A rapid method for estimating the plant available water capacity of Vertosols

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Abstract

Using cropping systems simulation models such as APSIM requires knowledge of various soil characteristics, especially the Plant Available Water Capacity (PAWC). Obtaining data required for soil characterisation is slow, laborious and costly to obtain. It would be beneficial to have a rapid and less labour intensive method of estimating soil PAWC without significant loss in accuracy. This paper reports on a method termed 'rapid soil characterisation' (RSC) to estimate the PAWC of Vertosols in the northern region. Characterisation for eleven typical soil profiles, spanning a range of PAWC values, were created based on published and new relationships between drained upper limit, bulk density, and the crop-specific 'lower limit' of soil water extraction. Soil cores from paddocks of unknown soil type were hand-assayed using a set of rules to estimate the current plant-available water status. These estimates were used in combination with measured gravimetric water content to match the samples to one of the eleven typical soil types & their PAWC. Using this RSC method, accurate estimates of soil PAWC were obtained for soils with no subsoil constraint. However, measured crop lower limit was greater than that estimated in layers where subsoil constraints were present.

Keywords

Soil characterisation, APSIM, Drained Upper Limit, Crop Lower Limit, APSOIL, Vertosols.

Introduction

Cropping systems simulation models such as APSIM (Keating *et al.* 2003) are increasingly used to conduct virtual experiments that assess the impact of management changes on environmental and economic outcomes in farming systems. APSIM is also being used by commercial growers as a decision support tool for in-season crop management via the Yield Prophet? online management tool (Hochman *et al.* 2009).

In order to use APSIM or Yield Prophet? to conduct on-farm crop simulations, it is necessary to measure the Drained Upper Limit (DUL) and Crop Lower Limit (CLL) (Dalgliesh and Foale, 1998) for the soil of the paddock in question. DUL and CLL represent the maximum and minimum soil water content available to a specific crop on a given soil. Together they are used to define the Plant Available Water Capacity (PAWC) of the soil, an important determinant of crop yield, and fundamental to the use of APSIM and Yield Prophet?. While the importance of understanding paddock PAWC is widely known, growers, consultants and researchers alike find it difficult to characterise soil PAWC due to lack of labour resources or difficulty in accessing appropriate soil sampling equipment. It is also a slow process as it takes an entire season to obtain the first set of CLL measurements, and several seasons of CLL data to generate a precise measure of CLL for single crop. An accurate method for rapid estimation of PAWC would facilitate the use of crop models for on-farm management.

Some progress has previously been made in estimating CLL from DUL (Hochman *et al.* 2001) for specific soil types, and in estimating CLL's in the presence of subsoil constraints (Hochman *et al.* 2007). The APSOIL database (Dalgliesh *et al.* 2006) uses these functions to estimate CLL values where no other data is available. However, matching a soil to one of the many available in the database is difficult without some knowledge of the soil's characteristics. This paper reports on a rapid method for selecting appropriate soil characterisations from the APSOIL database, based on a hand assay of plant available water content obtained from pre-season soil samples, in conjunction with gravimetric moisture content data. An improved relationship between DUL and CLL for northern region Vertosols is also described, which was derived as part of the process of developing the rapid soil characterisation method.

Materials and Methods

Rapid soil characterisation was developed through three stages: (1) development of updated relationships between DUL and CLL on Vertosols in the northern region, (2) the consolidation of 101 Vertosols from APSOIL into a set of 11 typical soil types for easy selection of an appropriate soil, and (3) development of a simple hand-assay for use on shrink-swell soils when collecting soil cores for initial soil water content. The use of the typical soil types and data from the hand assay, in conjunction with measured gravimetric soil moisture is collectively termed 'Rapid Soil Characterisation'.

1. Revisiting the relationship between DUL and CLL on Vertosols

While the relationship between DUL and CLL has previously been described for various crops grown on black and grey Vertosols (Hochman *et al.* 2001), it was decided to revisit the analysis with the now substantially larger soil data set available, and establish the relationship between DUL and CLL across the entire range of Vertosols in the APSOIL database.

Vertosols from QLD and Northern NSW (101 in total) with measured DUL, and measured CLL for wheat, sorghum or cotton, were extracted from the APSOIL database. The wheat CLL was measured in 77 of the 101 soils, but soils with CLL measured for cotton (17 soils) or sorghum (7 soils) were also included in the analysis as CLL in the top 150 cm is similar for these crops (Hochman *et al.* 2001). Gravimetric water content (grams of water per gram of dry soil) at $DUL_{g/g}$ and $CLL_{g/g}$ was back-calculated for each soil, by dividing the APSOIL volumetric measures of DULmm^3/mm^3 and CLLmm^3/mm^3, by bulk density. (DUL and CLL for each APSOIL entry is field measured as gravimetric moisture content, but the data is stored in the database as DUL or CLL mm^3/mm^3, hence back-calculation was necessary to regenerate the original gravimetric data). Linear regressions between CLL $_{g/g}$ and DUL $_{g/g}$ were then conducted for each individual depth layer. Depth layers used for each soil characterisation were the standard APSOIL configuration of 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm below the soil surface.

2. Consolidation of data into 11 typical soil types

The large number of soil types in APSOIL makes it difficult to sort through and identify the best soil type to use in an individual paddock crop simulation. A range of 'typical' Vertosols was generated from the APSOIL database and ranked from highest to lowest PAWC, simplifying the selection of an appropriate soil for one-off or pre-characterisation simulations. The 104 soils were sorted according to DUL $_{g/g}$ of the 0-15cm depth layer. Soils with similar DUL $_{g/g}$ were grouped and the mean of DUL $_{g/g}$ was calculated across each group for individual depth layers thus creating 11 DUL $_{g/g}$ soil profiles. Each group of soils had a range of less than 0.033 g/g for DUL $_{g/g}$, and soils were grouped such that the PAWC of one typical soil differed from the next typical soil in the sequence, by 10-20 mm.

CLL $_{g/g}$ for each typical soil was then generated using the relationships between DUL $_{g/g}$ and CLL $_{g/g}$ for individual soil layers reported above. Bulk density of each layer was derived from the existing relationship described by Gardner (1985) and also used by Dalgiesh and Foale (1988), using the air-filled porosity of 0.05 of Gardner (1985) which applies to a greater range of Vertosols.

3. The development of a hand assay to select an appropriate soil type

The use of APSIM or Yield Prophet[?] to simulate production from a paddock requires sampling at (or near) sowing to measure soil water content and nitrogen status. The use of a simple hand assay at this time to rate the soil moisture content of the soil gives additional information that can be used to identify an appropriate soil type from the APSOIL database. Sowing soil water (measured across multiple depth layers) may be dry (close to CLL), wet (close to DUL) or intermediate. If this relative wetness is unknown, the same gravimetric moisture content data may logically fall close to DUL on a low PAWC soil, or close to CLL on a high PAWC soil. However, by estimating whether the soil is wet or dry based on touch, the gravimetric soil water data can be matched to a typical soil PAWC graph.

Through trial and error, a hand assay has been developed for use when taking soil cores for starting soil water (Table 1). While it is only designed for use on clay soils, different rules could be developed for different soil textures.

Results and Discussion

High correlations were observed between $CLL_{g/g}$ and $DUL_{g/g}$ for the 101 soils in the database (Table 2, Figure 1). However, in some soils, particularly in the 120-150 and 150-180cm depth layers, measured $CLL_{g/g}$ was frequently equal to $DUL_{g/g}$ (results not shown). It also probable that in shallower layers, measurement error has skewed the CLL measurement in the direction of DUL in some soils due to delays in installation of rain-out tents, poor crop nutrition, or runoff infiltrating under the rain-out tents prior to sampling. As such, the regression line may not represent the lowest (or boundary) CLL applicable across a range of soil textures, particularly in the deeper layers. Further work will be conducted to develop a CLL 'boundary' function, and a predicted CLL response to subsoil constraints similar to that developed by Hochman *et al.* (2007).

Table 1: Rules for estimating soil moisture content on Vertosols using a hand assay.

Estimated Soil Moisture Status	Soil properties during hand assay
0% (at, or below CLL)	Soil core is very hard, barely able to create thumbnail imprint
25%	Soil core can be broken easily with one hand into pieces but doesn't crumble easily
50%	Soil core is crumbly – when compressed with one hand it Crumbles easily and feels moist
75%	Soil core is malleable and adhesive – when compressed it forms a ribbon rather than crumbling
100% (at, or above DUL)	Soil core is very malleable and feels sticky or 'squishy'

Table 2. Regression equation and r^2 value for the relationship between $CLL_{g/g}$ and $DUL_{g/g}$

Depth Layer	Regression equation	r^2
0-15 cm	= 0.4601*DUL + 0.0186	0.85

15-30 cm	= 0.5116*DUL + 0.0103	0.84
30-60 cm	= 0.5869*DUL + 0.0008	0.85
60-90 cm	= 0.5804*DUL + 0.0206	0.86
90-120 cm	= 0.6532*DUL + 0.0328	0.81
120-150 cm	= 0.6899*DUL + 0.0427	0.87
150-180 cm	= 0.8532*DUL + 0.0244	0.89

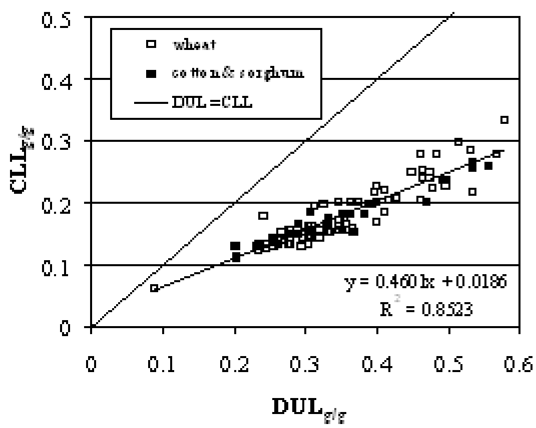

Figure 1: $CLL_{g/g}$ vs $DUL_{g/g}$ for the 0-15cm layer

Using the typical Vertosols greatly simplifies the identification of appropriate soils for use in situations where a full soil characterisation is not available. Figure 2 demonstrates the use of rapid soil characterisation to match sowing soil water content with typical PAWC graphs for two soil types. Sowing soil water data and matched typical vertosol PAWC are displayed along with the CLL measured for the paddock.

The measured CLLs show greater variability from layer to layer than the typical CLLs, as seen in Figure 2. Accurate determination of CLL requires measurements to be made over multiple seasons, as the pattern of water extraction down the soil profile can vary with the variable seasonal rainfall patterns. It is possible that where the typical Vertosol differs from CLL measured in a single season, the typical Vertosol values may actually provide a better estimate of the underlying soil characteristics.

Preliminary assessment across 4 soil types where hand assessments of starting soil water were conducted and CLLs were measured, showed good agreement between predicted and estimated plant available water at sowing (PAW) with a 1mm, 7mm and 20mm difference between estimated and measured PAW in three of the soils. In the fourth soil a 44mm difference between estimated and measured PAW was observed, however 34mm of this difference occurred in layers deeper than 90cm and in the presence of a subsoil constraint.

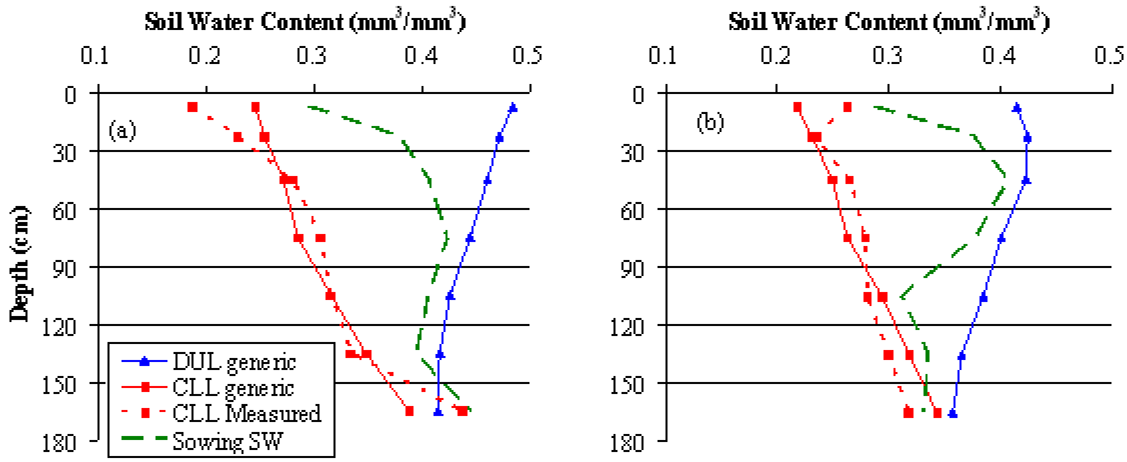

Figure 2: Typical PAWC graphs matched to sowing soil water content and measured CLL using Rapid Soil Characterisation at (a) Brookstead and (b) Collarenebri.

Conclusions

Accurate new relationships have been developed that allow the prediction of CLL from measured DUL across a wide range of Vertosols in the northern region. Where soil characterisations are unavailable, a hand assay coupled with gravimetric water content can be used to match any Vertosol with one of 11 typical Vertosols for use in APSIM simulations, a process termed 'Rapid Soil Characterisation'. Further work is necessary to (1) test the use of this method more widely with inexperienced operators, and (2) to add a subsoil constraints adjustment to CLL, particularly in deeper soil layers where it is probable that the CLL-DUL regression does not represent the true boundary for CLL in the absence of subsoil constraints.

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