The effect of initial soil water on grain crop yield and yield variability in north-eastern Australian dryland cropping systems

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Abstract

Successful grain production in the NE Australian dryland cropping region relies on the accumulation of soil water during fallow periods to supplement in-crop rainfall, in order to meet the water requirements of subsequent crops. While the importance of maximising fallow water storage is well understood by farmers, advisors and scientists, and is the driver behind practices designed to maximise fallow efficiency such as reduced tillage and fallow weed control, the relationship between the level of plant-available water in the soil at planting, or Initial Soil Water (ISW), crop yield and yield variability has not been well quantified. An understanding of this relationship for a range of environments and crop types is required so that farmers and advisors can make more informed decisions about management options at planting. Here we use simulation modelling to quantify the relationship between ISW, crop yield and yield variability for the major grain crops (wheat, chickpea and sorghum) across a transect of environments in Qld and northern NSW. The mean grain yield response to additional soil water at planting was linear for a wide range of ISW and ranged between 14.0 and 17.4 kg/ha/mm for sorghum, 13.0 and 16.5 kg/ha/mm for wheat, and 7.9 and 10.5 kg/ha/mm for chickpea. The response in any individual year was up to 50.1, 40 and 26.6 kg/ha/mm for sorghum, wheat and chickpea respectively. The effects of ISW on yield variability and risk were also quantified.

Key Words

Soil water, dryland cropping, wheat, sorghum, chickpea, simulation modelling

Introduction

In the north-eastern Australian grain cropping region, rainfall tends to be summer dominant (e.g., 72% Oct-March at Emerald, 60% at Narrabri) but it is evenly enough distributed throughout the year to allow the production of both summer and winter grain crops. Due to high pan evaporation rates, particularly in summer, in-crop rainfall alone is insufficient to meet crop water demand in either summer or winter cropping seasons in most years. Successful dryland crop production is only possible on soils that have the capacity to store fallow rainfall for use by crops in the subsequent growing season. The widespread occurrence of soils with relatively high plant-available water capacities (PAWC), generally between 100 and 300 mm, allows the cropping industry to exist in this region.

Farmers, advisors and scientists have long been aware of the importance of fallow rainfall storage to successful crop production in this region (Darbas and Lawrence 2010; Freebairn et al. 2006). Modern, widely adopted fallow management practices such as zero-tillage, controlled-traffic farming and fallow weed control using herbicides have evolved to maximise the proportion of fallow rainfall that is stored (fallow efficiency) (Thomas et al. 2007). The relationship between ISW and crop yield has been quantified in a number of environments using both field studies and simulation modeling. Wheat yield has been shown to increase by between 4 and 22 kg/ha/ for each additional mm of ISW across a number of locations in the USA (Norwood 2000; Nielsen et al. 2002) and southern Australia (Sadras et al. 2002; Moeller et al. 2009). Nielsen et al. (2009) measured the response of maize yield to ISW at between 0 and 67 kg/ha/mm, depending on seasonal conditions. Using simulation modeling, Lyon et al. (2003) found a grain yield response to ISW of between 8 and 13 kg/ha/mm for maize on the central Great Plains, USA. Despite the apparent importance of ISW to grain crop production in the NE Australian cropping region,

there has been little attempt to quantify the relationships between ISW, crop yields and yield variability in this region.

NE region cropping systems are both complex and flexible as a result of their ability to produce both winter and summer crops. Farmers and advisors in the region are faced with a myriad of decisions at strategic (e.g., crop rotations and sequences) and tactical levels (e.g., whether to plant a crop now or wait until the next opportunity; rates of crop inputs such as fertiliser, plant population and row configuration). Darbas and Lawrence (2010) reviewed farmer and advisor knowledge, attitudes and practices with respect to soil water and planting decisions and concluded that there was a need for the development and communication of more quantitative information on the effect of stored soil water on crop production at both the single crop and multiple crop/whole farm scales to assist farmer and advisor decision making. Here we used a cropping system simulation model to quantify the effect of ISW on crop yield, yield variability and the risk of low yields for the major grain crops at a range of locations across the NE cropping region.

Methods

The APSIM (v7.1) cropping system simulation model (Keating et al. 2003) was used to simulate yields of sorghum, wheat and chickpea crops at a number of locations across the NE cropping region. Results from the five locations depicted in Figure 1, which represent the range of total rainfall (east/west transect; Roma, Miles, Pittsworth) and seasonal rainfall distribution (north/south transect; Emerald, Miles, Narrabri) experienced in the region, are reported here.

Figure 1. Location of sites

Table 1. Annual rainfall and seasonal rainfall distribution

Site	Mean annual rainfall (mm)	% summer rainfall(1)
Emerald	625	72.3%
Roma	595	66.9%
Miles	652	67.2%
Pittsworth	697	67.3%
Narrabri	644	59.9%

(1) % of annual rainfall occurring from Oct - Mar

For each crop x location, factorial combinations of ISW (50 to 300 mm in 50 mm increments) and planting date (15th of each month from September – January for sorghum and April – July for winter crops) were simulated for each of 100 years of daily climate records (1909-2008). A standard soil type (vertosol, 310 mm PAWC) was used at all locations to avoid any confounding effect of soil properties. A preliminary analysis revealed that the effect of ISW was largely independent of PAWC over the range of values of interest. Soil water was reset to the ISW values and soil nitrate to non-limiting levels (350 kg N/ha) at planting. Plant populations of 6, 100 and 30 plants/m^2 were used for sorghum, wheat and chickpea respectively. Other crop management options were set to reflect standard district practice.

Simulated grain yield for each year was used to determine grain yield probability distributions. The grain yield response to increased ISW was calculated as ΔGrain yield/ΔISW for each level of ISW for each year simulated. Probabilities of not achieving ‘acceptable’ yields of 2t/ha for wheat and sorghum and 1.5 t/ha for chickpea were calculated as a measure of risk. Coefficients of Variation (CV) of grain yield were calculated as a measure of yield variability.

Results and discussion

An example of the effect of ISW on grain yield probability distributions is given in Fig. 2.

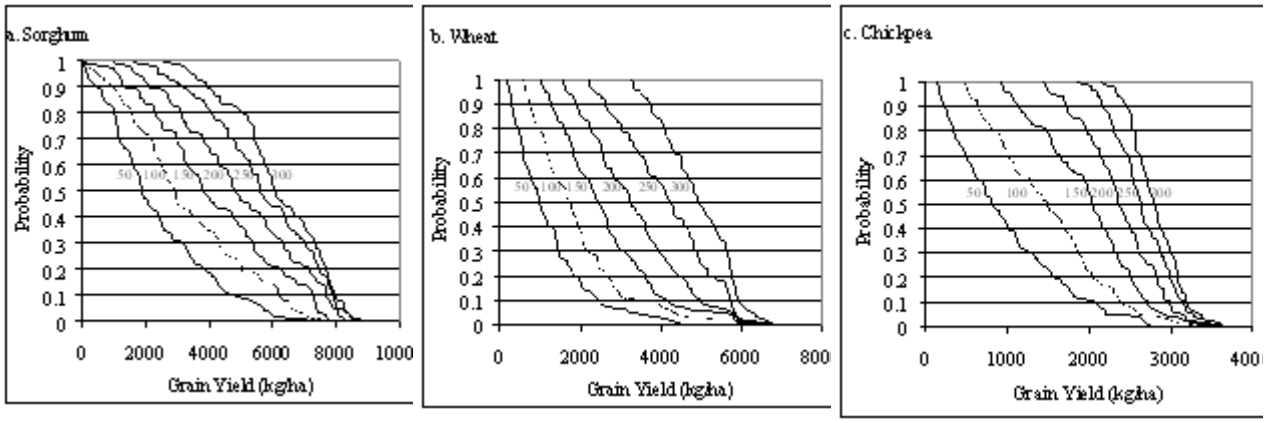

Figure 2. Grain yield probability distributions at Miles (numbers adjacent to lines indicate ISW in mm).

Median grain yields increased in a near-linear response to ISW at all locations for wheat and sorghum (Fig. 3). There was some evidence of a 'levelling off' of the yield response for the cereal crops at ISWs over 250 mm as crop water supply approached the physiological demand of the crop. The response of chickpea was more curvilinear in nature.

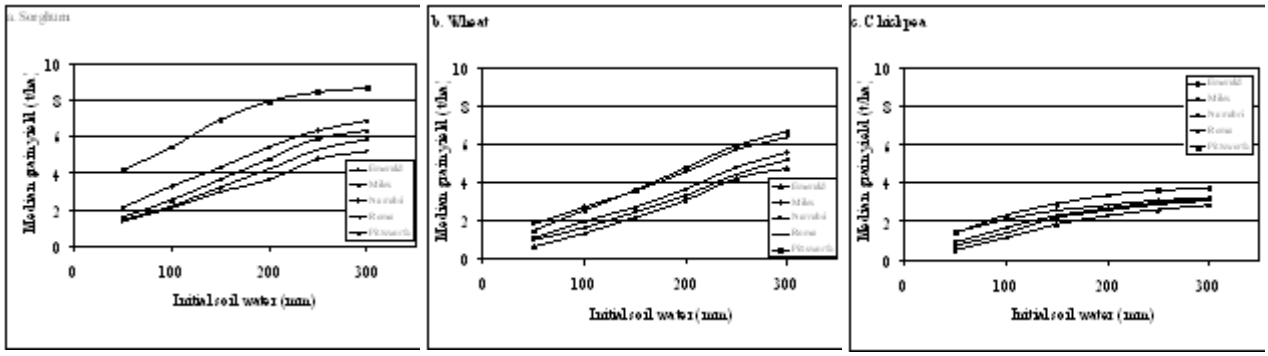

Figure 3. Effect of ISW on median grain yields.

There was no evidence of any consistent trends in the mean grain yield response to additional ISW along a north-south transect (Table 2). The mean response appeared to increase slightly for all crops along the west – east transect, reflecting the higher transpiration efficiencies that are likely to occur in the more favourable growing environments. The grain yield response to ISW reached quite high levels in some years (i.e., the maximum values in Table 2). There was little evidence of any straightforward relationship between in-crop rainfall and the yield response in a particular year, with the size of the response presumably being determined by the patterns of distribution of in-crop rainfall in relation to crop water demand.

Table 2. Grain yield responses to additional ISW (kg/ha/mm) – means of all years and maximum in any year.

Crop		Location				
		Emerald	Miles	Narrabri	Pittsworth	Roma
Sorghum	mean	16.4	17.1	14.0	17.4	15.1
	max	45.7	52.2	50.1	46.8	44.6
Wheat	mean	13.0	14.2	14.6	16.5	13.4
	max	28.1	40.0	32.1	35.8	28.6
Chickpea	mean	8.8	9.1	7.9	10.5	9.0
	max	14.5	18.0	20.9	26.6	21.8

ISW had a marked effect on the riskiness of crop production, defined here as the probability of not achieving a particular yield level. At low ISW levels, risk is high, approaching 1.0 in the more marginal production environments (Fig. 4). Risk is virtually eliminated for all crops at ISW of 250 or more. Similarly, increasing ISW greatly decreases yield variability for all crops (Fig. 5)

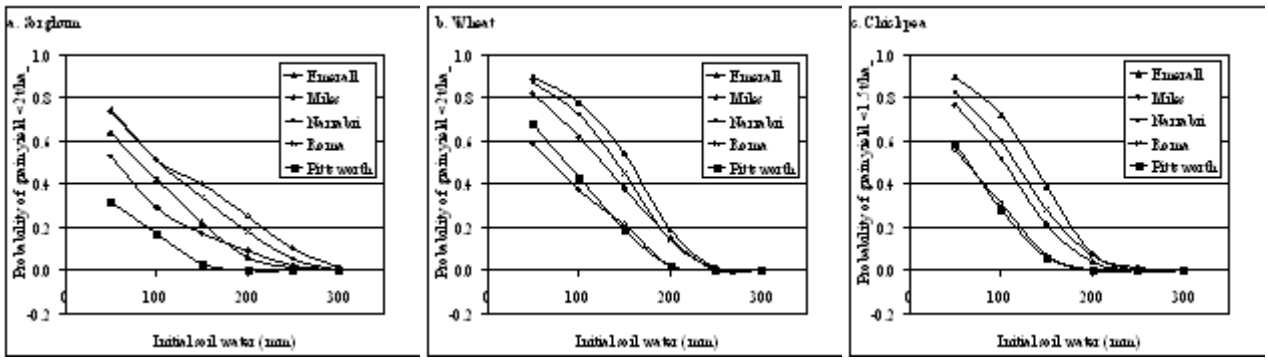

Figure 4. Effect of ISW on the probability of achieving acceptable yields

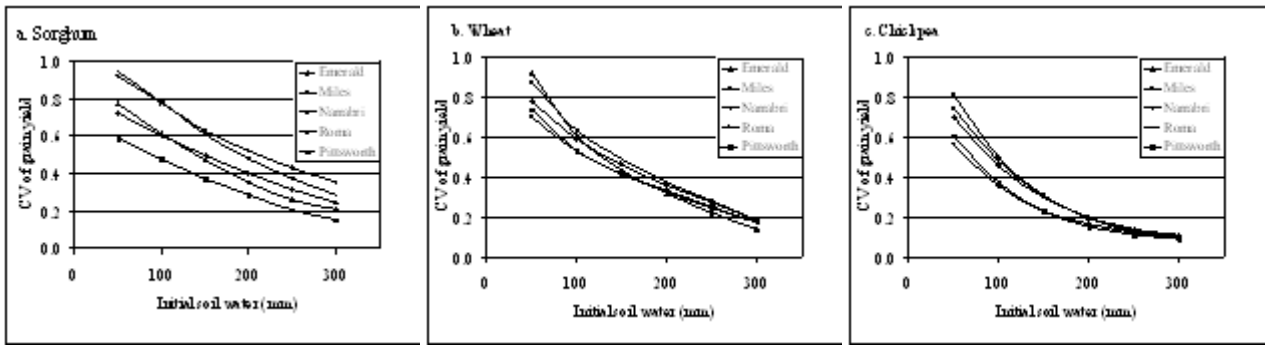

Figure 5. Effect of ISW on yield variability

Conclusion

Here we have used simulation modelling to quantify the effect of Initial Soil Water on crop yield, yield variability and risk for major grain crops at key locations in the northern grain cropping region. This information is of value to producers and advisors to help make more informed crop planting decisions, in particular, the decision whether or not to plant a crop when a marginal planting opportunity occurs. This information has been packaged and delivered to producers in the region through workshops, in hard-copy and through software tools that allow users to determine yield, gross margin and risk for a wider range of scenarios than have been presented here.

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