Fluctuations in spatial variability of wheat yield

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Abstract

A recommendation of precision agriculture to lift profits and minimise the off-site impact of farming, is to zone paddocks into areas of similar soil properties and thus similar yield potential and to implement more site-specific management. One problem sometime faced during zoning is ambiguity due to climate variability, which leads to temporal variability in both yield and the yield classification membership of each zone. In extreme cases, a zone may fall in the high yielding class in one year and in the low yielding class in another. These fluctuations are sometime observed even with the relatively short history of yield mapping in Western Australia. Lack of longer-term yield mapping data is currently a shortcoming and prevents us from determining with reasonable confidence the probability of membership of a zone to a particular yield classification. We used crop simulation in the APSIM framework to overcome this problem and to account for the effect of climate variability on yield performance. The simulations reproduced wheat yield classification measured in the last few years well and showed that temporal variations in both yield and in zone classification would occur in all zones due to interactions between seasonal rainfall, soil moisture retention properties and fertiliser use. In spite of these fluctuations, some zones are more likely to perform well whereas others are more likely to perform poorly based on likely conditions during crop growth. Our findings suggest that the concept of assigning a probability of membership of a zone to a yield classification may be more appropriate than assigning definite classifications to these zones. This property is well suited to fuzzy classification, which assigns a degree of membership to a zone rather than a rigid membership. Actual zone classification for a particular year can be determined when the actual conditions for wheat growth are known.

Media summary

The spatial pattern of wheat yield fluctuates temporally due to interactions between soil properties, seasonal rainfall and fertiliser use. Site-specific yield performance is therefore better expressed in terms of probability.

Key Words

Precision agriculture, temporal variability, management zones, yield map, plant available water, APSIM

Introduction

One recommendation that has emerged from precision agriculture research to lift profits and minimise the off-site impact of farming, is to zone paddocks into areas of soil properties and thus similar yield potential and to implement more site-specific management. Depending on the grower's preference and the extent of spatial variability, a number of zones can be identified and then classified, for example as high yielding, average yielding and low yielding. The history of yield mapping that these zones are based on is normally less than eight years in Western Australia. During that period, we would expect to have three to four wheat crops in rotation with other crops and pasture. The relatively few yield maps are normally complemented with additional spatial data such as satellite imagery, elevation, soil conductivity and gamma ray emission maps to add confidence to paddock zoning (Whelan and McBratney 2003, Wong and Lyle 2003). However, even within the short history of yield mapping, we sometime observe zones that fluctuate between different classifications in different years. In extreme cases, a zone may fall in the high yielding class in one year and in the low yielding class in another year. This temporal variability in yield performance complicates the assignment of management zones to specific yield classes. The lack of sufficient yield maps prevents us from always determining the probability of class membership for each zone with confidence. We used crop simulations to reduce this difficulty and determine long-term crop yield at contrasting paddock locations based on the seasonal conditions for the year of simulation and the site-specific plant available water contents (PAW).

Methods

Site selection and field measurements

Yield maps for 1998 to 2002 were obtained for a wheat-lupin rotation for a 70 ha paddock in Three Springs, Western Australia to select contrasting sites for soil sampling. These yield maps were combined using the Weighted Linear Combination technique to determine the most likely grain productivity zones based on five years of observation. The weight given to each yield map was dependent on closeness to long-term seasonal rainfall: yield maps in years close to the long term average seasonal rainfall were given more weight than maps from recent very dry years (Wong and Lyle, 2003). Ten sampling sites were selected using the combined yield map to represent the range from low to high productivity zones within the paddock. The soil lower limit, drained upper limit and bulk density were measured at each site at intervals down to a maximum depth of 2.5 m wherever possible to calculate PAW. Five contrasting soil profile data were used for crop modeling to predict long term yield patterns in relation to seasonal rainfall, initial soil water content and N management (Table 1).

Simulation experiment

APSIM was configured with the NWHEAT crop module (version 1.55s), SOILN2, SOILWAT2 and RESIDUE2 soil and residue modules (www.apsim.info). This model configuration simulates carbon, water and nitrogen dynamics and their interactions within a wheat crop/soil system that is driven by daily weather information (rainfall, maximum and minimum temperature and solar radiation). It calculates the potential yield, that is, the yield not limited by pests, diseases, P and K, but limited only by temperature, solar radiation, water and N supply. The model has been successfully tested against data from field experiments in Western Australia and elsewhere (e.g. Asseng et al. 1998a). Simulation experiments were carried out for each of the five soil types (Table 1) with long-term daily weather records (1900-2000) from Three Springs (average annual rainfall of 445 mm). In order to study in-season effects and to control initial conditions, each simulation run commenced on 1 May and was re-set each year with 50 kg mineral N/ha in the top 90 cm. At 1 May each year, soil water was set at the lower limit (LL) (treatment dry initial soil water) or 30 mm of PAW below 20 cm (treatment wet initial soil water). Wheat was sown between 5 May and 31 July after rainfall of >25 mm in May or > 10 mm thereafter. Nitrogen fertiliser treatments of nil, 30, 60, 90, 120, 150, 180 and 210 kg N/ha were applied.

Results

The selected sites for APSIM modelling covered a broad range of PAW and wheat yield within the paddock (Table 1). The pale deep sandy site (site 3) had lowest PAW and performed consistently poorly over the period of yield mapping whereas the deep yellow sand (site 2) had the highest measured PAW and performed best in two years (1998 and 2000) out of three. In 2002, yield on the duplex sandy gravel at site 9 outperformed yield at site 2 by about 12%. This difference is small and both sites would fall within the same yield classification. There is nevertheless a tendency for sites 9 and 2 to exchange yield ranking within the yield classification during three years of yield observation.

Table 1. Measured soil and plant characteristics at field sites in Three Springs.

Site number	Root depth (cm)	PAW (mm)	Soil type	Wheat Yield (t/ha)

				1998	2000	2002	Mean
2	230	162	Deep yellow sand	3.70	2.50	3.10	3.10
3	150	40	Pale deep sand	0.88	0.15	0.51	0.51
6	230	100	Duplex sandy gravel	2.26	1.22	2.38	1.95
7	150	57	Pale deep sand	1.41	0.44	0.88	0.91
9	230	110	Duplex sandy gravel	3.28	2.33	3.48	3.04

Measured wheat yield was dependent on both seasonal (April to October) rainfall and site-specific PAW. Increase in seasonal rainfall from 260 to 291 mm increased yield at all sites (Figure 1). Additional seasonal rainfall to 428 mm increased yield on the sandy sites (2, 3 and 7) and depressed yield on the duplex sites (9 and 6).

It is not possible to make direct comparison between simulated and measured yield in our experiment because of uncertainty in initial soil conditions. The APSIM modules we used have however been tested extensively with field experiments in WA where the initial conditions were known (e.g. Asseng et al., 1998a; b). It is therefore justifiable to compare the relative patterns of simulated and measured yield. The average APSIM simulated wheat yield for 1900- 2000 identified site 2 as the best performing part of the paddock and site 3 as the poorest performing part (Figure 2).This ranking of simulated yield performance is in accord with yield measurements shown in Table 1 and with grower's knowledge of the property and suggests that soil properties (PAW) had a major impact on site-specific potential yield.

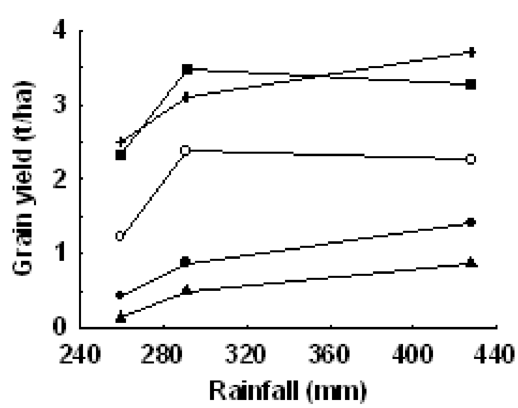

Figure 1. Observed grain yield for site 2 (+), site 9 (■), site 6 (○), site 7 (●) and site 3 (▲) for years 1998 (April to October rainfall = 428 mm), 2000 (April to October rainfall = 260 mm) and 2002 (April to October rainfall = 291 mm) with about 50 kg N/ha.

Application of adequate nitrogen fertilizer (210 kg N/ha) could however lift production at all sites but did not change the yield ranking of the extreme sites. Within those extremes, the ranks of sites 9 and 6 were predicted to change with application of nitrogen fertilizer. The predicted site-specific yield performance ranking obtained for non-limiting nitrogen fertilizer application (site 2>9>6>7>3) matched the average ranks measured in the field more closely than the ranks predicted for no nitrogen fertilizer application (site

2 >6>9>7>3). The field experiment was given about 50 kg N/ha. Depending on the rate of N fertiliser applied, either sites 2 and 6 or sites 2 and 9 could fall in the high yielding class.

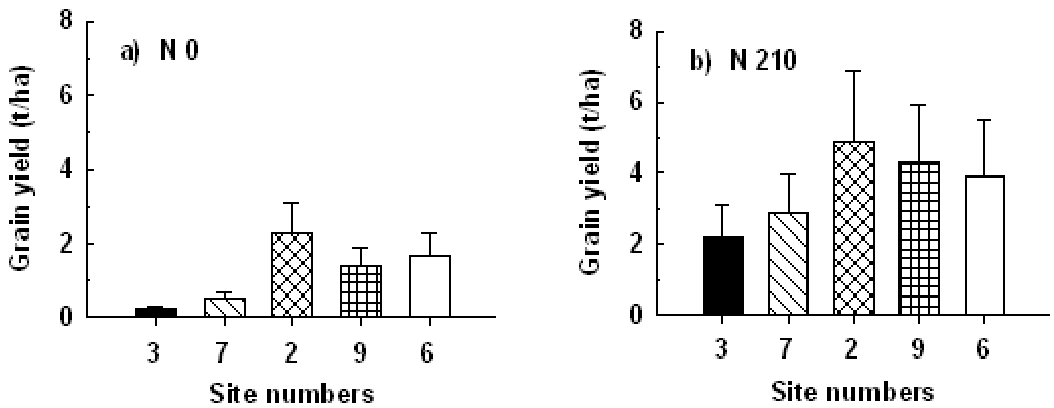

Figure 2. Simulated wheat yield at (a) 0 Kg N/ha and (b) 210 kg N/ha for 5 sites with contrasting PAW contents (see Table 1).

In addition to response to nitrogen fertilizer, reversal of site-specific yield performance occurred in response to seasonal conditions (Figure 3). Simulated yield on site 2 fluctuated between 0.5 to 9.0 t/ha in 1900 to 2000, the highest yield occurring twice in a century under favorable seasonal conditions with 210 kg N/ha. During that period, site 6 outperformed site 2 twenty seven times if the model was initialized with dry soil conditions and eighteen times if the model was initialized with wet soil conditions. There is therefore a probability of about 22% that site 2 and 6 would swap zones classification depending on seasonal conditions and initial soil water content at sowing. Even for the most different sites 2 and 3, the model predicts that site 3 will outperform site 2 fourteen times in a century particularly in extremely dry seasons when the model was initialized with dry soil and three times in a century if the model was initialized with wet soil conditions: There is roughly a 1 in 10 chance of the worst soil being the best but in fact all soils are also performing poorly due to lack of water! Growers in Western Australia sometime report that their worst soil gave the best yield during drought years due to ‘haying-off’ of the crop on the better soils.

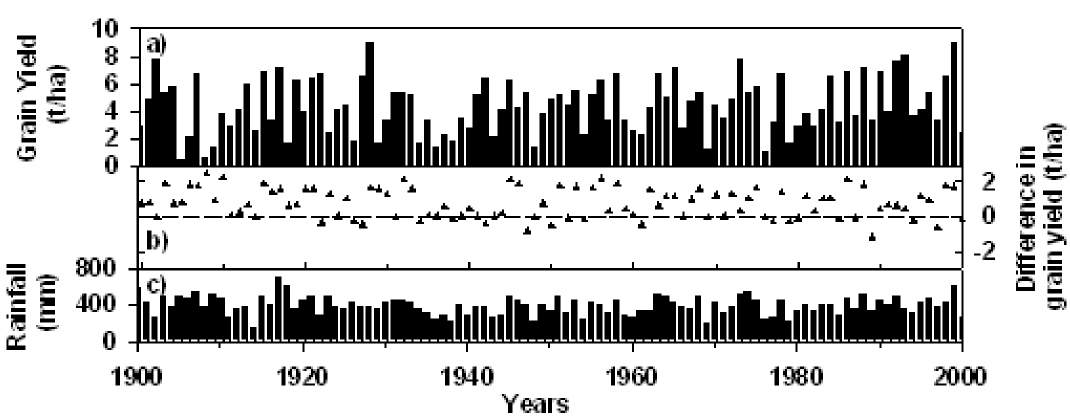

Figure 3. (a) Simulated grain yield for site 2 (PAW = 162 mm), with initial dry soil and initial low mineral N, (b) difference in grain yields between site 2 and site 6 (PAW = 100), and (c) April to October rainfall at the sites. Dashed line in b) is the zero line. Adequate N (210 kg N/ha) applied at both sites.

Conclusion

The membership of a zone to a given yield classification is not fixed but is a result of interaction of soil properties, seasonal rainfall and fertiliser use. Modelling allowed us to attribute a probability of membership of a zone to a given classification based on rainfall data, initial soil condition and fertiliser use. This concept of assigning a probability of membership of a zone to a yield classification is more appropriate than assigning definite classifications to these zones. This property is well suited to fuzzy classification, which assigns a degree of membership to a zone rather than a rigid membership (Wong and Lyle 2003). Actual zone classification for a particular year can only be determined when the actual conditions for wheat growth are known. Based on the frequency of rainfall events measured in 1900 to 2000 and the site-specific PAW, we conclude that site 3 has a high probability of performing poorly whereas site 2 has a high probability of performing very well. The uncertainty in the yield classification membership of each zone minimises the benefit of subdividing the paddock into many zones. It is partly because of this uncertainty that growers world-wide choose to have a maximum of three zones within their paddock to represent their most contrasting areas.

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