Explaining differences between sorghum fields: Do we need to reconsider extension topics?

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Abstract
Sorghum production is a major cropping activity in Australia's northern grain region. The Darling Downs is one of the most important agricultural areas of this region. Between 2005 and 2015, average on-farm sorghum yields in the Eastern Darling Downs were 4.15 t ha^{-1}, but yields can be as high as 12 t ha^{-1}. We conducted interviews with 12 highly-engaged sorghum farmers in the Eastern Downs (total 75 fields characterised) to measure the diversity of sorghum fields and identify drivers of higher yield, water use efficiency (WUE), N fertiliser efficiency (NUE) and profitability. We observed substantial differences in yield (3.9 – 7.1 t ha^{-1}); WUE (8 – 15 kg mm^{-1} ha^{-1}); NUE (35 – 78 kg grain kg N applied^{-1}) and gross margin (397 – 930 AU \$ ha^{-1}). A logistic regression indicated that differences in basic agronomy (i.e. sowing date and N input) could explain the observed diversity in performance. Further analysis using crop simulation (via APSIM) showed no increase in downside risk from adopting earlier sowing associated with higher performance. Our results suggest that the importance of basic principles of agronomy remain underappreciated among farmers. The question, then, is why our extension efforts have not yet been able to instil these principles to clients. Our analysis suggests insufficient attention of research and extension has been given to the importance of sowing date, while N investment is constrained by the effects of high farm debt per hectare.

Keywords
Agronomy, Fertiliser, APSIM, Debt, Extension.

Introduction
Sorghum production is a major farm activity during the summer growing season of northern Australia. In 2015, the national sorghum production value was AUD $647 million or 18.7% of total grain production value (ABARES 2015a). In the Eastern Darling Downs, between 2004-2014 sorghum was sown to an average 37% of total area cropped (ABARES 2016). During that period, mean sorghum yield in the same region was 4123 kg ha^{-1}. Analysis from Potgieter et al. (2016) suggested that regional increases in sorghum yields have historically occurred due to better agronomic management (e.g. earlier sowing, enhanced plant arrangement) and plant breeding efforts (e.g. drought tolerance via StayGreen).

The Eastern Darling Downs has mostly high fertility clay and clay loam soils, with water holding capacities above 100 mm (ABARES 2015b) making it a potentially high-profit region for crop production. However, despite this, between 2004-2014 farm businesses in the region averaged a loss of AUD $5563 per annum while mean total farm debt was AUD $372,527 (ABARES 2016). Reporting from the Grains Research and Development Corporation (GRDC) suggested that addressing existing differences in farmers' yields could increase sorghum yields by 50-100% in the northern region – which includes the Eastern Darling Downs (GRDC 2014). Previous efforts to reduce yield gaps include the FarmScape program run over a decade ago in Queensland (Carberry et al. 2002). Present day extension is largely delivered through private consultants linked to input suppliers (Wylie 1992) and an assortment of State Government and GRDC websites and newsletters (DEEDI 2010; DAF 2010; 2011; 2015; GRDC 2017). Here we present the results of a study that combined a socio-economic data set and the use of crop modelling tools to answer: What are the key drivers of sorghum profit?

Methods
Farm interviews: Extensive interviews[1] were conducted with the managers of twelve properties located across the Eastern Darling Downs region. Participants represented 'first adopters' within the community.

[1] These interviews and its administration adhered to the guidelines of the ethical review process of The University of Queensland and the National Statement on Ethical Conduct in Human Research (approval number 2014000671)

Farmers were interviewed for approximately 2-3 hours. Each participant provided soil test results (0-0.1 m depth, up to 5 years) from fields in which historical management and yield were available. In total, comprehensive management, soil and financial information from 75 separate sorghum fields between 2010-11 and 2013-14 were collected. Daily climate records were sourced from the closest Australian Bureau of Meteorology (BOM) weather station (Jeffrey et al. 2001; DSITI 2015).

Data analysis and logistic regression: Above and below (seasonal) median values were used to identify 'High' and 'Low' performing fields (respectively) for WUE, NUE, yield and gross margin values. Logistic regression analyses (Hosmer et al. (2013) was used to derive probabilistic models to predict levels of field performance. 'High' and 'Low' debt levels were defined as debt per hectare (i.e. debt to equity) on each property supplying financial records (n=10). Each sorghum field was labelled as being managed on a High or Low debt farm based on whether that business had debt per hectare above or below the mean ($1540 ha^{-1}). Those fields on farms without financial records (n=11) were removed from this debt analysis.

Results and Discussion

Diversity in sorghum performance: Data collected through farm interviews indicated large variability in resource use efficiency, yield and profit among farmers' fields (Table 1). Fields with Low NUE produced on average 42.7 kg less of grain per kg of N applied. High WUE fields averaged 7.6 kg mm^{-1} ha^{-1} more than the Low WUE fields. The difference in sorghum yield between High and Low yielding fields was 3.1 t ha^{-1}. Finally, High gross margin fields had AU $ 532.78 ha^{-1} more than Low gross margin fields.

Table 1. On-farm field to field gaps in four key output variables (N use efficiency, water use efficiency, yield and gross margin) calculated from 75 sorghum fields planted between 2010 and 2013.

Output variable	Units	Mean value for low performers	Mean value for high performers	On-farm diversity
WUE	(kg ha^{-1} mm^{-1})	7.8 ± 0.4	15.4 ± 0.6	7.6
NUE	(kg grain kg N^{-1})	35.1 ± 1.10	77.8 ± 12.8	42.7
Yield	(t ha^{-1})	3.9 ± 0.1	7.0 ± 0.3	3.1
Gross margin	(AU $ ha^{-1})	397.0 ± 23.4	929.8 ± 27.1	532.8

Drivers of higher sorghum performance

Later sowing significantly decreased the probability of high performance regardless of environment (Figures 1a and b). N fertiliser significantly increased the probability of high yield and gross margin, as did in-crop rainfall and soil water at sowing (Figures 1a and b). Higher costs significantly decreased the likelihood of high gross margin under all circumstances (Figure 1b). Under low N input use (i.e. 60 kg N ha^{-1}), the probability of achieving a high gross margin was below 50% except under early sowing with abundant moisture and low variable costs (Figure 1b).

Lessons for extension?

Our findings are not at all novel. Basic principles of agronomy posit that earlier sowing dates for crops will increase the length of the growing season and increase yields - provided frost and late heat do not inhibit yield (Pratley 2003). Earlier sowing has been shown to increase sorghum yield since the 1960s (Stern 1968). Likewise, using N fertiliser has been a basic principle of sound agronomy for over half a century (Fageria and Baligar 2005; Luis et al. 2014). However, our study found that these topics are still decisive factors, constraining performance of present-day cropping. This implies that farmers must either be: a) ignoring extension advice on agronomy and fertiliser use; or b) not receiving correct advice on time of sowing and N input use. Regardless of which of these two scenarios are true, this suggests more work must be done by research and extension provision.

Some anecdotal evidence suggests that importance of sowing date may have been incorrectly downplayed in the study area. Influential research papers between 1990-2014 have implied it is not a determining factor for sorghum yields (Hammer and Muchow 1994; Hammer et al. 2014). Furthermore, when presented with our results, agronomists from major seed suppliers cited these same papers. It appears that *on-farm* impact of sowing date is different to that in the APSIM model, suggesting more empirical work is needed. For fertiliser use, our data showed more indebted businesses (high debt ha^{-1}) were less likely to use high N applications (Figure 2a). This suggests high debt may play a role in limiting fertiliser investment. Low fertiliser use and reliance on declining soil nutrients has been reported for many years (Visser et al. 1998). Farmers are said to be reluctant to conduct soil testing prior to sowing (Bell et al. 2013) . Instead N demand is estimated through 'back of envelope' calculations of expected N mineralisation and yield using field history and the French-Schultz model (French and Schultz 1984a; 1984b; Bell et al. 2013). Such methods for determining soil N supply and fertiliser requirements could be further contributing to the observed under-application of N.

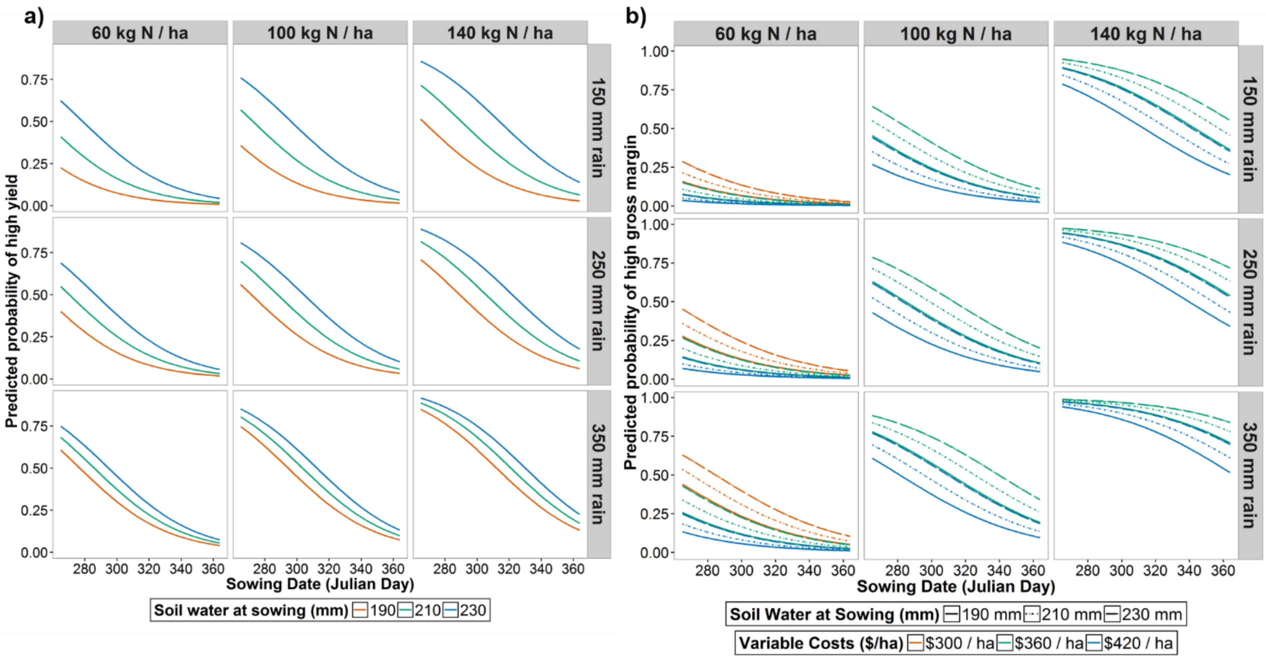

Figure 1. Predicted probabilities of high (i.e. above seasonal median) a) yield and b) gross margin at different times of sowing; environments differed through rainfall (three levels: 150, 250 and 350 mm), soil water at sowing (190, 210 and 230 mm) and N input (60, 100 and 120 kg N ha^{-1}); predictions derived from logistic model.

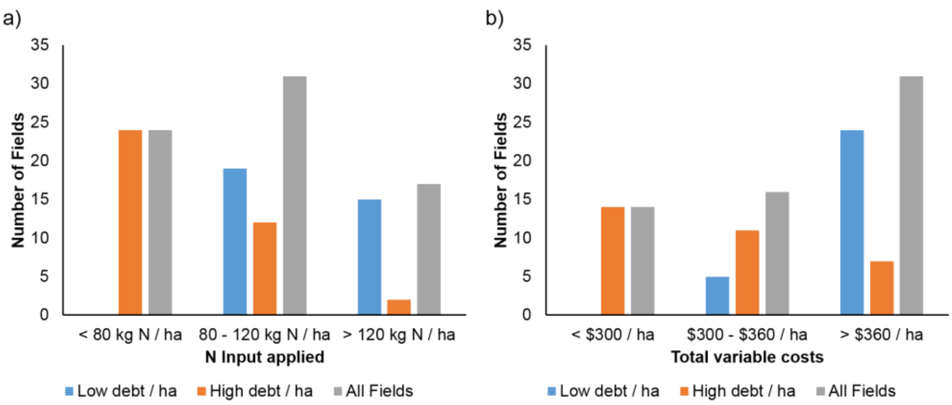

Figure 2. The number of low and high debt fields (i.e. above and below mean debt ha^{-1}) represented at each level of a) N input (Low = < 80 kg N ha^{-1}, Medium = 80-120 kg N ha^{-1}, High = > 120 kg N ha^{-1}) and b) variable cost investment (Low = < $300 ha^{-1}, Medium = $300-360 ha^{-1}, High = > $360 ha^{-1}); Results from subset of interview data (n = 64).

Conclusion

Basic principles of agronomy continue to determine the performance of cropping fields in the northern grains region. Despite participating farmers being highly engaged, differences in WUE, NUE, yield and gross margin existed among their fields. These were explained through primarily sowing date and N fertiliser use. Our findings also suggested that extension advice is either not emphasising basic agronomy, or that such advice is being ignored by farmers. We propose a critical discussion of extension priorities for northern cropping is needed, specifically considering importance of sowing date and N fertiliser use.

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