Estimating changes in Plant Available Soil Water in broadacre cropping in Australia

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Abstract

Rainfall is low and unreliable in most of Australia's grain growing regions, making management of crop water supply vital to profitability. Difficulties in measuring plant available water (PAW, mm) has led to using simulation models for estimating PAW and predicting crop water supply, leading to the development of reliable tools for farmers to estimate plant available soil water. This paper examines the accuracy of predictions of PAW from a water-balance model during summer fallows in the northern region and fallows and cropping in the southern and western regions. The water balance model HowLeaky? explained 69% (R^2) of observed changes in PAW with a RMSE of 32 mm across three sites (45 fallows). Analysis of in-field variability indicates that errors in estimating PAW with a water balance model are small relative to natural variability. The errors in estimating PAW and changes in PAW using computer simulation are modest relative to measurements and models can make a significant contribution to estimating and managing PAW.

Keywords

PAW, model, water balance, SoilWaterApp.

Introduction

Crop yields in Australia are most limited by water supply, and efficient use of this resource is a key element of farm management. In developing a smartphone App (SoilWaterApp) to provide estimates of Plant Available Water (PAW) for farmers and consultants, it was prudent to better understand the accuracy and reliability of estimates within an App. It has largely been assumed that crop models that accurately predict factors such as runoff or crop yield are also accurately predicting other components of the water balance, including PAW.

Most components of the water balance are difficult or expensive to measure, including; soil water content, runoff (temporally variable), deep drainage (spatially variable), evaporation and transpiration (require advanced instruments and complex analysis), and all are labour-intensive. The aim of this study was to assess the accuracy in predicting changes in PAW with a water balance model "Howleaky?" (McClymont et al. 2016) before inclusion in SoilWaterApp.

Methods

HowLeaky (V5.49.03, http://howleaky.net) was used to simulate all water balance components through fallow and crop periods. The model was evaluated by exploring three questions:

1. Is a simple Fallow Efficiency percentage (gain in PAW/rainfall) sufficient to estimate changes in PAW?
2. How accurate are the model estimates of changes in PAW during fallows and sequences of fallows and crops?
3. How do model errors compare with natural variability in measurements of PAW and the plant-available water-holding capacity (PAWC)?

Three groups of data were accessed for this comparison.

Summer fallows

Weather, agronomy, soil descriptions and soil water data were available for three long-term studies in Queensland: (i) Greenmount (Freebairn and Wockner 1986); (ii) Greenwood (loc cit.); and (iii) Wallumbilla (Freebairn et al. 2009). Treatments of stubble burnt after wheat harvest and zero till tillage were simulated because these are the most strongly contrasting.

Volumetric soil water content (SWC, %) was calculated from gravimetric samples from 9 soil cores (6 depth increments) and corresponding bulk density in the crop root zone (1.5 m depth). Data were accessed from a database of agro-environmental studies (http://howleaky.net/index.php/library). These sites had 7-17 years of soil water data collected at least three times per fallow (post-harvest, mid-fallow and pre-plant). Soil lower limit (LL) and Drained Upper Limit (DUL) was estimated at each site from gravimetric samples, collected at locations separated by 5 to100 metres. The duration and intensity of data collection at these three sites allowed for an examination of spatial variability in measurements of soil water content and estimates of PAWC in order to provide some context to errors associated with water balance model estimates.

Sites with measurements in winter crops and summer fallows

Weather and SWC data from logged sensors were obtained for three sites in Western Australia by digitizing detailed graphs available on the Precision Agriculture Australia website (http://precisionag.com.au/services/moisture-probes-project). These sites were selected to represent the northern cropping zone (Warradarge), the eastern zone (Merredin) and the south-east zone (Lake Varley, near Holt). Data from Warradarge and Merredin were available for a 12-month period (May 2014 - May 2015). Lake Varley has two years of data (May 2014 - May 2016. The rainfall data for the simulation were recorded at the site, while evaporation and other weather data were downloaded from SILO sites nearby (https://www.longpaddock.qld.gov.au/silo/ppd/). Rainfall and SWC data were logged at several sites in Victoria as part of the "Risk management through soil moisture monitoring" project (VDEDJTR 2014). Sites were selected for the quality of their data and relevance to dryland broadacre cropping (Dale Boyd pers. comm.); Hamilton in the high rainfall zone, Raywood in central-north Victoria and Youanmite, north-east Victoria. Approximately 18 months of daily SWC and rainfall data were available at each site.

Results and Discussion

Fallow Efficiency (FE) rule of thumb

FE, defined as the gain in PAW as a fraction of fallow rainfall (%), averaged 23% for bare fallow treatments and 32% for zero till (Table 1). While both are close to the 25% that is often used as a rule of thumb, the range in values was considerable - indicating that FE is likely to be unreliable for predicting changes PAW in individual seasons.

Table 1. Fallow efficiency values at Greenwood (1979-84).

Fallow management	Average	Range
Stubble burnt	23 %	12-28 %
Minimum/no tillage	32 %	16-43 %

Estimating soil water gain over summer fallows - Queensland

Observations from 45 fallows across three Queensland sites showed an average RMSE between predictions and observations of 32 mm (Figure 1). When each site and treatment is examined in detail (data not shown) it was apparent that at times, the model did not deal with (or know about) weeds.

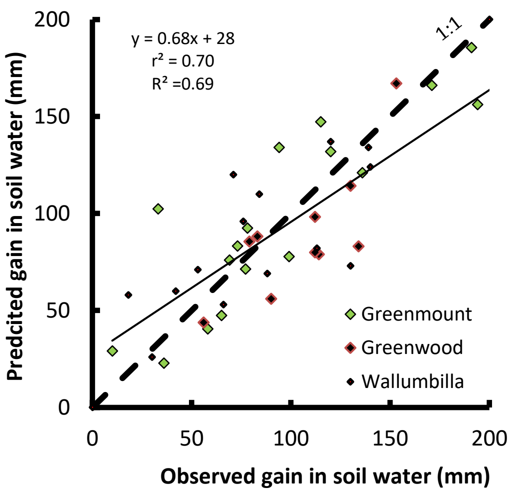

Figure 1. Observed and estimated gains in soil water during fallows at Greenmount, Greenwood and Wallumbilla (n = 45, RMSE = 32mm).

Estimating soil water gain over crops and fallows – Western Australia
The model estimated PAW within 20 mm of observed values at the Merredin site except for a 3-month period between May and September when measurements were not available, and in March when measured soil water did not reflect rainfall received. The Warradarge and Lake Varley sites showed a similar correspondence between predicted and measured soil water (data not shown).

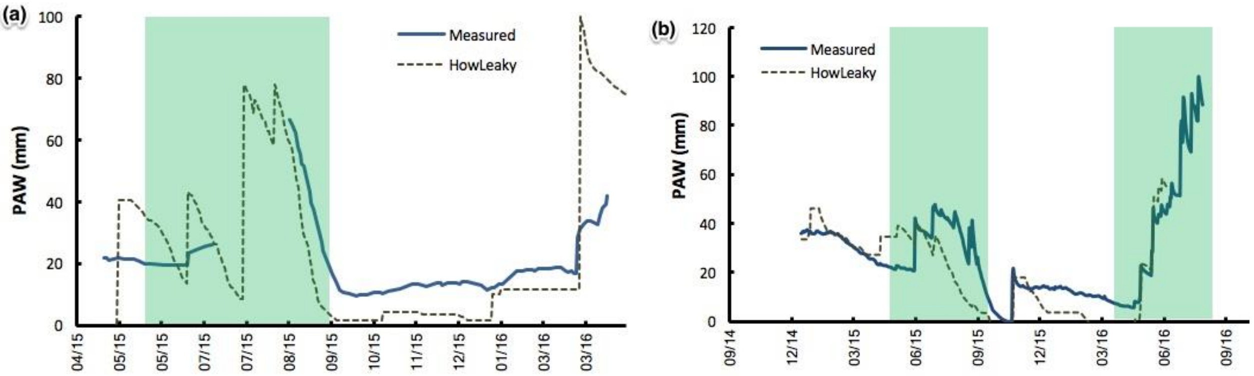

Figure 2. Measured and modelled daily PAW for soil layers 200 mm to 1000 mm at (a) Merredin (WA) and (b) Raywood (Vic) (right) in 2015/16. Green shading indicates the crop phase.

Examining Figure 2a in greater detail, the period from 1 May to the temporary end of measurements in July reveals little change in the measurements despite significant rainfall and an expectation that crop water use is high after the crop is established. When measurements recommenced, there is good agreement between measurements and simulation estimates in September with PAW drawn down by transpiration. After this period there is a consistent and small difference of ~ 10 mm that may reflect the crop failing to extract available water or the PAWC used being too large (i.e. lower limit set too low). In either case the error is small and unlikely to affect management decisions. Occasionally observations are difficult to explain and may be due to soil properties such as non-wetting not include in the model and spatial variability. Errors are more likely to be from rainfall data rather than the SW sensor data (D'Emden, pers. comm.), consistent with the rainfall amounts at the site being much greater than recorded at the nearest official meteorological stations.

Estimating soil water gain over crop and fallow – Victoria
At Raywood the patterns of measured and predicted changes in PAW were within 15 mm for 95% of the time (Figure 2b). The decline in PAW during the 2015 crop is less in in the HowLeaky predictions than the measured values, but they are not radically different. The greatest change in observed PAW was in mid-2016, where HowLeaky predicted the changes to within a few mm. May, June and July are the important times for management decisions, providing confidence in model estimates. The Results at Hamilton and Youanmite showed a similar level of agreement (data not shown).

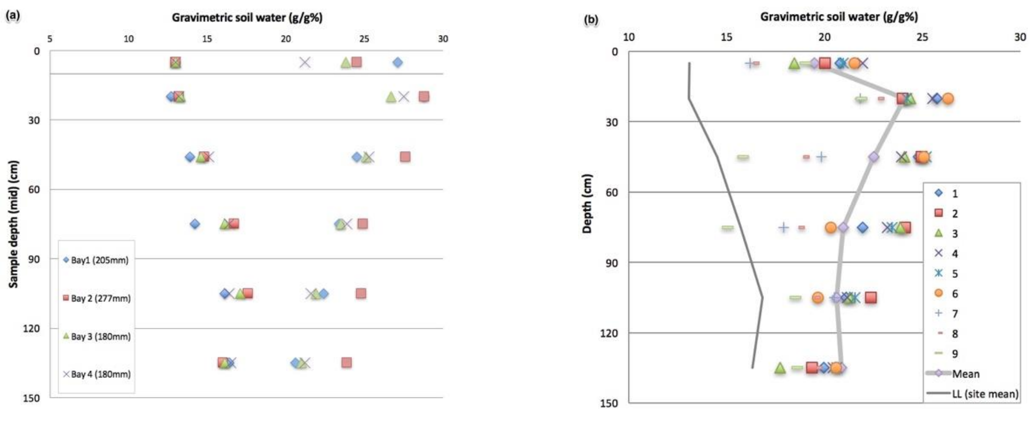

Figure 3. (a) Minimum and maximum soil water content observed over a 17-year period on four adjacent "catchments" near Wallumbilla: 1982-2000, and (b) gravimetric soil water content (g/g) for the nine sample locations within a ~3.5 ha catchment at a point in time (25/5/1998).

Variability in estimating PAWC
Apparent Lower limit (LL) and Drained Upper Limit (DUL) values varied at all locations, as shown in Figure 3a for Wallumbilla. These results from intensively sampled and visually uniform sites, demonstrate that LL and DUL are quite variable within sites spanning 200 to 2000 metres.

Spatial variability
Replicated soil water content data were available for several dates from the Wallumbilla study. Nine samples were collected by coring within each treatment of ~3 ha (Figure 3b). The standard deviation in soil water content for each depth is 1-2% (gravimetric) that is equal to a standard deviation of ~50 mm in the estimate of PAW for the soil profile from a single soil core.

Discussion

Is a simple Fallow Efficiency calculation sufficient for estimating gain in PAW over a fallow? FE was not a useful estimator of soil water accumulation. In hindsight, it is not surprising that FE with just one coefficient (FE, %) and one input (total fallow rainfall, mm) is too simplistic to predict the outcome of myriad conditions affecting soil water storage in fallows. This is likely to be because of variation in weeds, and the extent of trash cover.

Does the water balance model reliably predict gains in PAW during summer fallows? Yes. An RMSE of 32 mm is low relative to the PAWC of these heavy clay soils (150 to 250 mm). To achieve greater accuracy, the model requires collection and analysis of 4 or more cores with a standard deviation of 50 mm; an expensive and labour-intensive system relative to using the model.

*Did the water balance model track plant-available water through crops and fallows***?** Based on the high confidence in predicting gains in PAW during fallows and only small and generally explainable errors during periods of crop water use, we conclude that HowLeaky? satisfactorily predicts the patterns of PAW and change through fallows and crops. When tested at a range of sites in Western Australia and Victoria, there was good correspondence between measured values and simulated values for most sites at most times. In some cases, we found predictions were very accurate, such as at Hamilton. Analysis of the largest differences showed that HowLeaky was superior to some erroneous measurements but inferior to measurements when low-quality rainfall data was used, or when soil constraints weren't accounted for in the model.

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