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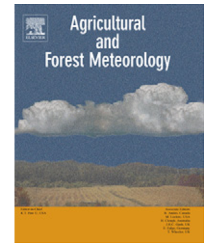

Capacity of soils to buffer impact of climate variability and value of seasonal forecasts

Enli Wang *, *Hamish Cresswell, Johnny Xu, Qiang Jiang*

CSIRO Land and Water, GPO Box 1666, Canberra, ACT 2601, Australia

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ABSTRACT

Soil provides a buffer to store water for use by plants between rainfall (or irrigation) events. This paper presents a study on how the plant available water holding capacity (PAWC) of soil interacts with rainfall variability and nitrogen input level to determine wheat yield, water use and the potential value of seasonal forecasting in nitrogen (N) management in southeast Australia. An agricultural production systems model was used to simulate those interactions. Results show that optimising N management towards maximum economic return led to increased production risk. Wheat yield, gross margin and crop water use increased, while deep drainage decreased with increasing soil PAWC. In high rainfall areas where the risk of crop loss was generally small, increased soil PAWC reduced the variability in gross margin, leading to higher yield, less water loss by deep drainage, and reduced potential value of seasonal forecasts. In low rainfall areas, the increase in wheat yield, gross margin and crop water use with increase in soil PAWC was much smaller due to limited rainfall. In those dry regions, the potential value of seasonal climate forecasts was simulated to increase with increased soil PAWC. Soils with higher PAWC enabled more rainfall to be used by crops, but did not change the seasonal crop water use efficiency in terms of kg grain produced per unit water consumed by evapotranspiration.

1. Introduction

In semi-arid and semi-humid areas, productivity of dryland agricultural systems is strongly influenced by the amount and variability of rainfall. Australia is among the countries with very high rainfall variability (Nicholls and Wong, 1990; Nicholls et al., 1997). Anderson (1987) estimated that nearly 40% of the year to year variation in Australia's gross agricultural production was attributed to climate variability. In some regions, 70–80% of farm profit has been made in only 30% of the years (Egan and Hammer, 1996). High climate variability also contributes to environmental impacts. In southeast Australia, increased water draining past the crop root zone, as a result of land use change, has contributed to development of dryland and river salinisation. Zhang et al. (1999) showed that at Hillston, NSW, just 10% of annual drainage events contributed to more than 85% of long-term total drainage. In such a variable climate, better knowledge of how soil type and management choices affect crop productivity and water balance can provide a scientific basis for improved agricultural management strategies.

Soil provides a buffer to store water and supply it to plants between rainfall (or irrigation) events to meet crop water demand. The water holding capacity of soils can have a significant impact on the efficiency of rainfall and productivity in dryland agriculture (Butler et al., 1983; Morgan et al., 2003; Wong and Asseng, 2006). It is a common observation that under the same climatic conditions, soils with larger plant available

* *Corresponding author.*
E-mail address: Enli.Wang@csiro.au (E. Wang).
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water holding capacity (PAWC) can lead to more crop water use, higher productivity and reduced water leakage below the crop root zone, resulting in increased rainfall use efficiency and decreased offsite impacts (Morgan et al., 2003; Wong et al., 2006; Ringrose-Voase et al., 2003). This would imply that good soil may provide a larger buffer that moderates the impact of rainfall variability. Such behaviour is, however, strongly dependent on seasonal variability. Wong and Asseng (2006) showed linear increases of measured wheat yield with soil PAWC to 100 cm depth in West Australia and larger temporal variability in the range of wheat yields in soils with higher PAWC due to increased yield response to rainfall. They also found that crops on soils with high PAWC were more likely to generate large vegetative biomass before running out of water and yielding poorly if late season rainfall did not eventuate (Wong and Asseng, 2007). This indicates that soil types can significantly impact on effectiveness of climate risk management strategies and the potential value of seasonal climate forecasts.

In Australia, various studies have been carried out to investigate the impact of climate variability on agricultural systems performance in terms of yield and profits (Carberry et al., 2000; Hammer, 2000; Hammer et al., 2001; Lythgoe et al., 2004; Wong and Asseng, 2007) and the environmental impacts of farming systems (Keating and McCown, 2001; Keating et al., 2002; Keating et al., 2003b; Wong and Asseng, 2007). Several studies have focused on the application of seasonal forecasts in crop management and evaluation of climate forecasting (e.g., Hammer et al., 1996; Meinke and Stone, 1997; Hammer, 2000; Hammer et al., 2001; McIntosh et al., 2005; McIntosh et al., 2007). Most of these studies were carried out at specific sites using a single soil type to assess the impact of long-term historical climate variability on cropping systems performance. There is a lack of quantitative information on how different soils interact with climate variability and how such interactions dictate cropping system performance and the value of climate risk management strategies.

Quantification of the capacity of different soils to influence the impact of climate variability and the potential value of seasonal forecasts requires assessment of the performance of cropping systems on a range of different soil types under long-term climate variations. An experimental approach is impractical. Well-validated agricultural systems models are an efficient means to tease out the complex interactions. The agricultural production systems simulator APSIM was developed to simulate the dynamic biophysical process in farming systems focusing on economic and ecological outcomes of management interventions under variable climate (Keating et al., 2003a,b). APSIM is a modular system for simulating the growth of more than 20 crops as well as grasses and trees, including predicting soil water and nitrogen dynamics for specific management options like residue management, irrigation and fertiliser rates. APSIM has been tested in Australia under a wide range of conditions (see Keating et al., 2003a,b). Verification results of the APSIM-wheat module can be found in Wang et al. (2003). The performance of APSIM in simulating crop yield and field water and nitrogen balance of wheat systems close to our study sites can be found in Verburg and Bond (2003), Lilley et al. (2003), Lilley et al. (2004) and Lilley and Kirkegaard (2007). These studies concluded that in general the APSIM model can adequately simulate wheat growth and yield in a yield range of 1–8 t ha^{-1}, closely reproduce water balance measurements, and reasonably simulate nitrogen balance and observed sensitivity to management changes under variable climate.

The objective of this paper is to quantify the effectiveness of different soils to influence (buffer) the impact of rainfall variability on crop yield, gross margin, water use and water balance. We use APSIM and 117 years of historical climate records to simulate how climate variations impact on the performance of a wheat-fallow system, and how such impact changes with differing soil type and nitrogen input levels. We will also quantify the role of soils in influencing crop water use efficiency and the potential value of seasonal forecasting as affected by natural climate variability.

2. Materials and methods

2.1. *Study sites, climate data and simulated cropping system*

Four sites, Young, Temora, Ardlethan and Griffith in a 230 km East-West transect were selected within the wheat-belt of southern New South Wales, Australia (Table 1). Daily historical climate data (1889–2005) were obtained from the SILO patched database (www.bom.gov.au/SILO). Along the transect from east to west, mean annual rainfall decreases from 646 mm at Young to 395 mm at Griffith. At all four sites rainfall distribution within the year is nearly uniform with slightly more rainfall in winter than in other seasons. Inter-annual variability of annual and seasonal rainfall is similar for all sites (Fig. 1).

A simplified dryland wheat-fallow system was adopted for the analysis, a wheat crop was assumed to be sown every year followed by a summer fallow period between wheat harvest and the next sowing date. The sowing rules for wheat are described below in Section 2.3.

2.2. *Variation of soils*

Attribute data for 10 representative soils with profile characterisation up to at least 1.5 m depth were obtained from the APSIM soil database (APSOIL, Dalgliesh, unpublished data) for

Table 1 – The geographic positions of the study sites and rainfall

Site no	Site name	Latitude (°S)	Longitude (°E)	Annual rainfall (mm)	May–November rainfall (mm)
73056	Young Post Office	34.32	148.30	646	406
73038	Temora A.R.S.	34.41	147.52	509	313
74000	Ardlethan Post Office	34.36	146.90	474	290
75028	Griffith CSIRO	34.32	146.07	395	247