Making better decisions about crop rotations in low-rainfall environments: should stored moisture and the timing of the seeding opportunity influence this decision?

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Abstract

In dry environments such as the upper north cropping zone of South Australia, high inherent variability of crop yields caused by seasonal conditions has substantial implications for farm profitability. Both the amount of plant available water (PAW) at seeding and the timing of the earliest seeding opportunity can strongly influence the yield and risk profile of sown crops. In order to measure the build up in soil moisture during the summer/ autumn period leading up to seeding and to validate the APSIM modelled soil water balance, field trials were established at 2 sites in this region during the 2008/09 summer to measure soil water dynamics in response to surface cover (bare or stubble) and weed control (mechanical, chemical or nil weed control). At the Port Germein site on a sandy loam soil, controlling weeds during the summer fallow was found to conserve an extra 30 mm of soil moisture compared to no control. In contrast at the less favourable Quorn site, a clay loam over medium clay was found to lose much of its stored moisture through capillary rise and evaporation. A simulation experiment compared crop growth in response to soil type, PAW at sowing, the timing of sowing opportunity and the season to assess whether farmers can utilise such information to select more robust rotation systems or crop types. Strong swings in the probabilities of different yield outcomes were observed based on changes in opening plant available water and seeding opportunity. The results show that the model may have a key role in establishing more robust trigger points for cropping decisions in these unreliable cropping environments, particularly in the face of uncertainty around climate change.

Key Words

Plant available water, seeding opportunity, climate variability, modelling, profitability

Introduction

Low-rainfall cropping districts face major challenges associated with high yield variability and its effect on profitability. It is commonly accepted that cropping businesses in these environments incur financial losses in 2 to 3 years in ten with substantial profits also occurring in the 2 to 3 years in ten when seasonal circumstances allow good crop yields. In these districts, production risk historically has been much more important than price risk. In the northern cropping regions of South Australia, the seasonal variability has been compounded over the past decade with a succession of below-average seasons raising the possibility of long-term climate change (CSIRO 2007). To combat variability in cropping yields, businesses adopt a range of practices such as diversification (mainly involving livestock) to provide more reliable cash flow during difficult seasons. The use of responsive farming systems allows flexibility in crop area and in crop type between years, and is an important component of risk management. In the absence of reliable seasonal climate outlook forecasts, other indicators are sought to provide robust trigger points to adjust decisions about crop type and area. It is widely accepted that seasons which allow earlier seeding times with higher initial plant available water (PAW) usually result in enhanced yield outcomes. The APSIM model can use historical data sets of weather information to produce yield outputs over different seasons for various soil types. An analysis of historical data sets was undertaken to provide the probability of favorable outcomes under different starting conditions of plant available water and seeding opportunity, to improve confidence in decision making around cropping intentions and to determine appropriate trigger points.

Methods

Field experiment

In order to measure the accumulation of soil moisture during the summer/autumn period leading up to seeding and to validate the APSIM model, field trials were established at two sites (Port Germein and Quorn) in the 2008/09 summer. Average rainfall is about 320mm annual rainfall following a Mediterranean type climatic pattern. Farming systems are based around the winter growing season and are typically mixed cropping and livestock enterprises. Summer rainfall events tend to be irregular and sporadic but are sometimes substantial. The trials were established to measure soil water dynamics in response to surface cover (bare or stubble) and weed control (mechanical, chemical or nil weed control) on two soil types. Drained upper limit (DUL) and crop lower limit (CLL) of wheat was measured at nearby characterisation sites following the procedures of Dalgliesh and Foale (1998). At Port Germein, the soil was a sandy loam (Calcarosol) with a plant available water capacity (PAWC) to 1.1 m of 138 mm and no subsoil constraints. The site at Quorn was located on a clay loam over medium clay (Sodosol) with a PAWC of 140 mm to 1.1 m. Below 45 cm, pH rose to >9, electrical conductivity to >1 mS/cm and boron to > 16 mg/kg, factors that together probably reduce the extraction of moisture by plants from these deeper layers. Volumetric moisture content was measured in 20 cm intervals to 80 cm on all plots on the dates 20 December 2008, 23 February 2009 and 22 April 2009 at the Port Germein site and 8 December 2008, 10 March 2009 and 23 April 2009 at the Quorn site. There were no measurements of weed growth made. The effects of the various treatments were assayed by growing crops during the 2009 growing season (not reported here).

Simulation of 2008/2009 summer fallow at Port Germein and Quorn

APSIM was used to simulate the water balance of the +stubble and weed control treatments (nil and chemical treatments only reported here). The parameter settings of first (U) and second stage (cona) evaporation, diffusivity (movement of water up and down the profile) and the runoff curve number for bare soil (CN2) have been found to be important for accurately modelling the water balance (Whitbread et al. 2008) (Table 1). The simulation was started and reset to the measured volumetric water content of the layers at the first soil sampling in December 2008. No other resets were used. Weed growth was simulated by the growth of a late summer grass in November and December triggered by 5 mm of rain over 3 days.

Table 1. APSIM parameter settings for modelling the water balance of contrasting textured soils.

Site	Surface texture	[a]CN2Bare	[b]Diffusivity constant	[b]Diffusivity slope	U (mm)	Cona (mm day$^{-0.5}$)
Port Germein	Sandy Loam	65	88	35	4	2.5
Quorn	Clay loam	85	40	16	6	4

[a] runoff curve number [b]coefficient defining diffusivity

Long-term simulation (1900-2009) of wheat grown at Port Germein and Quorn

Long-term simulations were undertaken using historical weather data sourced from SILO (Jeffery et al. 2001) for both sites. At Quorn, sowing of wheat (variety selection dependent on the window) was triggered by 25 mm of rain over 3 days during the dates 26 April- 31 May (cv. Yitpi) and 1 June -30 June (cv. AGT Scythe). At Port Germein, sowing of wheat was triggered by 15 mm of rain over 3 days during the dates 15 April- 31 April (cv. Strzelecki), 1 May -15 May (cv. Yitpi) and 15 May to 30 June (cv. AGT Scythe). Modelling assumed that residual soil water was carried forward from previous years with no weed growth during the fallow period. The simulations produced water limited potential yields because 150 kg/ha of N was applied at sowing effectively overcoming any potential N deficiency.

Results

Following the 2008 harvest, the Port Germein site received 89 mm of rainfall in a single event in mid-December (wetting depth of this event was about 80 cm). Prior to sowing in 2009, chemical weed control resulted in significantly more stored soil moisture compared with no weed control (Figure 1a). This resulted in an extra 30 mm of plant available moisture just prior to the sowing of the 2009 pea crop. Levels of stubble cover did not impact on retained soil water except at the February sampling date (data not shown).

At the Quorn site, 175 mm of rain was received in Nov-Dec, including 66 mm received on the 12 Dec. Some of this rainfall, particularly on the bare fallow treatment, would have been lost to runoff (not measured). Measured soil moisture at the 3 sampling times, remained close to the crop lower limit. Irrespective of weed control treatments, soil moisture eventually dried down to below crop lower limit, due to evaporation (Figure 1b).

Validation of APSIM water balance

Predicted PAW at the Port Germein site was in close agreement with the weed control treatments, but was generally lower than measured in the nil weed control treatments. At the Quorn site, simulated data were always in the range of measured error, which was substantial. Pooling all of the treatment simulations, with the exception of the initial sampling which served as a reset, there was excellent agreement between predicted and observed as indicated by the low root mean square error (RMSE) value of 0.02 mm/mm.

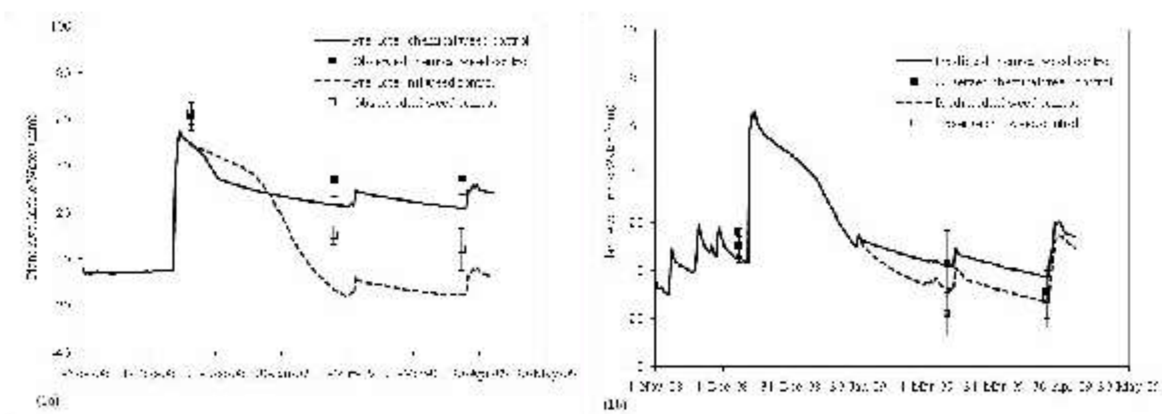
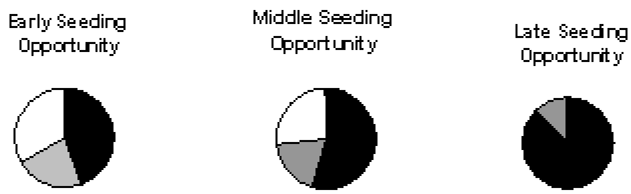


Figure 1. Predicted vs observed volumetric water content at a) Port Germein and b) Quorn

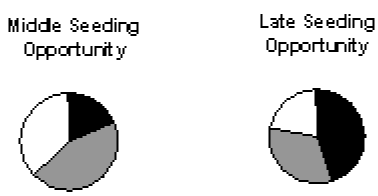
Analysis of simulation of historical crop yields

Simulated historic wheat yields were analysed for the Port Germein site to assess the impact of PAW at seeding and time of seeding opportunity on the variability of crop yields. This site is quite responsive to the storage of out-of-season soil water with relatively high simulated fallow efficiencies (average of 24%). The Quorn site has lower fallow efficiencies (average of 13%) and showed different responses but the conclusions drawn are very similar (not presented). Seeding opportunities were divided into 3 groups based on seeding date: (i) Early - 15th April to 3rd May; (ii) Middle - 4th May to 2nd June; (iii) Late - 2nd June to 30 June. The effects of different ranges of PAW and seeding opportunity on the probability of different yield outcomes (divided into terciles) are shown in Figure 1. Modelled data indicates that the interaction of plant available water at seeding and seeding opportunity is a strong indicator of final crop yield. The combination of low PAW and late seeding rarely produces a favourable outcome with most yields in the lower tercile. At the other extreme, poor crop yields (in the lowest tercile) are rare when PAW at seeding is categorised as high.

a) Low Modelled Plant Available Water at seeding (PAW <38 mm)



b) Moderate Modelled Plant Available Water at seeding (PAW 38-78 mm)



c) High Modelled Plant Available Water at seeding (PAW >78 mm)

Figure 3. Effect of variations in PAW and seeding opportunity on percentage of modelled yields in upper tercile (white), middle tercile (grey) and lower tercile (black).

Discussion

The strong correlation between measured soil water and APSIM modelled outputs suggest that the parameters used in the model to calculate water balance are reasonably representative of actual soil processes in the northern SA cropping districts. More testing and validation may allow further refinement of these parameters. Modelled outputs show strong swings in the probabilities of various yield outcomes associated with different opening PAW and seeding opportunities. This finding supports the use of these indicators as strong predictors of likely seasonal outcomes. Given that the profitability of mixed farming systems in individual years is heavily influenced by crop yield, it is likely this information can be used to improve farm profitability over a period of years.

In low-rainfall areas, poor crop yields usually result in significant financial losses being incurred. Decisions around modifying sowing intentions to limit exposure in poor seasons and capitalize on better years rely on reliable indicators to “trigger” appropriate changes to the farm programs. Farmers have often lamented the lack of more reliable seasonal outlook forecasts to provide such information. Plant available water at seeding when combined with the timing of the seeding opportunity is likely to be a far better indicator than seasonal forecasts. If farmers are to improve profitability through varying their crop intensity, they need to have alternative land uses which give more favourable outcomes than cropping in years identified as ones of poor opportunity. Alternatives in these environments are:

• Naturally regenerated or sown pastures utilized for stock feed.

• Fallow land to conserve moisture for the following year

• Reduce inputs or sow low-cost crop alternatives to limit exposure

• Sow crops with multi-purpose uses e.g. hay, graze or grain

Analysis of the financial and environmental outcomes of these alternatives would provide increased confidence in basing responsive decision making on PAW and seeding trigger points.

Conclusion

The ability to model accurately the water balance is an important step to then applying simulation and refining appropriate trigger points for responsive farming systems. The trigger points will change for different locations and soil types and analysis of localised data is required to ensure robust outputs. In an uncertain climate, local triggers will play an important role in improving long term sustainable outcomes.

Acknowledgements

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