Agricultural Systems 165 (2018) 252–263

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Estimating soil water in high-rainfall zones under pasture

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ARTICLE INFO

Keywords:
Field capacity
Wilting point
Soil water balance modelling
DairyMod
Howleaky
Soil water redistribution

ABSTRACT

Soil water is important for agricultural production, and is a key parameter in hydrologic models and weather prediction models. In this paper we explore the ability of two commonly used paddock scale models for pasture: HowLeaky and DairyMod, to estimate soil water in the topsoil (0–100 mm) and root-zone (0–1000 mm) at daily intervals. We also examined the influence of soil hydraulic properties on estimated amounts of soil water by using soil properties measured at the site, compared with properties from the national database. Soil water estimates were compared with field measurements from four grazing systems in the high-rainfall zone of western Victoria, Australia.

Daily soil water amounts in the topsoil and root-zone were well simulated by both Howleaky and DairyMod, with Howleaky performing better overall. Soil water was simulated more accurately for the root-zone than for the topsoil. On average, the error in root-zone water estimations with site-derived soil properties was 18% of plant available water capacity, and ranged from 8 to 24% of their plant available water. When soil properties were instead taken from the national database, the actual values of soil water were predicted poorly, with an average bias of 86 mm. However, relative soil water is the parameter of greater interest, and normalising by the waterholding capacity corrected these biases leading to an average error of 24% of the plant available capacity, with a range across sites from 8 to 31% of the plant available capacity. Nevertheless, with site-derived parameters bias was reduced by more than half in all sites. Errors in model predictions tended to increase during the growing season reaching a maximum at the most critical times of the year for tactical decision-making by farmers (November and December).

Superior performance of Howleaky in estimating soil water and other water balance components support the application of Howleaky for soil water simulations in pasture sites at point scale. Improving algorithms for soil water redistribution would be beneficial to increase the model performance.

1. Introduction

Soil moisture estimates are a pre-requisite for the prediction of crop yield and pasture growth, while catchment and atmospheric models rely on soil moisture for the prediction of streamflow, floods, rainfall and temperature. Models commonly used for agricultural applications in Australia include APSIM for cropping systems (Keating et al., 2003), DairyMod and SGS for pasture production (Johnson et al., 2008; Johnson et al., 2003), and HowLeaky (McClymont et al., 2008) for water balance and water quality assessments for a variety of land uses. At the catchment to basin scale, a wide variety of models (e.g. SYMHYD, Sacramento, IHACRES) are used; however, only a few including Catchment Analysis Tool (Beverly, 2009; Beverly et al., 2005) and SWAT (Arnold et al., 1998) have the ability to simulate both plant-soil-water-management dynamics in agricultural systems and their environmental impact. At the atmospheric scale the ACCESS model (Bi et al., 2013), in combination with Land Surface Models, is run routinely by the Australian Bureau of Meteorology for its numerical weather forecasts.

Some of these models including Howleaky are based on a semi-empirical, simple, layered soil water balance approach of Ritchie (1972). DairyMod and SGS use a capacitance approach. The Land Surface models CABLE (Kowalczyk et al., 2006) or JULES (Best et al., 2011) apply Richards' equation. Other models (Catchment Analysis Tool, DairyMod) have a combination of approaches to choose from. In models where the Richards' equation is used a variety of constitutive

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https://doi.org/10.1016/j.agsy.2018.06.019
Received 29 August 2017; Received in revised form 29 June 2018; Accepted 30 June 2018

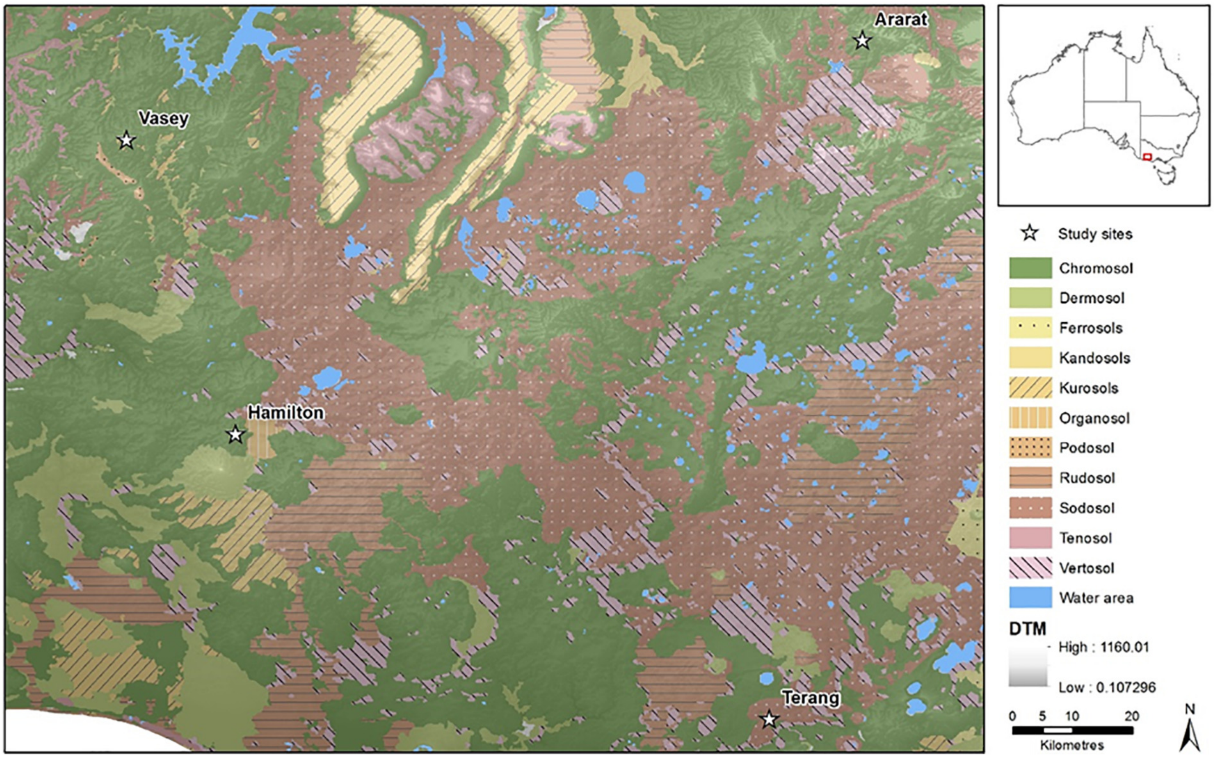

Fig. 1. Locations of the four sites (Ararat, Hamilton, Terang and Vasey), soils and DTM.

relationships, including Brooks and Corey (1964), van Genuchten (1980) and Clapp and Hornberger (1978), are also applied, all of which have several parameters to be measured or determined. Despite the large number of applications there have been few published comparisons between model predictions and direct measurements of soil moisture because it is a difficult property to measure.

A good fit between model predictions and measurements depends not only on the structure of the model, but on the appropriateness of its input data and the quality of the measured validation data. While weather data influence the surface soil moisture predictions, soil physical properties and vegetation characteristics affect predictions of vertical changes in soil moisture in the root zone, specifically at smaller spatial scales (Crow et al., 2012). In most Australian applications, soil parameters are drawn from a coarse scale national database by McKenzie et al. (2000) and weather data from the SILO database (https://silo.longpaddock.qld.gov.au) rather than from site measurements due to limited data availability and scale incompatibilities. Soil water measurements derived by indirect methods such as the neutron moisture meter and electronic systems are also subject to potential calibration bias.

Models that simulate agricultural processes such as plant growth and yield generally require root-zone soil water, most of which is stored between 0 and 1000 mm depth. There are, however, processes including seedling growth, trafficability, nitrous oxide emissions, frost and heatwave formation that depend on topsoil water content. There is a strong relationship between soil water content and thermal conductivity, heat capacity, and thermal diffusivity (Campbell, 1985; Snyder and de Melo-Abreu, 2005). In late spring and summer, dry areas are sources for heatwaves (Lorenz et al., 2010; Wu and Zhang, 2015), while dry soils in early winter and spring are more conducive to frost. Nitrous oxide production and emission will be primarily influenced by oxygen availability which is regulated by soil water content of the top soil layers (van der Weerden et al., 2017). Therefore it would be an added benefit if the models used in agricultural applications also provide reasonable predictions of soil water in the top layer.

In this paper we used two models with different approaches to their soil moisture estimation in uncalibrated mode – Howleaky and DairyMod – and compared them with daily and monthly soil water measurements from pasture sites in western Victoria, Australia undertaken between 1998 and 2010. Comparisons are made for the topsoil (0–100 mm) and root-zone (0–1000 mm) soil water for four grazing paddocks located in the high-rainfall zone.

2. Materials and methods

2.1. Sites

Data were collected from 4 sites as ancillary measurements to pasture-based studies for the sheep and dairy industries in south-western Victoria (Fig. 1). The sites were,

- Ararat (2003–2007) – a native pasture on a Yellow Dermosol derived from Ordovician sediments (McCaskill et al., 2010). This was a steep site (14% slope grazed by sheep).
- Hamilton (2006–2014) – a perennial ryegrass-based pasture on a Brown Chromosol derived from basalt (Ward et al., 2013), which was rotationally grazed by sheep.
- Terang (1998–2001) – a perennial ryegrass-based pasture on a Brown Chromosol derived from basalt (McKenzie et al., 2003a). This site was rotationally grazed by heifers.
- Vasey (1998–2001) – a phalaris-based pasture on a Yellow Sodosol derived from rhyolite (Chapman et al., 2003). The data reported here are for a plot that was set-stocked by sheep.

Mean annual rainfall during the monitoring periods for the sites ranged from 476 mm for Ararat to 731 mm for Terang. The seasons are defined as Spring (March, April, May), Summer (June, July, August), Autumn (September, October, November) and Winter (December, January, February) at these sites. At each site soil moisture was measured using electronic moisture sensors (CS615 frequency domain reflectometer (FDR), Campbell Scientific Logan, Utah) at depths of 0–100 mm (angled), 100–200 mm, 400 mm, and 750 or 800 mm.