PAWC determines spatial variability in grain yield and nitrogen requirement by interacting with rainfall on northern WA sandplain

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Abstract

Spatial variability in grain yield within paddocks presents an opportunity for more efficient targeting of fertiliser application through the use of precision agriculture technology. The ability to manage this yield variability depends on understanding the underlying factors, and their spatial patterns, that cause yield variation. One of the key factors which influences spatial variation and interacts strongly with season is plant available soil water storage capacity (PAWC). If variation in yield can be related to PAWC then management zones can be defined with confidence. Seasonal influences on yield expectation, and hence fertiliser requirement, can then be defined for each management zone.

Using two highly-variable focus-paddocks on the northern sandplain of the WA wheatbelt, we measured spatial variation in PAWC, grain yield over a number of seasons and through the use of simulation tested the ability of measured PAWC to describe the variability in wheat yield. PAWC varied 3-fold across both paddocks and was consistent with farmer maps of soil type distribution. Measured and simulated yield were related to PAWC with the shape of the relationship dependent upon the total amount and within-season distribution of rainfall. We used modelled relationships between potential yield and PAWC for different season types to arrive at economic optimum rates of fertiliser N for wheat and hence potential economic gains to zone management over uniform paddock management.

Key words

Precision agriculture, plant available soil water storage capacity, APSIM, wheat

Introduction

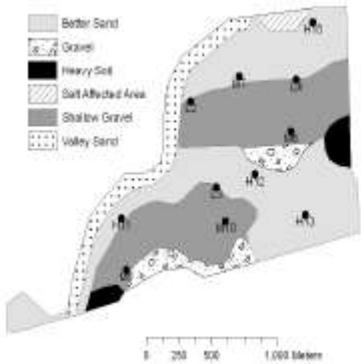
Spatial variability in grain yield within paddocks presents an opportunity for more efficient targeting of fertiliser application through the use of precision agriculture technology. The availability of PA technology can allow variability to be managed within a paddock or farm. Management zones can be defined by methods which estimate soil types/properties such as traditional soil survey, EM38 and gamma radiometrics (Wong and Asseng, 2006). However, this approach relies on there being a strong linkage between soil variation and variation in crop yield.

Knowledge of soil properties provides some understanding about the causes of variation. However knowledge of the soil property that affects the yield is still required to predict the yield and nutrient requirement over a range of season types. One soil property which strongly influences the variation in yield and fertiliser requirements is plant available soil water storage capacity (PAWC). By combining knowledge of PAWC with yield modelling (APSIM) we can calculate yield and nutrient requirements for a range of PAWCs, over a range of seasons.

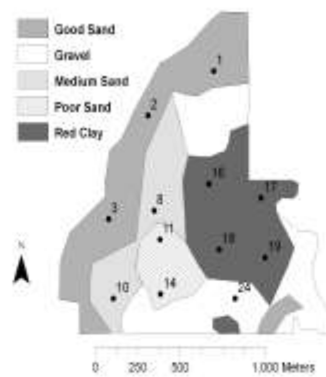
The aim of this paper was to determine if PAWC is the main driver of yield variation in two focus-paddocks that were studied as part of the GRDC precision agriculture initiative SIP09, and if so outline a method by which soil type and seasonal influences on yield potential and nutrient requirement could be quantified.

Methods

Two farmers in Buntine, (Paddock A- 436078E, 6683629N and Paddock B- 442461E, 6694078N) on the northern sandplain of the WA wheatbelt, provided two highly variable paddocks to study. At 23 points over the two paddocks, PAWC was measured in 2004 following the methods of Dalgliesh and Foale (1998) and the soil analysed (Fig. 1, Table 1). The crop lower limit (CLL) of PAWC was measured at the end of the season (when there was little end of season rainfall) by soil coring to 1.8m to determine water content. The drained upper limit (DUL) of PAWC was measured after a 16 m^2 area was wet up over 7 days, covered with plastic and allowed to drain for 14 days before soil samples were taken and water content measured. The yield at these points was measured from quadrat cuts in 2003-2005 and read off the yield maps collected by farmers over 1997-2002.



Paddock A



Paddock B

Fig. 1. Farmer soil maps and sites where soil and crop measurements were taken.

APSIM was used to simulate the wheat yield at each point where PAWC had been determined. Simulation used measurements of available soil nitrogen at sowing, crop management and rainfall data for Buntine. If soil N was not measured, we assumed the same amount of available N across all soils. Yield was also simulated over a number of seasons using a range of fertiliser rates (from 0 to 150 kgN/ha applied at sowing) and 50 kgN/ha in the soil profile, to determine an economically optimal N rate. For this analysis, PAWC was varied by holding the CLL and DUL constant, typical for a soil of sand texture, and varying the rooting depth. A sensitivity analysis, where we varied the CLL, DUL and rooting depth, showed that 'soil type' had little effect on the simulated relationship between PAWC and yield.

Results and Discussion

PAWC and soil properties

Measured values of PAWC varied across the two paddocks from 32 to 107 mm with soil types ranging from shallow and deep sands to duplex soils and clays. There was a large variation in the PAWC within a soil type, as defined by the WA soil group classification (Table1). Much of the variation of PAWC within a soil type was often due to inferred rooting depth variation (Table 1) caused by impeding layer or a subsoil constraint such as acidity. For example, yellow sands varied in PAWC from 63 to 110 mm. As there is large variation in PAWC within a soil type, it may be more useful to delineate or assign management zones based on estimates of PAWC.

Table 1. The soil type (WA soil group) of the sampling sites, measured PAWC to the rooting depth (inferred from where the CLL and DUL converge).

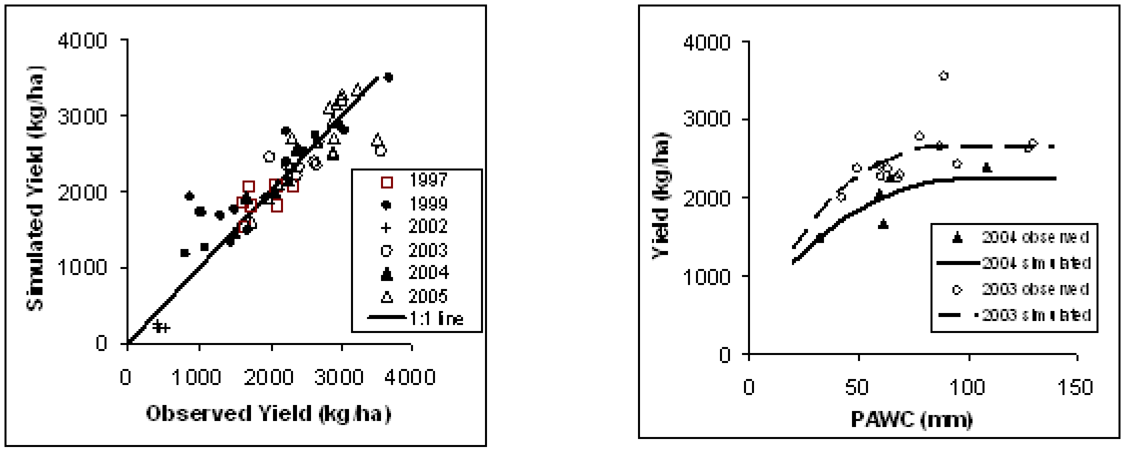
Soil type (approx WA soil group)	Site	Measured PAWC (mm)	Inferred rooting depth (m)
Shallow sand/gravels	L2, L4	43, 32	0.6, 0.5
	10	52	0.6
Sands (yellow)	H12, H13, H15	89, 105, 110	1.5, 1.8, 2.2
	1, 8	90, 107	1.8, 1.8
	11,14	63[A], 74[A]	1.2, 1.2
Shallow loam	24	79,	0.6
(some gravel)	L3, H11	61, 72	1.0, 1.2
Deep loam	2, 4	107, 89	1.8, 1.5
Shallow loamy/sandy duplex	M6, M9	60, 64	1.2, 0.8
Deep sandy/loamy duplex	3	68	1.6
Clay	16, 17, 18, 19	94, 77, 62, 60	1.5, 1.2, 0.9, 0.9

[A] These sites have acid subsoils

At the measurements points, the soil type assigned by the farmer mud map sometimes differed slightly from the WA soil group. This is because soil assignment by farmers is based on surface soil properties. In addition, the scale of resolution can make matching of soil type descriptions difficult. For example, the soil at H11 in map A (Fig. 1) was textured as a shallow loam with a PAWC of 72 mm, but from the farmer map it falls in an area assigned to “Better Sand”, but this area is adjacent to an area of shallow gravel. In other cases a mis-match can occur because the farmer description includes some notion of productivity in the soil description i.e. sites 11 and 14 on Map B are textured as a sand but have subsoil constraints, and so have a lower PAWC than other sands in the paddock, whereas the farmer has taken this into account by describing that area as a poor sand.

PAWC can be used to predict yield

Using measured soil properties and known crop management, APSIM was able simulate wheat yield at the measured points over a number of season (RMSD 518kg/ha n= 69, 302kg/ha with 4 outlying points removed) (Fig. 2a). If ‘soil type’ is ignored by assuming PAWC varies as a function of rooting depth, the simulated relationship between PAWC and yield describe the measured response in 2003 and 2004 (RMSD 364 kg/ha n =15 or 218 kg/ha with 1 outlier removed) (Fig. 2b). As PAWC appears to explain a high degree of variation in yield, this suggests that zones delineated by PAWC are reliable for crop management.

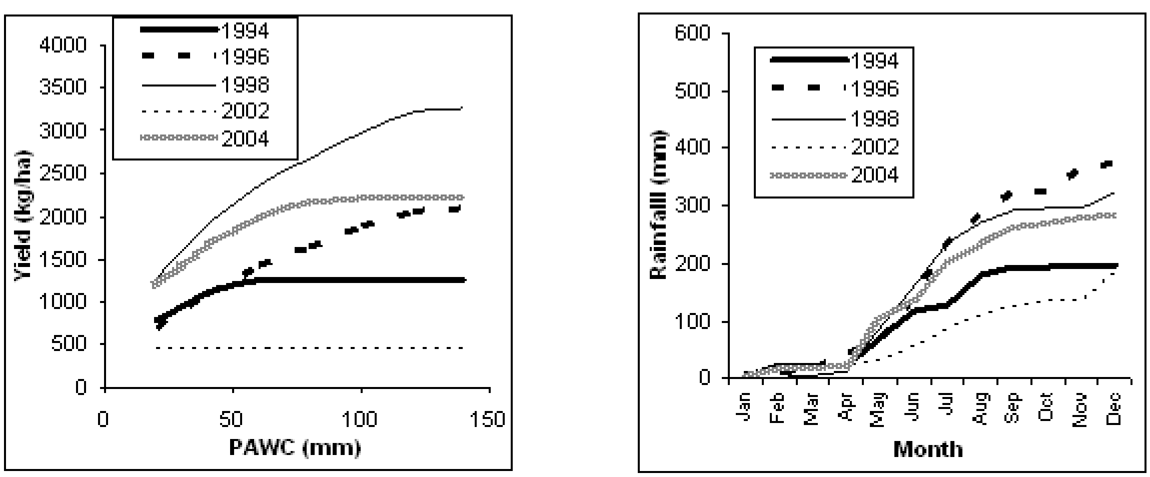


a) b)

Figure 2. a) Observed versus APSIM simulated yield for 1997-2005 (excluding 1998, 2000, 2001). b) The relationship between PAWC and observed yield (points) and simulated yield (line) for 2003 and 2004.

Seasonal interactions of PAWC and yield

Why some yield maps have large spatial variation in some years and less in others may be explained by how the season and soil interact to affect crop yield. In good seasons, PAWC becomes important particularly if the rainfall can be stored deeper in the profile and is accessed by crop roots, i.e. the linear response in 1996 and 1998, which had high season rainfall (decile 8 and 6), good start of season rainfall but less rainfall at the end of the season (Fig. 3a,b). However in poor seasons, such as the decile 1 year of 2002, there is little relationship between yield and PAWC as crops mostly just survived off current rainfall (Fig 3a,b). A curvilinear response to yield was seen in 1994 and 2004, with good start-of-season rainfall but below-average growing season rainfall (decile 3 and 4). The yield response flattens at a larger PAWC in seasons with higher rainfall (2004 vs. 1994) (Fig. 3a,b).



a) **b)**

Figure 3a) PAWC vs simulated yield and b) Cumulative rainfall for 1994, 1996, 1998 and 2004

A strong relationship between yield and PAWC enables the potential use of inverse modelling to estimate the PAWC from a yield map, with known paddock management. This will enable the division of the paddock into PAWC management zones and will not require the many, time-consuming measurements to obtain the spatial variation of PAWC. A "good" season with a large dynamic range in the relationship between yield and PAWC is ideal for the purposes of inversely estimating PAWC.

How the season affects N recommendation

The relationship between N rate and yield was determined for a PAWC of 40mm and 100mm for 1994; 1996, 1998 and 2004 (Fig.4 – showing PAWC of 100mm only). The optimal N rate, 90% of maximum yield, was the same for the 40mm and 100mm for 1994 and 1998 (Table 2).Therefore managing these two zones differently in these years would not produce an economic benefit. In 1996 the optimal N rate was 20kg/ha higher at the higher PAWC of 100mm, making it economically beneficial to manage these zones differently. In 2004, the optimal N rate was 20kg/ha lower on the higher PAWC of 100mm, which although may indicate benefits to managing these zones differently, it would be unusual to recommend a lower rate of N on the higher yielding area with the higher PAWC. This shows that it is important to understand the seasonal effect of yield responses to nitrogen when making nutrient recommendations.

Table2. Economic optimal N rate for a PAWC of 40mm and 100mm over 1994, 1996, 1998 and 2004

	Economic optimal N rate	
year	40mm	100mm
1994	0	0
1996	40	60
1998	140	140
2004	60	40

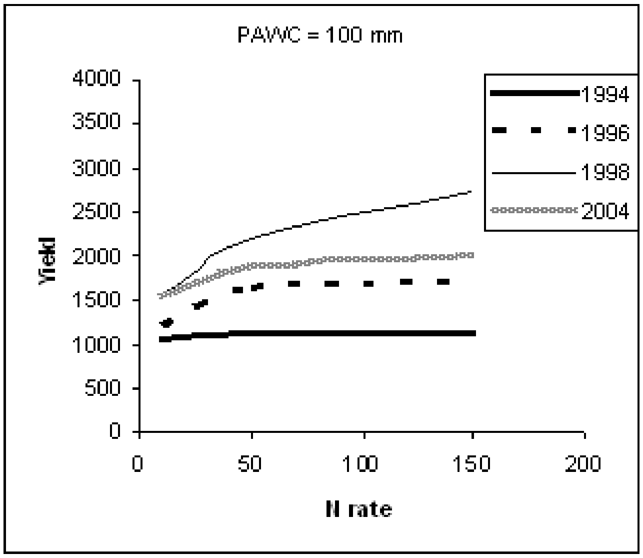


Fig. 4. Modelled relationship between applied N and yield for a PAWC of 100mm

Conclusions

PAWC appears to explain a high degree of variation in wheat yield which suggests that zones delineated by PAWC are reliable for crop management. The PAWC varies widely within paddocks, and within soil types due to subsoil constraints affecting rooting depth and to difficulties in correctly identifying and mapping soil types. There is a potential to estimate PAWC from yield maps by inverse modelling, where the paddock management is known and in years where there is a high variation in yield or "good" seasons.

The response of yield to PAWC differs due to the distribution and amount of rainfall or "season type" Increasing yield with increasing PAWC occurred when the crops needed to use water stored deep in the profile. The optimal N rate in different zones was dependant on the combination of season, PAWC and the steepness of the Yield-N rate response curve.

Acknowledgements

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References

Dalgliesh N and Foale M (1998) 'Soil Matters. Monitoring soil water and nutrients in dryland farming'. (Agriculture Production Systems research unit: Toowomba, Qld).

Wong MTF and Asseng S (2006) Determining the causes of spatial and temporal variability of wheat yields at sub-field scale using a new method of upscaling a crop model. Plant and Soil. **283**: 209-221.