heavier soils can take a number of months to drain, although Burk and Dalgliesh (2013) suggest that sampling after one or two months provides a good estimate as drainage rates become very low.
- Insufficient water application or application at too high a rate leads to underestimation of DUL at depth. This is particularly an issue with heavy clay soils, dispersive sodic soils and strong duplex (texture contrast) soils where water may move sideways. Both the GRDC *PAWC booklet* and the *Soil Matters* book provide indicative rates and amounts for different soils. The wetting and drainage processes may be monitored (e.g. using NMM or a moisture probe), but this is not often done due to cost constraints (time, money).
- Bulk density sampling, which is often done in conjunction with DUL sampling, requires a relatively high level of precision as any error in bulk density values will propagate when used to convert gravimetric water contents (including DUL, CLL and PAW) into mm of water. The procedure is described and illustrated in detail in the GRDC *PAWC booklet*.
- Snakes like to hide under the plastic, so take care when wetting and sampling the plot.

<u>CLL</u>

- The CLL method as described above relies on crop roots exploring the soil to the fullest extent. If the crop had insufficient moisture to establish its root system prior to anthesis, the CLL may not reflect maximum soil water extraction. Roots will not grow through a dry layer even if there is moisture underneath. It is, therefore, important to perform CLL measurement in paddocks with a well-established and healthy crop. Wetting up of the CLL site prior to the growing season may help, but requires close attention to weeds and to supplying the right amount of nitrogen fertiliser.
- Rainfall in the weeks just prior to the erection of rainout shelters at anthesis may refill the PAWC 'bucket'. If the PAWC is large, this may prevent the crop from using all soil water and result in an overestimate of CLL (too wet). Ideally CLL is measured over multiple seasons, but this is rarely done in practice. Calibrated moisture probes can be an effective tool to assess a crop's ability to extract moisture over a range of different seasons.

- The CLL measured for one crop type may not apply to a different crop type, especially where growing season length or susceptibility to subsoil constraints differs. It is possible that long-season varieties may extract water from a greater depth than short season varieties because of more extensive root development, and hence result in a different CLL.
- If sampling is not deep enough to capture the full root zone, PAWC will be underestimated. In this case the CLL and DUL do not reach the same value at the bottom of the profile.
- If there is insufficient wetting of the profile prior or during the growing season, the measured CLL may reflect the CLL of a previous crop. If the current crop has a shallower root system this could cause the PAWC to be overestimated. Wetting up of the CLL site prior to the season may help. Taking a soil core when the rainout shelter is installed and comparing values against those determined at the time of final sampling can assist with interpretation of the data.
- Rainout shelters have blown loose or away on occasions, so it is important to make sure the tent corner posts are well braced using star pickets at 45 degrees and using rope to stabilize the central post at each end as well as to secure the sides firmly into the soil (fit in trench and cover up).
- For duplex soils located on hills slopes > 3-5% or soils at the break of slope, subsurface lateral flow can cause soil wetting despite the presence of a well-constructed rain-out shelter. Keep an eye on late season rainfall and note any unusual wetness in samples collected.
- Sampling after harvest when the soils are dry and hard, or have hard layers can be tricky. Digging a soil pit can be a better alternative than soil coring from the surface in these situations.

General:

- Soil variability may mean there is more than one PAWC profile within the paddock. Variability in depth of layers, e.g. texture contrast in duplex soils, can occur over small distances. This makes mixing replicates and selecting a 'representative soil' difficult.
- High soil variability can cause the DUL and CLL measurements to effectively be on different soils (even though they are usually only 2-3 m apart). It is essential to measure DUL and CLL on the same soil type. Yield or soil maps may assist in deciding where to sample.
- Despite the use of a rainout shelter for CLL, seasonal climate conditions may affect the measurements. Ideally measurements would be repeated in different seasons, but this is usually not possible. The estimates, while presented in APSoil to the nearest mm, will not be accurate to the nearest mm.
- For instructions how to collect information for a full APSoil characterisation, see the 'Field protocol for APSoil characterisations' and 'Protocol for the development of soil parameter values for use in APSIM' (see Section 9 Resources).

5 Sampling for soil chemistry

Along with the field characterisation of BD and DUL, samples are collected for soil chemical analysis. These data are used to assist with the interpretation and sensibility checking of the PAWC data. As described in Burk and Dalgliesh (2013) samples are dried for four to five days at 40°C and then analysed for EC, chloride (Cl), cations, CEC, pH (H_2O and $CaCl_2$), boron, aluminium, manganese, organic carbon and particle size.

Details of the analytes included in this report are given below in Table 1

Table 1: Analytes, analysis method and results ranking (where used in this report).

Analyte	Unit	Method	Results ranking[1]
OC	%	Walkley Black	
EC	dS/m	1:5 H2O	< 0.2 VL, 0.2-0.5 L, 0.5-0.7 M, > 0.7 H[2]
pH water		1:5 H2O	
pH $CaCl_2$		1:5 $CaCl_2$	
Cl	mg/kg		< 300 L, 300-600 M 600-1200 H, < 1200 VH[4]
CEC	cmol+/kg	Calculation (eCEC)	< 6 VL, 6-12 L, 12-25 M, 25-40 H, > 40 VH[3]
Ca, Mg, Na, K	cmol+/kg	NH_4Cl/ICP	
ESP	%	Calculated from the above	< 6 NS, 6-15 S, 15-25 SS, > 25 VSS[3]
Course sand	%	Sieve	
Fine sand	%	Sieve	
Silt	%	Hydrometer	
Clay	%	Hydrometer	<10 VL, 10-25 L, 25-40 M, 40-50 H, > 50 VH[3]

[1] VL = very low, L = low, M = moderate, H = high, VH = very high, NS = non-sodic, S = sodic, SS = strongly sodic, VSS = very strongly sodic
[2] Based on Dalgliesh and Foale (2005)
[3] Based on Banks (1998); used for descriptive purposes only and results classification only applicable to this report
[4] Tentative classes used in this report

6 Where to find existing information on PAWC

Characterisations of PAWC for more than 1200 soils across Australia have now been collated in the APSoil database and are freely available to farmers, advisors and researchers. The database software and data can be downloaded from https://www.apsim.info/Products/APSoil.aspx. The characterisations can also be accessed via Google Earth (KML file from APSoil website) and in SoilMapp, an application for the iPad available from the Apple App store. The yield forecasting tool Yield Prophet® also draws on this database.

In Google Earth the APSoil characterisation sites are marked by white circles with a green shovel symbol (Figure 4), with information about the PAWC profile appearing in a pop-up box if one clicks on a site (Figure 5a). The pop-up box also provides links to download the data in APSoil database or spreadsheet format.

In SoilMapp the APSoil sites are represented by green dots (see Figure 5b). Tapping on the map results in a pop-up that allows one to 'discover' nearby APSoil sites (tap green arrow) or other soil (survey) characterisations. The discovery screens (see Figure 5c,d) then shows the PAWC characterisation as well as any other soil physical or chemical analysis data and available descriptive information.

Most of the PAWC data included in the APSoil database have been obtained through the field methodology outlined above, although for some soils estimates have been used for DUL or CLL. Some generic, estimated profiles are also available. While field measured profiles are mostly geo-referenced to the site of measurement (+/- accuracy of GPS unit), generic soils or those for which geo-referencing was not approved are identified with a regional town.

The report '*PROFILE descriptions – District guidelines for managing soils in north-west NSW'* by Daniells et al. (2002) provides PAWC characterisations for 17 soils in the NW region of NSW drawing on the same methodology. In addition this report provides valuable soil descriptions for areas around Coonabarabran, Coonamble, Moree, Pilliga, and Walgett.

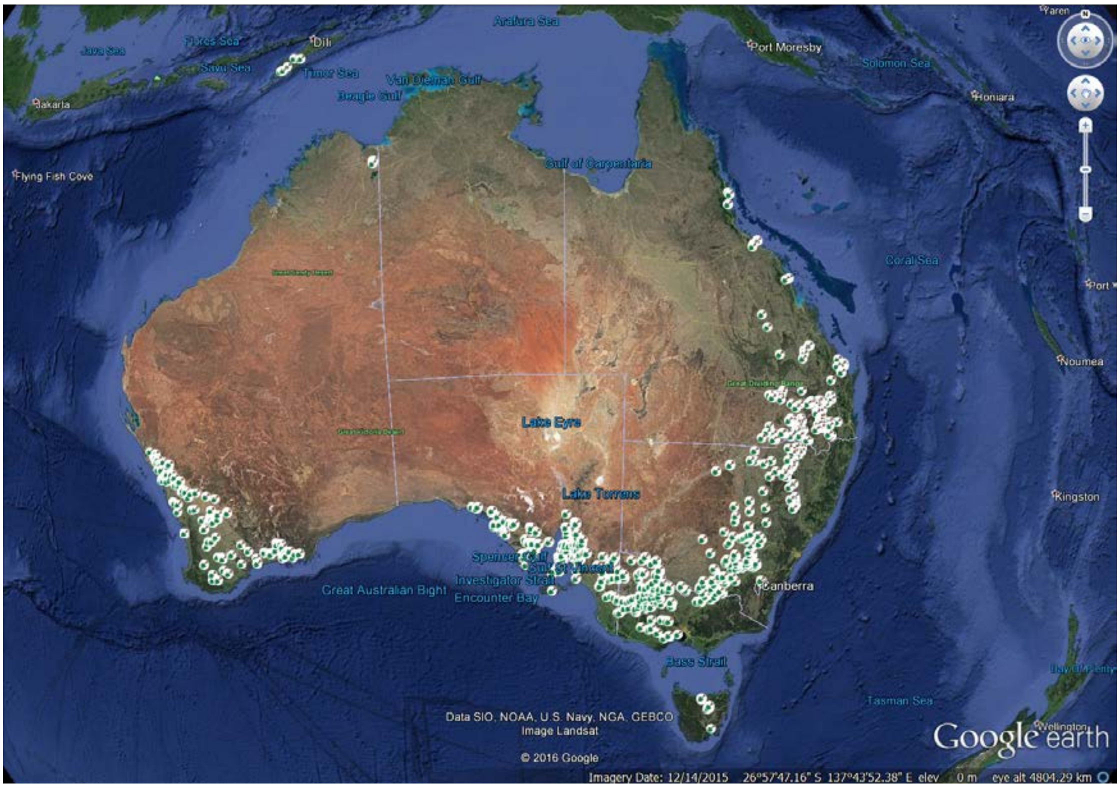


Figure 4. Access to geo-referenced soil PAWC characterisations of the APSoil database via Google Earth.

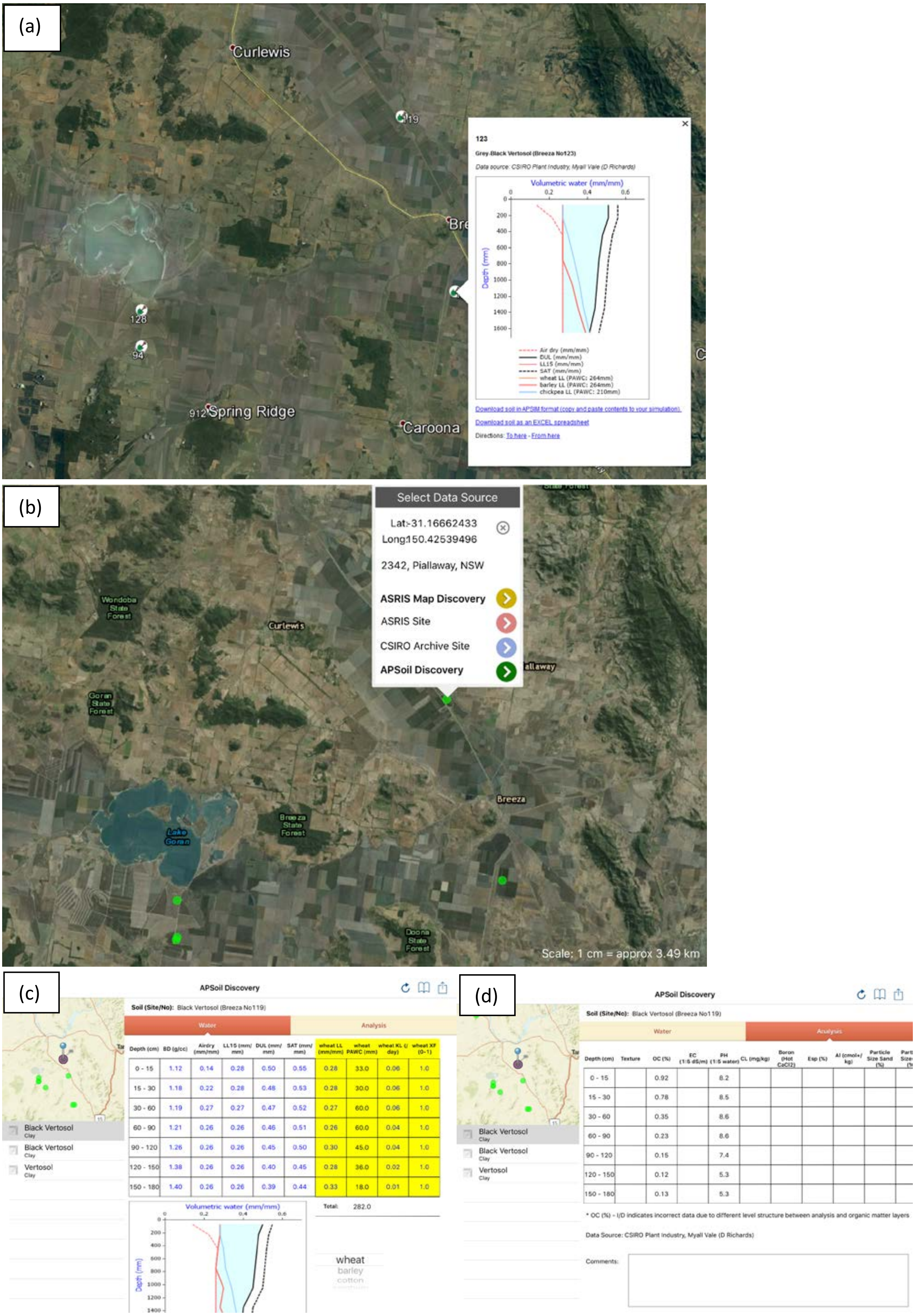


Figure 5. Access to geo-referenced soil PAWC characterisations of the APSoil database via (a) Google Earth and (b) SoilMapp; (c) and (d) APSoil discovery screens.

7 Choosing an APSoil characterisation

As shown in Part II of this report, the soil PAWC can vary significantly. How do we choose the most appropriate APSoil characterisation, if we are not in the position to do a local field PAWC characterisation? This is still research in progress, but some guidance can already be provided.

- The nearest APSoil site may not be the most appropriate as its soil, parent material and landscape position could be quite different (cf. Figure 2).
- Compare soil with descriptions of the APSoil sites (texture, colour, soil classification, chemical analysis). More recently collected APSoil characterisations include chemical analysis and particle size. As illustrated in Figure 2 and described for the various soils documented in Part II both particle size and subsoil constraints strongly affect the PAWC.
- Dig a hole (soil auger, soil core, backhoe trench, roadside bank or cutting); note surface features (cracking, hard setting), subsoil issues (salinity, sodicity, etc), rooting depth. This can assist with APSoil selection as well as adapting an APSoil profile to local conditions (e.g. if depth of texture change or rooting depth is different).
- A measured soil water profile at sowing (converted to volumetric water content) needs to 'fit' between CLL and DUL and can assist with APSoil selection (Figure 1b). If the measured (volumetric) water content profile is below CLL or above DUL then the texture of the soil does not match that of the chosen APSoil.
- Opportunistic CLL (e.g. soil core following a dry finish; convert to volumetric) can be compared with CLL of APSoil characterisations.
- Check for nearby soil survey characterisations (SoilMapp, eSpade, and local soil reports) to help describe soils.
- Seek out soil experts who understand how soils vary across the landscape. In some regions, there are soil and land resource officers in state agencies (usually with a training in pedology) who have the detailed knowledge that can help.
- Draw on soil-landscape mapping (where available) to find APSoil sites in similar landscape positions (see Section 8 and Part III).
- Native vegetation is often a useful indicator of soil type too and is indeed often included in information about soil-landscape, land resource area and land systems units.

8 Finding soil-landscape information in the Liverpool Plains

In many landscapes the soil properties are tightly linked to a soil's development and position in the landscape. These same aspects underpin soil and land resource surveys that have been carried out over the years, which are increasingly becoming available on-line. Many of these present a mapping of so-called soil-landscape units that are based on a combination of geology, landscape features like slope and relief, vegetation and groups of soils. Effectively the distribution of soil types described by these maps and their mapping units descriptions are based on a conceptual model of the landscape. These descriptions, where available, can be used to interpret and potentially extrapolate APSoil characterisations.

In parts of NSW soil-landscape mapping can be accessed through the eSpade tool (see Section 9 Resources), which delineates the units and provides a description and typical soil profiles for each unit. The Liverpool Plain has good coverage (see Figure 6). In parts of Queensland, similar land resource area (LRA) mappings are used as part of land management manuals (e.g. Harris et al. 1992). Where this information is available, it may be possible to use it to find an APSoil site in a similar landscape position as a first approximation of PAWC.

The concept of using soil-landscape information to classify and inform soil properties relevant to agricultural management is not new. The Queensland land management manuals accompanying the LRA maps draw on the same concept as do the ‘Glovebox Guide to Soil of the Macquarie-Bogan Flood Plain’ by Hulme (2003) and several ‘Soil Specific Management Guidelines for Sugarcane Production’ in different sugarcane growing areas from northern NSW to northern Queensland (e.g. Wood et al 2003). The availability of these maps on-line makes them more accessible and assists with visualising a location’s position in the landscape. Combining these maps with the geo-referenced APSoil PAWC characterisations will increase the value that both resources can provide to farmers and advisors.

Using these resources to inform or even predict PAWC profiles is, however, still research in progress. In particular its predictive power and spatial accuracy has not been assessed, nor the required level of soil and landscape information. Not all areas within the northern region are covered by these soil-landscape maps and availability of other soil data within these areas varies too.

Another resource that may prove useful in the future but requires further testing for its use in predicting PAWC profiles, is the new Soil and Landscape Grid of Australia (see Section 9 Resources) which provides digital soil and landscape attribute predictions at a spatial resolution of 90 m x 90 m.

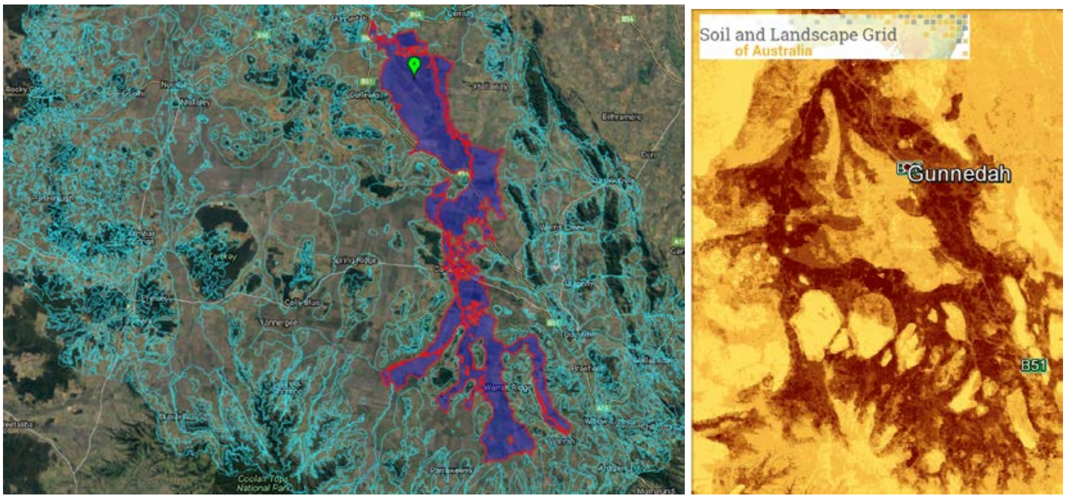


Figure 6. (left) Soil-landscape mapping for the Liverpool Plains available via the on-line tool eSpade, (right) Predicted % clay in 5-15 cm layer across Liverpool Plains from Soil and Landscape Grid of Australia (SLGA).

Source: Screenshot of eSpade and Screenshot Google Earth with SLGA layer.

9 Resources

APSoil, PAWC methodology and national information:

APSoil database: http://www.apsim.info/Products/APSoil.aspx (includes link to Google Earth file)

SoilMapp (soil maps, soil characterisation, soil archive and APSoil sites): Apple iPad app available from App store; documentation: https://confluence.csiro.au/display/soilmappdoc/SoilMapp+Home

GRDC PAWC booklet: http://www.grdc.com.au/GRDC-Booklet-PlantAvailableWater

Soil Matters book: http://www.apsim.info/Portals/0/APSoil/SoilMatters/pdf/Default.htm

Field protocol APSoil characterisations: https://www.apsim.info/Products/APSoil.aspx

Protocol for the development of soil parameter values for use in APSIM: https://www.apsim.info/Products/APSoil.aspx

Soil and Landscape Grid of Australia: http://www.csiro.au/soil-and-landscape-grid

Yield Prophet®: http://www.yieldprophet.com.au

Google Earth: https://www.google.com/earth/

NSW:

eSpade: http://www.environment.nsw.gov.au/eSpade2Webapp (with soil-landscape and land systems mapping and reports, location and reports of soil characterisation sites from various surveys, and a number of other derived layers)

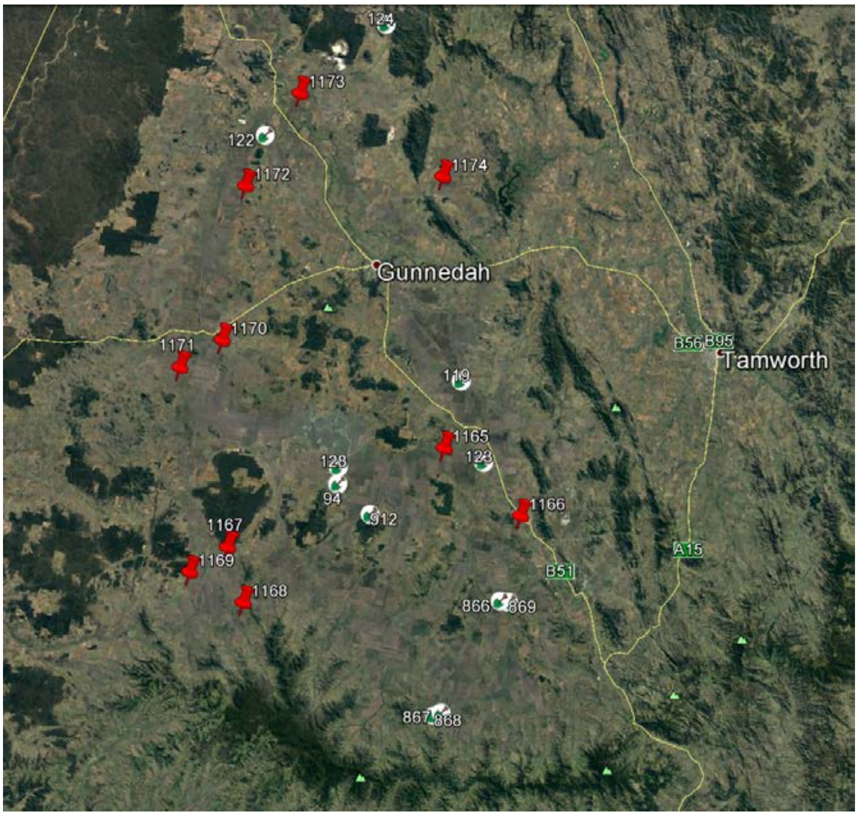
Geology maps: http://www.resourcesandenergy.nsw.gov.au/miners-and-explorers/geoscience-information/products-and-data/maps/geological-maps (includes links to Google Earth files)

NSW Geology phone maps: https://www.geoscience.nsw.gov.au/phonemaps/ (with link to NSW Geology Maps Apple instructions for iPad and iPhone app, and instructions for using NSW Geology maps within Locus Map Free or Locus Map Pro)

Soil Profile Descriptions - District guidelines for managing soils in north-west NSW (Daniells et al. 2002)

Part II PAWC of select soils in the Liverpool Plains

a. Characterisations from CSIRO GRDC project CSP00170



10 Grey Vertosol (Breeza No1165)

Location and landscape position: This site is located south west of Breeza NSW on the floodplain west of the Mooki River. A second CLL site (Cotton) was established in 2016 150 m NNW of original site.

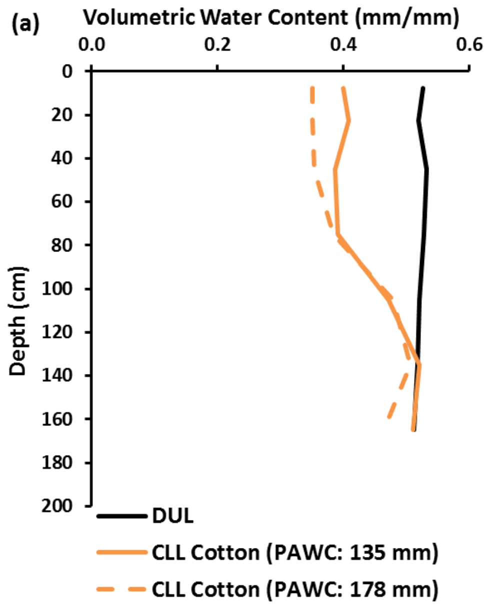
Soil type: Grey Vertosol

Soil description: The soil has a very high clay content throughout, which is accompanied by a very high CEC; EC and Cl increase in the bottom two layers (below 120 cm) and the soil is strongly sodic below 60 cm and very strongly sodic beyond 150 cm (see Table 2).

Table 2: Chemical analysis for Grey Vertosol (Breeza No1165).

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-15	1.04	0.4	7.5	7.0	10	57	25	29	2	2	4	0	14	18	67
15-30	0.79	0.4	8.2	7.5	11	60	25	30	4	1	7	0	8	15	77
30-60	0.71	0.5	8.6	7.7	13	60	22	31	7	1	11	0	7	20	73
60-90	0.52	0.6	9.1	8.0	11	58	16	30	11	1	19	0	1	15	84
90-120	0.29	0.7	9.3	8.1	40	56	13	28	14	1	25	1	7	10	81
120-150	0.30	0.9	9.4	8.2	136	57	11	28	16	1	29	1	5	13	82
150-180	0.23	1.2	9.2	8.2	315	56	12	26	17	1	30	1	5	12	81

PAWC: The soil had 135 mm of plant available water for cotton to 120 cm depth in 2015 and 178 mm for cotton to 180cm in 2016 at a nearby site (Figure 7). The high salinity and/or ESP may have reduced water uptake from 90 cm with the measured CLL suggesting minimal water uptake below 120 cm and reducing the overall PAWC relative to the unconstrained profile. The low PAWC, however, also appears due to the relatively high crop lower limit in the top 90 cm. Data on Cl and ESP do not provide an explanation for the reduced soil water extraction in the top 60 cm, although EC is high compared with other, unconstrained profiles. It is possible that the CLL was influenced by poor establishment.



Depth	BD	DUL	CLL	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15	1.04	0.53	0.40	19	19
15-30	1.06	0.52	0.41	17	36
30-60	1.03	0.53	0.39	44	79
60-90	1.04	0.53	0.39	41	120
90-120	1.06	0.52	0.47	15	135
120-150	1.07	0.52	0.52	0	135
150-180	1.08	0.51	0.51	0	135

Depth	BD	DUL	CLL	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15			0.35	26	26
15-30			0.35	25	52
30-60			0.35	53	105
60-90			0.38	43	148
90-120			0.48	13	160
120-150			0.51	4	164
150-180			0.46	14	178

Figure 7: PAWC and associated data for Grey Vertosol (Breeza No1165).

11 Grey Vertosol (Caroona No1166)

Location and landscape position: This site is located east of Caroona NSW on a small patch of flood plain off Quirindi Creek.

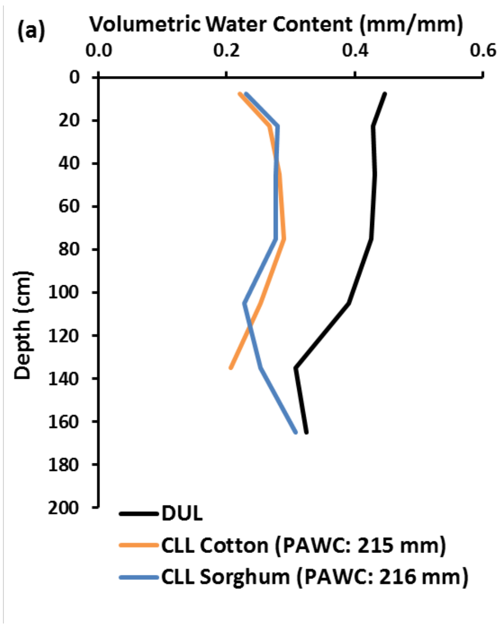
Soil type: Grey Vertosol

Soil description: The soil has a very high clay content in the surface 60 cm. Below 60 cm the soil's clay content decreases and its sand content increases. The CEC, while still considered high, changes accordingly. EC and Cl are low throughout. ESP is relatively low, with the soil only becoming (just) sodic below 120 cm depth (see Table 3).

Table 3: Chemical analysis for Grey Vertosol (Caroona No1166).

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-15	1.03	0.3	7.4	6.8	7	37	26	10	0	1	1	9	16	26	50
15-30	0.95	0.3	7.7	7.1	6	41	27	12	1	1	2	9	18	16	56
30-60	0.80	0.3	8.0	7.3	7	40	25	14	1	1	2	11	9	22	59
60-90	0.60	0.3	8.3	7.5	7	35	20	13	1	1	4	17	17	20	46
90-120	0.38	0.3	8.6	7.7	6	32	18	12	2	1	5	21	12	19	48
120-150	0.18	0.3	8.7	7.8	7	30	17	10	2	1	6	31	14	16	38
150-180	0.12	0.2	8.8	7.9	9	29	17	10	2	1	6	18	30	18	34

PAWC: The soil had 215 mm of plant available water for cotton to 150 cm depth (deepest sampling depth; 2015) and 216 mm for sorghum to 180 cm depth (2016). The shift in DUL towards lower water content at depth is linked to the lower clay content and higher sand content in these layers.



Depth	BD	DUL	CLL Co	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15	1.26	0.45	0.22	34	34
15-30	1.30	0.43	0.27	24	58
30-60	1.30	0.43	0.28	45	103
60-90	1.31	0.43	0.29	41	144
90-120	1.40	0.39	0.25	41	185
120-150	1.62	0.31	0.21	30	215
150-180	1.58	0.32			

Depth	BD	DUL	CLL S	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15			0.23	32	32
15-30			0.28	22	55
30-60			0.28	46	101
60-90			0.28	45	145
90-120			0.23	49	194
120-150			0.25	16	211
150-180			0.31	5	216

Co = Cotton, S = Sorghum

Figure 8: PAWC and associated data for Grey Vertosol (Caroona No1166).

12 Black Vertosol (Premer No1167)

Location and landscape position: This site is located southeast of Premer NSW just south of Trinkey Forest. It is situated on the west facing foot slope of a ridge extending from the Liverpool Ranges.

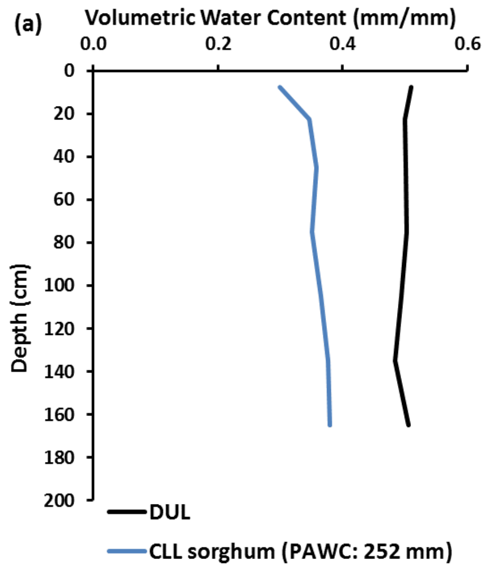
Soil type: Black Vertosol

Soil description: The soil has a very high clay content and CEC throughout; EC and Cl are low throughout; ESP increases slightly with depth with the soil becoming sodic from 90 cm depth (see Table 4).

Table 4: Chemical analysis for Black Vertosol (Premer No1167).

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-15	1.41	0.3	7.1	6.6	8	48	27	19	1	1	1	6	13	18	63
15-30	1.07	0.3	7.6	7.1	8	50	28	20	1	1	1	5	13	18	65
30-60	1.07	0.3	7.9	7.3	9	52	28	22	1	1	2	5	18	16	61
60-90	0.86	0.4	8.4	7.6	9	52	25	24	3	1	5	6	12	14	68
90-120	0.61	0.4	8.7	7.8	29	51	22	24	4	1	8	4	12	17	67
120-150	0.36	0.4	8.8	7.9	35	50	21	23	5	1	9	4	13	15	68
150-180	0.23	0.3	8.9	8.0	28	51	21	24	5	1	9	4	15	13	68

PAWC: The soil had 252 mm of plant available water for sorghum to 180 cm depth reflecting an unconstrained profile.



Depth	BD	DUL	CLL	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15	1.09	0.51	0.30	31	31
15-30	1.11	0.50	0.35	23	54
30-60	1.11	0.50	0.36	43	98
60-90	1.11	0.50	0.35	46	143
90-120	1.13	0.49	0.37	39	182
120-150	1.15	0.48	0.38	32	214
150-180	1.10	0.51	0.38	38	252

Figure 9: PAWC and associated data for Black Vertosol (Premer No1167).

13 Brown Vertosol (Bundella No1168)

Location and landscape position: This site is located southeast of Bundella NSW on the west facing foot slope of a ridge extending from the Liverpool Ranges.

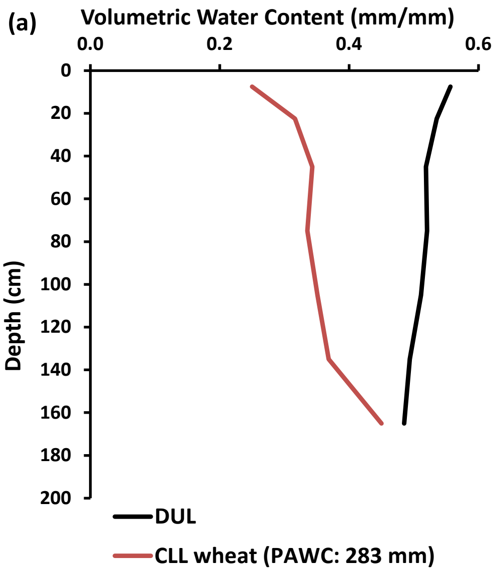
Soil type: Brown Vertosol

Soil description: The soil has a very high clay content and a high CEC throughout; EC and Cl are low throughout; ESP increases with depth with the soil becoming sodic from 30 cm depth (see Table 5).

Table 5: Chemical analysis for Black Vertosol (Bundella No1168).

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-15	1.23	0.3	7.1	6.6	12	36	25	9	1	2	2	5	17	19	59
15-30	0.98	0.3	7.4	6.9	13	36	23	10	2	1	5	5	14	18	64
30-60	0.95	0.3	7.4	6.9	11	38	23	12	3	0	8	10	19	13	58
60-90	0.64	0.4	7.4	6.9	21	37	21	13	4	0	10	16	5	17	63
90-120	0.32	0.4	7.7	7.2	38	37	20	13	4	0	10	4	12	17	67
120-150	0.15	0.4	8.1	7.6	42	34	18	13	3	0	10	8	14	14	64
150-180		0.4	8.3	7.8	28	30	15	11	3	0	10	12	16	10	62

PAWC: The soil had 283 mm of plant available water for wheat to 180 cm depth reflecting an unconstrained profile.



Depth	BD	DUL	CLL	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15	0.96	0.56	0.25	46	46
15-30	1.02	0.54	0.32	33	79
30-60	1.06	0.52	0.34	53	132
60-90	1.06	0.52	0.34	56	187
90-120	1.08	0.51	0.35	48	235
120-150	1.13	0.49	0.37	38	273
150-180	1.15	0.49	0.45	11	283

Figure 10: PAWC and associated data for Brown Vertosol (Bundella No1168).

14 Black Vertosol (Premer No1169)

Location and landscape position: This site is located south of Premer NSW on the edge of the flood plain of upper Coxs Creek where it meets the lower slopes of the hills to the west of the site.

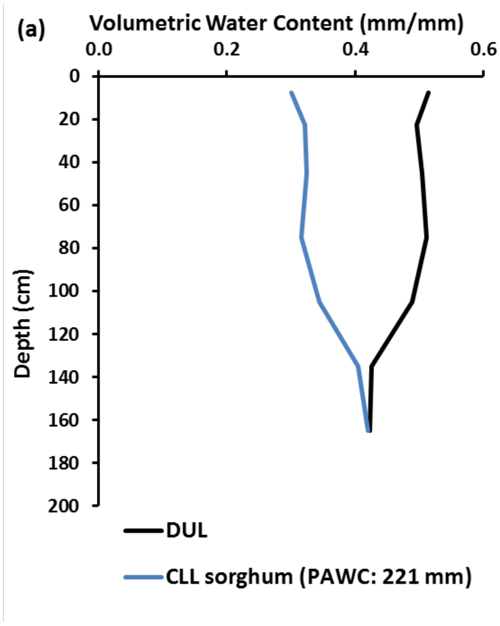
Soil type: Black Vertosol

Soil description: The soil has a very high clay content and CEC throughout. The bottom layer from 150-180 cm has a slightly lower clay content and this is reflected in the slightly lower CEC. EC is low in the top 90 cm, but along with Cl and ESP increases with depth, becoming more saline and strongly sodic below 120 cm (see Table 6).

Table 6: Chemical analysis for Black Vertosol (Premer No1169).

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-15	1.34	0.3	7.7	7.1	4	45	28	15	1	1	1	3	10	23	64
15-30	1.37	0.2	7.9	7.3	9	46	27	16	1	1	3	3	15	19	64
30-60	1.09	0.2	7.9	7.3	9	47	26	19	2	1	5	3	8	21	69
60-90	1.19	0.3	8.2	7.3	8	47	21	21	4	1	9	3	9	19	68
90-120	0.85	0.5	8.8	7.9	47	45	17	21	6	1	14	5	10	18	67
120-150	0.42	0.8	8.9	7.9	233	45	16	21	8	1	17	4	10	18	67
150-180	0.20	0.6	8.8	7.9	365	37	12	17	7	1	19	16	17	17	50

PAWC: The soil had 221 mm of plant available water for sorghum to 180 cm depth. Subsoil constraints appeared to limit the PAWC below 150 cm, which appears to be linked to high EC. It is possible that DUL at depth is low due to insufficient wetting, alternatively the soil is more difficult to wet due dispersion from to the high ESP, although the increased EC would be expected to counteract that. Slightly coarser texture at depth may have contributed to lower DUL.



Depth	BD	DUL	CLL	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15	1.08	0.51	0.30	32	32
15-30	1.12	0.50	0.32	26	58
30-60	1.10	0.50	0.32	54	112
60-90	1.08	0.51	0.32	58	170
90-120	1.14	0.49	0.34	44	214
120-150	1.31	0.42	0.40	6	220
150-180	1.32	0.42	0.42	1	221

Figure 11: PAWC and associated data for Black Vertosol (Premer No1169).

15 Grey Vertosol (Mullaley No1170)

Location and landscape position: This site is located south east of Mullaley NSW on the flood plain on the eastern side of mid Coxs Creek. A second CLL profile (wheat) was determined at a site ~ 1km away.

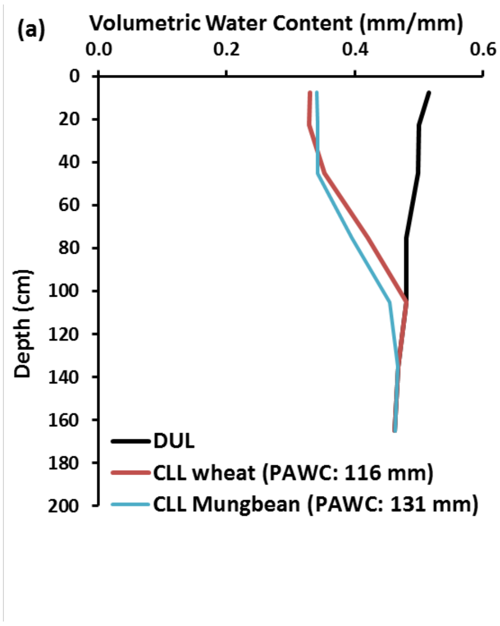
Soil type: Grey Vertosol

Soil description: The soil has a very high clay content and CEC throughout; EC is low in the surface 60 cm, increasing along with Cl and ESP below 120cm; becoming more saline and very strongly sodic at depth (see Table 7).

Table 7: Chemical analysis for Grey Vertosol (DUL site, Mullaley No1170).

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-15	0.75	0.3	7.7	7.1	7	46	22	21	1	1	3	14	9	17	60
15-30	0.52	0.3	8.3	7.6	11	48	22	23	2	1	5	12	9	15	63
30-60	0.51	0.4	8.7	7.7	11	48	19	24	4	1	8	13	4	18	66
60-90	0.32	0.5	9	8.0	7	48	15	25	7	1	15	10	8	14	68
90-120	0.30	0.6	9.1	8.0	53	46	12	23	10	1	21	10	7	14	69
120-150	0.14	0.5	9.6	8.4	174	46	12	22	11	1	24	10	5	17	68
150-180	< 0.05	0.9	9.4	8.2	472	49	12	23	12	1	25	11	5	12	72

PAWC: The soil had 131 mm for mungbean to 120 cm depth in 2015 and 116 mm of plant available water for wheat to 90 cm at a nearby site in 2015. Subsoil constraints (Cl, ESP) appear to limit rooting / water uptake beyond this depth. Crops may differ in their response to subsoil constraints and deeper rooting crops like wheat, cotton and sorghum often have a larger PAWC than chickpea and mungbean, but in this case the ESP is very high and may be limiting PAWC for the deeper rooting crops too. It is also possible the subsoil constraints were stronger at the nearby site where the wheat CLL was determined.



Depth	BD	DUL	CLL W	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15	1.07	0.52	0.33	28	28
15-30	1.11	0.50	0.33	26	54
30-60	1.12	0.50	0.35	44	98
60-90	1.16	0.48	0.42	18	116
90-120	1.16	0.48	0.48	0	116
120-150	1.20	0.47	0.47	0	116
150-180	1.21	0.46	0.46	0	116

Depth	BD	DUL	CLL M	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15			0.34	26	26
15-30			0.34	24	50
30-60			0.34	47	97
60-90			0.40	25	123
90-120			0.45	8	131
120-150			0.47	0	131
150-180			0.46	0	131

Figure 12: PAWC and associated data for Grey Vertosol (Mullaley No1170).

16 Grey Vertosol (Nombi No1171)

Location and landscape position: This site is located north east of Nombi NSW on the flood plain on the western side of mid Coxs Creek and close to the lower footslopes of the Mullaley hills to the southwest. A second CLL was obtained at nearby site, 1.8 km NW of the main site.

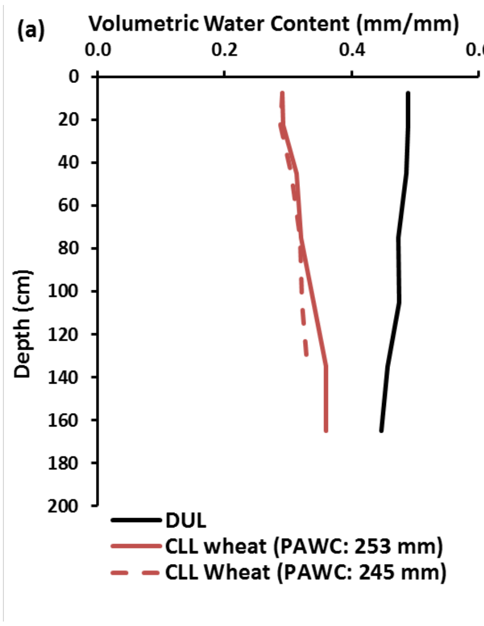
Soil type: Grey Vertosol

Soil description: The soil has a very high clay content and CEC throughout, with a slight decrease in both clay content and CEC in the bottom layer (150-180 cm); while EC and Cl are low, ESP increases with depth, especially below 120 cm where the soil becomes increasingly sodic (see Table 8).

Table 8: Chemical analysis for Grey Vertosol (Nombi No1171).

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-15	0.75	0.3	7.9	7.2	5	45	25	17	1	1	1	16	9	19	55
15-30	0.81	0.1	8.2	7.4	4	46	24	20	1	1	2	17	12	15	56
30-60	0.78	0.2	8.5	7.5	6	47	22	22	2	1	3	16	10	12	62
60-90	0.66	0.3	9	7.9	3	46	17	24	4	1	8	13	8	16	62
90-120	0.58	0.3	9.2	8.1	4	45	14	24	5	1	12	15	8	16	61
120-150	0.40	0.3	9.3	8.1	4	44	14	23	6	1	14	14	12	14	61
150-180	0.10	0.3	9.5	8.2	4	37	13	18	5	1	14	20	11	14	55

PAWC: The soil had 253 mm of plant available water capacity for wheat to 180 cm depth in 2015 and 245 mm to 150 cm depth (150-180 not sampled) at a nearby site also in 2015 reflecting a reasonably unconstrained profile.



Depth	BD	DUL	CLL	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15	1.14	0.49	0.29	30	30
15-30	1.14	0.49	0.29	29	59
30-60	1.15	0.49	0.31	52	111
60-90	1.19	0.47	0.32	46	157
90-120	1.18	0.47	0.34	41	198
120-150	1.23	0.46	0.36	29	227
150-180	1.25	0.45	0.36	26	253

Depth	BD	DUL	CLL	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15			0.29	30	30
15-30			0.29	30	60
30-60			0.30	55	115
60-90			0.32	46	161
90-120			0.32	46	207
120-150			0.33	38	245
150-180					

Figure 13: PAWC and associated data for Grey Vertosol (Nombi No1171).

17 Brown Vertosol (Emerald Hill No1172)

Location and landscape position: This site is located west of Emerald Hill NSW on the flood plain of the lower Coxs Creek.

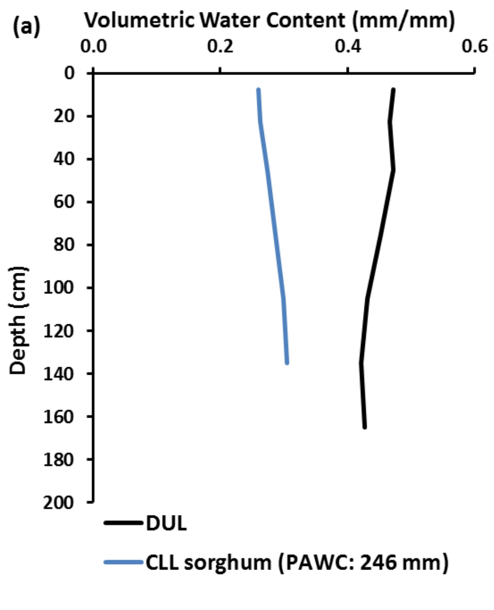
Soil type: Brown Vertosol

Soil description: The soil has a very high clay content throughout; CEC is high; EC is low in the surface 60 cm, but along with Cl increases with depth becoming quite saline below 120 to 150 cm depth; ESP increases with depth with the soil being sodic from 15 cm depth and strongly sodic from 60 cm depth (see Table 9).

Table 9: Chemical analysis for Brown Vertosol (Emerald Hill No1172).

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-15	0.98	0.3	7.3	6.6	5	40	17	20	1	1	4	12	8	24	56
15-30	0.66	0.3	8	7.4	6	41	16	22	2	1	6	11	8	24	57
30-60	0.50	0.4	8.8	7.9	14	42	14	22	4	1	10	12	10	19	60
60-90	0.23	0.4	9.1	8.2	18	39	11	21	6	1	15	12	14	25	50
90-120	0.12	0.5	9.1	8.2	97	38	10	20	7	1	19	14	10	21	54
120-150	0.08	0.8	9.1	8.1	462	37	10	18	7	1	20	19	11	14	56
150-180	0.07	0.8	9.1	8.2	619	36	11	16	7	1	19	24	11	21	44

PAWC: The soil had 245 mm of plant available water for sorghum to 150 cm depth, which was the deepest sampled depth for CLL. It is possible that PAWC could be 35 mm more if the crop roots could extract water to 180 cm. Subsoil constraints like Cl may, however, be limiting rooting below 150 cm.



Depth	BD	DUL	CLL	PAWC	Cum.
(cm)	g/cm^3	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15	1.19	0.47	0.26	32	32
15-30	1.20	0.47	0.26	30	62
30-60	1.19	0.47	0.27	59	122
60-90	1.24	0.45	0.29	50	171
90-120	1.30	0.43	0.30	39	211
120-150	1.32	0.42	0.30	35	246
150-180	1.31	0.43			

Figure 14: PAWC and associated data for Brown Vertosol (Emerald Hill No1172).

18 Brown Vertosol (Boggabri No1173)

Location and landscape position: This site is located east of Boggabri NSW on the flood plain just east of the Namoi River.

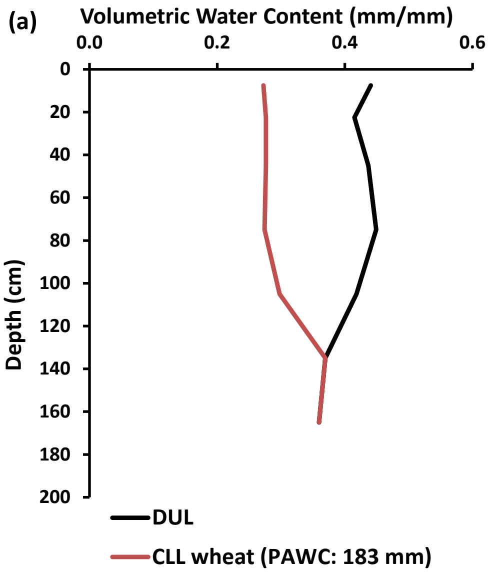
Soil type: Brown Vertosol

Soil description: The soil has a very high clay content throughout; CEC is high, gradually decreasing slightly with depth; EC and Cl are low, ESP increases slightly with depth becoming sodic below 90 cm (see Table 10).

Table 10: Chemical analysis for Brown Vertosol (Boggabri No1173).

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-15	1.15	0.3	7.8	7.4	4	38	25	12	1	1	1	2	10	24	63
15-30	0.66	0.3	8.3	7.7	5	37	23	12	1	1	2	4	14	23	59
30-60	0.65	0.3	8.4	7.8	6	38	20	15	1	1	3	4	9	22	65
60-90	0.65	0.3	8.7	7.9	3	36	17	16	2	1	5	3	9	25	62
90-120	0.29	0.3	8.8	8.0	3	35	15	17	2	1	7	3	5	24	68
120-150	0.19	0.3	8.9	8.1	2	33	14	15	3	1	8	5	9	21	64
150-180	0.15	0.3	9.0	8.1	6	32	14	15	3	1	9	8	10	27	55

PAWC: The soil had 183 mm of plant available water for wheat to 180 cm depth. This is lower than expected as the chemical analysis (Table 10) does not suggest any subsoil constraints to rooting. It is possible that the DUL at depth is an underestimate. The clay % does not decrease with depth until the last sample for 150-180 cm depth range, so in the absence of strong sodicity DUL is not expected to reduce as strongly as it does. It is possible that the profile did not wet sufficiently to depth. If DUL continued at 0.42 to 180 cm then PAWC would increase to 215 mm.



Depth	BD	DUL	CLL	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-15	1.27	0.44	0.27	25	25
15-30	1.34	0.42	0.28	21	46
30-60	1.28	0.44	0.28	48	94
60-90	1.25	0.45	0.27	52	147
90-120	1.33	0.42	0.30	36	183
120-150	1.46	0.37	0.37	0	183
150-180	1.48	0.36	0.36	0	183

Figure 15: PAWC and associated data for Brown Vertosol (Boggabri No1173).

19 Grey Vertosol (Kelvin No1174)

Location and landscape position: This site is located south east of Kelvin NSW in an area containing very gently inclined to level alluvial fan and plain systems (Banks, 1998). A second CLL site (wheat) was established 80 m east of the main site.

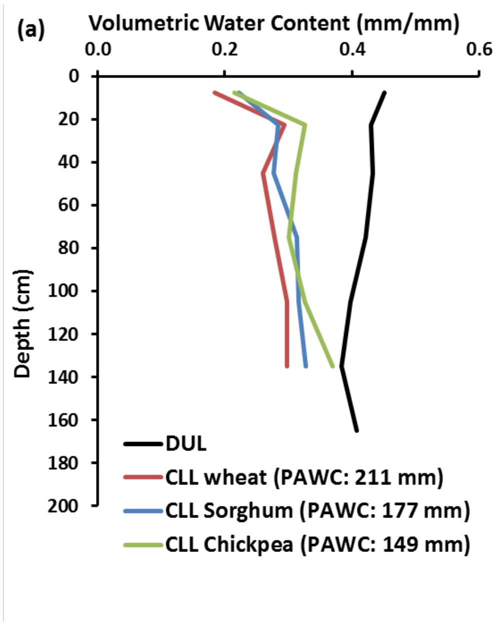
Soil type: Grey Vertosol

Soil description: The soil has a high to very high clay content throughout; CEC is high throughout; EC is low and Cl only increases very slightly with depth; ESP increases with depth with the soil sodic below 90 cm (see Table 11).

Table 11: Chemical analysis for Grey Vertosol (Kelvin No1174).

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-15	0.89	0.4	7.7	7.2	2	41	29	10	0	1	1	1	27	30	42
15-30	0.73	0.2	7.8	7.1	3	40	26	12	1	1	2	1	13	26	60
30-60	0.69	0.3	8.1	7.5	7	40	24	14	1	1	3	1	24	27	48
60-90	0.62	0.3	8.3	7.6	5	39	21	15	3	1	7	3	9	21	67
90-120	0.50	0.4	8.7	7.7	3	37	18	15	4	1	10	2	9	32	57
120-150	0.28	0.4	8.9	7.8	4	34	16	14	4	1	12	3	11	20	66
150-180	0.16	0.4	8.9	8.0	9	31	14	13	4	1	13	5	6	34	54

PAWC: The soil had 149 mm of plant available water capacity to 150 cm depth for chickpea in 2015 and 177 mm for sorghum to 150 cm depth in 2015. It had 211 mm for wheat to 150 cm depth in 2015 at a nearby site. The CLL were only sampled to 150 cm depth. In the case of wheat and sorghum it is possible that there is another ~25 mm between 150 and 180 cm depth that the crop may be able to access. In the case of chickpea, the maximum rooting depth appears to have been reached.



Depth (cm)	BD g/cm^3)	DUL (cm^3/cm^3)	CLL W (cm^3/cm^3)	PAWC (mm)	Cum. (mm)
0-15	1.24	0.45	0.18	40	40
15-30	1.30	0.43	0.29	20	61
30-60	1.29	0.43	0.26	52	112
60-90	1.32	0.42	0.28	43	155
90-120	1.38	0.40	0.30	30	185
120-150	1.42	0.38	0.30	25	211
150-180	1.36	0.41			

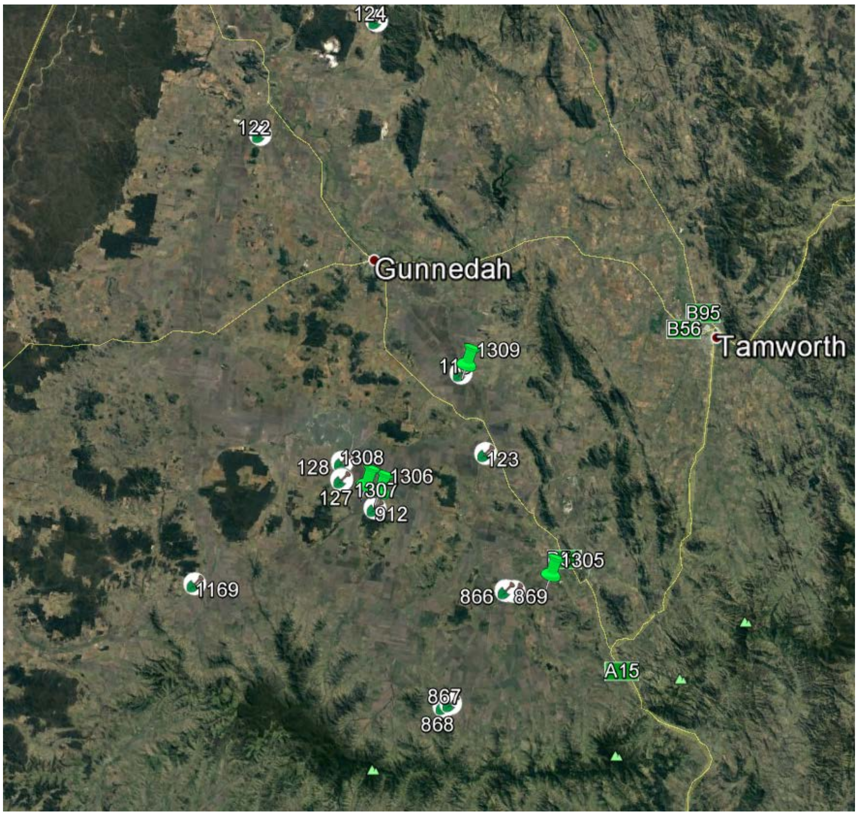
Depth (cm)	BD g/cm^3)	DUL (cm^3/cm^3)	CLL S (cm^3/cm^3)	PAWC (mm)	Cum. (mm)
0-15			0.22	34	34
15-30			0.28	22	56
30-60			0.28	47	103
60-90			0.31	32	135
90-120			0.32	25	160
120-150			0.33	17	177
150-180					

Depth (cm)	BD g/cm^3)	DUL (cm^3/cm^3)	CLL Ch (cm^3/cm^3)	PAWC (mm)	Cum. (mm)
0-15			0.21	35	35
15-30			0.33	16	51
30-60			0.31	36	87
60-90			0.30	36	123
90-120			0.33	22	145
120-150			0.37	4	149
150-180					

Figure 16: PAWC and associated data for Grey Vertosol (Kelvin No1174).

Part II PAWC of select soils in the Liverpool plains

b. Characterisations from NSW DPI NANORP project and NSW DPI component of GRDC project SIP08



20 Black Vertosol (Quirindi No1305)

Location and landscape position: This site is located between Pine Ridge and Quirindi on a narrow alluvial plain between sand hills to the east and west.

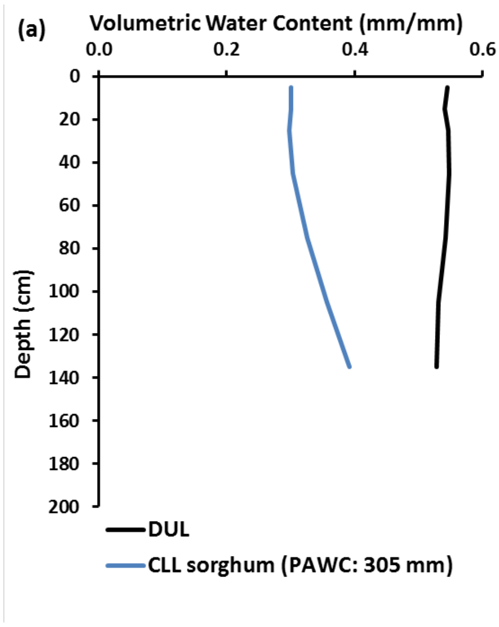
Soil type: Black Vertosol

Soil description: The soil has a high to very high clay content throughout; EC is low and increases slightly with depth; Cl was not measured. CEC and ESP were only measured in the surface layers and the soil was not sodic at these depths (see Table 12).

Table 12: Chemical analysis for Black Vertosol (Quirindi No1305).

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-10	1.16	0.2	8.7	7.8		70	37	31	1	1	1	4	3	10	83
10-30	1.10	0.3	8.5	7.7		72	33	36	2	1	2	3	5	12	80
30-60	0.96	0.4	8.9	8.0								4	5	14	77
60-90	0.82	0.5	9.4	8.4								3	5	10	83
90-120	0.91	0.5	9.3	8.3								3	3	13	81

PAWC: The soil had 305 mm of plant available water capacity to 150 cm depth for sorghum in 2013. The CLL was sampled to 150 cm depth. It is possible the crop had access to more water in the 150-180 cm layer, although comparison with similar PAWC profiles in the same soil-landscape unit suggests that subsoil constraints may be expected to limit crop water use at depth (see Section 27). The DUL is slightly higher than in these other characterisations, which could relate to the shorter drainage time adopted in this project (around 2 weeks compared with 4-8 weeks used in the other characterisations).



Depth (cm)	BD g/cm^3	DUL (cm^3/cm^3)	CLL (cm^3/cm^3)	PAWC (mm)	Cum. (mm)
0-10	0.99	0.54	0.30	24	24
10-20	1.00	0.54	0.30	24	49
20-30	0.99	0.55	0.30	25	73
30-60	0.98	0.55	0.30	73	147
60-90	1.00	0.54	0.33	65	211
90-120	1.03	0.53	0.36	52	264
120-150	1.04	0.53	0.39	41	305

Figure 17: PAWC and associated data for Black Vertosol (Quirindi No1305).

21 Vertosol (Spring Ridge No1306)

Location and landscape position: This site is located north of Spring Ridge on the alluvial plain.

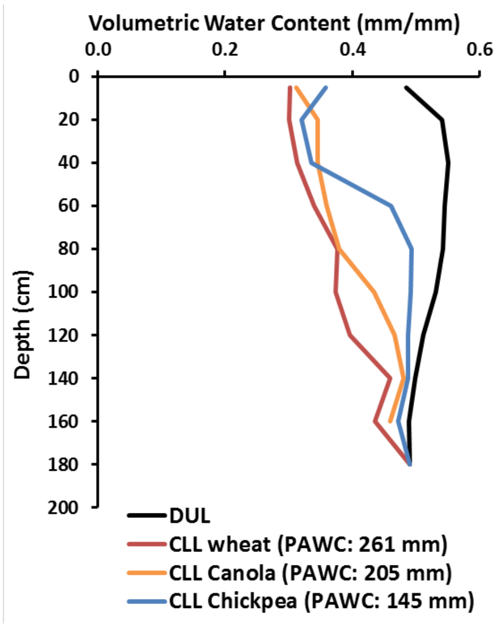
Soil type: Vertosol

Soil description: The soil has a very high clay content throughout; Cl increases with depth (to 170 cm depth) becoming high from 110 cm depth and very high from 130 cm depth. EC was not measured. CEC is very high throughout. Along with the subsoil salinity ESP rapidly increases with depth to exceed 40% from 90 cm depth (see Table 13).

Table 13: Chemical analysis for Vertosol (Spring Ridge No1306); based on pooled samples from 9 cores taken across an adjacent cropping trial area.

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-10			8.8		22	59	34	27	3	2	5	3	7	21	69
10-30			9.2		49	63	25	32	7	2	10				
30-50			9.4		104	76	19	37	13	1	16	2	7	12	81
50-70			9.6		187	76	13	40	19	2	25				
70-90			9.8		336	71	8	35	23	1	32	1	7	11	81
90-110			10		482	61	5	32	26	3	43				
110-130			9.6		1108	66	4	31	28	1	43	2	8	17	77
130-150			9.5		1206	62	4	27	26	2	42				
150-170			9.5		1241	48	4	25	20	1	42	2	9	20	71
170-190			10		502	59	4	27	27	2	45				

PAWC: The soil had 261 mm of plant available water capacity to 170 cm depth for wheat, 205 mm for canola and 145 mm for chickpea in 2006. PAWC is limited by subsoil constraints at depth, but not as strongly as the profile of Spring Ridge No1307, which reaches even higher salinity levels.



Depth	BD	DUL	CLL W	PAWC	Cum.
(cm)	(g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-10	1.15	0.49	0.302	18	18
10-30	1.01	0.54	0.301	48	66
30-50	0.98	0.55	0.313	48	114
50-70	0.99	0.55	0.339	41	155
70-90	1.00	0.54	0.376	33	188
90-110	1.03	0.53	0.374	31	220
110-130	1.08	0.51	0.396	23	243
130-150	1.12	0.50	0.460	8	251
150-170	1.14	0.49	0.436	11	261
170-190	1.19	0.49	0.490	0	261
Depth	BD	DUL	CLL Ca	PAWC	Cum.
(cm)	(g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-10			0.312	17	17
10-30			0.345	39	56
30-50			0.346	41	97
50-70			0.359	37	135
70-90			0.379	33	167
90-110			0.433	20	187
110-130			0.466	9	196
130-150			0.480	4	199
150-170			0.460	6	205
170-190			0.490	0	205
Depth	BD	DUL	CLL Ch	PAWC	Cum.
(cm)	(g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-10			0.359	13	13
10-30			0.321	44	57
30-50			0.335	43	100
50-70			0.461	17	117
70-90			0.492	10	127
90-110			0.492	8	135
110-130			0.487	5	139
130-150			0.488	2	141
150-170			0.472	3	145
170-190			0.490	0	145

W = wheat, Ca = canola, Ch = chickpea

Figure 18: PAWC and associated data for Vertosol (Spring Ridge No1306).

22 Vertosol (Spring Ridge No1307)

Location and landscape position: This site is located north of Spring Ridge on the alluvial plain.

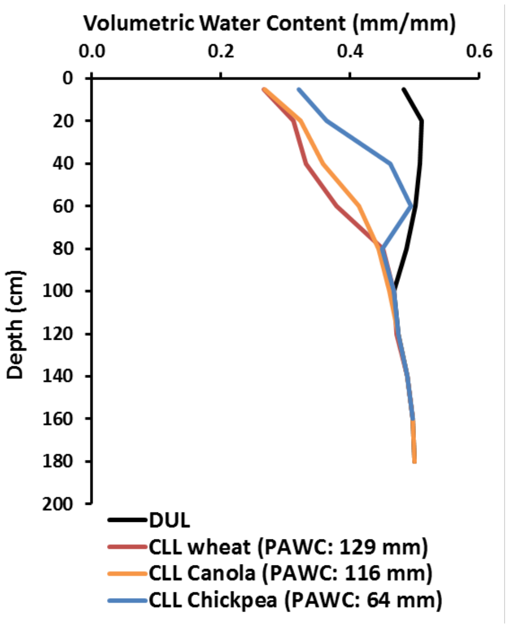
Soil type: Vertosol

Soil description: The soil has a very high clay content throughout; Cl increases rapidly and strongly with depth becoming very high from 50 cm depth and exceeding 2500 mg/kg below 70 cm. EC was not measured. CEC is very high throughout, with ESP rapidly increasing with depth to very high levels (up to 50 %) (see Table 14).

Table 14: Chemical analysis for Vertosol (Spring Ridge No1307) based on pooled samples from 9 cores taken across an adjacent cropping trial area.

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-10			9.1		65	63	33	21	3	2	5	2	9	25	65
10-30			9.2		202	63	27	27	7	1	12				
30-50			9.2		589	57	18	28	14	1	24	1	9	17	74
50-70			9.1		1537	68	10	30	21	1	30				
70-90			9.2		2555	62	5	27	26	1	41	3	9	17	72
90-110			9.2		2797	59	3	26	28	1	47				
110-130			9.2		2919	63	3	26	30	1	47	3	9	18	73
130-150			9.2		2930	65	4	27	32	1	49				
150-170			9.2		2895	67	4	28	34	2	50	1	10	14	78
170-190			9.2		2919	68	4	28	32	2	47				

PAWC: The soil had 129 mm of plant available water capacity to 170 cm depth for wheat, 116 mm for canola and 64 mm for chickpea in 2006. PAWC was severely limited beyond 90 cm depth (Figure 19a).



Depth (cm)	BD (g/cm^3)	DUL (cm^3/cm^3)	CLL W (cm^3/cm^3)	PAWC (mm)	Cum. (mm)
0-10	1.16	0.48	0.27	22	22
10-30	1.09	0.51	0.31	40	61
30-50	1.09	0.51	0.33	35	97
50-70	1.11	0.50	0.38	24	121
70-90	1.15	0.49	0.45	7	128
90-110	1.20	0.47	0.47	0	128
110-130	1.18	0.47	0.47	0	129
130-150	1.14	0.49	0.49	0	129
150-170	1.12	0.50	0.50	0	129
170-190	1.12	0.50			

Depth (cm)	BD (g/cm^3)	DUL (cm^3/cm^3)	CLL Ca (cm^3/cm^3)	PAWC (mm)	Cum. (mm)
0-10			0.27	22	22
10-30			0.32	37	59
30-50			0.36	30	89
50-70			0.41	17	106
70-90			0.44	9	115
90-110			0.46	1	116
110-130			0.47	0	116
130-150			0.49	0	116
150-170			0.50	0	116
170-190			0.50	0	116

Depth (cm)	BD (g/cm^3)	DUL (cm^3/cm^3)	CLL Ch (cm^3/cm^3)	PAWC (mm)	Cum. (mm)
0-10			0.32	16	16
10-30			0.36	29	46
30-50			0.46	9	55
50-70			0.49	1	56
70-90			0.45	7	64
90-110			0.47	0	64
110-130			0.47	0	64
130-150			0.49	0	64
150-170			0.50	0	64
170-190					

W = wheat, Ca = canola, Ch = chickpea

Figure 19: PAWC and associated data for Vertosol (Spring Ridge No1307).

23 Vertosol (Spring Ridge No1308)

Location and landscape position: This site is located WNW of Spring Ridge on the alluvial plain.

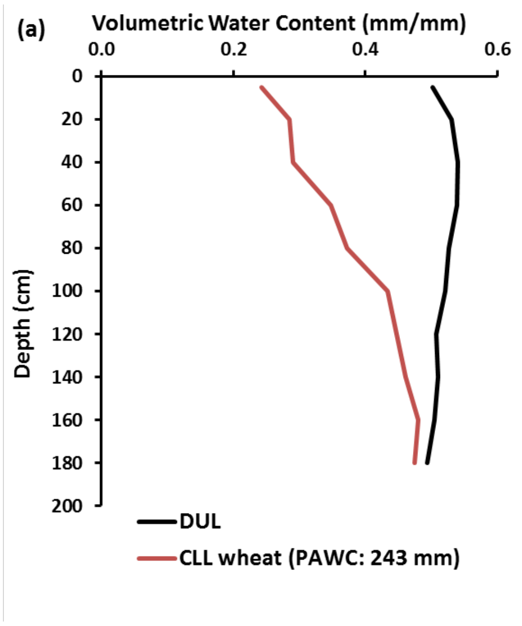
Soil type: Vertosol

Soil description: The soil has a very high clay content throughout; Cl increases rapidly and strongly with depth and would likely fall in the high range at depth where it was not measured. EC was not measured. CEC is very high throughout, with ESP increasing rapidly with depth to exceed 40% below 70 cm (see Table 14).

Table 15: Chemical analysis for Vertosol (Spring Ridge No1308) based on pooled samples from 9 cores taken across an adjacent cropping trial area.

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-10			8.2		21	58	33	25	2	2	4				
10-30			8.9		<6	70	28	29	6	1	8	3	8	18	71
30-50			9.2		11	69	19	32	14	1	20	3	8	21	69
50-70			9.4		30	67	9	31	21	1	32	3	8	16	73
70-90			9.6		110	69	5	29	27	1	40	2	9	18	74
90-110			9.8		304	60	3	26	31	1	52	2	9	15	74
110-130			9.9		562	64	3	26	30	1	48	2	8	19	73
130-150			9.7												
150-170			9.6												
170-190			9.5												

PAWC: The soil had 243 mm of plant available water capacity to 190 cm depth for wheat in 2004. PAWC is limited by subsoil constraints at depth, but not as strongly as APSoil No1307.



Depth	BD	DUL	CLL W	PAWC	Cum.
(cm)	g/cm^3)	(cm^3/cm^3)	(cm^3/cm^3)	(mm)	(mm)
0-10	1.11	0.50	0.24	26	26
10-30	1.03	0.53	0.29	49	75
30-50	1.01	0.54	0.29	50	125
50-70	1.01	0.54	0.35	38	163
70-90	1.04	0.53	0.37	31	194
90-110	1.06	0.52	0.43	17	212
110-130	1.09	0.51	0.45	12	224
130-150	1.08	0.51	0.46	10	234
150-170	1.10	0.51	0.48	5	239
170-190	1.13	0.49	0.47	4	243

Figure 20: PAWC and associated data for Vertosol (Spring Ridge No1308).

24 Vertosol (Breeza No1309)

Location and landscape position: This site is located at the Breeza agricultural research station on the alluvial plain.

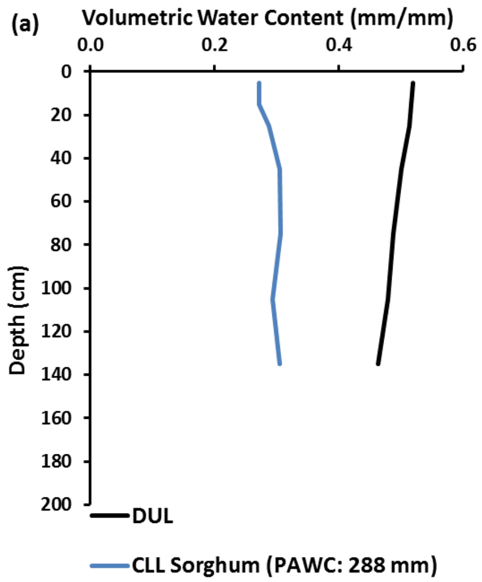
Soil type: Vertosol

Soil description: The soil has a medium clay content in the 0-10 cm layer, and very high clay content below 10 cm; EC in the top 30 cm was low. Cl, CEC and ESP were not measured (see Table 16).

Table 16: Chemical analysis for Vertosol (Breeza No1309) based on pooled samples from 9 cores taken across an adjacent cropping trial area.

Depth	OC	EC 1:5	pH water	pH $CaCl_2$	Cl	CEC	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Silt	Clay
(cm)	(%)	(dS/m)			(mg/kg)	(cmol+/kg)					%	%			
0-10	1.17	0.2	8.4	7.7								3	33	27	36
10-30	0.80	0.3	8.7	7.9								3	20	20	58
30-60												3	14	21	62
60-90												3	14	22	61
90-120												3	16	20	60

PAWC: The soil had 288 mm of plant available water capacity to 150 cm depth for wheat in 2015. There do not seem to be any subsoil constraints to PAWC. The DUL is high compared with that of a nearby existing APSoil site (see Section 27), which may relate to the shorter drainage time used (approximately 2 weeks compared with 4-8 weeks) or slightly different properties.



Depth (cm)	BD g/cm^3)	DUL (cm^3/cm^3)	CLL (cm^3/cm^3)	PAWC (mm)	Cum. (mm)
0-10	1.06	0.52	0.27	25	25
10-20	1.07	0.52	0.27	25	49
20-30	1.08	0.51	0.29	23	72
30-60	1.11	0.50	0.31	58	131
60-90	1.15	0.49	0.31	54	185
90-120	1.17	0.48	0.29	56	241
120-150	1.21	0.46	0.31	47	288

Figure 21: PAWC and associated data for Vertosol (Breeza No1309).

Part III Landscape contexts

25 Geology of the parent materials of the Liverpool Plains

The Liverpool Plains are characterised by extensive plains with quaternary alluvial deposits originating from the surrounding hills of different age, origin and composition.

The NSW Geology app (see Section 9 Resources) provides an impression of the different geologies within the Liverpool Plains area (Figure 22). The soil-landscape mapping in the Liverpool Plains draws on this geology information as well as geomorphology and soil type. Some of the soil-landscape unit descriptions in Part III refer to these geologies.

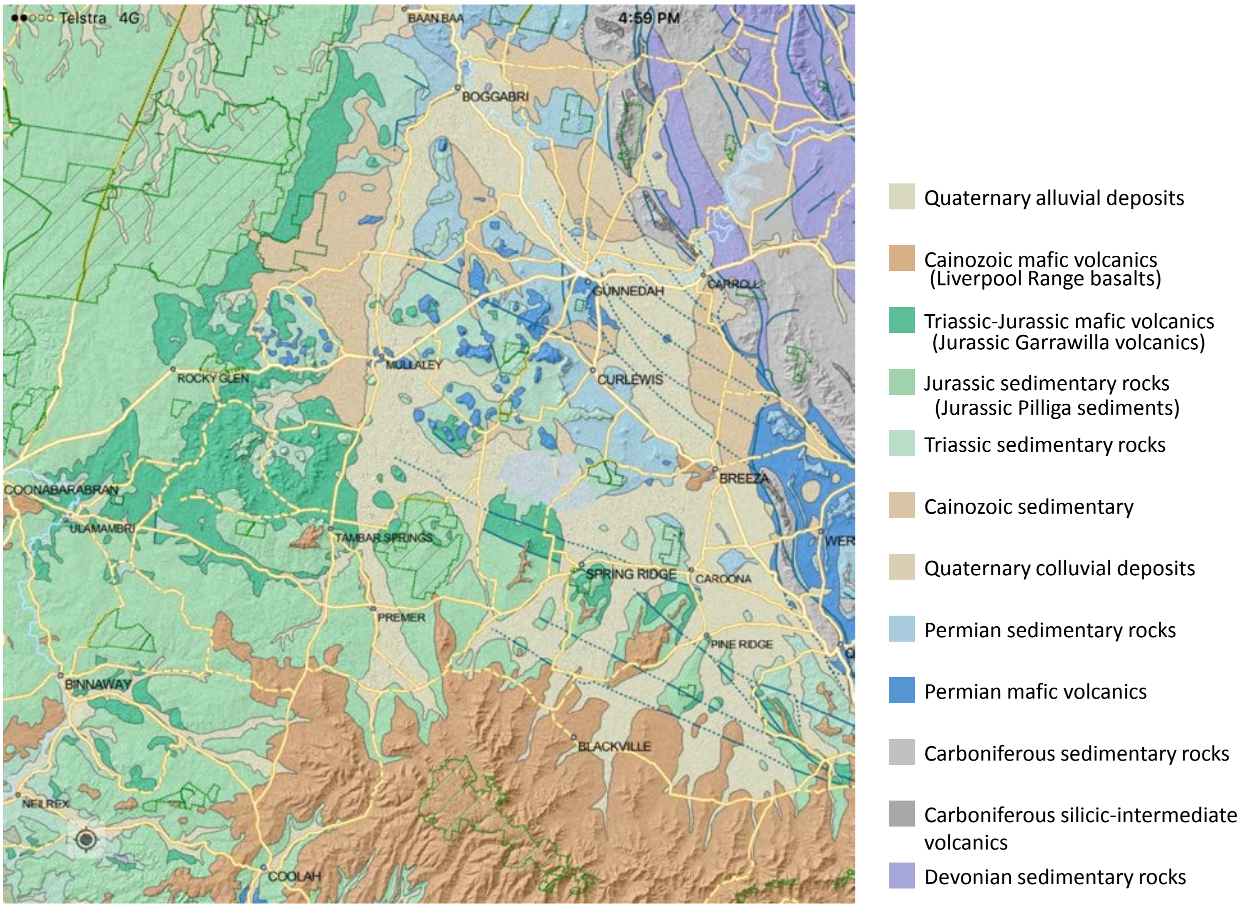


Figure 22: Geology of the Liverpool Plains.

Source: Screenshot from NSW Geology app (with select legend elaborations based on Land Management Units (LMUs) of Ringrose-Voase et al. (2003) in parentheses)

26 Geomorphological terms used

In the descriptions of the various soil landscape units (SLUs) that follow a number of geomorphological or landform terms are used, which are explained here. Most of the SLUs considered in this report are alluvial soil landscapes. These are formed by deposition along rivers and streams. The term 'alluvium' refers to deposits resulting from the action of rivers and streams and an 'alluvial plain' refers to the landform pattern that includes the stream channel (stream bed and bank) and plain. A flood plain is an alluvial plain which is 'frequently active' (meaning with an interval of 50 years or less).

A number of the APSoil characterisations are in so-called transferral soil landscapes (Banks 1995, 1998), which are formed in deep deposits that mostly come from eroded parent materials washed from areas directly upslope. Material that has moved largely by gravity is referred to as colluvium. This landscape includes footslopes and (alluvial) fans.

Figure 23 illustrates some of these terms in the landscape along a transect from Upper Coxs Creek to the Trinkey Hills. The image was obtained from Google Earth, which allows one to insert a path and then view the elevation along that path (note that the terrain layer must be switched on).

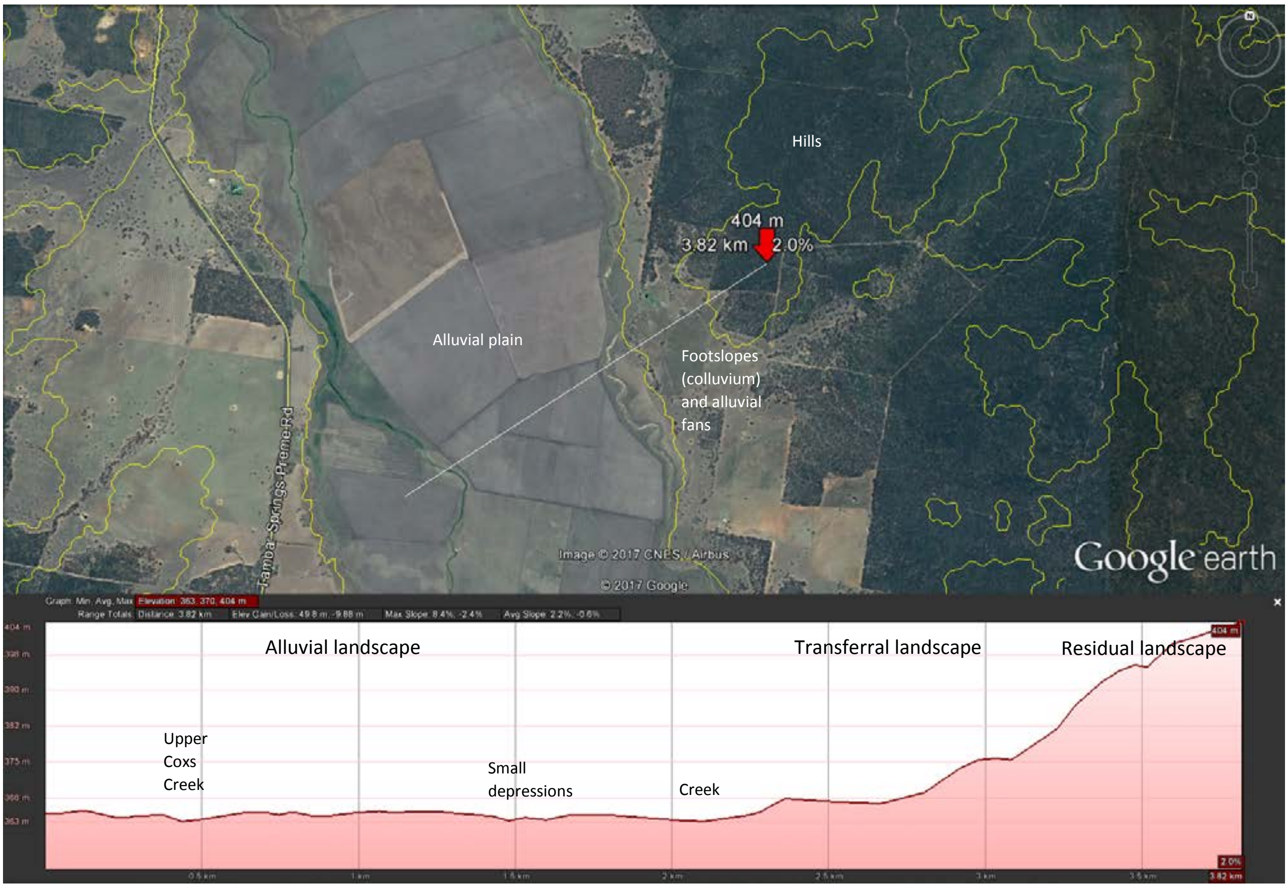


Figure 23: Relative positions of alluvial landscape, transferral landscape and residual landscape illustrated using a cross-section from Upper Cox Creek to the Trinkey Hills.

Source: Screenshot from Google Earth with SLU line work from 'Soil and Land Resources of the Liverpool Plains Catchment' (© State of New South Wales and Office of Environment and Heritage 2012).

27 Breeza and Pine Ridge areas and Conadilly SLU

New APSoil characterisations: Grey Vertosol (Breeza No1165), Black Vertosol (Quirindi No1305), Vertosol (Breeza No1309)

Existing APSoil characterisations: Black Vertosol (Breeza No119), Grey-Black Vertosol (Breeza No123),

Vertosol (Quirindi No866), Vertosol (Quirindi No869)

The Conadilly SLU is described by Banks (1998) as consisting of “broad, level floodplains ... of the Mooki River on Quaternary alluvium derived from the Tertiary basalts of the Liverpool Range Beds (see Figure 22), and the Gunnedah Basin.” Its extent is shown in Figure 24 (right) and covers the flood plains around and north of Breeza as well as the floodplains near and east of Pine Ridge. The northern part of the SLU consists of wider plains, whereas those in the southern part are narrower and bordered by sandstone hills.

Banks (1998) describes the two main soil types in this SLU as the poorly drained self-mulching Black Vertosols that dominate the landscape, and poorly drained self-mulching Grey Vertosols in areas of episodic waterlogging. Banks (1998) also notes that ‘almost all subsoils are moderately sodic, moderately to highly saline and moderately to very strongly alkaline.’

Not far from the new APSoil site No1165 near Breeza NSW there were two existing characterisations, APSoil sites No119 and No123 (locations in Figure 24, top left). New APSoil site No1305 is in a similar landscape as two existing APSoil sites No866 and No869 near Pine Ridge (locations in Figure 24, bottom left). The new site APSoil No1165 near Breeza is described as a Grey Vertosol. APSoil sites No119 and No123 were described as Black Vertosol and Grey-Black Vertosol, respectively, whereas the three southern sites were all described as Black Vertosols.

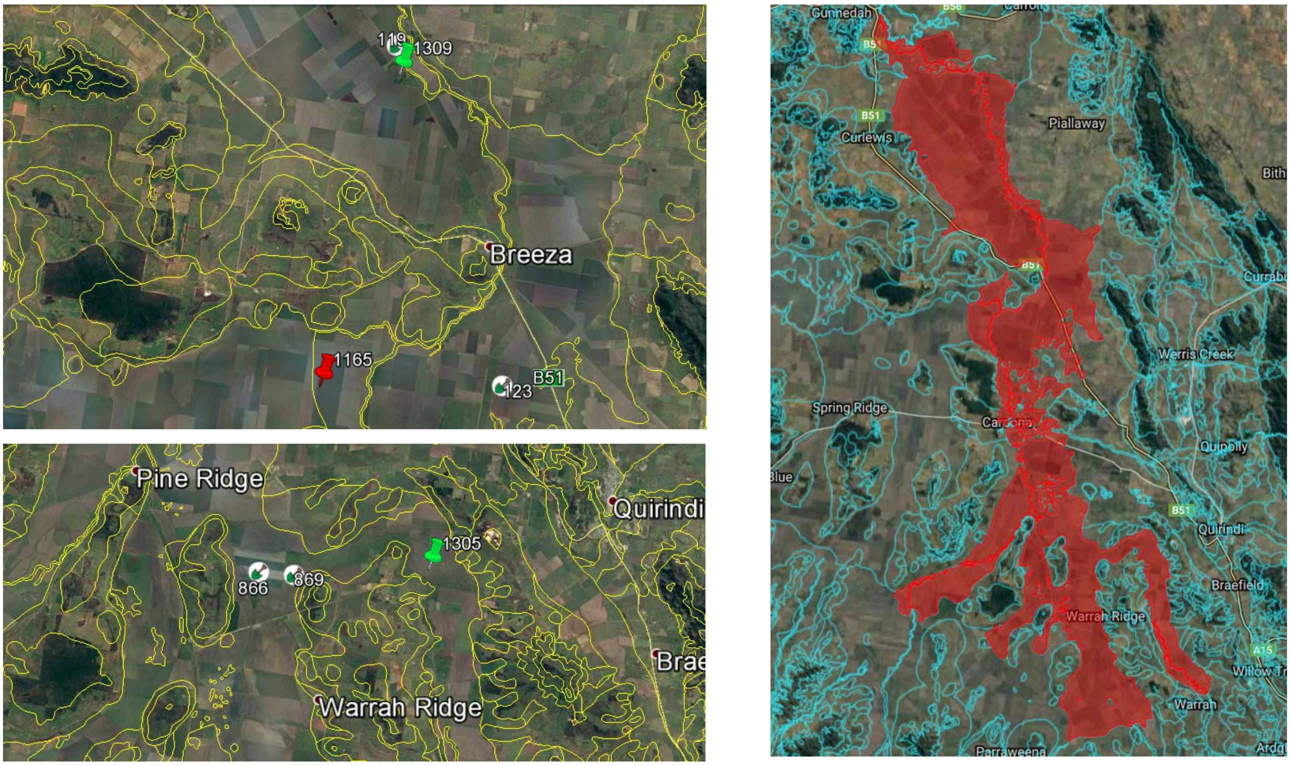


Figure 24: (left) PAWC characterisations in the Breeza (top) and Pine Ridge-Quirindi (bottom) areas and (right) spatial extent of the Conadilly SLU. [Note maps not at the same scale.]

Source: Screenshots from Google Earth with APSoil sites and SLU line work from ‘Soil and Land Resources of the Liverpool Plains Catchment’ (© State of New South Wales and Office of Environment and Heritage 2012) and eSpade Liverpool Plains Soil and Land Resources layer.

APSoil sites No119 and No123 have remarkably similar PAWC buckets (Figure 25b,c). The wheat PAWC is 282 mm for APSoil site No119 and 264 mm for APSoil site No123, the PAWCs for cotton and sorghum are of similar magnitude and in both cases chickpea has a reduced rooting effectiveness at depth, hence higher CLL and lower PAWC.

The two southern existing APSoil sites No866 and No869 also had very similar PAWC buckets (Figure 26a,b) that show a clear narrowing of the PAWC at depth compared with the above Breeza sites (Figure 27b). The reduction in PAWC is likely linked to strongly increased EC and Cl below 90 cm (Figure 27b). Banks (1998) notes that 'where the floodplains are constricted between low sandstone hills, saline water tables are generally high.' The new characterisation APSoil No1305 appeared to be less constrained (Figure 26c), but comparison with these other nearby sites (Figure 27a) shows that CLL is consistent and the higher PAWC is due to a higher DUL. This may be a methodological difference due to a shorter period of drainage prior to DUL measurement. APSoil site No1309 also has a higher DUL than nearby APSoil No119 (Figure 27c), but is otherwise consistent in showing an unconstrained PAWC profile for sorghum.

The new APSoil No1165 PAWC characterisation shows a considerable narrowing of the PAWC bucket (Figure 25a). While increased salinity and sodicity in the subsoil (Table 2) suggests a reduced effectiveness of crop roots, the effect is larger than expected based on the comparison with subsoil chemistry of APSoil sites No866 and No869. In addition, the surface CLL at this site is also higher, reducing PAWC, which is not explained by the available chemistry. This site warrants further investigation.

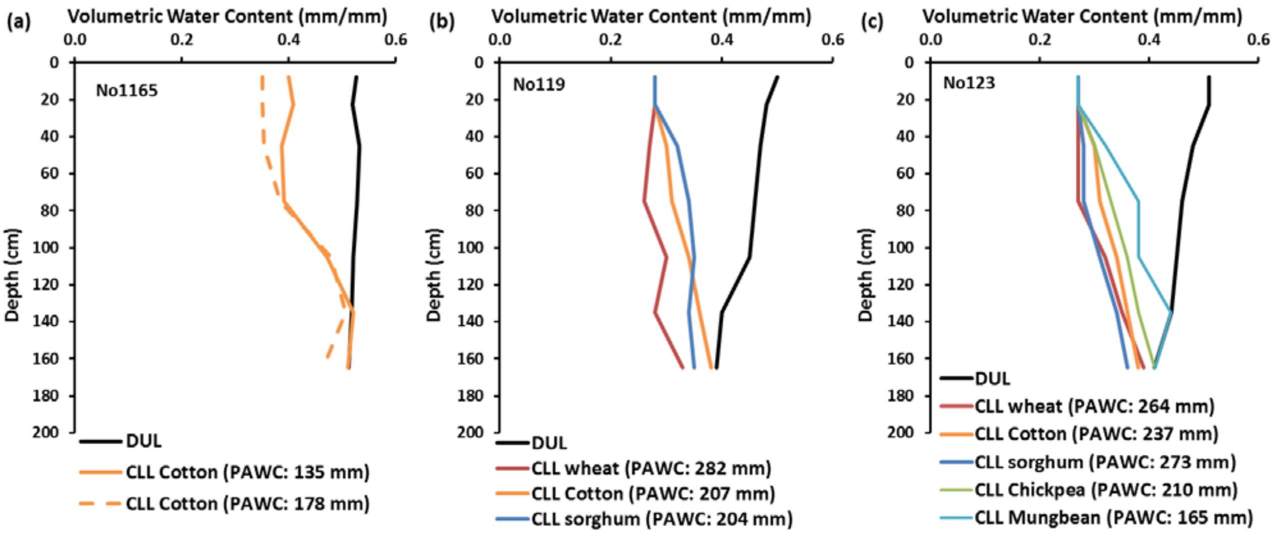


Figure 25. PAWC characterisations in the Breeza NSW area: (a) APSoil No1165, (b) Apsoil No119 and (c) APSoil No123.

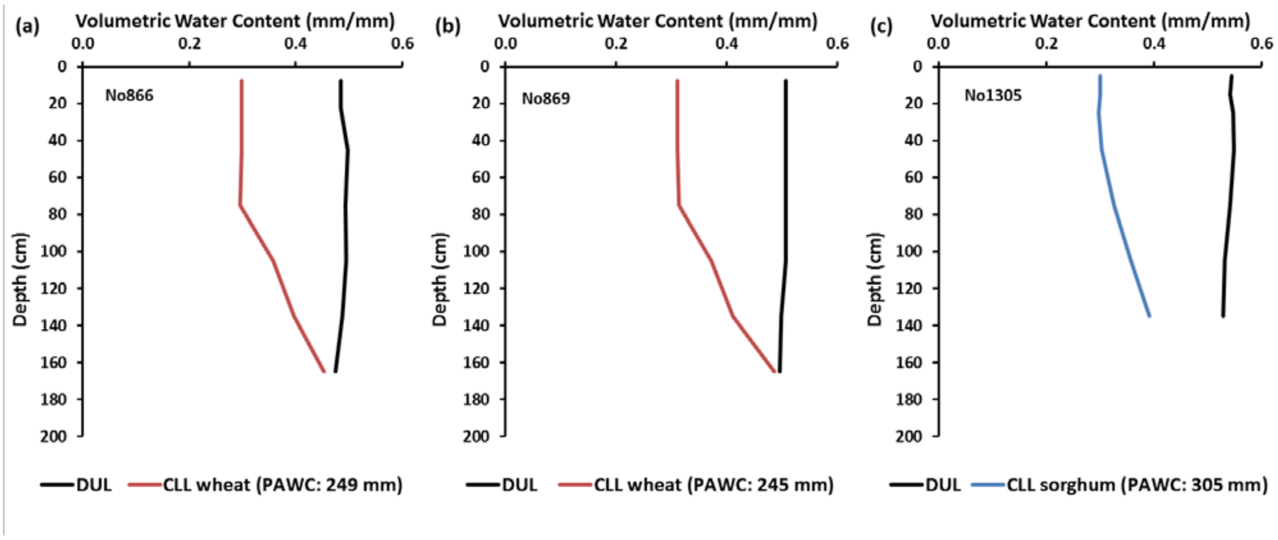


Figure 26. PAWC characterisations near in the Pine Ridge area: (a) Apsoil No866, (b) APSoil No869, and (c) APSoil No1305.

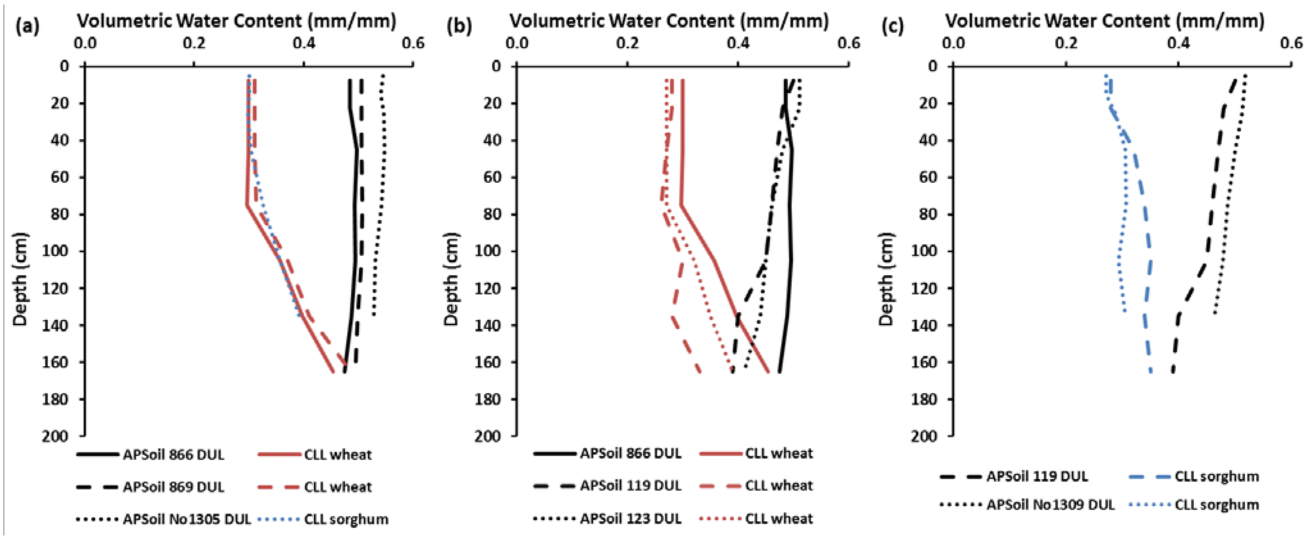


Figure 27: Comparison of PAWC characterisations (a) in Pine Ridge - Quirindi area, (b) between Pine Ridge and Breeza, and (c) near Breeza Agricultural station.

Table 17: Chemical analysis for Vertosol (Quirindi No866) and Vertosol (Quirindi No869).

APSoil 866				APSoil 869			
Depth (cm)	EC 1:5 (dS/m)	Cl (mg/kg)	ESP %	Depth (cm)	EC 1:5 (dS/m)	Cl (mg/kg)	ESP %
0-15	0.2	25	1	0-15	0.2	14	1
15-30	0.2	20	3	15-30	0.2	1	2
30-60	0.4	96	7	30-60	0.3	10	5
60-90	0.6	355	14	60-90	0.4	25	10
90-120	1.2	1107	18	90-120	0.5	166	15
120-150	1.6	1510	19	120-150	0.9	605	18
150-180	1.4	1292	19	150-180	1.1	936	18

With particle size data not available for the existing APSoil sites and chemistry not available for the existing Breeza APSoil sites, it is difficult to explore whether the more subtle differences between the profiles, e.g. the higher DUL for APSoil sites No1305 and No1309 (Figure 27a,c), the higher DUL for Pine Ridge compared with Breeza sites (Figure 27b), and the differences in CLL for sorghum and cotton between APSoil sites No119 and No123, are real or due to methodological uncertainties or seasonal differences (Figure 25b,c).

It is difficult to make generalisations about the likely PAWC for the Conadilly SLU based on these seven APSoil characterisations alone. It would appear, however, that APSoil No1165 is an outlier that warrants further investigation into the causes of its constrained PAWC (especially near the surface) and to what area these constraints, if confirmed, on PAWC may extend. For the northern part of the Conadilly SLU in broad, level plain positions that are not affected by subsoil salinity, the PAWC is likely to be unconstrained for deeper rooted crops such as wheat, cotton and sorghum, and in the order of 240 to 280 mm. However, this may be reduced considerably where subsoil salinity is present, e.g. in depressions. In the Pine Ridge area the PAWC are somewhat constrained at depth, but this may be off-set by higher clay content and hence higher DUL. The three APSoil profiles currently suggest a PAWC for wheat in the range of 250 to 300 mm for sites in similar landscape positions. PAWC will likely be reduced in landscape positions with more severe subsoil salinity.

28 Spring Ridge area and Yarraman SLU

New APSoil characterisation: Vertosol (Spring Ridge No1306), Vertosol (Spring Ridge No1307), Vertosol (Spring Ridge No1308)

Existing APSoil characterisations: Grey-Black Vertosol (Spring Ridge No912)

West of Conadilly SLU is the Yarraman SLU which also consists of flood plains of basaltic alluvium. That of the Yarraman SLU is derived primarily from basalts of the Liverpool Range Beds (see Figure 22; Banks, 1995, 1998). The boundary between the two SLUs near the new site APSoil No1165 is related to the divide between alluvium of the Mooki River on the eastern side (Conadilly SLU) and alluvium of the Yarraman Creek on the western side (Yarraman SLU).

There was only one existing APSoil characterisation located within Yarraman SLU. Three new APSoil characterisation sites were added as part of a project investigating spatially variable subsoil constraints. All four soils were described as Vertosols. Other nearby existing APSoil sites to the west are located in a different soil-landscape – the transitional Noojee SLU on 'broad, very gently to gently inclined, very long (500 m - 2,000 m) footslopes (Banks, 1995, 1998) – see Section 34.

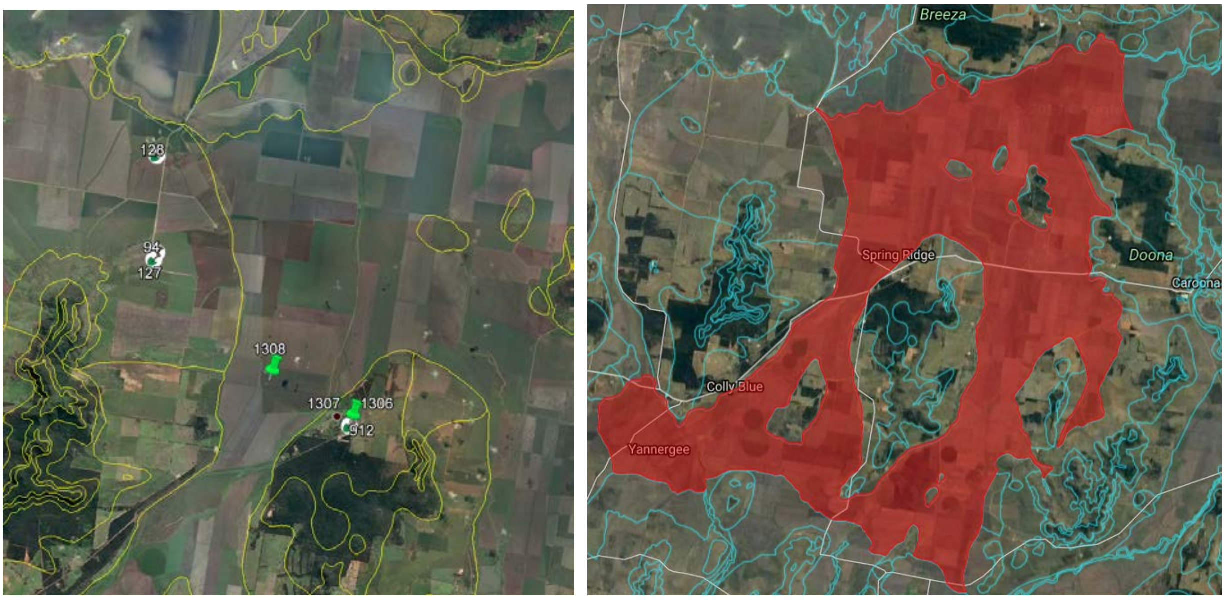


Figure 28: (left) PAWC characterisations in Yarraman SLU (Spring Ridge NSW area) and (right) spatial extent of the Yarraman SLU. Exact location of site 912 is unknown, those of 1306 and 1307 are on the Yarraman SLU plains north of Spring Ridge. [Note maps not at the same scale.]

Source: Screenshots from Google Earth with APSoil sites and SLU line work from 'Soil and Land Resources of the Liverpool Plains Catchment' (© State of New South Wales and Office of Environment and Heritage 2012) and eSpade Liverpool Plains Soil and Land Resources layer.

The variable subsoil constraints between the three new APSoil sites had clear impacts on PAWC. There was very little water use by the crops below 80-100 cm in the constrained APSoil No1307 reducing PAWC by about half compared with the other two characterisations (Figure 29). The differences are explained by the considerably higher Cl contents at depth. While APSoil sites No1306 and No1308 also reached appreciable levels of Cl (e.g. > 1000 mg/kg below 110 cm for APSoil No1306), that of APSoil site No1307 exceeded 2000 mg/kg below 70 cm depth.

Further investigation is warranted to explore the reasons for the increased salinity at APSoil site No1307 compared to that of nearby APSoil site No1306 and whether other available mapping, e.g. terrain analysis, electromagnetic induction (EM) mapping or data from other surveys, can assist with identifying the areas within this flood plain that are most severely affected by subsoil salinity. APSoil site No1307 is positioned slightly lower in the landscape, but the differences are subtle and it is also possible that the salinity is linked to a local depression. The online eSpade tool provides access to the data of an old Goran Basin soil survey (EC and pH 1:5 water) by Ben Turner in 1992. The data from this 1 km x 1 km grid did not provide a clear pattern of subsoil salinity in the area, except that high subsoil ECs were found at all locations on the northern edge bordering the Goran Lake SLU, which is known for its high saline water tables (Banks, 1995).

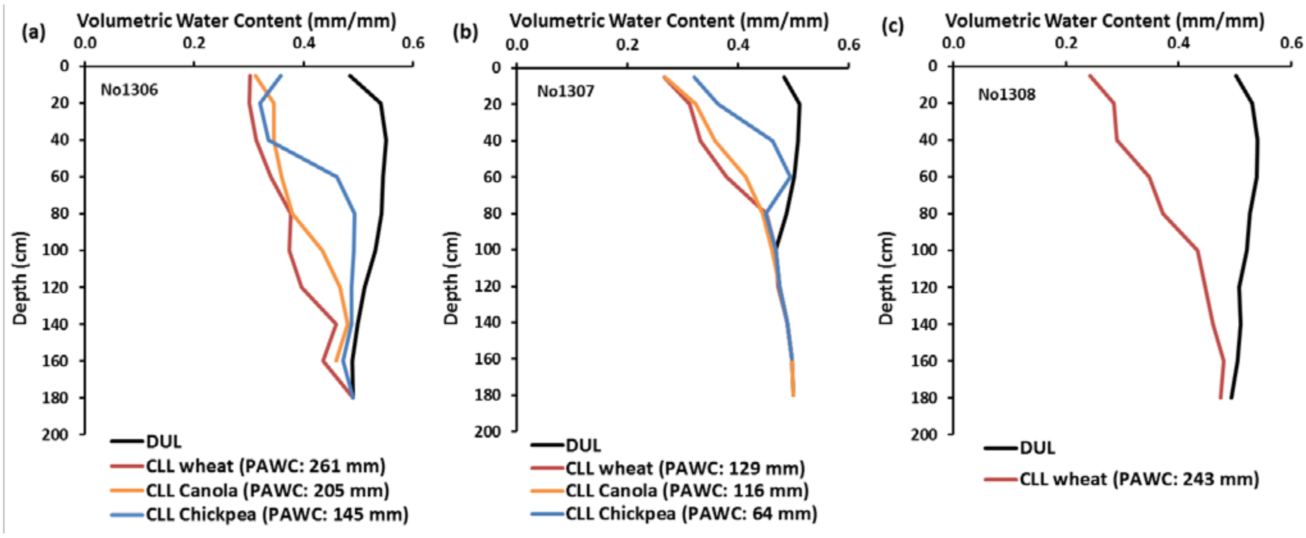


Figure 29. PAWC characterisations NNW of Spring Ridge, NSW: (a) Apsoil No1306, (b) APSoil No1307, and (c) APSoil No1308.

The PAWC of APSoil site No912 near Spring Ridge NSW was characterised by a significant narrowing of the bucket at depth (Figure 30), but DUL was reduced too, giving a very different shape PAWC profile than the other three characterisations. Chemistry for this site did not confirm presence of salinity with EC ~ 0.3 dS/m and Cl 15 mg/kg. As location and history of the site are unknown, it is difficult to draw any conclusions from it.

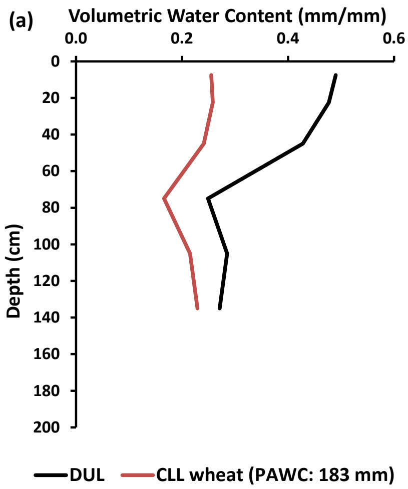


Figure 30: Existing PAWC characterisation in Spring Ridge NSW area: (a) APSoil No912.

It is difficult to provide generalisations about the magnitude of expected PAWC for soils in the Yarraman SLU on the basis of these APSoil profiles alone. However, it is clear that subsoil constraints induced by subsoil salinity can reduce the PAWC considerably. PAWC for wheat at APSoil sites No1306 and No1308 was in the 240-260 mm range, whereas that at APSoil site No1307 was only half of that. EC was not measured at these sites, but the effect of Cl is clear. Further work is required to establish the extent of constraints to PAWC induced by different levels of salinity, e.g. Cl > 1000 mg/kg which may still allow some uptake (Figure 26a,b; Figure 29a,c) and Cl > 2000 mg/kg which appears to prevent water uptake all together (Figure 29b). See also the work by Hochman et al. (2007) and Dang et al. (2008). Further work is also warranted to explore whether these areas with high subsoil salinity can be mapped or whether a within-paddock deep soil core needs to be taken to establish presence of subsoil constraints. In an alluvial plain like the Yarraman, the substrate material may be consistent enough to allow EM to identify subsoil salinity differences.

29 Caroona area and Quirindi Creek SLU

New APSoil characterisation: Grey Vertosol (Caroona No1166)

Existing APSoil characterisations: none

The new APSoil site No1166 near Caroona is located in the Quirindi Creek SLU (Figure 31), which is described (Banks, 1998) as 'an extensive ... floodplain system of alluvium from the Melville Ranges to the southeast.' It is distinguished from Conadilly SLU 'by the presence of relict floodplain features and coarser or sodic soils.' The distribution of soils is determined by the stream and fan deposition patterns (Banks, 1998). The SLU contains deep Grey and Black Vertosols, but also non-swelling, well-drained clay soils such as Dermosols and hard-setting texture contrast soils (Chromosols and Sodosols) (Banks, 1998). Coarser textured soils would be associated with higher energy (former) streams (Banks, 1998).

With this variety of soil types within the SLU, the PAWC is expected to also vary considerably. The Grey Vertosol at the APSoil No1166 site is on a small patch of flood plain off Quirindi Creek on a heavier soil without subsoil constraints (Table 3) resulting in a relatively large PAWC (Figure 8), although the coarser particle size has reduced the PAWC somewhat (just above 200 mm) compared with e.g. APSoil sites No119 and No123 in the Conadilly SLU (240 mm - 280 mm).

The texture contrast soils in the Quirindi Creek SLU will have a much lighter texture in the surface soil than APSoil No1166. They are also likely to have 'tight' B horizons of non-swelling clay which may limit root growth, especially if sodic (Sodosols). This would result in a smaller total profile PAWC. If these soils are of agronomic interest, further PAWC characterisations would be required to establish the range of typical soil PAWC in this SLU.

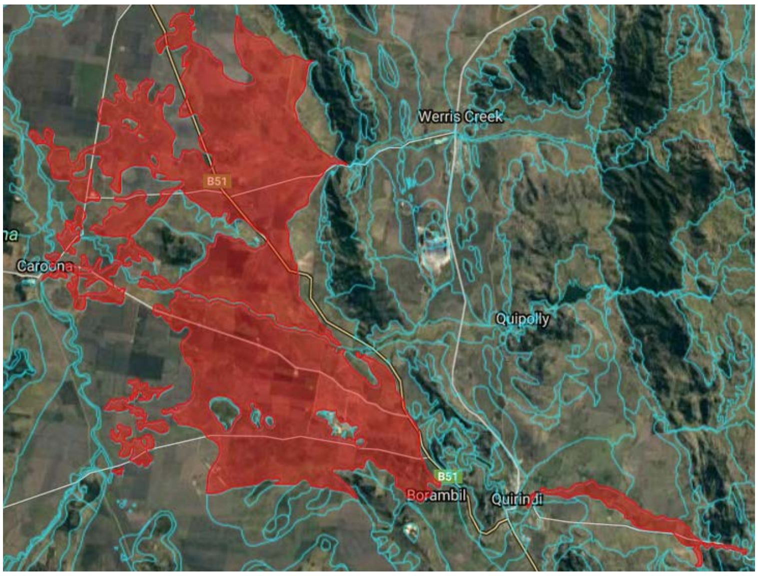


Figure 31: (left) PAWC characterisations in the Caroona NSW area and (right) spatial extent of the Quirindi Creek SLU. [Note maps not at the same scale.]

Source: Screenshots from Google Earth with APSoil sites and SLU line work from 'Soil and Land Resources of the Liverpool Plains Catchment' (© State of New South Wales and Office of Environment and Heritage 2012) and eSpade Soil and Land Resources layer.

30 Premer-Bundella area and Lever Gully SLU

New APSoil characterisation: Black Vertosol (Premer No1167), Brown Vertosol (Bundella No1168)

Existing APSoil characterisations: Vertosol (Blackville No867), Vertosol (Blackville No868)

Experimental APSIM characterisations: Black Vertosol Hudson site (Paydar et al. 2005)

The Lever Gully SLU is described by Banks (1998) as consisting of 'gently to moderately inclined, very long footslopes and drainage plains of the Liverpool Ranges.' The two new APSoil sites (Black Vertosol (Premer No1167) and Brown Vertosol (Bundella No1168)) are located 11 km apart within this SLU and in a similar landscape position, although the Digital Elevation Model (DEM) suggests APSoil site No1168 is slightly higher on the slope (Figure 32). The unit extends all along the Liverpool Ranges, as shown in Figure 33(left). Downslope is the Windy Creek SLU (Figure 33(right)) which is described as (Banks, 1998) 'very gently inclined extensive drainage plains, alluvial fans and sheet flood fans.' Near Parraweena NSW these SLUs contain a number of existing PAWC characterisations (Figure 34). Below Windy Creek SLU we transition into the alluvial floodplains of the Conadilly and Yarraman SLUs (see Sections 27 and 28).

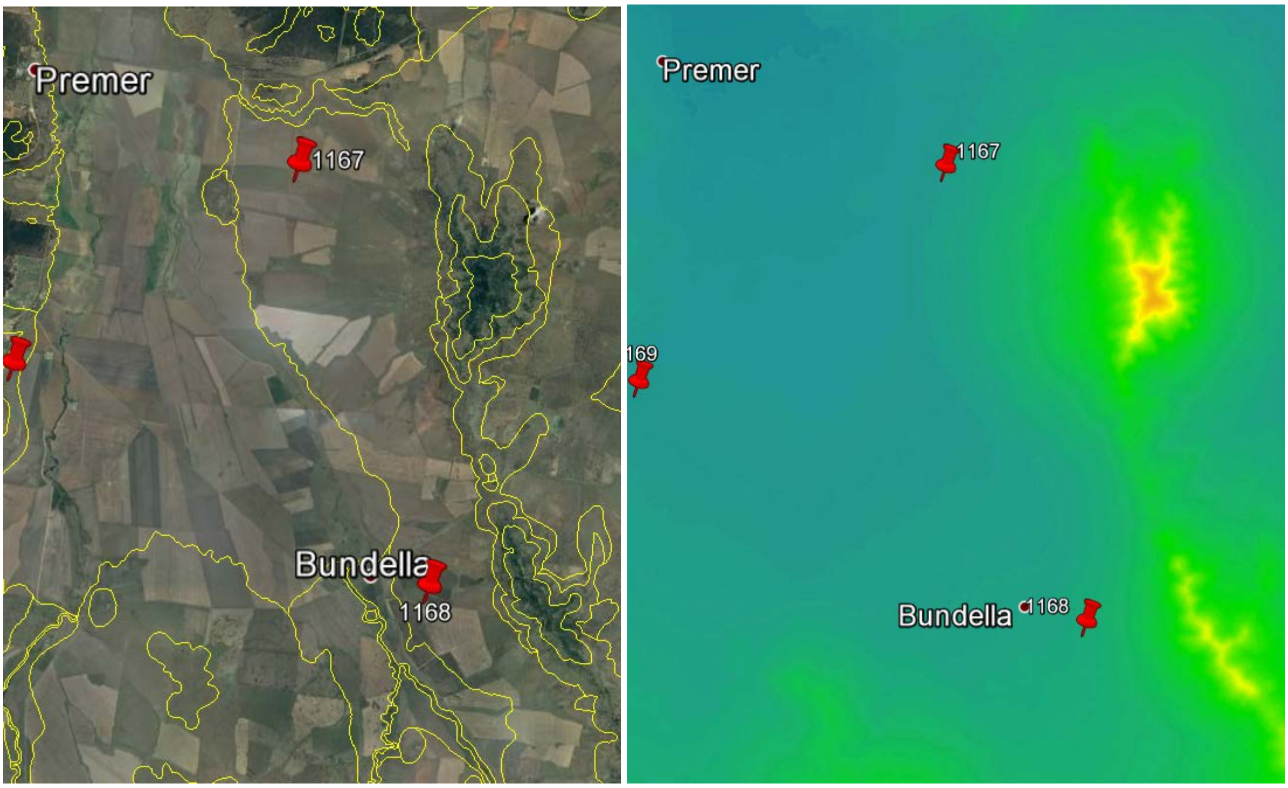


Figure 32: (left) Locations of new APSoil sites No1167 and No1168 located within Lever Gully SLU and (right) DEM indicating relative slope position of the two sites (elevation ranging from orange highest to blue lowest).

Source: Screenshots from Google Earth with APSoil sites and SLU line work from 'Soil and Land Resources of the Liverpool Plains Catchment' (© State of New South Wales and Office of Environment and Heritage 2012) and national 1 second (~30m) DEM (Gallant et al. 2011; Geoscience Australia)

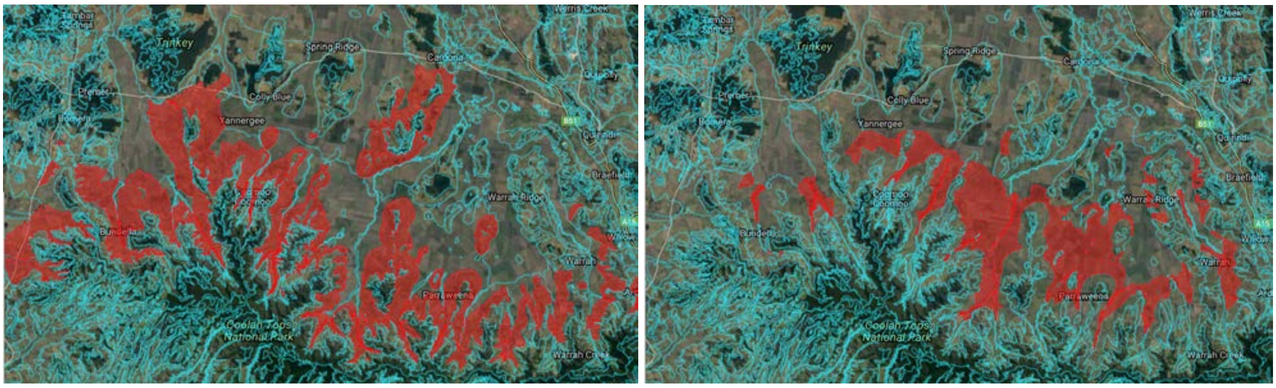


Figure 33: Spatial extent of (left) Lever Gully SLU and (right) Windy Creek SLU.

Source: Screenshots from eSpade Liverpool Plains Soil and Land Resources layer.

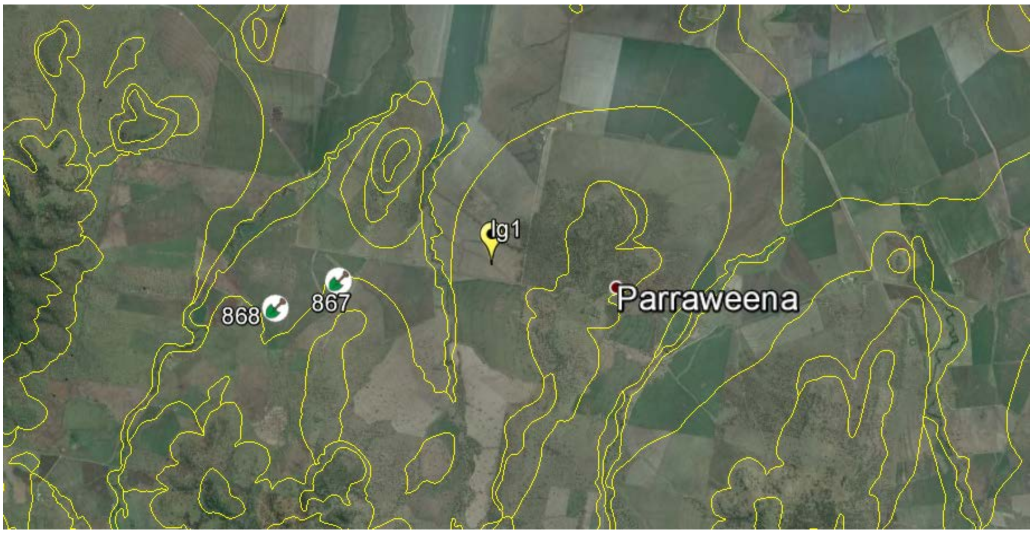


Figure 34: Location of sites in Lever Gully SLU (867 lg1 = Hudson) and Windy Creek SLU (868) near Parraweena NSW.

Source: Screenshots from Google Earth with APSoil sites and SLU line work from 'Soil and Land Resources of the Liverpool Plains Catchment' (© State of New South Wales and Office of Environment and Heritage 2012).

The material of Lever Gully SLU is derived from tertiary basalts of the Liverpool Range Beds. The mid to lower footslopes of Lever Gully SLU as well as Windy Creek SLU are covered with quaternary alluvium derived from these materials. Soils in the Lever Gully SLU include Black Vertosols, well drained Red Ferrosols where bedrock is close to the surface or in recent deposits of basalt rock colluvium, imperfectly drained Red Vertosols below landscapes containing red basaltic breccia (rock with large angular volcanic fragments) and at the footslope-plain junction saline Grey Vertosols.

APSoil sites No867 and No868 have identical results for their CLL (wheat) and DUL, suggesting they are based on a single measurement. The data for these sites do have small differences in soil chemistry (EC, Cl and ESP). The exact location of which is unknown, nor is the history of having almost identical results. Nearby a PAWC was derived based on 4 years of neutron moisture meter (NMM) measurements in a cropping trial ('Hudson') and used to satisfactorily verify APSIM's ability to predict soil water dynamics, deep drainage and crop productivity in opportunity cropping systems (Paydar et al. 2005).

The new APSoil sites Premer No1167 and Bundella No1168 (Figure 35) have PAWCs that are in a similar range to those of the sites in the Parraweena area. There are slight differences in CLL, causing the PAWC to range from 252 to 292 mm to 180 cm depth (Figure 35, Figure 36).

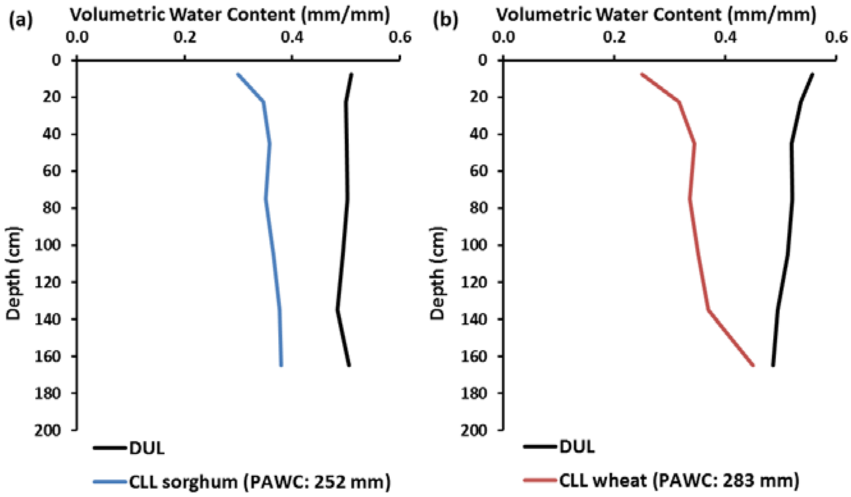


Figure 35: PAWC characterisations in Lever Gully SLU in Premer – Bundella area: (a) APSoil No1167, (b) APSoil No1168.

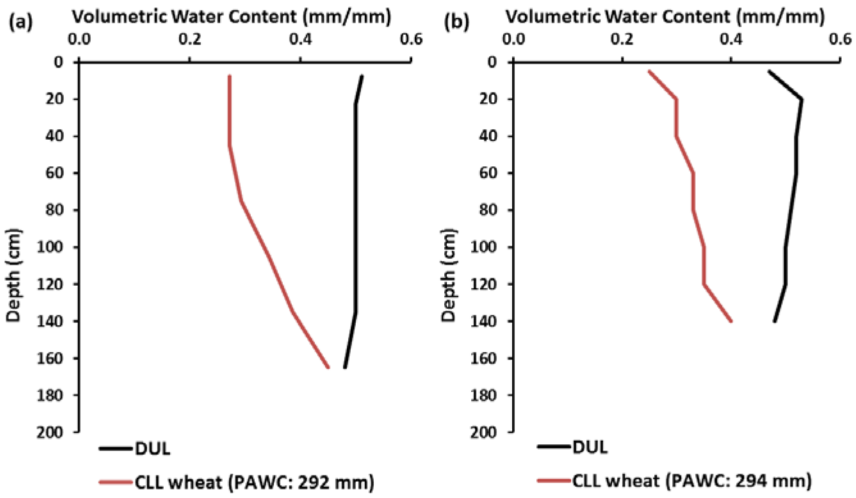


Figure 36: PAWC characterisations in Lever Gully SLU: (a) APSoil No867-868, (b) Hudson experimental site.

CLL for sorghum at Premer No1167 and for wheat at Bundella No1168 are very similar while DUL is slightly higher at Bundella (Figure 37). Available particle size data for three of the sites (Table 18) do not explain these differences. The larger PAWC of sites No867 and No868 stems from the lower CLL.

Table 18: Particle size analysis of Hudson site, and APSoil sites No1167 (Premer) and No1168 (Bundella).

lg1 - Hudson					APSoil No1167					APSoil No1168			
Depth	Coarse Sand	Fine Sand	Silt	Clay	Depth	Coarse Sand	Fine Sand	Silt	Clay	Coarse Sand	Fine Sand	Silt	Clay
(cm)	%				(cm)	%				%			
0-5	0	7	14	79	0-15	6	13	18	63	5	17	19	59
5-22.5	0	7	13	80	15-30	5	13	18	65	5	14	18	64
59-80	0	8	13	79	30-60	5	18	16	61	10	19	13	58
80-127	2	7	14	77	60-90	6	12	14	68	16	5	17	63
					90-120	4	12	17	67	4	12	17	67
					120-150	4	13	15	68	8	14	14	64
					150-180	4	15	13	68	12	16	10	62

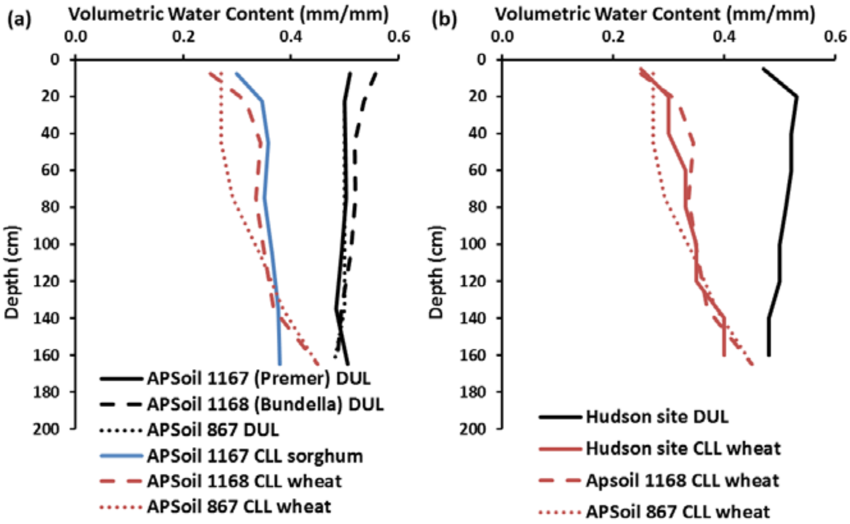


Figure 37: Comparison of DUL and CLL between sites within Lever Gully SLU.

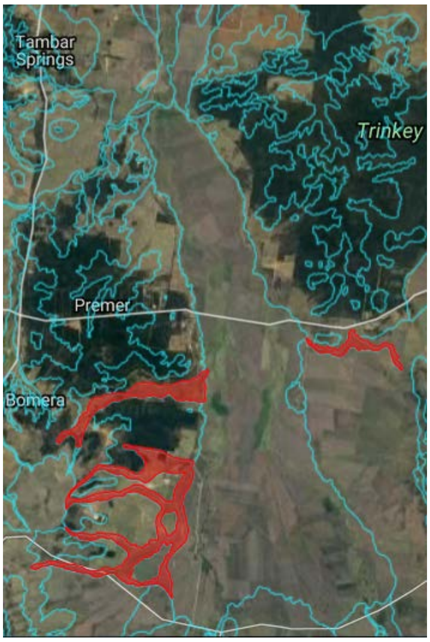
At the sites of Lever Gully SLU that were characterised, subsoil constraints were absent, giving rise to PAWC values in the 250-290 mm range. With only partial particle size and chemistry data no further differentiation could be provided. Given that the description of Lever Gully SLU (Banks 1998) also refers to saline Grey Vertosols at the footslope-plain junction, further investigation should explore to what extent the sampled sites are representative for all Lever Gully soils, or whether the similarity was a consequence of similar slope position.

31 Premer area and Upper Coxs and Sleigholmes Road SLUs

New APSoil characterisation: Black Vertosol (Premer No1169)

Existing APSoil characterisations: None

The other new APSoil site No1169 near Premer is also a Vertosol, but falls within a different SLU. In fact, on the map the paddock in which the characterisation was carried out falls in two different SLUs. The eastern part is within the Upper Coxs SLU, a unit described as 'broad alluvial plains on Quaternary basaltic alluvium of Upper Coxs Creek in the Liverpool Plains, south of Bomera Creek' (OEH 2012). The western part (with the characterisation site) lies in the Sleigholmes Road SLU, which consists of 'broad drainage plains and fans on mixed Quaternary alluvium derived from Jurassic Pilliga sandstones (see Figure 22) and Tertiary basalts' (OEH 2012). Both the Upper Coxs SLU and Sleigholmes Road SLU contain imperfectly drained Black Vertosols and poorly drained Grey Vertosols on the basaltic alluvium, much like the other alluvial SLUs (Conadilly, Yarraman, Bando, Lower Coxs). However, Sleigholmes Road SLU also has imperfectly drained texture contrast soils (Brown and Yellow Sodosols and Chromosols) on sedimentary alluvium. However, the characterisation site was had a very high clay content and CEC throughout the profile, confirming its classification as a Black Vertosol. The PAWC of Vertosols in these SLUs may be similar to those of other alluvial Vertosols, but will depend on severity of subsoil constraints. Soils further upslope transition into texture contrast soils which will have smaller PAWC. It could be worth characterising a number of profiles on a transect to capture texture changes and changes in severity of subsoil constraints.



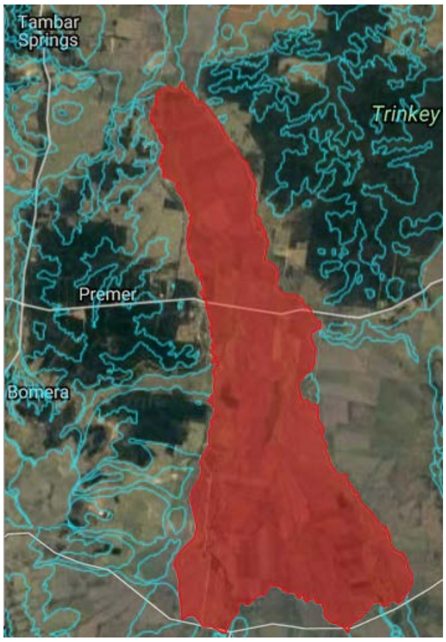


Figure 38: (left) APsoil site No1169 near Premer NSW, and spatial extent of (middle) Sleighholmes Road and (right) Upper Coxs SLU. [Note maps not at the same scale.]

Source: Screenshots from Google Earth with APSoil sites and SLU line work from 'Soil and Land Resources of the Liverpool Plains Catchment' (© State of New South Wales and Office of Environment and Heritage 2012) and eSpade Liverpool Plains Soil and Land Resources layer.

32 Mullaley area and Bando and Lower Coxs Variant A SLUs

New APSoil characterisation: Grey Vertosol (Mullaley No1170)

Existing APSoil characterisations: None

The new Grey Vertosol (Mullaley No1170) falls within the Bando SLU (Figure 39 middle), an extensive alluvial plain system along mid Coxs Creek in the Liverpool Plains (OEH 2012). Like other alluvial SLUs it has imperfectly drained Black Vertosols, with imperfectly drained Grey Vertosols in poorly drained areas. In addition (OEH 2012) describes that it contains Brown Vertosols adjacent to footslopes and residual rises. The classification of the site as Grey Vertosol suggests a position in a poorly drained area.

The site is located close to the boundary with another alluvial SLU, namely Lower Coxs variant A (Figure 39 right). OEH (2012) describes this SLU as 'stagnant alluvial plain on Coxs Creek Quaternary alluvium in the Liverpool Plains south of Mullaley, with potentially high groundwater and increased salinity hazard.' The proximity of the new site to this SLU could possibly explain its salinity at depth and its strongly reduced PAWC (Figure 12). The range of PAWC that may be expected for this SLU is expected to be mainly related to variability in subsoil constraints. EM survey could be explored to map these constraints.

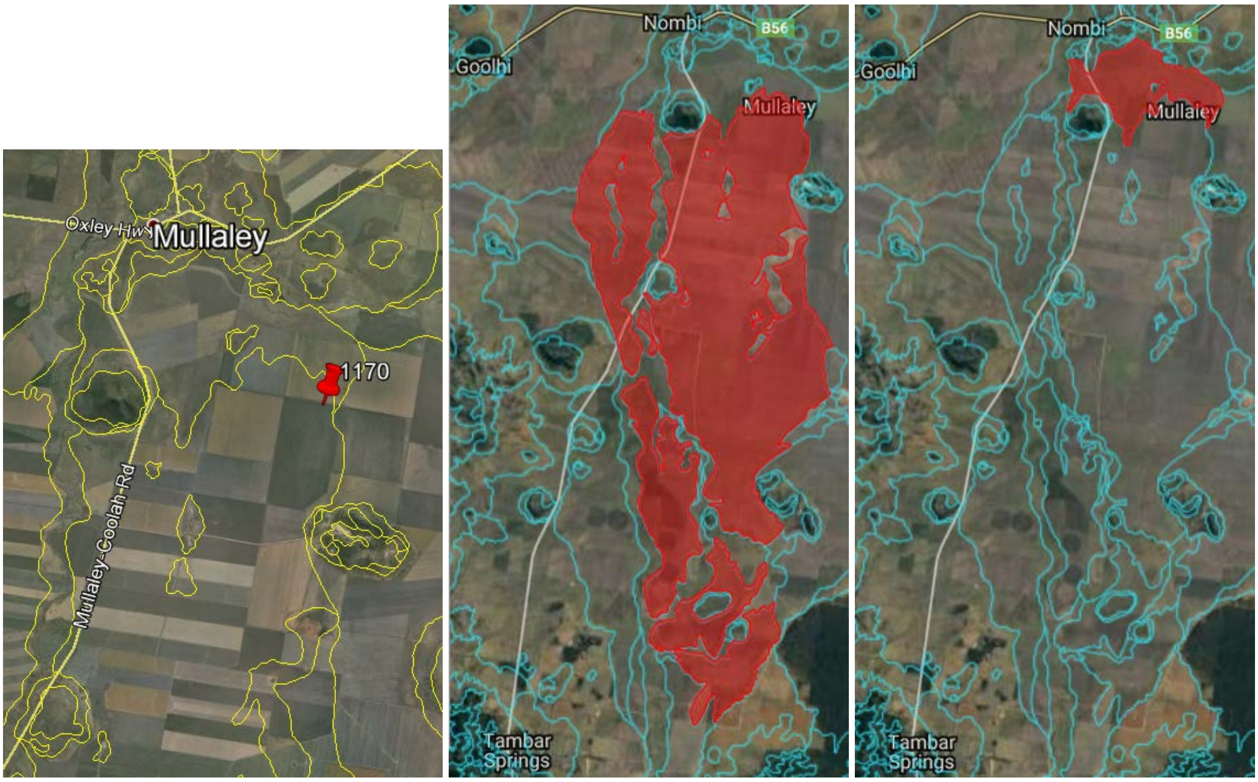


Figure 39: (left) APsoil site No1170 near Mullaley NSW and spatial extents of (middle) Bando SLU and (right) Lower Coxs variant a SLU north of APSoil site No1170. [Note maps not at the same scale.]

Source: Screenshots from Google Earth with APSoil sites and SLU line work from 'Soil and Land Resources of the Liverpool Plains Catchment' (© State of New South Wales and Office of Environment and Heritage 2012) and eSpade Liverpool Plains Soil and Land Resources layer.

33 Nombi area and Bando, Noojee and Leslie Rd variant A SLUs

New APSoil characterisation: Grey Vertosol (Nombi No1171)

Existing APSoil characterisations: None

The nearby site of Grey Vertosol (Nombi No1171) also appears to fall within the Bando SLU. However, the mapping (Figure 40) illustrates that this is a complex area where several SLUs meet. Noojee SLU is described as (Banks 1995) ‘Broad, very gently to gently inclined, very long (500 - 2000 m) footslopes and coalescing (multiple merging) fans on alluvium and colluvium from the Jurassic basalts of the Garrawilla Volcanics (see Figure 22) in the Mullaley Hills.’ Whereas Leslies Road Variant A is described as (OEH 2012) ‘level to gently inclined, slightly elevated lower footslopes, drainage plains, and alluvial fans on early Quaternary alluvium derived from Jurassic and minor Tertiary basalts of the Mullaley Hills and Liverpool Plains.’

In terms of soils, the lower slopes of these SLUs have the same soils as the Bando SLU: Black and Grey Vertosols. Whether the differences in geology affect PAWC to a measurable extent would require more detailed investigation. The soil at the characterisation site has a similar PAWC in the surface soil as APSoil No1170, but due to the absence of salinity limitations, its total profile PAWC is much larger (Figure 40b).

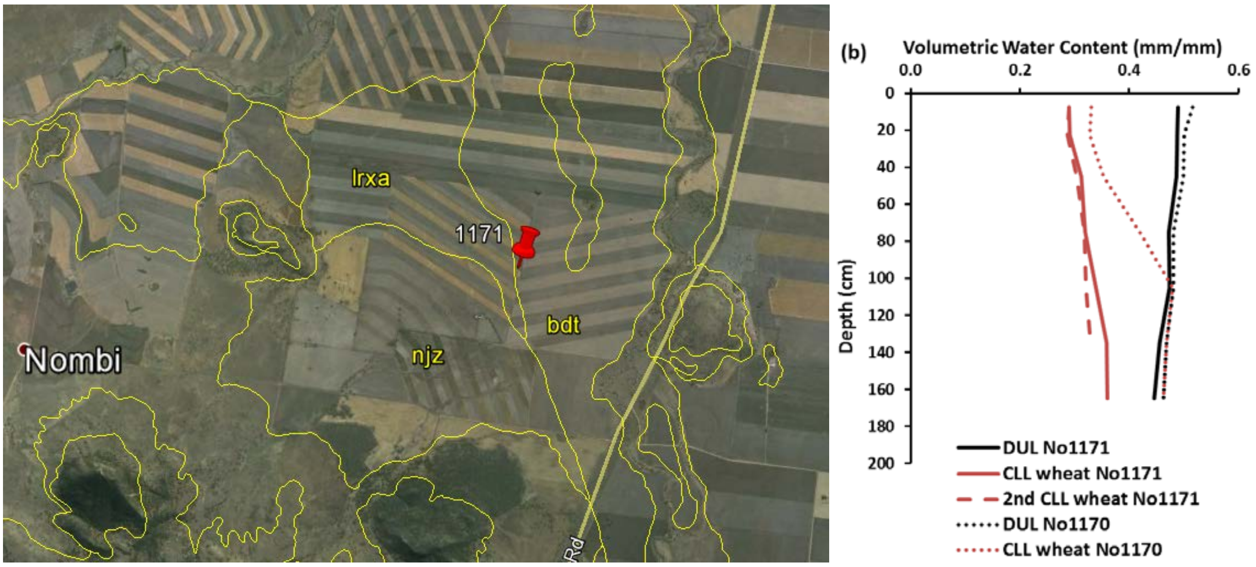


Figure 40: (left) Ballycale Park APSoil No1171 site and three nearby SLUs: Bando (bdt), Noojee (njz), and Leslies Road variant A (lrxa) and (b, right) comparison of DUL and CLL wheat of APSoil No1170 and No1171.

Source: (left) Screenshots from Google Earth with APSoil sites and SLU line work from ‘Soil and Land Resources of the Liverpool Plains Catchment’ (© State of New South Wales and Office of Environment and Heritage 2012).

34 Nojee SLU

New APSoil characterisation: None

Existing APSoil characterisations: Black Vertosol (Spring Ridge No094), Grey-Black Vertosol (Spring Ridge No127, Grey-Black Vertosol (Spring Ridge No128)

Upslope of new APSoil site No1171 was a patch of Noojee SLU. This soil-landscape occurs in several locations on the western side of the Liverpool Plains (Figure 41). Combined, these soil-landscape patches are characterised by (Banks 1995) as 'broad, very long, very gently to gently inclined footslopes composed mainly of coalescing alluvial fans.' The origin of the alluvial material is Jurassic Garrawilla volcanics (see Figure 22).

The soils in the cropped mid to lower slopes are characterised by self-mulching Grey, Brown and Black Vertosols with poorly drained Grey Vertosols often associated with poorly drained areas (OEH, 2012). The eSpade report for this SLU (OEH, 2012) also comments that 'sodicity and/or salinity is often present in deep subsoils on lower footslopes.'

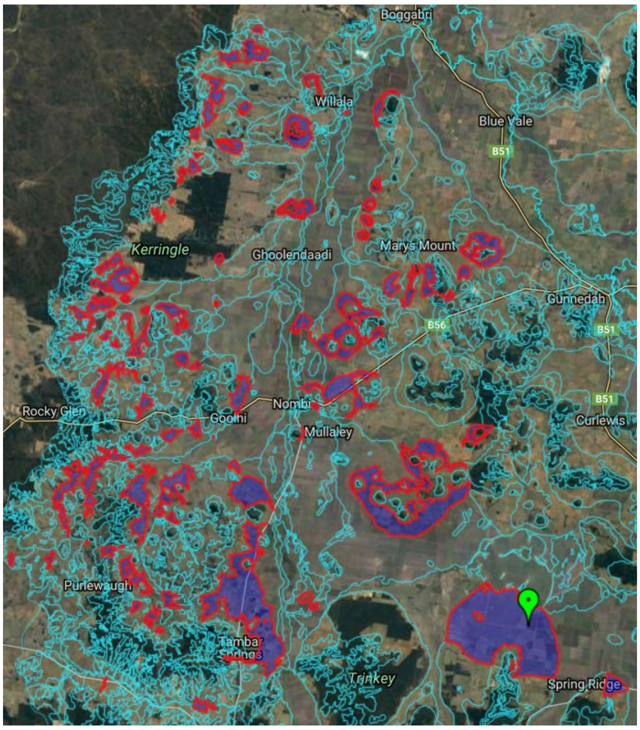


Figure 41: (left) Apsoil sites in Noojee SLU and (right) spatial extent of Noojee SLU within the Liverpool Plains (green marker indicates the location of the part of Noojee SLU with the APSoil sites). [Note maps not at the same scale.]

Source: Screenshots from Google Earth with APSoil sites and SLU line work from 'Soil and Land Resources of the Liverpool Plains Catchment' (© State of New South Wales and Office of Environment and Heritage 2012) and eSpade Liverpool Plains Soil and Land Resources layer.

The three existing APSoil sites in this SLU near Spring Ridge NSW (west of the sites in Yarraman SLU) were all examples of profiles with minor constraints to root water uptake at depth and total profile PAWC ranging from 250 to 350 mm for the deeper rooting crops and around 220 mm for chickpea and 190 mm for mungbean (Figure 42). No chemistry was available to confirm the (likely low) level of subsoil constraints. The higher PAWC compared with other profiles developed in basaltic alluvium (e.g. Lever Gully SLU, Conadilly SLU, Yarraman SLU), relates to the different origin/age of the basalt – Jurassic Garrawilla volcanics (see geology map in Figure 22). DUL and CLL were very consistent between APSoil sites No127 and No128. CLL for cotton and sorghum was slightly higher for APSoil site No94 (Figure 43). As APSoil site No94 was co-located with APSoil site No127 (they share the same DUL) the differences could be due to seasonal differences as the two characterisations appear to have been carried out for different projects.

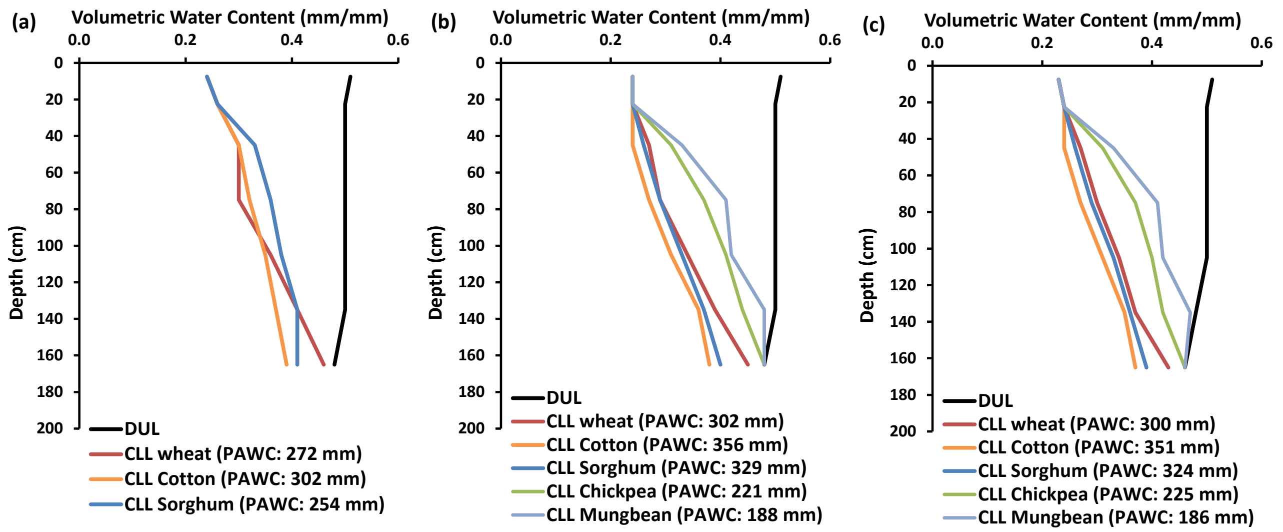


Figure 42: PAWC characterisations in Noojee SLU: (a) APSoil No94, (b) APSoil No127, (c) APSoil No128.

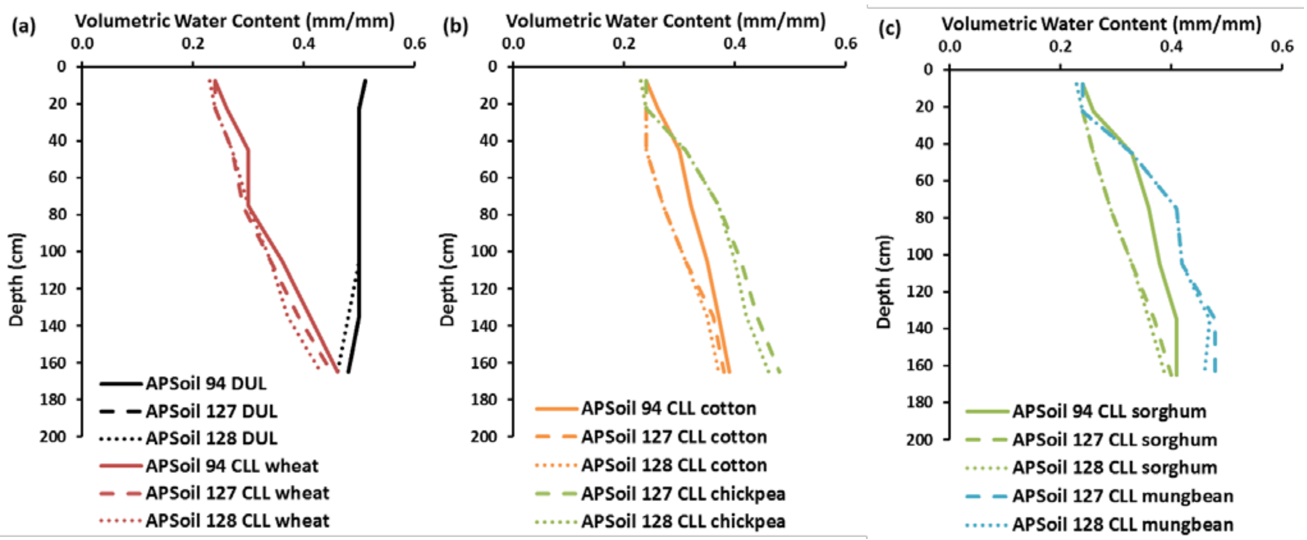


Figure 43: Comparisons of DUL and CLL across the three sites (APSoil 94, 127 and 128) in Noojee SLU.

Based on the limited dataset but with some consistency within, soils in the Noojee SLU are likely to have a large PAWC, although there may be some limitations at depth where subsoil constraints are more severe. Further investigation would need to explore if this can be predicted from slope position.

35 Lower Coxs Creek SLU

New APSoil characterisation: Brown Vertosol (Emerald Hill No1172)

Existing APSoil characterisations: Grey-Black Vertosol (Boggabri No122)

The new Brown Vertosol (Emerald Hill No1172) site is situated in the Lower Coxs Creek SLU, which is described as ‘Extensive level alluvial plains, localised stagnant alluvial plains, and inset (incised) floodplains on Quaternary basaltic alluvium of Coxs Creek in the Liverpool Plains’ (Pengelly 2010). Soils in this SLU are described as ‘moderately well-drained Black Vertosols, with moderately well-drained Grey Vertosols along drainage lines and well-drained Brown Vertosols in isolated patches’ (Pengelly 2010).

An existing APSoil site is located in the same soil-landscape unit further north on the plain just south of Boggabri NSW (Figure 44).

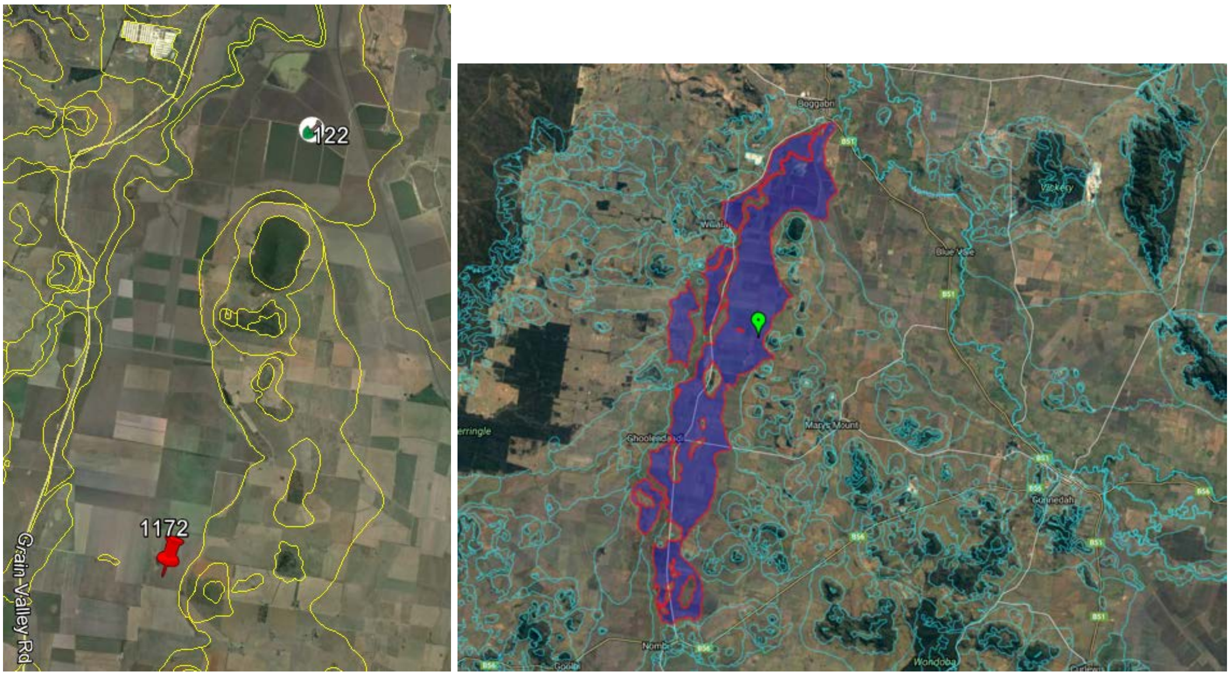


Figure 44: (left) New APSoil site No1172 west of Emerald Hill NSW and existing APSoil site 122 south of Boggabri NSW; and (right) spatial extent of Lower Cox’s Creek SLU. Green marker is location of new site No1172. [Note maps not at the same scale.]

Source: Screenshots from Google Earth with APSoil sites and SLU line work from ‘Soil and Land Resources of the Liverpool Plains Catchment’ (© State of New South Wales and Office of Environment and Heritage 2012) and eSpade Liverpool Plains Soil and Land Resources layer.

The PAWC of the new site is similar to that of the existing APSoil site further north on the plain, despite the two soils being described as different colour Vertosols (Figure 45). Both obtained a PAWC of around 250 mm for wheat. The Boggabri site characterisations for multiple crops showed CLL for sorghum and cotton to be > 250 mm and that of chickpea and mungbean lower (200 and 150 mm, respectively). Both CLL and DUL were consistent (Figure 45c).

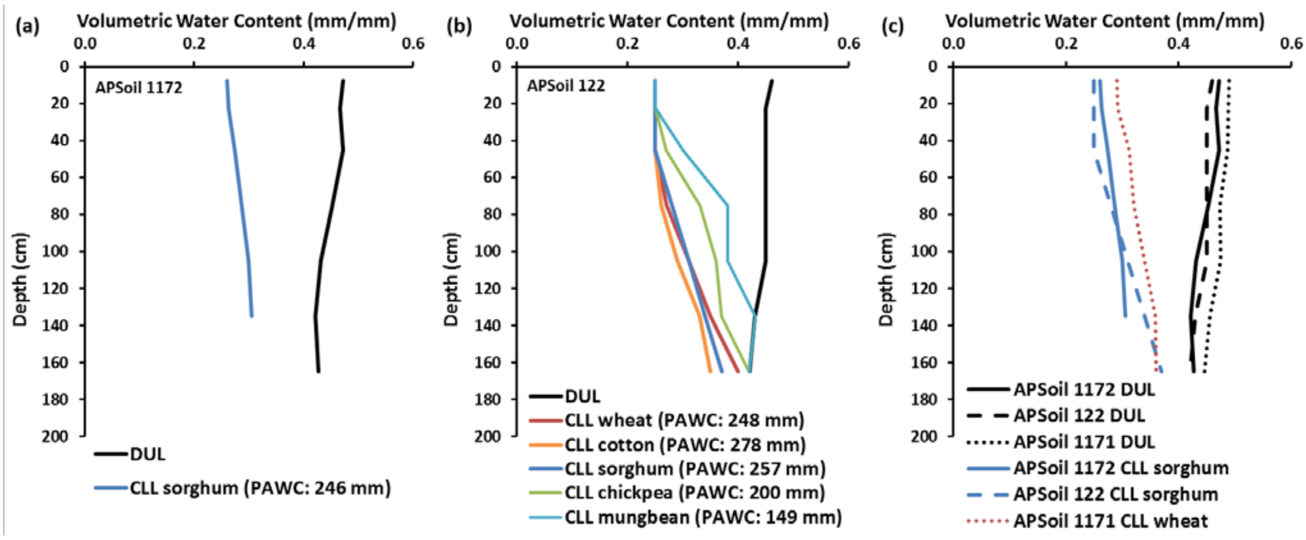


Figure 45: (a) new site Brown Vertosol (Emerald Hill No1172), (b) Grey-Black Vertosol (Boggabri No122) and (c) comparison between sites and with APSoil 1171 (Bando SLU).

While it is difficult to generalise from just two APSoil profiles, the consistency between the two profiles may suggest that profiles in similar positions without subsoil constraints could also have PAWCs around 250 mm or more. Further investigation is required to establish whether these two sites are representative for the whole SLU, or only certain positions. The description of soils in this unit as moderately well drained may reduce the risk of subsoil salinity reducing the PAWC. Further research is also required to explore crop differences in more detail.

36 Boggabri area and Burburgate SLU

New APSoil characterisation: Brown Vertosol (Boggabri No1173)

Existing APSoil characterisations: None

Predicted APSoil characterisations: None

The new Brown Vertosol (Boggabri No1173) is situated in the Burburgate SLU (Figure 46), which is described as ‘Extensive, broad, level, mixed stagnant alluvial plains and floodplains of the Namoi River on the Liverpool Plains’ (OEH 2012). The parent material is alluvium, but, unlike those alluvial SLUs described above, derived from a range of geologies in the Liverpool Plains catchment.

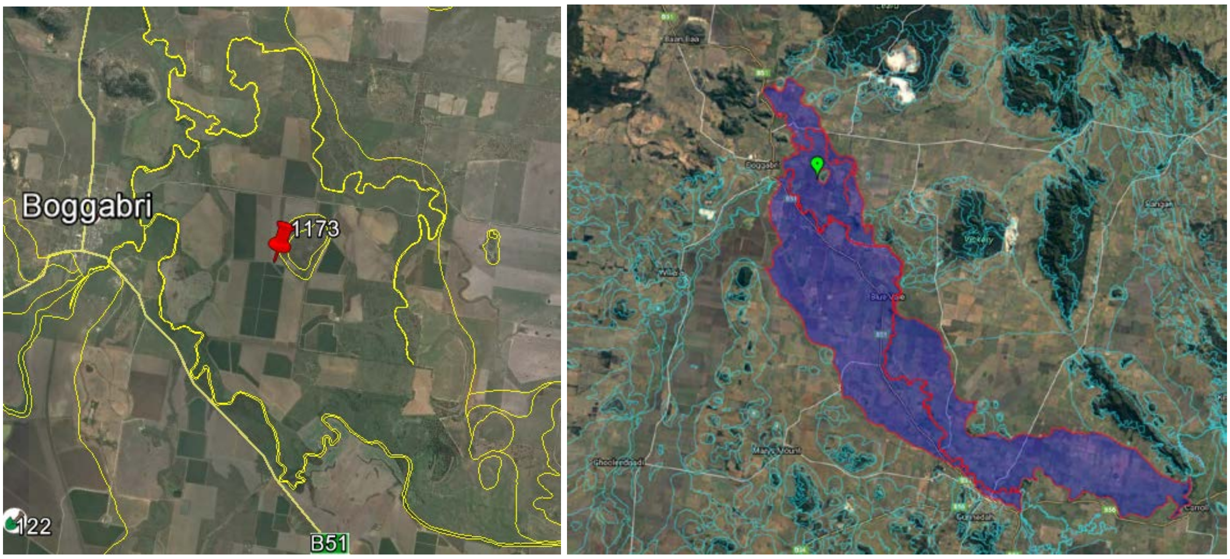


Figure 46: (left) New APSoil site No1173 east of Boggabri NSW; and (right) spatial extent of Burburgate SLU. Green marker is location of new site No1173. [Note maps not at the same scale.]

Source: Screenshots from Google Earth with APSoil sites and SLU line work from ‘Soil and Land Resources of the Liverpool Plains Catchment’ (© State of New South Wales and Office of Environment and Heritage 2012) and eSpade Liverpool Plains Soil and Land Resources layer.

The soils of Burburgate SLU are described as complex because ‘their distribution is determined by alluvial processes operating in an often relatively flat landscape’ (OEH 2012). However, OEH (2012) suggests that there is some predictability in some parts of the plain: ’Plain areas are dominated by poorly drained Vertic Brown Chromosols or moderately well-drained self-mulching Brown Vertosols or imperfectly drained self-mulching Red Vertosols. Oxbow beds, locally extensive backswamps and broad flood channels are dominated by poorly drained self-mulching Grey or Black Vertosols. Small areas of high floodplain (very seldom flooded) often have imperfectly drained Vertic Brown Chromosols. Inset (incised) floodplains (most frequently inundated) along the Namoi River tend to be dominated by imperfectly drained Black Dermosols.

The single PAWC characterisation is hence insufficient to make any statements about typical PAWC values within this SLU, especially since APSoil No1173 also showed some discrepancy between the shape of the PAWC profile, which suggests subsoil constraints, and its chemistry which is not indicative of any subsoil constraints.

37 Kelvin area and Gunnembene SLU

New APSoil characterisation: Grey Vertosol (Kelvin No1174)

Existing APSoil characterisations: None

Predicted APSoil characterisations: None

The new Grey Vertosol (Kelvin No1174) site is located in the Gunnembene SLU, but close to its boundary to Rangiri Creek SLU (Figure 47). The soil type and visual appearance on Google Earth suggest it does indeed belong to Gunnembene SLU. This SLU is described as ‘Broad, very gently inclined to level alluvial fan and plain systems dominated by heavy soils below Carboniferous and Devonian landscapes (see Figure 22) of the Duri Hills’ (OEH 2012). Whereas the Rangiri Creek SLU is described as ‘level to very gently undulating, broad floodplains and stagnant alluvial plains derived from mixed Carboniferous and Devonian geologies of the Kelvin Valley in the Liverpool Plains.’ The two units have contrasting soil types. Those of Gunnembene SLU are ‘Red and Black Vertosols, with Grey Vertosols in lower slope positions and deep, well-drained Red Dermosols (uniform structured clay soils) on upper edges’ (OEH 2012), whereas those of Rangiri Creek SLU are lighter textured and texture contrast (duplex) soils: ‘moderately well-drained Red Chromosols with moderately well-drained Brown Chromosols in low-lying areas; imperfectly drained Grey Dermosols and some Sodosols in isolated patches and near downstream boundary’ (OEH 2012). The new site being characterised as a Grey Vertosol would appear to confirm its fit with the Gunnembene SLU.

Compared with the existing APSoil characterisations No119 and No123 in the Conadilly SLU, we see a reduction in PAWC that mainly relates to the position of the DUL (Figure 47 (right)). This could relate to texture or mineralogy differences.

Further sampling of the Gunnembene SLU would be required to establish how representative this PAWC is for the soils in this units. Soils in the Bangiri Creek SLU would be expected to have lower PAWC on account of the lighter surface soil texture.

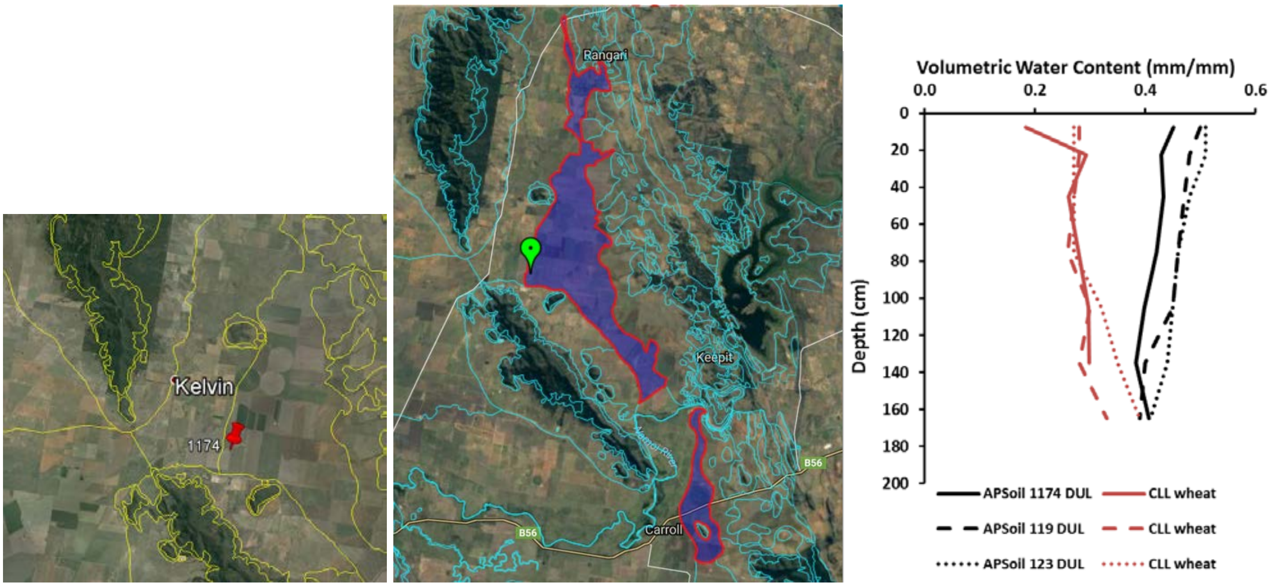


Figure 47: (left) New APsoil site No1174 near Kelvin NSW; (middle) spatial extent of Gunnembene SLU with green marker indicating site No1174. [Note maps not at the same scale.]; (right) Comparison of DUL and CLL wheat with those of the northern APSoil sites in the Conadilly SLU.

Source: Screenshots from Google Earth with APSoil sites and SLU line work from ‘Soil and Land Resources of the Liverpool Plains Catchment’ (© State of New South Wales and Office of Environment and Heritage 2012) and eSpade Liverpool Plains Soil and Land Resources layer.

38 Concluding remarks

The ten new PAWC characterisations from the CSP00170 project have enhanced the coverage of the Vertosols of the cropping areas within the Liverpool Plains considerably and the five extra APSoil characterisations near Breeza, Quirindi and Spring Ridge provided valuable insights into location and effects of subsoil constraints, especially for the Yarraman SLU. While this now gives growers and advisors a total of 26 APSoil profiles in the Liverpool Plains to choose from, picking the right one remains a challenge.

To evaluate whether the available soil-landscape mapping could be used not only to explain observed PAWC profiles, but also to generalise them into typical PAWC profiles or PAWC ranges for different soil types and/or soil-landscape units, the new PAWC characterisations were reviewed in the context of the available soil-landscape mapping information and existing PAWC characterisations in the APSoil database. The soil-landscape description for each soil characterisation site was compared with the observed PAWC and soil chemistry. In addition, where multiple characterisations fell within one soil-landscape unit, these were compared too.

From this exercise we can make the following observations:

- The characterisations showed mostly good internal consistency between the observed PAWC profiles and the soil particle size and chemical analyses.
- Knowledge of geology of parent material and soil formation explained differences in PAWC between some soil-landscape units (e.g. Quirindi vs Conadilly, high PAWC of Noojee compared with Lever Gully and the various alluvial plains units).
- Subsoil constraints (as indicated by chloride and EC) were, however, often found to affect PAWC more strongly and led to significant variability within soil-landscape units. Effects can vary depending on crop species and variety.
- The observed consistent link between PAWC and soil chemistry in relation to subsoil constraints suggests that paddock soil sampling or EM mapping (in areas with uniform parent material) in conjunction with rules of thumb that predict crop rooting limitations from soil chemistry may assist in predicting the constraints on PAWC. Yield mapping may provide an indirect measure.
- Some soil-landscape units also have, through the nature of their formation, more inherent variability (e.g. the outwash floodplain system of Quirindi SLU and the mixed stagnant alluvial plains and floodplains of Burburgate SLU) and may require multiple PAWC profiles to characterise typical profiles within them.
- PAWC estimates for unconstrained profiles in similar soil-landscape positions could vary as much as 30 mm - 50 mm. Local advisors suggested this may be sufficiently accurate for application with yield forecasts and management decisions, but this should be further tested.
- As the older existing APSoil profiles in this region often lacked particle size analysis and soil chemistry, the reasons for this variability could not be fully explored. Spatial variability in soil properties as well as uncertainty associated with the methodology, including the possibility of seasonal effects, could all play a role.
- Despite the observed variability in PAWC within SLUs often being larger than variability between SLUs, analysis of PAWC data by SLU nevertheless appears to be a useful approach due to the soil-landscape understanding it provides and which explains some of the features of the PAWC profiles. For purposes of assigning typical PAWC profiles or ranges some SLUs can, however, be grouped. Further work attempting to assign PAWC ranges to different SLU or soils within SLU could build on the hypotheses contained in Table 19 and Table 20 below.

A useful follow-up exercise to better understand the within-SLU variability would be to re-sample the older APSoil profiles so particle size, clay reactivity and indicators of subsoil constraints can be compared and variability studied in more detail. It could also be useful to study the variability in texture and subsoil constraints of the original soil survey data points (that underpin the soil-landscape mapping) as a first approximation of likely variability in PAWC. Unfortunately, most of these lack a measure of chloride which was found to be a useful indicator of subsoil constraints. While EC in many instances provided the same information, this will not work if subsoil gypsum is involved. The brochure '*Constraints to cropping soils in the northern grains region – A decision tree*' developed by the SIP08 (north) Combating subsoil constraints project (http://www.cropit.net/sites/default/files/content/soil/files/Decision%20tree%20pages_6.pdf) recommends that EC be used as a first test on any suspected constrained soils. If EC is high, then chloride analysis could be done to confirm salinity and possible chloride toxicity. If EC is high but chloride is low, gypsum, which poses no constraint to crop growth, may be present, as indicated by a high sulfur concentration.

Electromagnetic induction (EM) mapping could be explored to map variability due to subsoil salinity in some SLU where parent material is uniform enough not to confuse the signals. The use of fine scale terrain analysis could also be explored to assist with prediction or mapping of within-SLU variability, in particular for those SLUs where soil types vary with slope position or subsoil constraints like salinity are associated with break of slope. Yield mapping and aerial crop imagery (e.g. Normalised Difference Vegetation Index, NDVI) may provide an indirect measure of the constraints. These mapping approaches may, however, not always capture the variability in PAWC. Where more accurate estimates of PAWC are required a deep soil sample in the paddock or paddock zone to determine texture and soil chemical constraints may be unavoidable.

An alternative to the approach tested in Part III of generalising PAWC data into typical PAWC profiles or PAWC ranges for different soil types and/or soil-landscape units could be digital mapping of PAWC predictions from soil and landscape attributes (e.g. clay %, org C %). The development of the Soil and Landscape Grid of Australia (SLGA; Grundy et al. 2015), which provides digital mapping of soil and landscape attributes at approximately 90 x 90 m pixels across Australia, may provide the opportunity for that. The accuracy of the PAWC predictions will, however, be dependent on the accuracy of the predicted attributes upon which the prediction is based. As these rely in many regions on relatively sparse soil data, this application is yet to be tested for paddock scale use. It would be a useful exercise to compare the two approaches for the Liverpool Plains. As the SLGA comes with estimates of uncertainty for each attribute, the uncertainty in PAWC prediction could be calculated, allowing an assessment of suitability for decision making.

Having the soil-landscape mapping for the Liverpool Plains available on-line along with the detailed SLU descriptions proved highly valuable for explaining the PAWC results and development of tentative hypotheses about PAWC ranges for different SLUs. The increasing availability of regional, state and national soil information on-line, and possibly prediction of PAWC via the SLGA, opens the way to more soil specific management and digital agriculture. The exercise in Part III highlights, however, that while much of the data is freely accessible online, interpreting it, testing it and turning it into soil PAWC estimates for a location of interest will require more research and development before it will be accessible to growers and advisors.

Table 19: Sampled transferral soil landscapes (see eSpade mapping) and tentative hypotheses on PAWC for deeper rooted crops for testing in future research. Subsoil salinity may affect crops or even varieties differently.

Soil landscape	APSoil sites	Hypotheses to be tested in future work
Lever Gully SLU	1167, 1168, 867	The PAWC of Black Vertosols without subsoil constraints in mid to lower slope positions is 250-300 mm; subsoil salinity reduces PAWC in Grey Vertosols at footslope-plain junction.
Windy Creek SLU	868	
Sleigholmes Road SLU	1169?	Black Vertosols on lower slopes have PAWC > 220mm if unconstrained by subsoil salinity; subsoil salinity likely at footslope-plain junction. Higher slope positions are duplex soils with lower PAWC.
Noojee SLU	94, 127, 128	High PAWC of 300-350 mm due to parent material (Jurassic Garraville volcanics) in unconstrained or slightly constrained profiles.
Gunnembene SLU	1174	PAWC of 170-220 mm in unconstrained profiles based on limited data.

Table 20: Sampled alluvial soil landscapes (see eSpade mapping) and tentative hypotheses on PAWC for deeper rooted crops for testing in future research. Subsoil salinity may affect crops or even varieties differently.

Soil landscape	APSoil sites	Hypotheses to be tested in future work
Conadilly SLU	1165, 119, 123, 866, 869, 1305, 1309	The PAWC for Vertosols in landscape positions without subsoil constraints is 250-300 mm. Where subsoil salinity is present PAWC is reduced, possibly considerably. Where the floodplains are constricted between low sandstone hills, saline water tables are generally higher and reducing PAWC, although the effect may be compensated if clay content is higher or clay mineralogy is more reactive. The flood plain area N of Spring Ridge in the Yarraman SLU has variable subsoil constraints relating to salinity which can reduce PAWC to less than 150 mm.
Yarraman SLU	912, 1306, 1307, 1308	
Quirindi creek SLU	1166	PAWC depends on texture of parent material which in turn depends on conditions during deposition. PAWC of Vertosols are 200-250 mm, but the effect of subsoil constraints on PAWC are still to be assessed.
Upper Coxs SLU	1169?	PAWC of around 250 mm (+/- 25 or 50 mm) in unconstrained positions based on limited data; appreciable reduction (PAWC < 150 mm) due to subsoil salinity depending on depth and severity.
Bando SLU	1170, 1171	
Lower Coxs SLU	122, 1172	PAWC is 250 mm+ in unconstrained positions, based on limited data, but with substantial reductions likely where subsoil salinity is present (to be confirmed).
Burburgate SLU	1173	Wide range of PAWC depending on texture, which is related to conditions of deposition of parent material, and subsoil constraints.

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CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

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FOR FURTHER INFORMATION

CSIRO Agriculture and Food
Kirsten Verburg
t +61 2 6246 5954
e kirsten.verburg@csiro.au
w www.csiro.au/en/Research/AF

CSIRO Agriculture and Food
Brett Cocks
t +61 7 4688 1580
e brett.cocks@csiro.au
w www.csiro.au/en/Research/AF

NSW NW Local Land Services
Bill Manning
t +61 2 6742 9210
e william.manning@lls.nsw.gov.au
w northwest.lls.nsw.gov.au