Initial soil water: myth and management

Carina Moeller[1], Senthold Asseng[1], Jens Berger[1] and Stephen Milroy[1]

[1] CSIRO Plant Industry, Private Bag 5, Wembley WA 6913, carina.moeller@csiro.au

Abstract

The APSIM-Nwheat model was used to assess how plant available soil water at sowing affects gross margins from wheat cropping on different soil types (clay, loam, sand) at two locations (225 mm and 300 mm seasonal rainfall) in Western Australia’s wheat belt. Managing nitrogen (N) fertiliser rates for different levels of initial soil water was warranted on the two heavier soils, where interactions between N rate and initial soil water where significant. Only at the dry site, Merredin, did interactions result in a set of different optimal N application rates for maximum average gross margin (GM) depending on initial soil water. Thus, in only two of the six soil type by location combinations was it beneficial to adjust the N management based on initial soil water. In these cases, the impact on GM was large in some years, but average increases in GM did not exceed 21 AUD/ha due to high seasonal variability. The optimisation of the N fertiliser management based on both initial soil water and dry/wet seasonal conditions resulted in higher average GM compared to an optimisation based on initial soil water alone. Not sowing was warranted on the clay soil at Merredin in dry seasons with less than 15 mm of available soil water at the start of the cropping season.

Key words

Soil water, wheat, simulation, Mediterranean environment, rainfall variability, risk management.

Introduction

In dryland wheat production systems, soil moisture stored during fallow periods stabilises the yield of the following crop and adds to its yield potential (French, 1978). It has also been hypothesised that knowledge of the amount of plant available soil water at sowing can help wheat farmers to improve their nitrogen (N) fertiliser management (Rinaldi, 2004), and to decide whether or not to sow a crop (Fischer et al., 1990). In Mediterranean agriculture, the summer is often too dry to successfully grow a rainfed crop. However, rainfall during this period can still be significant. In the Mediterranean regions of Western Australia (WA), cumulative pre-sowing rainfall from January to April averages around 80 to 120 mm. Depending on soil type, the intensity of rainfall events and their timing relative to the start of the cropping season, a proportion of this pre-sowing rainfall is available as stored soil moisture to the crop. Here we investigate (i) whether long term profitability is increased when decisions on N fertiliser rates, or whether or not to sow are modified in light of initial plant available soil water at sowing (PAW_{ini}), and (ii) whether these decisions should be altered to allow for the expectation of below and above median seasonal rainfall. We used the APSIM-Nwheat model v1.55 (Keating et al., 2001) to simulate the outcomes from scenarios in which management was either modified according to PAW_{ini} or not. The value of the informed decision-making, modified in light of PAW_{ini} (conditional strategy), was defined as the increase in average gross margin achieved over a strategy that does not consider information on PAW_{ini} (baseline strategy).

Methods

Simulations with ASPIM-Nwheat were run for each year in the historical weather record (1900-2004) for three soil types at each of two locations. Growing season rainfall (May-October) is 225 mm at Merredin and 300 mm at Wongan Hills. Characteristics of the three soil types (clay, loam, sand) are given in Table 1. The timing of sowing was dependent on the opening rains of the season; being triggered by adequate moisture in the seedling layer. If sowing occurred between 5 May and 5 June, a late maturing cultivar was used, while for sowing from 6 June onward an early cultivar was simulated. Initial plant available N was set at 50 kg N/ha in 0-90 soil depth (15 kg N/ha in 0-10 cm depth, the remainder evenly distributed) on 5

May in every year. The simulations included 11 N fertiliser treatments: 0, 20, 40, … 200 kg N/ha, with up to 100 kg N/ha applied at sowing, and the reminder 40 days later. Initial soil water was treated as (i) an experimental factor with discrete factor levels (PAW_{fix}) initialised on 5 May in each year, or (ii) varied with the amount of summer rainfall (PAW_{ini}) following initialisation at zero PAW on 1 January in each year (Table 1). Gross margins (GM) were calculated as yield by grain price minus variable costs. Grain price varied with protein content. Variable costs, excluding N fertiliser were set 127 AUD/ha. Only the variable cost of N fertiliser changed with the total amount applied, and was AUD 1 per kg N.

Baseline and conditional strategies

In order to assess the potential benefits from an informed decision-making, we compared outcomes from a baseline strategy with those from conditional management strategies. In the baseline strategy, initial soil water varied with the amount of pre-sowing rainfall (PAW_{ini}), and the optimal N fertiliser rate corresponded to the single N rate that returned the highest average GM across all 105 years.

In the conditional N management strategy, the N fertiliser rate for each year was selected based on the soil water that had accumulated between January and sowing (PAW_{ini}). The optimal N rate for a range of initial soil water levels had been previously determined from N response curves of GM as shown in Figure 1: the optimal N rate being the application that gave the maximum average GM for each fixed amount of PAW_{fix} (i) across all 105 years, and (ii) in below (dry) and above (wet) median rainfall seasons. The conditional sowing strategy (sow *vs.* do not sow) was such that in cases where the average GM at a level of PAW_{fix} was negative, the decision rule ‘do not sow’ applied and the consequent GM was set to 0 AUD/ha.

Statistical analysis

An ANOVA was performed on GM obtained with PAW_{fix}. Thus, by analysing the effect of PAW_{fix}, results were not confined by subsets of years each with different rainfall distributions. ‘PAW_{fix}’ and ‘N rate’ were modelled with polynomial contrasts. Factor levels of ‘season type’ corresponded to below/above median rainfall seasons. Sites and soil types were analysed separately.

Table 1. Sites and soils: total plant available soil water capacity (PAWC), potential rooting depth (RD), and initial plant available soil water (PAW) at sowing either as discrete (PAW_{fix}) or continuous (PAW_{ini}) data.

				Merredin	Wongan Hills
	PAWC (mm)	RD (cm)	PAW_{fix} (mm)	PAW_{ini} (mm)	
Clay	109	130	0, 10, 20, … , 80	0 to 103	0 to 101
Loam	130	230	0, 10, 20, … , 100	0 to 127	0 to 112
Sand	55	150	0, 10, 30, 40	0 to 55	0 to 55

Results

Across all 105 years, two-way interactions between N fertiliser rate and PAW_{fix} on GM were significant on the clay and loam ($p \leq 0.05$), whereby the response of GM to increasing N had a flat slope, or was negative in case of the clay at Merredin (Figure 1a), at low levels of PAW_{fix}, but had a steeper slope at high levels of PAW_{fix}. There were no interactions on the sand because the shapes of the N response curves were the same for any level of PAW_{fix} (Figure 1d).

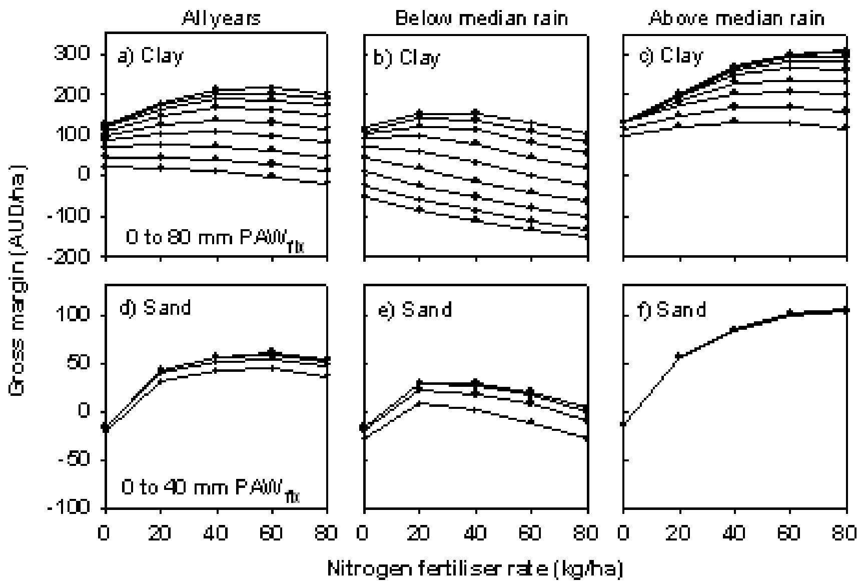

Figure 1. Effect of N fertiliser rate and initial plant available soil water (PAW_{fix}) on average gross margins (1900-2004) on a clay (a, b, c) and a sand (d, e, f) at Merredin: across all 105 years (a, d), and for seasons with below (b, e) and above median (c, f) rainfall. The lowest curve represents 0 mm PAW_{fix}, the second lowest 10 mm PAW_{fix}, etc., and the highest curve represents 80 mm PAW_{fix} on the clay and 40 mm PAW_{fix} on the sand.

Three-way interactions would potentially warrant N management according to both initial soil water and dry or wet seasonal conditions. On the clay soil at Merredin and Wongan Hills, there were highly statistically significant three-way interactions between season type and the linear effect of the N rate and the quadratic effect of PAW_{fix}. In dry seasons at Merredin the N response curves can be characterised by parallel lines where GM decreased linearly with N at all levels of PAW_{fix} (Figure 1b). In contrast, in wet seasons GM increased linearly with increasing N in proportion to PAW_{fix} from 0 to 40 mm, whereafter there was no additional response to the N fertiliser rate (Figure 1c). On the loam, three-way interactions between season type and the linear effects of N rate and PAW_{fix} were close to significant at Merredin ($p \leq 0.07$) and highly significant at Wongan Hills ($p \leq 0.01$). On the sand, only two-way interactions between N rate and season type were significant (Figure 1e, f).

For those cases where interactions between N fertiliser rate and PAW_{fix} occurred, we identified the optimal N rates for maximum average GM for each level of PAW_{fix}. Optimal N rates were derived from N response curves as illustrated in Figure 1. On the clay at Merredin, for example, the optimal N rates across all years were 0 kg N/ha with 0 and 10 mm PAW_{fix}; 20 kg N/ha with 20 mm PAW_{fix}; 40 kg N/ha with 30, 40, 60 and 60 mm PAW_{fix}; 60 kg N/ha with 70 and 80 mm PAW_{fix} (Figure 1a).

However, not all cases resulted in different optimal N fertiliser rates despite significant interactions between N rate and PAW_{fix}. On the clay and loam at Wongan Hills there was a single optimal N rate in all years and in above median rainfall seasons (not shown). Consequently, there was no difference in GM between the baseline and the conditional N fertiliser strategy at Wongan Hills (Table 2). At Merredin, the N management conditional upon PAW_{ini} resulted in higher average GM and reduced risk (i.e. higher chance to break-even) compared to the baseline strategy, except on the loam in dry seasons (Table 2). Because average GM in were positive at all levels of PAW_{fix} (not shown), sowing was warranted in every season on the loam.

Table 2. Average gross margin (GM) for a baseline (applying the same N fertiliser rate in every season) and a conditional (N fertiliser rate/s based upon initial soil water, PAW_{ini}) management strategy in wheat production systems. Also given: optimal N fertiliser rate/s, and the chance to break-even (CBE).

			All seasons	---- Dry seasons ----		---- Wet seasons ----	
Site	**Soil**	**N (kg/ha)**	**GM (AUD/ha)**	**GM (AUD/ha)**	**CBE (%)**	**GM (AUD/ha)**	**CBE (%)**
Baseline strategy							
Merredin	Clay	20	65	-42	25	175	85
	Loam	60	99	6	49	190	94
Wongan	Clay	80	305	85	55	529	100
Hills	Loam	160	296	116	68	478	100
Conditional strategy based on PAW_{ini}							
Merredin	Clay	0, 20, 40, 60	77	-29	30	192	94
	Loam	60, 80, 120	120	-10	45	215	94
Wongan	Clay	80	305	85	55	529	100
Hills	Loam	160	296	116	68	478	100

When including the season type (dry/wet) in the analysis, sowing was warranted in almost all cases except on the clay at Merredin (Table 3). Here, average GM was negative at 0 and 10 mm PAW_{fix} in dry seasons (Figure 1b). Not sowing under these conditions resulted in reduced risk and higher average GM. In general, a conditional strategy based on both PAW_{ini} and dry/wet seasons lead to higher average GM and reduced risk in dry seasons, while in wet seasons increases in GM occurred along with increases in risk by 2-13% compared to a strategy based on PAW_{ini} alone (Tables 2, 3). This trade-off between GM and risk only occurred on the clay soil.

Table 3. Average gross margin (GM), sowing opportunity (SO) and chance to break-even (CBE) with a conditional management strategy based on both initial plant available soil water and season type in wheat production systems. The chance to break-even is given across years where a sowing opportunity occurred.

---------- Dry seasons ----------	---------- Wet seasons ----------

Site	Soil	SO (%)	GM (AUD/ha)	CBE (%)	SO (%)	GM (AUD/ha)	CBE (%)
Merredin	Clay	40	67	52	100	192	79
	Loam	100	32	57	100	224	96
Wongan	Clay	100	129	68	100	534	98
Hills	Loam	100	153	81	100	497	100

Discussion

Under Mediterranean conditions, the amount of plant available soil water at the time of wheat sowing adds to the yield potential of the crop (Rinaldi, 2004). Modifying the N management based on initial soil water is warranted where interactions between N rate and initial soil water occur, as on soils with a sufficiently high water holding capacity. However, only at the dry site Merredin interactions resulted in a set of different optimal N applications rates depending on initial soil water. Thus, in only two of the six soil type by location combinations was it beneficial to adjust the N management based on initial soil water. Where a more tailored N management was possible, increases in GM and reductions in risk were generally achieved.

In dry seasons on the loam at Merredin, however, an optimisation based on initial soil water alone had a negative effect on GM and risk, although average GM increased across all seasons. This can be explained by the effect of the seasonal rainfall variability, that is the response of the crop to the unfolding dry seasons was often stronger than the response to initial soil water. Relatively high amounts of initial plant available soil water together with an optimistically high N rate followed by dry seasonal conditions can cause a negative yield response to N fertiliser (van Herwaarden et al. 1998).

In general, the importance of initial soil water for the productivity of wheat crops in the WA wheat belt is likely to increase, as increases in summer rainfall and decreases in winter rainfall due to climate change have been reported (Smith et al. 2000). The optimisation of the N fertiliser management based on both initial soil water and dry/wet seasonal conditions resulted in higher average GM compared to an optimisation based on initial soil water alone. However, the analysis also showed that increases in GM can be associated with higher risk. Not sowing was warranted on the clay at Merredin in dry seasons with less than 55 mm in the soil profile at the start of the cropping season. These increases in GM associated with adjusting management for initial soil water and below/above median rainfall seasons are potentially achievable, but can only be realised with skilful forecasts of rainfall in the forthcoming season, which are currently not available (Moeller et al. 2006).

Conclusion

Surprisingly, it was only beneficial to modify management based on initial soil water in two of the six situations examined: on the clay and loam at Merredin. Adjusting management for season type as well, improved the situation but more skilful forecasts of seasonal rainfall are required to realise this potential.

References

Fischer RA, Armstrong JS, Stapper M (1990) Simulation of soil water storage and sowing day probabilities with fallow and no-fallow in southern New South Wales: I. Model and long term mean effects. Agricultural Systems 33, 215-240.

French RJ (1978) The effect of fallowing on the yield of wheat. II The effect on grain yield. Australian Journal of Agricultural Research 29, 669-684.

Keating BA, Meinke H, Probert ME, Huth NI, Hills IG (2001) NWheat: documentation and performance of a wheat module for APSIM. In 'Tropical Agriculture Technical Memorandum No. 9'. (CSIRO Tropical Agriculture: Indooroopilly, Australia)

Moeller C, Smith I, Asseng S, Ludwig F, Telcik N (2006) Assessing the value of seasonal climate forecasting - case studies from the wheatbelt in Western Australia's Mediterranean region. Agricultural and Forest Meteorology (submitted).

Rinaldi M (2004) Water availability at sowing and nitrogen management of durum wheat: a seasonal analysis with the CERES-Wheat model. Field Crops Research 89, 27-37.

Smith IN, McIntosh P, Ansell TJ, Reason CJC, McInnes K (2000) Southwest Western Australian winter rainfall and its association with Indian Ocean climate variability. International Journal of Climatology 20, 1913-1930.

Van Herwaarden AF, Farquhar GD, Angus JF, Richards RA, Howe GN (1998) 'Haying-off', the negative grain yield response of dryland wheat to nitrogen fertilizer: 1. Biomass, grain yield, and water use. Australian Journal of Agricultural Research 49, 1067-1081.