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Fallow management increases soil water and nitrogen storage

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ABSTRACT

In regions where rainfall during the cropping season is low and variable, such as most parts of Australia, stored soil moisture determines the yield and sowing time of the following crop. A long-season fallow experiment was conducted in south-eastern Australia, and a biophysical simulation model, APSIM, was evaluated and applied. Stubble cover did not significantly affect fallow soil water storage; once the soil profile was filled during the winter fallow, the presence or absence of stubble cover during the summer fallow made little difference. However, weed growth during the summer period significantly affected the soil water storage. By the time of winter crop sowing, the plant available water (PAW) was depleted by 11% (18 mm) in weed free – stubble covered treatment, 14% (23 mm) in weed free – stubble free treatments, 34% (52 mm) in the weedy – stubble covered treatment, and 42% (64 mm) in weedy – stubble free treatment. The weedy (39 kg ha^{-1}) and weed free (98 kg ha^{-1}) treatments differed significantly in the amount of soil mineral nitrogen at the end of the fallow period. APSIM was able to simulate the change in soil water storage under the weedy treatment accurately ($R^2 = 0.93$, NRMSE = 4%). Long term simulation showed that there was an 88% probability of accumulating 140 mm PAW by the time of sowing, compared with only 13% probability when weeds were present. If the summer fallow period was not properly managed, the water stored during the winter season could be lost to weeds. While soil water and nitrogen storage may vary with soil type, rainfall amount, rainfall distribution, and weed pressure, fallow weeds must be controlled to ensure accumulation of fallow soil water and nitrogen for a subsequent crop.

1. Introduction

In the summer-dominant rainfall regions of Australia, a short fallow over summer between successive winter grain crops is commonly used to conserve rain water. However, rainfall in south-eastern Australia is mainly winter-dominant with less frequent and higher intensity rainfall during summer (Sadras, 2003; Gentilli, 1971). In the latter environment, a long fallow (>6 months), which spans over winter and summer seasons, is likely to be more effective. However, studies on the effects of long fallow on water storage in winter-dominant rainfall environments are generally rare. The difference in stored water between a summer (short) fallow and a long fallow depends on the summer rainfall and the soil type (Oliver and Sands, 2013). If there is high summer rainfall, the soil profile can be filled even in a short/summer fallow, so the stored soil water can be similar under short or long fallow. Long fallow can be more effective in soils with high water holding capacity which can also store water from the winter season. Thus, the soil profile can be filled from rainfall during the summer-autumn-winter period. Depending on the spring-summer management condition, however, this stored soil water can remain stored for the winter crop or be lost to soil evaporation and weed transpiration. Therefore, strategies to better capture and store fallow rain include (*i*) retention of crop residues on the soil surface to improve water infiltration and reduce evaporation; and (*ii*) control of summer fallow weeds to reduce transpiration (Kirkegaard and Hunt, 2011).

Improvement in the capture and storage of water derived from stubble management depends on soil type and rainfall pattern (Incerti et al., 1993; Gregory et al., 2000). Stubble mulch is more effective in reducing evaporation in frequent low-intensity rainfall and clay soils than in less frequent high-intensity rainfall and sandy soils (Gregory et al., 2000). Residues slow the flow of water on the soil surface, allowing more time for infiltration (Freebairn and Boughton, 1981), as well as slowing soil evaporation following rainfall events. However, if conditions remain dry for an extended

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period, total evaporation can be unaffected by residues (Verburg et al., 2012). As a result, increases in fallow efficiency due to reduced evaporation are minor, and they occur only when large amounts of residue are present and rainfall patterns are favourable (Kirkegaard et al., 2007b; Browne and Jones, 2008). That means stubble mulch might not be effective in the less frequent, less intense south eastern Australian summer rainfall on well drained Red Kandosol soil.

O'Leary and Connor (1997) compared water accumulation under long fallows with residue retention and weeds controlled during the summer fallow, and found that, although the retention of residues during the long fallow did not increase soil water accumulation on sandy loam soils, there were significant increases measured in heavy clay soils. Hunt et al. (2013) found no effect of stubble on soil water accumulation on a clay soil in the Mallee region of Victoria. However, they found that controlling summer weeds increased soil water accumulation (mean 45 mm) and mineral N (mean 45 kg ha^{-1}) before sowing on sand and clay soils. Sadras et al. (2012) reported that stubble treatments did not affect soil water content during a fallow period. Summer weed control was found to be more important than stubble management in conserving both water and N with complete control increasing the level of mineral nitrogen by 69 and 45 kg N ha^{-1} in the two years of study (McMaster et al., 2015).

The above studies leave uncertainty regarding the relative effects of residue management and weed control on soil water and N accumulation, as most of the experiments focussed on either residues or tillage. In addition, studies on the effect of weed on summer fallow soil water storage are mostly based on soil profiles already depleted by the winter crop. However, if the soil profile is full, the chance of germinating and growing abundant summer weeds increase. Although summer weeds can grow on episodic summer rain, in a long fallow the soil water can be full from the winter/spring rainfall and weeds can grow easily (Hunt et al., 2009). This study evaluates how stubble and weed affect an already full soil profile from a winter fallow. It assesses the effect of stubble and weed on soil water and nitrogen stored during the winter period of a long fallow in an equiseasonal rainfall environment of Wagga Wagga (NSW), a transition zone between summer and winter dominant rainfall. The objective is: (1) to experimentally verify the relative effects of stubble management and weed control on both soil water and nitrogen accumulation; and (2) to validate and apply a biophysical model to analyse the effect of summer fallow weed on soil water storage. In order to overcome season-specific factors over-riding the conclusions from the experimental data, the biophysical simulation model is used to extend the findings across multiple seasons.

2. Materials and methods

2.1. Field experiment

This study involves two phases: field experiment and computer simulation. The field experiment was conducted at Wagga Wagga, NSW in Australia during the 2015-16 seasons. The soil of the experimental site is a sandy clay loam Red Kandosol with good drainage characteristics (Isbell, 2002). The soil hydrologic characteristics of the Red Kandosol soil are as described in Zeleke et al. (2014b). The mean bulk density, drained lower limit (DLL) (also called wilting point) and drained upper limit (DUL) (also called field capacity) of this soil (0–120 cm) are 1.46 g cm^{-3}, 0.185 cm^3 cm^{-3} and 0.277 cm^3 cm^{-3}. The experimental plots were fitted with a drip irrigation system, neutron probe access tubes for soil water content measurement, and gypsum blocks for soil water tension measurement. The experimental plots were sown to wheat during the 2014 winter cropping season (May–November). After wheat was harvested at the end of November 2014, the stubble was removed and left fallow. On 30 April 2015, the plots were sprayed with herbicide to kill the weeds and four treatments, stubble/stubble free and irrigation/nonirrigated, were applied as factorial design with six replications. Stubble was applied at a rate of 5 t ha^{-1}. The irrigation treatments were to see the effect of rainfall on fallow storage efficiency. For the irrigated treatments, three irrigations were applied, two in May and one in October. Soil water content was measured, at two-three week intervals at six depths (15, 30, 45, 60, 90 and 120 cm) using neutron moisture meter calibrated at the site. Soil water tension was measured with gypsum blocks fitted with data loggers recording soil water tension every 2 h at four depths 30, 50, 75 and 105 cm. Daily recording of weather data during the experimental period was obtained from the bureau of meteorology weather station located near the site. There was a high amount of rainfall (102 mm) between 7 October 2015 and 20 November 2015 which brought the water content of all the treatments almost to the same level and triggered a large amount of weed growth. On 20 November 2015, neutron probe was read and the treatments commenced. While weed was left to grow on half of the plots, on the remaining half it was completely controlled using herbicide and manual weeding. Thus, as of 20 November 2015, the experimental design was a factorial comprising two levels of stubble (nil, 5 t ha^{-1}) and two levels of weeding (nil, weeded), with six replications.

The most abundant weed in the experimental plots was witchgrass (*Panicum capillare*) which has a fibrous and shallow root system. Fleabane (*Conyza* spp.) was the second most abundant weed. Heliotrope (*Heliotropium europaeum*) was the third abundant weed. Established heliotrope has a well developed tap root and will grow under conditions dry enough to wilt-out most other plants (Hunt et al., 2009). The other weed species were wireweed (*Polygonum aviculare*) and cathead (*Tribulus terrestris*) both of which have long tap root systems. Summer-fallow weed density was estimated by identifying and counting all weeds within three 1 m by 2 m quadrates in each plot. To determine the dry biomass of the weeds, biomass cuts of 2 m^2 were taken and dried in a dehydrator (70 °C) for 48 h. Weed ground cover was measured using GreenSeeker® (NTech Industries Inc., Ukiah, CA, USA), a handheld tool that determines Normalized Difference Vegetative Index (NDVI). The Greenseeker canopy reflectance sensor was used to measure the proportion of green-coloured material in the field against the background of exposed soil as described by Holzapfel et al. (2009).

To determine the amount of mineral nitrogen in the soil, on 31 March 2016, 12 soil samples (4 treatments and 3 replications) were taken from 0 to 60 cm depth (composite). The soil was oven dried (70 °C) for 24 h, clods broken, thoroughly mixed and passed through 2 mm sieve. The effects of the treatments on all data were analysed using analysis of variance (ANOVA) in R (R Core Development Team, 2015).

2.2. Modeling – validation and application

The biophysical model APSIM (Agricultural Production Systems sIMulator) (Holzworth et al., 2014) was used to simulate soil water balance. The performance of APSIM in simulating the soil water dynamics under bare and cropped conditions has already been tested in the area (Zeleke et al., 2014a). Here only the validation of APSIM in simulating soil water balance in weed and weed plus stubble conditions is presented. The soil water balance in weedy, weed free, stubble, stubble free conditions was simulated during the 2015-16 spring-summer-autumn period (20 November 2015–31 March 2016). Statistical performance parameters (RMSE, NRMSE, R^2) were used to validate the model. The SILO patched point climate dataset of the Wagga Wagga Agricultural station was used (Jeffrey et al., 2001). In the stubble plots, 4 t ha^{-1} wheat stubble