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Improving the prediction of soil evaporation for different soil types under dryland cropping

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ABSTRACT

Soil evaporation (E_S) is a major fraction of water loss in dryland farming worldwide. Precise estimation of E_S is therefore crucial for improved decision-making in agriculture water management. Ritchie's two-stage E_S algorithm is commonly used in crop models to estimate E_S. However, use of different E_S input values for the same soil type, and lack of understanding on how different soil types affect E_S and crop yield in these models can negatively impact the prediction accuracy. To address these issues, a range of input values for stage 1 and stage 2 E_S were collated, and their effects on modelled E_S and yield were compared for a dryland wheat crop. The results using APSIM farming system model suggest that while in-crop E_S increases and yield decreases with the increase of both stage 1 and stage 2 E_S input values, the stage 2 values can have a greater effect, especially under lower rainfall conditions across the soil types. Fallow E_S and in-crop E_S were higher (by 7 and 12 mm yr^{-1} respectively) and yield was lower (by 0.27 t ha^{-1} yr^{-1}) under Empirical datasets that used higher stage 2 E_S input values than the default datasets. With all the datasets, E_S and yield were higher (by 4–51 mm yr^{-1} and 1.51–1.98 t ha^{-1} yr^{-1} respectively) for Black Vertosol than the other soil types. As rainfall and/or E_S input values increased, variability in both E_S and yield (in turn the modelling error between the datasets) increased, and was higher for Black Vertosol and Red Kandosol soils. These insights will improve the prediction accuracy of E_S and dependent factors in the models that apply Ritchie's algorithm for E_S estimation.

1. Introduction

Soil evaporation (E_S) is a major fraction of the water loss in dryland farming worldwide. The E_S can be 30–75% of growing season rainfall (Mellouli et al., 2000) and as high as 84% of fallow rainfall (Onder et al., 2009). In the northern grain growing regions of Australia, the experimental sites of this study (Fig. 1), the E_S can be 53–73% of annual rainfall (Robinson et al., 2010; Kodur et al., 2014) and 44–73% of fallow rainfall (Gardner et al., 1988; Freebairn et al., 2009; Kodur et al., 2013). Therefore, improved understanding of E_S is fundamental for improved decision-making in soil and crop water management.

One dimensional simulation models such as APSIM (Holzworth et al., 2014) are commonly used to estimate E_S. They are cost effective, easy to use and functional over a broad range of environments. The E_S in these and other similar models is based on a modified Ritchie's two-stage E_S algorithm (Ritchie, 1972). Stage 1 E_S (E_{S1}) is the amount of cumulative E_S from a wet soil surface until the water supply to soil becomes limiting. E_{S1} is considered as a constant rate phase in which net radiation at the soil surface controls the E_S rate. The amount of E_S during E_{S1} is directly related to the drying potential of the air and is assumed to last until a given volume of water has evaporated (Ritchie, 1972). Stage 2 E_S (E_{S2}) is the subsequent E_S that lasts until next E_{S1} (triggered by a new rainfall event). E_{S2} is considered as a falling rate phase where soil hydraulic properties control the E_S rate (Philip, 1957), and the rate declines as a function of the square root of time (Hillel, 1980; Monteith, 1981; Ritchie, 1972). In APSIM model, E_{S1} and E_{S2} is respectively represented by the parameters U (mm day^{-1}) and Cona (mm $day^{-0.5}$). E_{S1} occurs after any rainfall event up to the value of U (the upper limit of stage 1 drying) and it equals the potential E_S rate until the cumulative loss exceeds this value. The parameter Cona specifies the change in cumulative E_{S2} against the square root of time, which commences when the specified U value exceeds. The E_S in these stages can be expressed as;

$$\sum E_{S1} = \sum E_{os}, \text{ when } \sum E_S \leq U$$

$$\sum E_{S2} = \text{Cona}(t - t_1)^{0.5}, \text{ when } \sum E_S > U$$

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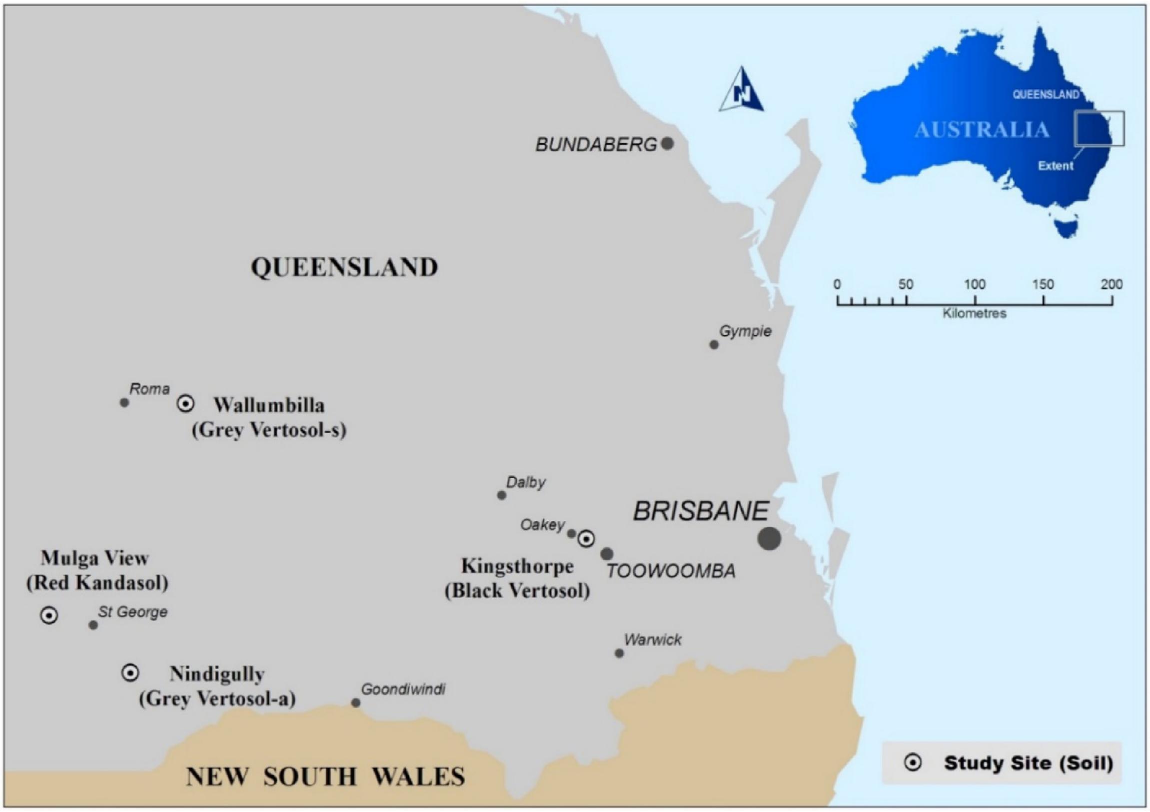

Fig. 1. Map showing study sites/soil types.

Where, E_S = total soil evaporation ($\sum E_{S1} + \sum E_{S2}$); E_{S1} and E_{S2} are respectively the evaporation during stage 1 and stage 2, E_{OS} is the potential evaporation from soil surface, t is the day since rainfall, and U and Cona are E_S parameters respectively for stage 1 and stage 2.

Given U and Cona values are the major driver of E_S in these models, inaccuracies in their values can lead to uncertainties in the modelled outputs. The sources of inaccuracies may come from the inherent variability in soil and climate or errors from measurements, calculations or approximation of inputs (Zhang et al., 2001; Bah et al., 2009). The U and Cona values are soil-specific and require precise estimates for the study area (Place and Brown, 1987). Research on direct measurement of $E_{S,}$ and for different soil types, is extremely limited in Australia and elsewhere, given the complexity of the field experimentation. The small number of studies available (e.g. Yunusa et al., 1994; Singh et al., 2014) are further constrained by shorter study duration (e.g.<4 seasons) and lack of wide range of soil types. Furthermore, use of different U and Cona input values for the same soil types, without knowing their impact on modelled results, can decrease the trustworthiness of the modelled outputs.

In this regard, recent bare-soil lysimeter studies (Foley et al., 2015) measured E_S directly, for over 3 years and have provided comprehensive and improved input values of U and Cona (referred to hereafter as Empirical dataset) for several soil types. These datasets are also validated for E_S using APSIM model for bare soil conditions (Foley et al., 2015). However, they require evaluation for the cropping conditions under different soil types and rainfall conditions and necessitate quantification against other commonly used U and Cona values (referred hereafter as Default dataset) (Table 1).

The objectives of this study were to i) determine the differences in E_S and wheat yield among soil types and between datasets (Empirical and Default) across seasons and rainfall conditions of dryland farming, and ii) provide insight on the mechanisms by which U and Cona parameterisation in the model affects E_S. Using four common soil types and two separate datasets for each soil type (8 sets of input values in total), this study will improve the prediction accuracy and transparency of all the models that use Ritchie's algorithm to predict the E_S.

2. Methods

2.1. Datasets of E_S

The Empirical datasets of E_S were derived from weighting lysimeter experiments established in a replicated field trial at Kingsthorpe, Queensland (Fig. 1). Each lysimeter comprised of undisturbed soil monolith (0.56 m circular diameter and 0.8 m deep) and was placed on three weighing strain gauges. Weights were logged every 15 min and the changes in weights were attributed to either E_S losses from bare-soil (after accounting for runoff and drainage) or weight gains from rainfall. Any excess water accumulating at the inner base of the lysimeter was removed by applying a suction of 10 KPa to an array of ceramic cups installed at the bottom soil layer. A rainout-shelter was used to cover the lysimeters during selective rain events to derive longer duration drying curves (E_S curves). The study comprised of four soil types (each with four replicate lysimeters) namely a Black Vertosol, a Red Kandosol and two Grey Vertosols (alluvial 'a' and sedentary 's' in origin) (Isbell, 1996), collected respectively from Kingsthorpe, Mulga View, Nindigully and Wallumbilla locations of the study region (Fig. 1).

Measured bare-soil E_S data were collected for over 3 years (March 2010–Oct 2013) comprising E_{S1} and E_{S2} drying curves from over 46 rainfall events. The $\sum E_S$ was plotted against days since rainfall (E_{S1}) or as square root of time (E_{S2}) for each rainfall event and for each soil type. The U was obtained as the maximum $\sum E_S$