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Combinations of tall standing and horizontal residue affect soil water dynamics in rainfed conservation agriculture systems

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ABSTRACT

Residue retention is a key component of modern conservation agriculture systems. However, conflicting evidence exists on the role of residue and its architecture on the capture of rainfall and subsequent water storage in the soil in rainfed environments. Experiments were conducted in 2010 and 2011, on a sandy soil, to investigate the effect of crop residue height and architecture on the capture of rainfall and spatial variability of soil water across the standing-residue rows. We hypothesised that: (1) high residue rates, particularly horizontal residue, prevent water reaching the ground during small rainfall events, but maximise soil water retention during larger rainfall events; and (2) tall standing-residue increases the capture of rainfall and reduces evaporation from the soil surface, but increases spatial variability of soil water. To test this we investigated the effect of combinations of vertical (0–0.3 m) and horizontal (0–4.0 t ha^{-1}) residues on water capture (using simulated rainfall, sprinkler irrigation and rainfall events), and the quantity and spatial distribution of water stored in the soil. The quantity of water intercepted by residue in the inter-row position increased with rate of horizontal residue and standing-residue height. However, the quantity of stored water concurrently increased under and adjacent to the standing-residue row, suggesting that some of this 'lost' water was intercepted by the high-cut residue, much of which infiltrated deeper into the soil, where it was less prone to evaporation. The quantity of stored soil water increased with increasing residue cut-height and horizontal residue, with bare soil having the least water. Most soil water was stored with straw cut high (0.25–0.3 m) in combination with at least 2 t ha^{-1} horizontal residue, with soil directly under the standing straw row having the most water. Thus, retaining tall standing-residue in combination with horizontal residues can increase soil water capture in the no-till system.

1. Introduction

Rainfed crop production is limited by precipitation and soil factors, such as texture and profile depth, which affect water storage in the soil (Unger et al., 1997). Soil and crop management practices that enhance the quantity of soil water, and its availability, are likely to increase yield and overall productivity (Imaz et al., 2010). Indeed, water stress is the main limiting factor for crop production in many parts of Australia (Tullberg et al., 2007); therefore research on various aspects of soil water and management in conservation agriculture has received attention in recent years (Li et al., 2008).

The architecture of crop residues (stubble)—defined here as the arrangement of standing and horizontally-distributed residues—can alter the surface microclimate and impact water storage in the soil (McMaster et al., 2000). Thermal and vapour transport properties of different residue types and architectures have received limited attention and remain poorly understood (Flerchinger et al., 2003). There is also large spatial and temporal variability of soil water in no-tillage (NT) cropping systems (i.e. zero tillage with surface retention of residues), which complicates matters (Teuling et al., 2007). A better understanding of the effect of crop residue management on evaporation may help to determine management strategies to conserve water in irrigated as well as rainfed crop production (Todd et al., 1991). Precipitation interception by residue affects the water balance by altering the quantity of water reaching the soil surface (Seastedt, 1985) and is a

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function of crop residue type, residue architecture, rainfall intensity and duration and potential evaporation (Kozak et al., 2007; Monzon et al., 2006). The most important physical characteristics affecting vapour transport are the thickness and density of the residue layer, where thick residue increases the relatively non-turbulent air layer above the soil surface, decreasing vapour transport away from the soil (Bond and Willis, 1970; Unger and Parker, 1976; Flury et al., 2009; Klocke et al., 2009). Studies have also shown that high rates of residue may intercept rain from light showers, which then evaporates directly into the atmosphere without reaching the soil, though information is limited (Cook et al., 2006; Cantero-Martínez et al., 2007; Passioura and Angus, 2010; Sommer et al., 2012). Verburg et al. (2012) reported that the reduction in evaporation by surface cover was greatest for frequent rain combined with low evaporative demand and least for infrequent rain and high evaporative demand. Ward et al. (2012) showed that, under conditions of high evaporative demand, evapotranspiration rate could be reduced by thick residue cover, but only for a few days. Standing residues also have important micro-climatic effects at the soil surface and can reduce wind speeds by up to 70% and water loss through evaporation, resulting in higher grain yields due to greater water use efficiency (Cutforth and McConkey, 1997; Cutforth et al., 2002).

Such information may be important for increased adoption of NT systems in Australia (Thomas et al., 2007). In a wider context, Govaerts et al. (2007) concluded that, for sustainable crop production under conservation agriculture, further research is needed to establish the rates of residue required for maintaining soil productivity in a particular environment, but under Mediterranean conditions this has not been established in terms of either quantity (Verburg et al., 2012) or architecture. Cutting crops high at harvest then seeding between the residue rows in the following season has significant economic and crop management advantages, such as faster harvest and easier seeding. However, little is known about the influence of this strategy on the capture or subsequent distribution of water in the soil, or potential impacts on crop growth. The challenge is to develop crop production systems that maximise the benefits of surface and standing residue (Lafond et al., 1992). While cutting residue tall in NT systems maintains a more favourable microclimate for plants (Aase and Siddoway, 1980; Cutforth and McConkey, 1997), further research in Mediterranean climates is needed to identify whether this is the best way of reducing soil evaporation (Ward et al., 2009; Sommer et al., 2012). This study investigated the effect of standing residue height and quantity of horizontal residue on the capture of rainfall, evaporation from the soil surface and spatial variability of soil water across the standing residue rows. We hypothesised that: (1) high residue rates, particularly horizontal residue, prevent water reaching the ground during small rainfall events, but maximise soil water retention during and after larger rainfall events; and (2) tall standing residue increases the capture of rainfall and reduces evaporation from the soil surface, but increases spatial variability across standing-residue rows. This research may give farmers and advisors more confidence to alter residue management to maximise soil water conservation, which may be important for crop production in rainfed Mediterranean-type environments.

2. Materials and methods

All the experiments were conducted at the Shenton Park Field Station at The University of Western Australia (32°13′S; 115°38′E) on a flat field. The soil at the site is known locally as Karrakatta sand (McArthur and Bettenay, 1960) and is classified as a Dystric Xeropsamments (USDA, 1992). The surface soil (0–0.2 m) contains 920 g kg^{-1} coarse sand, 20 g kg^{-1} fine sand, 20 g kg^{-1} silt, and 40 g kg^{-1} clay (Pathan et al., 2003). The volumetric soil water content at field capacity is approximately 11% and at permanent wilting point is 3% (P. Ward, personal communication). The surface soil has a pH of 4.7 (1:5 soil: 0.01 M $CaCl_2$ extract), electrical conductivity of 0.01 dS m^{-1} (1:5 soil/water extract), cation exchange capacity of 3.22 cmol (+) kg^{-1}, C concentration of 6.5 mg g^{-1} and N concentration of 0.4 mg g^{-1}. The subsurface soil (>0.2–1.0 m) has an average pH of 5.6, electrical conductivity of 0.003 dS m^{-1}, cation exchange capacity of 1.33 cmol (+) kg^{-1}, C concentration of 0.9 mg g^{-1} and N concentration of 0.2 mg g^{-1}. The climate is Mediterranean-type, characterised by mild, wet winters and hot, dry summers, with high solar radiation and high rates of evaporation. Rainfall and hourly air temperature and potential evapotranspiration were recorded at a weather station located approximately 500 m from the site.

2.1. Crop residues

The first three experiments were done on the same crop residues, which came from a wheat crop (*Triticum aestivum* cv. Bonnie Rock) sown at 90 kg ha^{-1} in 0.22 m-wide rows on 8 June 2009. The crop had about 225 plants m^{-2} and the wheat rows were E–W oriented. The wheat was harvested on 6 December 2009 using a plot harvester with a straw spreader which cut the crop 0.3 m above ground level. The rate of horizontal and standing residue present after harvest was determined, before the treatments were implemented, by cutting and collecting all residues in a 0.53 m^2 (0.66 × 0.80 m) quadrat at ten randomly-selected points (Whitfield et al., 1962). The residue was oven dried at 75 °C for 6 h and soil particles removed prior to weighing.

A second wheat crop was sown on 21 May 2010, using similar management, to provide residues for Experiment 4. The wheat was harvested on 10 December 2010 using a plot harvester and the residue was cut to 0.25 m in height because the plants were slightly shorter than the previous year due to drier seasonal conditions. The rate of horizontal and standing residue present after harvest was determined as previously described.

2.2. Experimental design and approach

The first three experiments were carried out successively using the same plots over nine weeks (21 January to 4 April 2010) after the wheat harvest in December 2009, while the fourth experiment was conducted for seven weeks (17 April to 4 June 2011) the following year, after the second wheat crop was harvested in December 2010. The first experiment used a rainfall simulator to apply water; in the second experiment, water was applied by sprinkler irrigation; and a rainfall event was used in the third. The fourth experiment, to determine the effect of residues on soil water variability across the rows, occurred following rainfall.

2.2.1. Experiment 1 – rainfall simulation

The first experiment, using a rainfall simulator, was conducted over 10 days (20–30 January 2010). Plots were 1.76 m (8 crop rows) × 2.7 m long. The trial consisted of a factorial arrangement of four replications in a randomised block design with two simulated rainfall quantities (2 and 4 mm) applied to nine crop residue treatments. Initially, larger applications of water were planned, but problems arose in controlling the system so this was not possible. The crop residue treatments consisted of three standing-residue heights (0.1, 0.2 and 0.3 m tall), three horizontal residue quantities (0, 1 and 4 t ha^{-1}) and a bare soil control. A hedge clipper was used to cut the standing wheat residue to the required heights. The designated horizontal residue rates were obtained by randomly scattering measured quantities of straw collected from bare plots or by raking to remove excess straw. Sampling within plots was