Can we close crop yield gaps in Australia?

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Abstract
Why do Australian grain growers achieve only half the yield potential of their crops? We took three approaches to investigate this question. First, we applied *in silico* experimentation to quantify the impact of eight suboptimal practices at 50 sites across the grain zone. This analysis highlighted the critical importance of nitrogen nutrition. Other management-related factors included: conventional tillage, summer weeds, low seedling density and late sowing. Second, we interviewed 232 wheat producers from 14 contrasting local areas. The findings linked yield gaps to farm and grower characteristics as well as to farming management. Farms with smaller yield gaps are more likely to be smaller holdings growing less wheat on more favourable soil types. Growers with smaller yield gaps are more likely to apply more N fertiliser, to have a greater crop diversity and to be less likely to grow wheat following either cereal crops or a pasture; they are more likely to soil-test a greater proportion of their fields, use a fee-for-service agronomist, have a university education and adopt new technologies, and they are less likely to have problems with herbicide-resistant weeds. Third, we applied a profit-risk-utility trade-off analysis and showed that risk aversion has a strong influence on the choice of practice in low yield potential sites, which help explain yield gaps in those agro-climatic zones. However, in medium to high yielding areas, applying the management inputs required to achieve water-limited yield is the most economical choice even for highly risk averse growers.

Key Words: water-limited yield, biophysical factors, psycho-social, risk aversion, wheat, APSIM

Introduction

Yield gaps are the difference between the theoretical water-limited yield (Yw) that can be obtained for rainfed crops with best management practice and the yields that are achieved by growers in their fields (Ya). Because "you can't manage what you can't measure", the first challenge on the journey to close Australia's yield gaps was to quantify them. This challenge has been met for wheat, barley, canola, sorghum and the major pulse crops. The results of this analysis have been mapped in the Yield Gap Australia website (Hochman et al. 2016) at multiple scales from statistical local areas (SA2) to sub regional and regional resolutions (Figure 1). A quick appraisal of the data shows the potential to double crop production if yield gaps can be eliminated. Can these yield gaps be closed? In this paper we describe research into the causes of yield gaps including management-related biophysical factors as well as the underlying social and economic constraints.

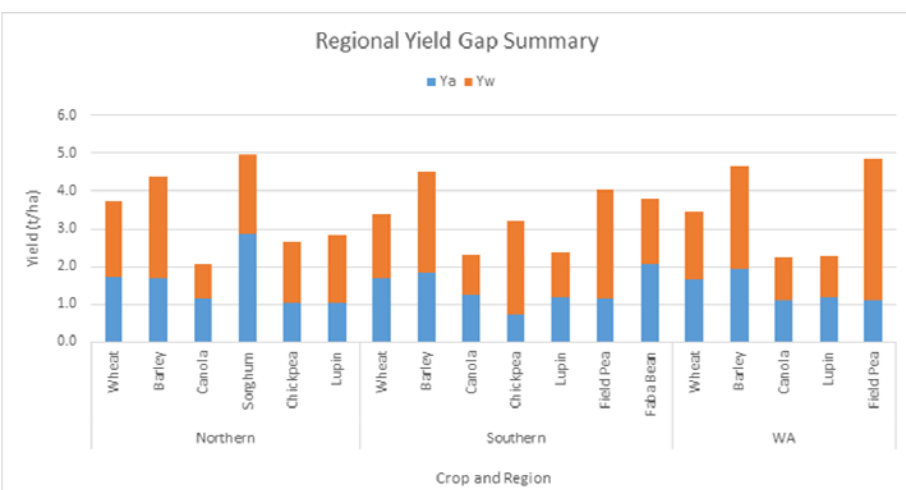

Figure 1. Mean water-limited (Yw) yields and actual regional yields (Ya) for a range of crops by GRDC regions (Source: www.yieldgapaustralia.com.au). The orange areas represent yield gaps.

Biophysical causes of wheat yield gaps

We conducted *in silico* experiments over 15 years at 50 weather stations to ascertain the impact of a range of suboptimal practices on grain yield against the 'best management practice' rules that were used to calculate the benchmark water-limited yields (Hochman and Horan 2018). Average national losses per suboptimal practice (Treatments 2-7) relative to Yw (Treatment 1) are presented in Table 1. Treatment 8 illustrates that combined suboptimal practices are not necessarily additive. The combined impact of frost and heat stress accounted for yield losses of 16% to 26% depending on the stress function used (Treatments 9, 10). The key message is that current levels of N fertiliser application (45 kg N/ha/year) are by far the most limiting biophysical factor, holding back yields by 40%. Treatments 2-8 were not only lower yielding than the Yw treatment but also had higher CV values, indicating greater yield instability. Additionally, likely biophysical factors that contribute to the yield gap include edaphic constraints, biotic stresses such as plant diseases, insects/pests and in-crop weeds along with extreme weather events other than frost and heat stress (e.g. hail).

Table 1. Impacts of sub-optimal management factors, as well as of frost and heat stress, on water-limited yield (Yw) at a national scale.

Treatment Number	Treatment	Mean (t/ha)	Std Dev (t/ha)	CV (%)	Yield (%)
1	Yw (water-limited yield)	4.28	0.91	21	100
2	Seedling density (50 plants/m^2)	3.78	1.10	29	88
3	Late sowing (2-week delay)	3.97	1.04	26	93
4	Summer weeds	3.18	1.17	37	74
5	Conventional tillage	2.86	1.08	38	67
6	N fertiliser (45 kgN/ha)	2.57	0.78	30	60
7	N fertiliser (90 kgN/ha)	3.30	0.96	29	77
8	Combined N fertiliser (45 kgN/ha) & Summer weeds	2.55	0.92	36	60
9	Frost and heat	3.15	1.00	32	74
10	Frost and heat 2 (moderate impact)	3.60	0.95	26	84

The relationship between yield gaps and grower and farm characteristics

We examined the causes of wheat yield gaps in relation to farm management practices, farm characteristics, and grower characteristics via computer-assisted telephone interviews of 232 wheat producers from 14 contrasting local areas (Zhang et al. 2019). We used the interview data, together with estimates of each farm's wheat yield potential (Yw), to develop a comprehensive framework to understand the causes of wheat yield gaps in 2016. Results revealed significant differences between farms with smaller yield gaps (mean = 96% of Yw) and those with greater yield gaps (mean = 47% of Yw) with respect to farming management as well as farm and grower characteristics. We found that farms with smaller yield gaps are more likely to be smaller holdings growing less wheat on more favorable soil types. Growers with smaller yield gaps are more likely to apply more N fertiliser, to have a greater crop diversity and less likely to grow wheat following either cereal crops or a pasture (Table 2). In addition, they are more likely to soil-test a greater proportion of their fields and to adopt new technologies and less likely to have problems with herbicide-resistant weeds. They are also more likely to use and trust a fee-for-service agronomist, and to have a university education.

Table 2. Preceding crops before wheat crop and average nitrogen applied

	% of farms		Nitrogen application	
	High relative yield group (%)	*Low relative yield group* (%)	*High relative yield group* M (*SD*) (kg N/ha)	*Low relative yield group* M (*SD*) (kg N/ha)
A cereal crop	37***	65***	79 (*51*)*	57 (*42*)*
A canola crop	44	48	116 (*146*)**	58 (*45*)**
A pulse crop	62	53	75 (*61*)***	42 (*34*)***
A pasture phase	22***	44***	64 (*58*)**	30 (*33*)**

The asterisk symbol indicates the statistical significance level of the differences between high and low relative yield groups: * $p < .05$, ** $p < .01$, *** $p < .001$.

The relationships linking grower characteristics and farm management practices to yield gaps are described by a path analysis that links grower characteristics to relative yields, where high relative yields indicate a small yield gap (Figure 2). There are several paths to achieving high relative yields: (1) A stronger sense of control over how crops perform (locus of control) is associated with a willingness to take and manage risk (e.g. considered multi-peril crop insurance) which is positively associated with relative yield; (2) The locus of control was also negatively associated with having a bigger weed problem which was in turn negatively associated with relative yield; (3) The locus of control and a university degree were positively associated with extension attendance, while age was negatively associated with extension attendance. Extension attendance was positively linked to crop diversity, which led to a smaller proportion of crop land area being planted to wheat, which was negatively associated with relative yield; (4) Managers with a university degree were more likely to use a fee-for-service agronomist, which was in turn positively associated with crop diversity and subsequently with higher relative yield. Moreover, using a fee-for-service agronomist was directly linked to greater relative yield. This finding suggests that private agronomists would have other influences on crop management, which also contributed to higher relative yield.

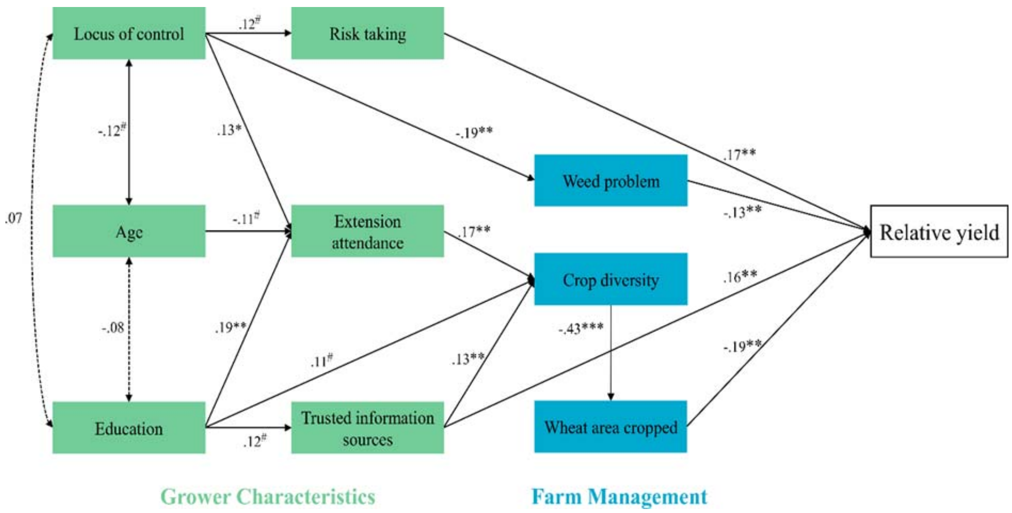

Figure 2. A path model for predicting relative wheat yield (# p < .10, * p < .05, ** p ≤ .01, *** p ≤ .001). The value next to each line is the regression coefficient between variables, positive numbers indicate positive relationships and vice versa. Overall model fit to data is very good (RMSEA < 0.001).

Do profit-risk-utility trade-offs explain wheat yield gaps in Australia?

A rational proposition explaining the large gap between water-limited yields and the yields farmers actually achieve in their paddocks is that it may be attributable to (rational) sub profit-maximising input levels in response to risk and risk aversion in many major grain-growing regions, particularly those with lower and more variable rainfall. Here we used fourteen case-study sites in seven different subregions across the Australian wheat-belt to examine the risk-return profile of a range of agronomic management practices and reveal the extent to which a farmer's attitude to risk determines their decision-making. Using a novel Profit-Risk-Utility Framework that incorporates crop simulation, probability theory, finance techniques, and risk aversion analysis, we were able to demonstrate how farmers might select practices that manage the trade-off between maximising economic net return and risk exposure using a risk-aversion analysis across sites ranging from low to high yield potential (Monjardino et al. 2019). Risk-adjusted profit (the difference between the expected mean net return and a risk premium) varied with risk preference and yield potential. For example, for Loxton (low Yw), the profit maximising N rate was 45 kg N/ha yet 30 kg N/ha or 22.5 kg N/ha would be chosen by more risk averse growers. For Northam (medium Yw), Yw is the profit maximising treatment but any degree of risk aversion would lead growers to select the 90 kg N/ha option. For Quirindi (high Yw) Yw is profit maximising regardless of risk aversion (Figure 3).

Conclusion

Suboptimal nitrogen nutrition is the most significant single management related biophysical driver of wheat yield gaps with the national average rate of N contributing to a 40% loss compared to water limited yield potential. Conventional tillage, uncontrolled summer weeds, low seedling density and late sowing also contribute to the yield gap. Yield gaps are the result of the intertwined dynamics between biophysical factors, grower socio-psychological characteristics and farm management practices. Socio-psychological factors not only directly contribute to yield gaps, but they also influence farm management practices that in turn contribute to yield gaps. Our findings suggest that, to close wheat yield gaps, it is important to develop integrated strategies that address both socio-psychological and farm management dimensions. Risk aversion has a strong influence on the choice of practice in low rainfall (low Yw) sites and this goes some way to explaining yield gaps in those agro-climatic zones. However, in high to medium rainfall areas (higher and more reliable Yw), best practice is the most economical choice even for highly risk averse growers. Importantly, our results emphasize the need for employing a range of research tools, such as crop growth simulation models in combination with profit-risk measures and risk aversion theory to help identify and reduce yield gaps and uncertainty in crop management across different agro-ecological zones.

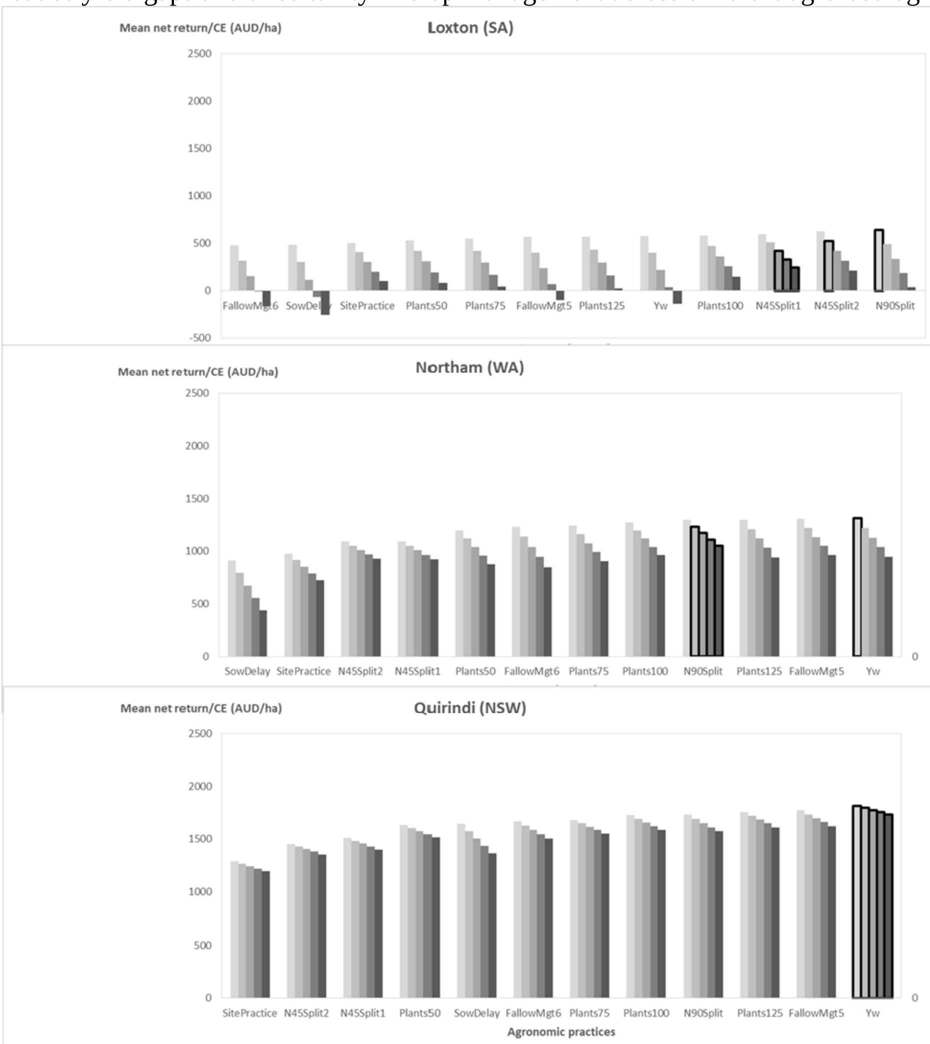

Figure 3. Risk-adjusted profit for 12 practices and five levels of risk aversion (shades of grey) for wheat in: low (Loxton), medium (Northam), and high (Quirindi) yielding sites. The most profitable agronomic practice per level of risk aversion (Certainty Equivalent) is outlined in black.

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