Assessing the impact of agronomy on wheat yield across soils and locations

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Abstract

Yield space is a concept describing a domain of possible yields; its size is defined by the magnitude of yield and shape determined by response to agronomic treatments. We describe the process of estimating yield space on four soil types at Cunderdin and Merredin using simulated wheat yield data (1900-2004) generated by APSIM and analysed by the statistical routines of RAPSIM. This process quantifies the impact of agronomic treatments such as time of sowing, variety, rotation and nitrogen management on the spatial and temporal variability in yield.

We show that from a landscape view year, agronomy and season and soil specific agronomy account for similar amounts of variability in yield. The most influential agronomic factor is time of sowing at both locations across all soil types.

Key Words

Wheat yield, simulation model, variability, agronomy, yield space

Introduction

Crop research, development, extension and production require methodologies to examine sources or drivers of variability in crop yield. The domain of possible yields is constrained by weather, soil type and crop agronomy and understanding, predicting and manipulating the domain of possible yields underpins technical innovation in the cropping industries.

Yield space is a concept describing a domain of possible yields; with size defined by variability of yield and shape determined by response to agronomic treatments (Abrecht *et al.*2004). In their review of the historical failure of farm management models McCown and Parton (2006) identify the importance of defining and adjusting a manager's view of their 'yield space' in improving farm management. Typically, the domain of possible yields is assessed from experience. Agronomic trials assess a few dimensions of the yield space at a time and often rely on a 'sites by seasons' strategy to sample a range of environments. Simulation models have also been used to predict the domain of possible yield for specified management decisions (Carberry *et al.* 2004) and YIELD PROPHET or to provide estimates of crop performance for a database, such as Whopper Cropper (Nelson *et al.* 2002). The upper boundary of the yield domain or yield potential is sometimes estimated from rainfall using relationships suggested by French & Schultz (1984).

This paper uses simulated yield data to examine key influences on the domain of possible yield on four soil types at two locations from 1900-2004. We examine the sources of variability in yield in response to key aspects of agronomy; starting with variability in yield amongst soils within in a landscape and progressing to variability on individual soils. We then turn to variability originating at various decision points in the crop year and changes in sources of variation amongst years.

Methods

Simulation model

APSIM wheat version 1.55s was used to simulate a factorial combination of treatments on four soil types at two locations in the Western Australian wheatbelt. APSIM uses specified soil and crop factors in simulating soil and crop water and nitrogen dynamics and crop development, growth and partitioning. Model performance has been validated against experimental data from a range of locations, seasons and soil types in Western Australia and is sensitive to treatments applied in the experimental design (Asseng 2004).

Locations

Cunderdin (31?39’ S, 117?14’ E, elevation 221m), in the central wheatbelt, and Merredin (31?29’ S, 118?17’ E, elevation 315m) in the eastern wheatbelt of Western Australia have a Mediterranean-type climate, typified by hot, dry summers and cool, wet winters. Cunderdin and Merredin have average annual rainfall of 368 and 325mm and April to October rainfall of 298 and 248mm, respectively.

Soils

Four common wheatbelt soils were specified which differ in soil water and nitrogen dynamics driven by difference in soil physical properties, depth and organic matter (Table 1).

Table 1. Soil characteristics

Soil name	PASW	Maximum root	PASW	Organic carbon %	
	(0-200mm depth)	depth (m)	(to root depth)	0-100mm	100-200mm
Yellow deep sand	18	1.5	63	0.90	0.39
Yellow sandy earth	14	2.3	146	0.83	0.37
Deep sandy duplex	28	0.7	83	0.81	0.26
Shallow loamy duplex	22	0.7	76	1.20	0.80

Experimental design

An experiment with 7 agronomic factors in factorial treatment combination; 2 rotations **[ROT**] (continuous wheat and pasture-wheat), 2 levels of stored soil moisture at April 1 **[PASW]** (lower limit and half-full profile), 2 ‘varieties’ **[VAR]** (long and short season), 6 times of sowing **[TOS]** (25th April, 10th May, 30th May, 5th June, 15th June, 5th July), 4 rates of nitrogen at sowing **[NAS]** (0, 30, 50, 100 kg N/ha), 3 rates nitrogen at four weeks after sowing **[N4w]** (0, 30, 50 kg N/ha) and 3 rates nitrogen at ten weeks after sowing **[N10w]** (0, 30, 50 kg N/ha). The experiment was simulated for each year from 1900-2004 for each of 4 soil types [n=1728*105*4=725,760] at Cunderdin and Merredin.

Analysis

A range of routines were developed in the R Statistical System to analyse and visualise the data including analysis of variance, estimation of a variance components (Snedecor&Cochran 1982), box plots and trellis plots. The routines have been standardised in a library called RAPSIM, described in detail by D’Antuono *et al.* (2006).

Results

Wheat yield at Cunderdin and Merredin responds strongly to annual conditions such as April-October rainfall (Figure 1, Table 2a), but, within a year, shows considerable variation due to agronomy and soil type. Regression of yield on April to October rainfall (Table 2a) shows that rainfall explains a small proportion of the total variability in yield (R^2=21%, 34% for Cunderdin and Merredin respectively) but a large proportion of the inter-annual variability in yield, R^2=75% and 81%.

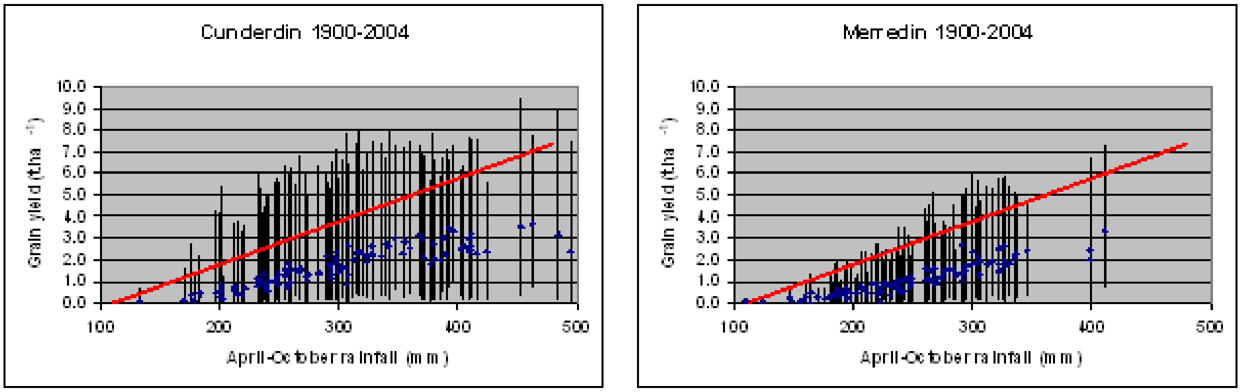

Figure 1. Wheat grain yield in relation to April-October rainfall at Cunderdin and Merredin. Mean yield (♦) and range in yield (whiskers) for all treatments with soil moisture at lower limit on April 1. The red line shows the relationship Y=20*(April-October rainfall*110) (French & Schultz 1984).

Strong similarities in components of variance between Cunderdin and Merredin (Table 2b) suggest that the relative impact of environmental and agronomic factors is consistent at the two locations. The sum of variance components *Soil.Year, Year.Agronomy* and *Soil.Year.Agronomy* (38%, 30% for Cunderdin and Merredin respectively) confirms that soil-specific or season-specific agronomy is equivalent to *Agronomy*, as a source of variability in yield. Variance component *Soil* is small, however, variance attributed to interactions *Soil.Year*, *Soil.Agronomy* and *Soil.Year.Agronomy* (31%, 30%) suggests that soil has an impact as a moderator of the response to other factors.

Table 2. a. Regression of yield and April-October rainfall b variance components at Cunderdin and Merredin.

a. April-October rainfall regression

% SS due to	Cunderdin	Merredin
Regress^n Apr-Oct rainfall	21	34
between years	7	8
within years	71	58

b. Variance components of yield

% variance	Cunderdin	Merredin
Soil	0	0
Year	19	22
Soil.Year	5	3
Agronomy[†1]	32	32

Soil.Agronomy	7	8
Year.Agronomy	14	13
Soil.Year.Agronomy	19	19
Residual[†2]	4	3

[†1] Agronomy=ROT*PASW*TOS*VAR*NAS*N4w*N10w (main effects+two factor interactions ONLY)

[†2] Residual, [Agronomy >2 factor interactions] + Soil*Year*[Agronomy >2 factor interactions]

ROT and aspects of nitrogen agronomy, *NAS*, *N4w* and *N10w* were an insignificant component of variance on all soil types at both locations (*Other*, Table 3).Closer examination of variance components within each soil type (Table 3) shows that elements of the *Year*, *Agronomy* and *Year.Agronomy* variance components change with soil type and location, suggesting changing importance of season, agronomy and season-specific agronomy as determinants of yield. For example smaller *Year* and larger *Agronomy* components for deep sandy duplex soil at both Cunderdin and Merredin suggests reduced seasonal influence on yield with almost 50% of the variance attributed to agronomic practices coupled with 30% from season-specific agronomy. In contrast, the yellow deep sand with 30% of variance attributed to season but 44% agronomy and 22% season specific agronomy at Cunderdin and 34% and 32% respectively at Merredin.

TOS and *VAR* are the dominant agronomic factors across all soil types at both locations (Table 3). The reduced influence of *TOS* in shallow loamy duplex and stronger influence of *VAR* on deep sandy duplex soil suggest different opportunities for management on those soil types. Season-specific agronomy (*Year.** components, Table 3) also tends to be dominated by *TOS, VAR* and *TOS.VAR* across all soil types and locations. While Agronomy components are accessible to decision makers, realising benefits of *Year.Agronomy* components is likely to be more problematic, since it relies on predicting the appropriate agronomy for the season, based perhaps on seasonal forecasts.

Table 3. Mean, variance and significant variance components of yield for 4 soils at Cunderdin and Merredin (1900-2004).

	Yellow deep sand		Yellow sandy earth		Deep sandy duplex		Shallow loamy duplex	
	Cunderdin	Merredin	Cunderdin	Merredin	Cunderdin	Merredin	Cunderdin	Merredin
Estimated mean	1.77	1.41	1.83	1.49	1.80	1.40	2.17	1.07
Estimated Variance[†1]	3.65	1.08	1.41	1.90	2.42	1.92	2.64	2.03
Variance								

Component (%)								
Year	***30***	***28***	***23***	***24***	***14***	***19***	***27***	***25***
TOS	25	28	30	22	31	24	19	19
VAR	7	0	0	0	7	10	0	8
PASW	8	1	0	8	3	8	4	11
TOS.VAR	1	4	6	1	1	1	5	1
TOS.PASW	3	0	0	2	4	5	1	4
VAR.PASW	0	1	0	3	0	1	2	1
Agronomy subtotal	***44***	***34***	***37***	***37***	***46***	***49***	***31***	***45***
Year.TOS	9	13	14	10	7	7	9	12
Year.VAR	2	3	4	4	4	2	5	3
Year.PASW	1	1	1	2	6	4	3	2
Year.TOS.PASW.	3	2	2	4	8	6	3	3
Year.TOS.VAR	8	12	11	13	7	7	14	8
Year.Agronomy subtotal	***22***	***32***	***31***	***32***	***31***	***26***	***33***	***27***
Other	0	4	0	4	0	4	2	2
Residual[†2]	2	2	3	3	4	3	4	1

[†1] Variance estimated as sum of variance components
[†2] Residual, >2 factor interactions Agronomy+>3 factor interactions Soil*Year*Agronomy

From a crop manager's point of view

Variability in crop yield creates opportunity and risk for crop managers. Once decisions relating to a source of variability, such as rotation or time of sowing are determined, then future decisions operate on a constrained set of variability. Table 4 shows that most of the variability in yield is associated with agronomy at sowing with around half of that variability being year specific agronomy, mainly TOS, VAR and PASW. The low proportion of variance attributed to higher order interactions shows that, within a year and soil type, most of the variability in yield rests with main effects and 2 factor interactions of agronomic factors.

Table 4. Percentage of variance in wheat yield determined at various stages of decision making

	Yellow deep sand		Yellow sandy earth		Deep sandy duplex		Shallow loamy duplex	
Stage	Cunderdin	Merredin	Cunderdin	Merredin	Cunderdin	Merredin	Cunderdin	Merredin
At year[†1]	30	28	23	24	14	19	27	25
Within year, pre sowing[†2]	10	2	2	10	10	12	8	13
At sowing-agronomy[†3]	36	34	37	30	43	41	27	34
At sowing-YearXagronomy[†4]	22	33	32	33	28	24	33	27
At sowing-TOTAL	*58*	*67*	*69*	*63*	*71*	*65*	*60*	*61*
Post sowing[†5]	0	2	3	1	2	1	2	0
Residual[†6]	2	2	3	3	4	3	4	1

Components included at each stage:[†1]Y; [†2]ROT*PASW+Y*(ROT*PASW);
[†3]TOS*VAR*NAS+(ROT*PASW)*(TOS*VAR*NAS);

[†4] Y*(TOS*VAR*NAS)+Y*[(ROT*PASW)*(TOS*VAR*NAS)];
[†5](N4WK*N10WK)*(Y*TOS*VAR*NAS*ROT*PASW); [†6] >3 factor interactions

Table 4 points to an important consideration; as factors are fixed, variability due to factors remaining becomes more significant as a proportion of the remaining 'negotiable' variability. This observation may account for discord between apparent insignificance of nitrogen agronomy in the broader view of variability in crop yield and its obvious significance in experimental and simulation studies with more restricted sources of total variability. Taking this approach our study shows that N agronomy after sowing accounts for 30-50% of the variance remaining post sowing (data not shown).

Annual variability in the impact of time of sowing on yield

Practitioners are concerned with the potential for agronomic intervention to influence yield or the size of the yield space. Table 5 shows 100-fold changes in variance of wheat yield amongst years which exceeds differences between soil type and locations.

Variability attributed to season-specific time of sowing responses *(Year.TOS.*)* accounts for more than 70% of variance due to season-specific agronomy (Table 3). Analysis of variance permits the influence of *TOS* to be expressed as a percentage of the total sum of squares (TSS) for each location, soil type and year. The large annual variability in %TOS shown in Table 5 suggests that a manager, working from year by year experience, may come to a very different view of the influence of *TOS* on the domain of possible yield.

Table 5. Statistics of variance and *%TOS* for each soil type at Cunderdin and Merredin (1900-2004).

	Yellow deep sand		Yellow sandy earth		Deep sandy duplex		Shallow loamy duplex	
	Cunderdin	Merredin	Cunderdin	Merredin	Cunderdin	Merredin	Cunderdin	Merredin
Variance $(t.ha^{-1})^2$								
Minimum	0.01	0.02	0.01	0.07	0.04	0.03	0.08	0.01
25% years greater	0.73	0.26	0.46	0.50	0.78	0.47	0.76	0.26
50% years greater	1.69	0.48	0.75	0.90	1.32	0.89	1.37	0.60
75% years greater	2.86	0.89	1.21	1.39	2.11	1.57	2.00	1.72
Maximum	5.66	2.31	2.68	3.89	4.96	3.66	3.82	4.23
%(TOS)								
Minimum	2	2	4	7	2	4	5	4
25% years greater	37	48	51	34	38	31	35	28
50% years	57	66	67	50	54	45	51	39

greater								
75% years greater	71	86	86	70	73	67	73	59
Maximum	94	97	97	93	85	89	93	87

Conclusion

Investigations of drivers of variability in yield at two locations using simulated yield data from a factorial experiment showed that season, agronomy and season specific and soil specific agronomy account for significant amounts of variability in yield. The most influential agronomic factor was time of sowing at both locations across all soil types. Identifying the source of variability does not imply that it is prospective for manipulation by management. Clearly, year and season specific agronomy are cases in which skill in identifying the season (year) is critical in predicting yield or specifying agronomy.

This paper takes a long term, historical perspective on sources of variability from a landscape, soil type and managers view. Changing the view changes the domain of possible yield, the importance of drivers of variability and the opportunity for management to influence crop performance.

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