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Fallow soil evaporation in a grey Vertisol under contrasting wheat stubble management practices in cotton cropping systems

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ABSTRACT

In comparison with incorporating wheat stubble, soil water storage in Vertisols is believed to be enhanced by standing wheat stubble. It is widely believed that a significant proportion of the enhanced water storage is attributable to reductions in soil evaporation. The objective of this study was to quantify the differences in fallow soil evaporation in a Vertisol under two cotton (*Gossypium hirsutum* L.)-wheat (*Triticum aestivum* L.) rotation systems where wheat stubble was either retained as an *in situ* mulch (standing stubble) or incorporated. Soil cores were extracted from the surface 70 mm of beds after the wheat phase of wheat stubble incorporated (post-incorporation) and standing wheat stubble plots in an ongoing cropping systems experiment near Narrabri, NSW during the 2008–09 and 2009–10 summer fallow periods. The cores were saturated, drained and subjected to drying cycles under two evaporation rates (4 and 6 mm d^{-1}) during which evaporation was assessed by weighing the cores. Although cumulative evaporation was generally greater with wheat stubble incorporation than with standing stubble, the differences were small. These results suggest that the more effective water storage observed under the latter practice when rainfall was the major source of water may be not due to large reductions in evaporation but to enhanced infiltration.

1. Introduction

Water losses through evaporation from agricultural soils are reported to be of the order of 25–50% of total evapotranspiration in temperate zone soils and 30–70% in semi-arid zone soils (Or et al., 2013; Singh et al., 2011, 2014; Tanner et al., 1960). Evaporation, thus, has a direct effect on crop production by reducing the amount of water available for transpiration. In semi-arid and arid zones, management practices that reduce evaporation can improve crop yields. Evaporation from a bare soil is reported to consist of three distinct stages; viz. (1) an initial stage in a wet soil, where the evaporation rate occurs at a constant rate and is the same as that of a saturated surface (i.e. potential evaporation); (2) a second stage in a drying soil at intermediate water contents, where the evaporation rate is independent of the potential evaporation and depends on the physical properties of the soil and the distribution of soil water; and (3) a third stage, in a dry soil where the evaporation rate depends on the heat flux from the soil (Philip 1957; Or et al., 2013). A simplified model for cumulative evaporation, CE was described by Black et al. (1969) who suggested that it was directly related to the square root of the time period under consideration, $t^{0.5}$. Later authors (Jalota & Prihar, 1986, 1987, 1990, 1991; Prihar et al., 1996; Singh et al., 2011, 2014; Wythers et al., 1999) modified this equation to account for frequent wetting and drying cycles that occur under irrigation, shallow tillage that accelerates surface drying, surface mulching and stubble incorporation. Both shallow tillage and mulching influence evaporation by extending the first and second stages of drying (Jalota and Prihar 1990; Prihar et al., 1996; Sauer et al., 1996; Singh et al., 2011, 2014; Todd et al., 1991; Vial et al., 2015).

Most research on soil evaporation has been conducted on coarse-textured, rigid soils with studies on fine-textured, swelling soils such as Vertisols being few in number. Due to the self-mulching and shrink swell nature of Vertisols, the soil evaporation pattern may differ. Magar et al. (1984) reported that under conditions of high evaporative demand, cumulative evaporation was described by previously published models. Tennakoon and Hulugalle (2006) described evaporation under irrigated cotton in Vertisols as a two-step process; *viz.* the first and second stages of evaporation as reported by Philip (1957) because the third stage of evaporation rarely occurs in irrigated systems (Jalota and Prihar 1990). Neither of these studies addressed the

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influence of the self-mulching layer on soil evaporation. Jalota and Prihar (1990), however, simulated the formation of a self-mulching layer in medium and coarse-textured soils by tilling the surface 20 mm, forming a dry layer above a relatively wet zone. They observed that this layer was effective in reducing soil evaporation under high evaporative demand but was far less effective when evaporative demand was low. Overall the literature indicates that research on soil evaporation from Vertisols is sparse with little research reporting on surface management practices such as stubble retention. It is widely believed, however, that standing cereal stubble in cotton farming systems will enhance water infiltration and reduce evaporation (The Australian Cotton Industry Development and Delivery Team, 2013; Cotton Australia, 2016). The objective of this study was to quantify the differences in fallow soil evaporation in a Vertisol under cropping systems that included both cotton (*Gossypium hirsutum* L.) and wheat where wheat stubble was either retained as an *in situ* mulch (standing stubble) or incorporated.

2. Materials and methods

2.1. Experimental site

The experiment was located at the Australian Cotton Research Institute (ACRI), near Narrabri (149°47′E, 30°13′S) in New South Wales (NSW), Australia. Narrabri has a sub-tropical semi-arid climate, BSh (Kottek et al., 2006) and experiences four distinct seasons with a mild winter and a hot summer. The hottest month is January (mean daily maximum of 35 °C and minimum of 19 °C) and July the coldest (mean daily maximum of 18 °C and minimum of 3 °C). Mean annual rainfall is 593 mm. The soil at the experimental site was a self-mulching, grey Vertisol that was classified as a fine, thermic, smectitic, Typic Haplustert (Soil Survey Staff, 2010).

2.2. Experimental layout

Two treatments in a long-term cotton-based cropping system experiment sown on permanent beds (Hulugalle et al., 2012b, 2013a,b) were assessed in our study. They were: cotton-wheat where wheat stubble was incorporated to a depth of ~0.10 m into the beds with 1 or 2 passes of a disc-hiller (CW), and cotton-wheat-vetch (*Vicia* spp.) where wheat stubble was retained as an *in-situ* mulch into which the following vetch crop was sown (CWV). All crops were furrow irrigated at a rate of 1 ML ha^{-1} (=100 mm) of water when rainfall was insufficient to meet evaporative demand. Cotton was picked with a mechanised picker during late April or early May after defoliation in early April. After cotton-picking, the cotton was slashed and incorporated into the beds with a disc-hiller (to facilitate destruction of exit holes of *Helicoverpa* spp. larvae). The depth of incorporation was approximately 0.10 m. Wheat was sown during late May or early June and harvested during late November or early December. Vetch in CWV was sown into wheat stubble during autumn following summer rains (any time between late February and early May), slashed and killed just prior to flowering through a combination of mowing and contact herbicides, and the residues retained as *in situ* mulch into which the following cotton was sown (Hulugalle et al., 2012a). The experiment was laid out as a randomized complete block with three replications and designed such that both cotton and rotation crop phases in CW and CWV sequences were sown every year. Individual plots were 165 m long and 20 rows wide. The rows (beds) were spaced at 1-m intervals with vehicular traffic being restricted to the furrows. Details of the experiment, its management and impact on cotton agronomy, energy efficiency, soil quality and hydrology have been reported previously (Hulugalle et al., 2012b, 2013a,b). Soil chemical properties in the surface 0.10 m did not differ between CW and CVW (Hulugalle et al., 2012b). Soil chemical properties in the surface 0.10 m did not differ between CW and CVW (Hulugalle et al., 2012b). Mean pH (0.01 M $CaCl_2$) was 6.8, $EC_{1:5}$ 0.36 dS m^{-1}, soil organic carbon 8.3 g kg^{-1}, exchangeable Ca 24 $cmol_c$ kg^{-1}, exchangeable Mg 13 $cmol_c$ kg^{-1}, exchangeable K 1.6 $cmol_c$ kg^{-1}, exchangeable Na 0.9 $cmol_c$ kg^{-1}, ESP 2.2 and ESI 0.16. Mean particle size distribution was of the order of 620 g kg^{-1} clay, 130 g kg^{-1} silt and 250 g kg^{-1} sand, and soil water contents at potentials of −10 kPa and −1500 kPa were 0.42 m^3 m^{-3} and 0.22 m^3 m^{-3}, respectively.

2.3. Soil sampling and analyses

Soil cores with a diameter of 72 mm were extracted with a spade using brass sleeves after the wheat phase from the surface 70 mm of beds in CW (wheat stubble incorporated, post-incorporation) and CWV (standing wheat stubble) during the 2008–09 (December 2008, February 2009) and 2009–10 (February 2010) summer fallow periods. Five cores were extracted from each of the abovementioned treatment plots in every replication using a stratified sampling design. They were weighed, the bases covered with cotton cloth held in place with rubber bands and then saturated from the bottom up. Following this, excess water was allowed to drain and the bases sealed with plastic film. In addition, the sides and bases of each core sleeve were covered with aluminium foil to minimise the occurrence of temperature gradients. The cores were then allowed to dry out by evaporation under two drying conditions, *viz.* bench in a climate-controlled laboratory (average evaporation of 4 mm d^{-1}) and in growth cabinets (average evaporation rate of 6 mm d^{-1}). These evaporation rates correspond to those that occur in the field site during cotton sowing (Tennakoon and Hulugalle, 2006; BOM, 2015). The cores sampled during December 2008 were subjected to a single drying cycle of 270 h, those sampled during February 2009 to 2 drying cycles of 120 h each, and those sampled during February 2010 to a single drying cycle of 240 h. The shorter drying cycles of 120 h (2009) were implemented to assess the effect of two wetting/drying cycles on the same cores. Core weights were measured during each drying cycle at intervals ranging from 12 h to 4 days. The results (cumulative evaporation, CE) for each plot were fitted by linear regression to the square root of time, t, using a model of the form: $CE = at^{0.5}$ (Black et al., 1969) in which a is a constant. The resulting equations were used to determine cumulative evaporation at various times during the drying cycles for individual plots, and the results analysed with analysis of variance for a split plot design where cropping systems were designated as main plots and time as sub-plots. During each drying cycle, evaporation from a free water surface (potential evaporation) was measured with an evaporimeter. After completion of each drying cycle, the cores were oven-dried at 110 °C, weighed, and the stubble and root material separated from the soil by washing over a 4-mm sieve. The washed stubble was then dried and weighed. Bulk density at the time of sampling (i.e. field bulk density) was determined as M_s/V where M_s is the weight of oven dried soil less stubble and root materials, and V is the core volume (Cresswell and Hamilton, 2002). Gravimetric soil water content at sampling ($M-Ms/M_s$ where M is the field weight of the core less root materials and stubble) was converted to volumetric soil water content by multiplying with the bulk density, and expressed as mm water/core by multiplying with the core height (Cresswell and Hamilton, 2002). Soil water contents, stubble amounts and field bulk densities were analysed with analysis of variance for a randomised complete block design. An empirical model using stepwise linear multiple regression analysis was fitted to CE at 120 h after pooling values for all drying cycles using independent variables such as field bulk density, stubble amounts and their