The gap between yield potential and reality for continuous wheat in wet years in a dry environment.

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Abstract
Mallee farmers identified fertiliser management on different soil types in continuous cereal paddocks as a key limit to water use efficiency after a series of drier-than-average years. In experiments established on three soil types in a continuously cropped paddock, upfront nitrogen (N) was revisited as a more practical alternative to in-season applications. The validity of ongoing low application rates of phosphorus (P) was also tested by repeated application of a range of rates.

The first two seasons of experiments had higher yield potential than had been anticipated, because of in-season rainfall (2010) and stored moisture (2011). Nitrogen fertiliser was important on soils where there were no agronomic issues and soil tests indicated deficiency; rate was more important than timing. Where there were other agronomic issues (weeds and disease on dune soil in 2011), there was evidence of a small response to P, but no response to N. On all soils in both years, yields were well below 'potential' predictions made by a range of models.

The results reinforce the need for flexibility when circumstances change, the importance of accounting for other agronomic limitations when making fertiliser decisions, and caution against the extrapolation of economic performance of continuous cereal systems in better years using rainfall-driven yield models.

Keywords
Variable rate, precision agriculture

Introduction
Farmers in the Victorian Mallee have been adopting continuous cereal rotations during a sequence of average and drier-than-average seasons (2001-2009). Yields have been higher in drier seasons on sandier soils, with electromagnetic surveys and soil testing revealing widespread 'subsoil constraints' on clay soils, which restrict water availability to crops in dry seasons (ie. Boron, salinity. Llewellyn *et al.* 2008). Expecting water-limited yield, farmers have responded by reducing fertiliser (nitrogen, N, and phosphorus, P) rates on clay soils, while increasing (N) or maintaining (P) rates on sandier soils. This has been supported by soil testing, which often shows high N fertility on clays and sufficient P on most soil types. In 2009, farmers and agronomists nominated the timing/rate-decision of N application (up-front or in-season) and whether it was possible to eliminate P application on soils with high soil tests as two main factors affecting water use efficiency (WUE). Subsequent experiments occurred in years with above-average yield potential because of growing season rainfall (2010) and stored water (2011). This work aims to explore the reasons for the failure of crops in these years to achieve water- and N-limited yield potential, and the implications for use of water- and N-driven crop simulation models in these systems.

Methods
A farmer paddock (35.05S, 142.33E) that had been continuously cropped to cereals (2003-2009, most crops wheat cv. Yitpi) was selected near Ouyen, Victoria. An electromagnetic survey of the paddock (EM38, vertical dipole) was used to select a part of the paddock where low (dune), medium (slope) and high (flat or swale) ECa areas were near each-other, and soil variation was approximately parallel to topography.

Experiments were established on each soil type comprising a 3 replicate factorial of 'up-front' or 'in-season' N strategies, and 0, 6 or 12 kg/ha P rates. Treatment plots (4.8 x 10m) were arranged in two rows of three plots per replicate, and replicates interspersed with buffer plots (two plots in a single column between each replicate), which were given a 'district practice' treatment and also measured for yield. Treatments began in 2010 and were repeated on the same plots in 2011. Prior to sowing in 2010, the site was topdressed with 200 kg/ha gypsum to ensure that sulphur deficiency was not a confounding issue. Foliar zinc was applied in 2010 only.

Plots were maintained in weed-free chemical fallow between harvest and sowing. Wheat (cv. Yitpi, 60 kg/ha) was sown in early May each year using knife points and press-wheels at 30cm spacing, with fertiliser applied below the seed. Trifluralin 480 (2l/ha) was used as a pre-emergent herbicide. In both 2010 and 2011 the pre-emergent was less successful on dune and slope soils. Post-emergent control was applied each year but failed in 2011 due to low winter rainfall, and plots were ultimately hand weeded.

Nitrogen rates for strategies (detailed in Table 2) were based on pre-sowing (April) measurements of soil mineral N and available water down to 1m. The up-front strategy was to apply a fixed amount of N sufficient for the yield that could be achieved given stored water at sowing and growing season rainfall typical of the preceding ten years (187mm). The in-season strategy was to apply nitrogen according to the seasonal outlook at early stem elongation (Zadoks 31), after applying urea at sowing to ensure sufficient N for a 1.5t/ha crop (combination of soil and fertiliser N equivalent to 60 kg/ha N).

Grain yield, protein, and crop biomass at maturity were measured on each plot. Crop transpiration was estimated from biomass by assuming transpiration efficiency for biomass of 55kg/ha/mm (Jones 2009). Per-plot apparent EC was kriged from the original EM38 survey and used as a covariate in analysis of variance.

Results

Good summer rainfall in 2010 and especially 2011 left stored water in all soils pre-sowing except the swale in 2010 (Table 1). More water was stored at depth in 2011. Soil mineral N levels were similar between years 0-60cm, apart from the dune soil which had 25kg N/ha less in 2011. Much less N was available at depth in 2011.

Stored water, together with growing season (April-October) rainfall of 271mm in 2010 and 167mm in 2011, gave French and Schultz (1984) potential yields of 3.7-4.1 t/ha in 2011, and 2.1-2.7t/ha in 2011 (Table 1). Including stored water at depth increased potential yields by 0.5-1.1t/ha in 2011. Yield Prophet estimated higher potential yields if N was unlimited.

Table 1. Pre-sowing available water, mineral nitrogen and water-limited (French and Schultz) and Yield prophet potential yields calculated for dune, slope and swale soil types in 2010 and 2011.

		Avail. Water (mm)		Mineral N (kg/ha)		F/S Yield pot. (t/ha)		Yield prophet (t/ha)	
Year	Soil	0-60cm	60-100cm	0-60cm	60-100cm	0-60cm	60-100cm	Act N	Lux N
2010	Dune	12.9	18.4	37.8	11.7	3.8	4.2		
	Slope	26.1	10.0	54.8	53.8	4.1	4.3		
	Swale	4.9	0.0	57.6	38.5	3.7	3.7		
2011	Dune	30.1	24.0	12.5	3.0	2.1	2.7	2.7	3.6
	Slope	49.3	41.3	54.6	12.3	2.6	3.5	3.1	4.0
	Swale	56.8	49.8	74.5	20.4	2.7	3.8	4.2	5.0

Yields (
Table 2) were much lower than water-limited potential (Table 1) in both seasons. The only significant response to P was on the dune in 2011 (
Table 2), and there were no significant interactions between N and P treatments for yield (not shown).

The two N decision treatments led to rates that were similar on the slope and swale in both years, albeit skewed to later application in the 'in-season' treatment (
Table 2). High potential yield estimates and low soil mineral N on the dune led to very high up-front N treatments in both years, but did not affect crop emergence (data not shown). In both years the up-front treatments were 25kg N/ha higher on the dune than the in-season applications in total.

There was a yield response to a difference in N fertiliser between up-front and in-season treatments on the dune in 2010, but not 2011. Yields for other up-front and in-season treatments were effectively equal, but comparing yields to buffer plots (which received less N) shows that there was a N response on the swale. The response on the dune in 2010 was 15.8 kg grain/kg N, similar to the response on the swale in 2011 (16.0 kg grain/kg N). Responses (compared to the buffer) on the dune and slope in 2011 were much smaller at 2.9 kg grain/kg N.

Grain proteins were significantly higher for the up-front treatments on the dune, where N rates were also significantly higher. Response rates were relatively low (0.012-0.027 %/t/kg N).

Table 2. Grain yield and protein from nitrogen and phosphorus fertiliser treatments in 2010 and 2011.

		N (kg/ha at sowing/Z31)			N treatment yields (t/ha)				P treatment yields (t/ha)			
Year	Soil	*Buffer	Upfront	Inseason	*Buffer	Upfront	Inseason	P(LSD)	P0	P6	P12	P(LSD)
2010	Dune		70/0	20/25		2.56	2.17	0.009 (0.27)	2.39	2.27	2.43	0.484 (0.30)
	Slope		20/0	0/25		2.11	2.05	0.451 (0.16)	1.99	2.18	2.07	0.143 (0.20)
	Swale		20/0	0/25		2.28	2.32	0.621 (0.17)	2.38	2.31	2.22	0.267 (0.21)
2011	Dune	15/0	100/0	45/30	1.01	1.26	1.15	0.266 (0.19)	1.09	1.10	1.42	0.086 (0.33)
	Slope	15/0	50/0	15/30	1.32	1.42	1.59	0.314 (0.15)	1.51	1.49	1.51	0.893 (0.12)
	Swale	15/0	50/0	0/50	1.86	2.42	2.49	0.011 (0.20)	2.39	2.45	2.53	0.47 (0.23)
					N treatment protein (%)				P treatment protein (%)			
2010	Dune		70/0	20/25		8.5	7.8	0.004 (0.4)	8.2	8.2	8.2	0.997 (0.4)
	Slope		20/0	0/25		7.9	7.7	0.261 (0.4)	7.7	7.9	7.7	0.476 (0.4)
	Swale		20/0	0/25		8.7	8.8	0.803 (0.6)	8.6	9.0	8.6	0.448 (0.7)
2011	Dune	15/0	100/0	45/30		11.4	10.7	0.042 (0.7)	11.4	11.0	10.8	0.221 (0.7)
	Slope	15/0	50/0	15/30		10.3	10.5	0.269 (0.5)	10.5	10.4	10.4	0.954 (0.6)
	Swale	15/0	50/0	0/50		10.7	11.6	<.001 (0.4)	11.1	11.1	11.2	0.87 (0.5)

* 14kg N/ha at sowing.

Components of water use/yield

Considering the available water in 2011, biomass at harvest was low especially on dune and slope soil types (Table 3). There was no improvement in harvest index with N treatment on the dune (compared to the buffer), but harvest index was higher with N on the slope and swale.

Despite similar water supply to the swale, 37-53mm less of the water on the slope was transpired (comparing by N treatment, Table 3). If only water 0-60cm was included in water supply, the unused water on dune and swale was similar to or lower than the evaporation estimate for 167mm growing season rainfall (100mm). Including water to 100cm the unused water was much higher, especially on the slope.

Table 3. Transpiration estimated from harvest biomass and used with soil available water and growing season rainfall (167mm) to estimate unused water for nitrogen fertiliser treatments (with 12P) in 2011.

		Biomass	Harvest	Estimated	Water supply (mm)		Unused water (mm)	
Soil	Trt	(t/ha)	Index	transpiration (mm)	0-60cm	0-100cm	0-60cm	0-100cm
Dune	Buffer	4.72	0.26	86				
	Upfront	6.18	0.26	112	201	235	88	122
	Inseason	4.62	0.28	84	194	208	110	124
Slope	Buffer	5.11	0.27	93				
	Upfront	4.71	0.34	86	220	265	134	179
	Inseason	4.69	0.34	85	213	251	128	165
Swale	Buffer	7.37	0.27 a	134				
	Upfront	7.60	0.33 b	138	220	275	81	137
	Inseason	6.72	0.39 c	122	228	272	106	150

Discussion

These experiments tested N and P management alternatives on different soils in a continuous cereal crop in the Mallee, but served mainly to highlight that in high yield-potential seasons, issues other than macronutrients may be of prime importance in these crops. Timing and amount of N nutrition relative potential was of secondary importance where weed and potential herbicide/micronutrient issues affected normally productive soil types. Although minimising seasonal risk is often given as the reason for applying N in-season rather than at sowing, avoiding agronomic risk (prematurely applying N on areas of crop with previously undiagnosed micronutrient or weed/disease issues) is potentially an important benefit in these systems. Adequate P nutrition at sowing could be of some benefit mitigating agronomic risks (dune in 2011) and has been observed elsewhere (Cook 2001).

Farmers operating continuous cereal rotations in the Mallee have never been under the illusion that they would achieve water-limited yields in wet years, or even close to them, but would have expected profitable responses to N. The low yield and protein response to N, especially on dune and slope, are characteristic of zinc deficiency, possibly exacerbated by application of sulfonylurea herbicide in a dry winter. Given the supposed fertiliser history of the paddock (consistent use of mono- or di-ammonium phosphate, without zinc), some sort of deficiency in a season with dry topsoil but good stored water would be unsurprising (but not yet confirmed by measurement).

The yield and protein results in this paddock, regardless of amount of N or P applied or timing, were not atypical of continuous cereal paddocks in the Mallee in 2010/11 and highlight some of the weaknesses of the continuous cereal system, as it is. Farmers have operated these systems in a series of dry seasons, often receiving their highest yields on the slope and dune soils, and achieving high grain protein. Low yields and sometimes prices, together with high soil test P levels, have encouraged cuts to inputs on ‘constraint’ soil types, principally starter fertiliser. Crops have been relatively disease- and weed-free in dry seasons, and single-cultivar monocultures (mainly Yitpi wheat) considered viable.

Having applied N and grown crops with low yields, farmers would (on the basis of dry year experience), expect high grain protein in compensation, but there was little evidence for this either. Some of the economics of continuous cereal cropping has been predicated on achieving relatively high yields across large areas in good years, and accepting more modest yields in dry to average years. Early experiences of no-till/continuous cereals in better years (eg. 2003) came relatively soon after transition from less intensive systems, and may have benefited more from residual fertility and break effects than continuous cereal crops in wet seasons growing 7-8 years later in 2010 and 2011. The expectation that the high yields and responses to inputs seen soon after establishment of continuous cereals would continue may have been unrealistic.

A considerable part of recent economic work in the Mallee has used crop simulation model runs (eg. APSIM, Cropsyst in Llewellyn *et al.* 2008; Sadras and Roget 2004) over historic seasons to augment the relatively dry years experienced in field experimentation. The yields and N responses measured in 2010/11 suggest that these simulations are likely to be overly optimistic for continuous cereal crops in wet years, and some sort of risk factor or yield/response modifier is needed to give realistic yield (and possibly quality) distributions, with some weighting for the likelihood of these risk factors in the population of paddocks being considered.

Alternatively, greater investment in inputs eg. fertiliser and trace elements, possibly augmented by increased soil and plant testing, fungicide, and use of occasional break crops for weeds and diseases may be required to maintain opportunity in the continuous cereal system, which will again decrease its attractiveness in drier years. Similar ‘opportunity break’ systems have been proposed in the past (Sadras *et al.* 2003; Sadras and Roget 2004). While well received by farmers and agronomists, in a run of dry seasons the actual adoption has favoured cereals at the expense of breaks, and breaks have only been widely sown in the second wet season (2011) after a learning experience (discovering they grew well, helped to spread workload, and were profitable) in 2010.

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