Soil Water Express – a system to generate approximate soil water characterisations and current soil water estimates from minimal input data

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Abstract
A simplified method for the estimation of Plant Available Water Capacity (PAWC) and Plant Available Water (PAW) is under development in response to the call, from agronomists and farmers, for an approximate method of Soil Water (SW) estimation that is free from the requirement for specialised equipment and knowledge.

Soil Water Express is a spreadsheet-based system that estimates PAWC and PAW. Correlation between the most relevant soil parameters in the APSoil database (Dalgliesh *et al.* 2012) were used to estimate the Crop Lower Limit (CLL) and Drained Upper Limit (DUL), which were then modified to reflect the effects of sub-soil constraints before being displayed graphically and numerically as an estimated SW profile. PAWC was derived as the difference between the two limits whilst PAW was derived as the difference between CLL and current SW, the latter being represented by raw SW monitoring device readings.

In an unusual approach to calibration, the above profile CLL and DUL estimates at each depth were used with the corresponding readings from electronic volumetric SW devices to generate a calibration equation for each sampling depth of the particular soil profile. This approach was taken to avoid the inevitable miss-match issues that occur when SW figures are estimated via different systems, particularly those based on a limited number of parameters.

The soil water output data from a properly calibrated and adjusted Soil Water Express profile is expected to usefully inform soil water-related farm management decisions; the release of the web-based version will improve the utility of this tool.

Key Words
Soil water estimation, plant available water capacity, APSoil, soil water monitoring, soil characterisation

Introduction
There is an increasing use of soil water monitoring devices in agriculture that output soil water status in units that bear little direct relevance to soil water availability. Experienced users develop an understanding of the meaning of such outputs in terms of soil water status. However, it was considered that a tool to bridge the gap between such output and the common unit of soil water measurement **-** mm of available water **-** would be useful to land managers, who make important decisions based on a soil's water holding capacity (its PAWC) and water status (its PAW) through time.

The Soil Water Express is based on a Microsoft Excel spreadsheet, however the release of a web-based version, for testing, is imminent. It provides estimates of the CLL and DUL, then calculates PAWC as the difference between these two limits. The difference between the CLL and the current SW, as estimated by an electronic volumetric SW monitoring device, is then used to estimate PAW.

The SW Express consists of three sections: the SW Profiler is the main input section for user data; the Site Calibrator provides automatic calculation of the calibration equations for each soil depth sampled; and the SW Worker provides numerical and graphical PAWC and PAW output plus user-input cells that enable calculation of the PAW estimate from raw SW monitoring device readings.

The key to the potential success of this system is its 'hybrid calibration', which is designed to allow a valid calibration to arise from data that is compromised by the necessary simplicity of the system. Such an approach to calibration avoids the internal miss-match issues that occur when SW is estimated via different systems, such as when CLL and DUL are generated via pedotransfer-functions and current SW is estimated via a calibrated electronic monitoring device.

After an initial establishment and calibration season, estimation of current SW simply requires the taking of SW monitoring device readings at the sampling points, averaging them by depth, and entering them into the SW Worker section of SW Express (Figure 1).

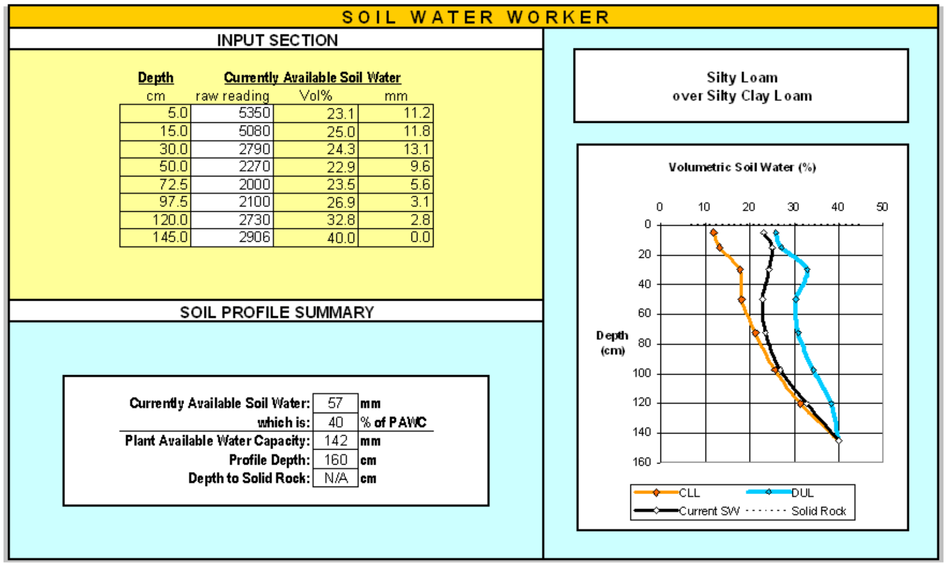

Figure 1. The SW Worker section showing numerical and graphical output, plus the Input section for monitoring device readings. The Current SW line (middle-black) shows recent rainfall moving down through the profile.

Field-testing of the tool will take the form of user trials after release of the web-based version, with further refinement occurring over time. Best results will come from users who gain experience with the tool on their own soil, particularly those that tailor its response using in-built adjustments.

Method

The Mechanism

Using South Australian soil data from the national APSoil database in the Minitab statistical package, the most relevant correlation between the most relevant parameters in the APSoil database for estimation of SW were determined to be: Clay, Sand and Depth for CLL and Clay, Sand and Bulk Density (BD) for DUL. The sand and clay figures were obtained via Particle Size Analysis (PSA). After removal of incomplete data lines and those deemed to contain outliers and/or errors, the balance of 387 lines of data were used to generate regression equations for the SW Profiler section. These equations, with R^2 indicating the strength of relationships, are as follows:

$$CLL_{vol} = 0.0826 + 0.00255(Clay) – 0.000713(Sand) + 0.000382(Depth); \quad R^2 = 77.5\%$$

$$DUL_{vol} = 0.453 + 0.00245(Clay) – 0.00144(Sand) – 0.123(BD); \quad R^2 = 81.1\%$$

Note: ‘Sand’ and ‘Clay’ are ‘Weight %’ data from the PSA; Depth in ‘cm’; Bulk Density in ‘g/cm^3’

The above equations were used to produce SW estimates for each depth, and were subsequently modified by the user to allow for the two most common root constraints, that is, soil chemistry and volumetric rock content. Adjustment via the Generic Depth Factor (GDF) function is made to the CLL values to represent the depletion of root density with depth and thereby close the conceptual SW ‘bucket’; adjustment via the Crop Factor (CF) function adjusts CLL for different crop types.

The GDF is a log-based function, scaled such that maximum affect occurs at maximum sampling depth, reducing the overall PAWC estimate by 19%. This was the average difference found between actual PAWC and that estimated from the quasi-parallel CLL/DUL lines formed via the non-depth-related parameters. Though the GDF acts on CLL alone, its derivation includes reference to the difference between DUL and CLL (which negatively correlates with sand content) so that the general soil texture proportions the strength of the GDF adjustment. The CF shifts all CLL values up or down to represent crops of lower or higher water-use relative to wheat, which has a CF of ‘1’. CF values for other crops can be greater than, equal to, or less than that for wheat. The GDF and CF are user-adjustable in the web-based version to aid site-specific calibration.

Basic accounting for soil chemistry was achieved via user-inputs for Exchangeable Sodium Percentage (ESP), Electrical Conductivity (EC), Chloride (Cl) and Boron (B), typically obtained along with PSA data. The most severe constraint, determined by the ratio Actual : Threshold for each sampling depth, adjusts CLL at the threshold depth and those below, since root density remains diminished below a root-hostile layer. The same second-order polynomial was used to adjust CLL for the influence of the four chemistry factors, that for EC being given below as an example:

$$CLL_{remaining} = -(EC_p)^2 + 1x10^{-14}(EC_p) + 1$$

where $CLL_{remaining}$ is the CLL remaining as a proportion of one; (EC_p) is the EC value as a proportion of the interval between the threshold EC value and 3 times that threshold, which was arbitrarily defined as the chemical severity at which no roots, and therefore no CLL, would remain. The four chemistry threshold values are user-inputs in the web-version of the SW Express to further aid site-specific calibration.

Since one of the drivers for the development of the SW Express was to avoid comprehensive soil sampling, it is unlikely that BD data will be available. However, BD is a necessary factor in the DUL equation above, so an automatic approximation of BD based on clay content was used in the Profiler section, calculated using the following function:

$$BD = 1.67 – 0.00469(Clay); R^2 = 29.3\%$$

(*Note: ‘Clay’ is ‘Weight %’ data from the PSA*)

Though the relationship between clay and BD exhibited high variation, it had a clear trend and it was considered a necessary component of this SW estimation system if comprehensive soil sampling was to be avoided. The variation arises from a number of factors not accounted for in this SW estimation system, such as soil structure, mineralogy and biology, but the error introduced by this simplification acts similarly on CLL and DUL, and both PAWC and PAW are difference calculations, so the impact on SW estimates are buffered somewhat.

After determination of the equation-based estimates of CLL and DUL and their subsequent modification to reflect the influence of soil chemistry, rock content and depth, the finalised SW estimates appear in the SW Profiler section. The previously mentioned process of ‘hybrid calibration’ then occurs, in which the finalised CLL and DUL values are used with their corresponding SW monitoring device readings to generate a calibration equation for each of the sampling depths. These equations are then used by the SW Worker section to perform any subsequent estimation of PAW via the entry of raw SW monitoring device readings.

The Process

The SW Express system requires an establishment season during which the following occurs:
a) Taking of hand-augured samples at the plots and depths chosen to represent the soil across the area of interest and the bulking of samples by depth.
b) Making an estimate of rock volume and subjecting the bulked samples to PSA and chemistry tests.
c) Installing electronic SW sensors in each plot at the depths previously sampled.
d) Wetting the sampling plots and allowing them to drain.
e) Taking DUL readings.
f) Sowing the crop across the plots and allowing it to grow to maturity without post-anthesis rainfall (through the use of a rain exclusion shelter).
g) Taking CLL readings, which are then used along with the DUL readings, rock volume, PSA and chemistry data in the Profiler and Calibrator sections to create an estimated SW profile.
After the calibration season, PAW estimates simply require entry of SW monitoring device readings into the Worker section of the SW Express.

Discussion

Comprehensive systems for modelling complex soil-crop interactions are often impractically expensive because of the extensive field and laboratory data required. The Soil Water Express intends to avoid this issue, whilst providing useful soil water data, through application of its hybrid calibration system. This system is based on elements of the following two known methods:

- Calibrating SW monitoring device readings with measured SW from soil samples.
- Developing pedotransfer functions via statistical analysis of regional soil data to create SW profiles.

The first method requires costly and laborious sampling. The second method can provide the CLL and DUL limits, but cannot practically provide intermediate SW estimates and will not reliably give sensible results when such data is used with SW estimated via another method. Such poor results arise from the lack of connection between the pedotransfer-function-based system and other SW estimation systems. Even if well managed, miss-match will occur between different systems due to inherent error, which is exacerbated by simplicity, and because there is nothing to 'tie' them together.

From this quandary arose the concept of the hybrid calibration system, which ties statistically generated pedotransfer-function SW figures for CLL and DUL to volumetric SW monitoring device readings to form the calibration equations, thus avoiding the miss-match issues and allowing SW estimation at any time simply by taking SW readings and entering them into the SW Express. In effect, the system converts absolute figures to relative figures with their upper and lower limits set by DUL and CLL readings respectively.

On the positive side, this system allows a valid calibration to occur, even though the data is compromised to some degree by system simplicity; on the negative side, it can allow an apparently valid calibration to occur irrespective of the validity of the data.

The SW Express should be considered a means of gaining insight regarding SW trends, the affects of constraints to root growth and the influence of soil texture on SW, rather than a means of determining absolute SW figures.

Conclusion

The Soil Water Express system for estimation of Plant Available Water Capacity and Plant Available Water provides a basis for the estimation of these parameters from minimal data and at relatively low cost. It represents the minimum complexity and encumbrance considered necessary for such a system to yield useful SW output and relies on the hybrid calibration, adjustability, user experience and familiarity to achieve this.

It is envisaged that testing, localised calibration and further development of the web-based version will improve the utility of the SW Express, but behind the user interface is a greatly simplified model of reality that leans more towards the qualitative than quantitative; is better used for relative than absolute output and will become most useful with familiarity, experience and informed adjustment.

References

Dalgliesh, N.P., Cocks, B. and Horan, H. (2012) APSoil-providing soils information to consultants, farmers and researchers. In proceedings of the 16th Australian Agronomy Conference, Armidale, NSW. October 2012.