Understanding the importance of matching sorghum hybrids and agronomy to site and seasonal conditions

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Abstract

Multi-environment trials (MET) (*n* = 15 environments, E) combining most commercially available sorghum hybrids (G), and agronomic managements (M) (i.e. plant density and configuration combinations), were run across Queensland in the Northern Grains Region of Australia during the 2014/15 and 2015/16 seasons to (i) characterise the yield potential and yield stability of the different hybrids; and (ii) derive simple crop design (G x M) rules that maximise yield across different environments. Irrespective of the environment yield, most modern hybrids out-yielded the very widely-grown hybrid, MR-Buster. There were a small number of hybrids that were more responsive than MR-Buster to changes in the environment. However, many hybrids had a lower yield stability, suggesting their yield is less likely to change across environments relative to the industry standard. Recursive partitioning showed that at all sites high starting soil water and narrow row spacing led to greater yields. At low yielding sites hybrid characteristics, especially high yield potential, led to improved productivity. The main conclusion from this work is that in sorghum what really matters is not just agronomy, but to understand how to match hybrids and agronomy to site and seasonal conditions.

Keywords

Queensland, crop design, yield stability, environmental index, multi-environment trials.

Introduction

Approximately three-quarters of sorghum production in Australia takes place in Queensland across a region that extends from the Burdekin River catchment in Central Queensland south to the Darling Downs and border with New South Wales (Australian Bureau of Statistics 2016). Climate variability and spatial variability in soil water-holding capacity create a range of stress environments (Chapman et al. 2000) across the region that interact with hybrid characteristics such as maturity type, tillering, and stay-green (Borrell et al. 2014; Jordan et al. 2012; Kim et al. 2010) to determine final grain yield. Here we propose that understanding how to match commercially available hybrids of contrasting characteristics (G), and agronomic management (M) across the different environments (E) of the Northern Grains Region, can help growers maximise yields and minimise risks. Thus, the objective of this research was to (i) characterise the diversity of sorghum hybrids in terms of their yield response across environments with a range of yield potentials, and develop simple crop design (G x M) rules for farmers.

Methods

Multi-environment field trial (MET)

In collaboration with seed companies and farmers, hybrid and management options were tested at field sites primarily located on both the Western and Eastern Darling Downs with additional sites in Central Queensland (Table 1). Across the MET the experiment design was unbalanced to accommodate appropriate treatment combinations for target environments and research participants. In most trials we investigated variations of within-row plant densities, often in combination with solid and skip row configurations. The number of hybrids tested at each site was typically four or five but as high as twelve. Although the set of hybrids varied between sites, each included the industry the hybrid MR-Buster as a check. The data reported here is final dry weight yield (kg/ha).

Yield stability and potential

An environmental index (EI) for each site and season was calculated from the mean yield across all hybrids and treatments for that environment. The MET median EI was then used to divide the site and year combinations into ‘low yielding’ and ‘high yielding’ environments (Verma et al. 1978). A yield stability parameter β was obtained using linear least squares regression to quantify the response of individual hybrid yield in solid row configurations to EI (Tollenaar and Lee 2002). Values for β > 1 reflect hybrids that are highly responsive to EI, where β < 1 hybrids are relatively unresponsive and hybrids with β ≈ 1 exhibit a response close to the group mean. Because β does not convey yield it is graphically portrayed (e.g. Finlay and Wilkinson 1963) in conjunction with median hybrid yield for each EI subset.

Table 1. Trial sites and designs for testing genotype x management interactions.

Site	Year sowing window opened	Experiment design (repetitions)	Hybrids (*n*)	Row configurations (*n*)	Row densities (*n*)	Environments (*n*)
Brookstead	2014	Split plot (4)	7	1	4	1
Capella (A)	2014	Split plot (2)	5	2	3	1
Capella (B)	2014	Split plot (3)	11	1	4	1
Gatton	2014, 2015	Split plot (3)	10	1	1	2
Jimbour	2014	Split-split plot (3)	5	2	3	1
Kingsthorpe	2014	Split plot (3)	4	1	3	1
Kupunn (A)	2014	Split plot (3)	5	2	3	1
Kupunn (B)	2014	Split plot (3)	5	2	3	1
Warwick	2014, 2015	Randomised complete block (3)	12	1	1	1
Condamine	2015	Split plot (3)	4	1	3	1
Emerald	2015	Split plot (3)	4	1	3	1
Pittsworth	2015	Split plot (3)	3	1	3	1

Decision tree construction

Recursive partitioning was used to repeatedly identify the factor that most effectively subsets the data into dichotomous nodes equally populated with observations of trial yield. To minimise the risk of over-fitting the data subsetting was discontinued before $n < \Sigma/10$ per node, where Σ is the initial number of observations per subset. The factors used to subset were hybrid maturity, propensity to tiller, yield stability and yield potential relative to MR-Buster, row configuration and row density, and initial soil water (mm, to 1.8 m depth). The process was repeated twice, once each for the low and high yielding environments defined above: this approach produced two sets of decision rules whose relevancy to other sites is readily assessed via expected site yield.

Results and Discussion

The reference for hybrid performance is MR-Buster, the most popular hybrid in the Australian sorghum market (Figure 1). Across the MET, the β of MR-Buster was intermediate, with several hybrids exhibiting a greater sensitivity to changes in the EI and many hybrids exhibiting reduced sensitivity. In low yielding environments most hybrids yielded slightly higher than MR-Buster, whereas in high yielding environments the range of yields was much greater with some hybrids yielding up to 45 % more than MR-Buster.

The decision trees (Figure 2) for low and high yielding environments differed in their structure and complexity. The latter was due to a larger number of treatment combinations at the high yielding sites compared to the low yielding sites (n = 252 and 100, respectively). At all sites lower starting soil moisture and skip row configurations generally contributed to lower yields. At lower yielding sites hybrids with a relative yield potential > 1 with a medium maturity were the most productive. At high yielding sites the productivity was curtailed by very high plant densities (> 7.3 plants m^{-2}).

Yield stability and potential across the MET

Interactions of G x E often result in changes to the relative performance of genotypes according to the environmental conditions that prevail when and where they are being evaluated. While this G x E interaction maybe problematic where the number of trials are small, a MET (such as that presented in Figure 1) that incorporates a large number of environments can effectively exploit variability in E across the production region. Due to the small size of the Australian market for sorghum hybrid seed and the spatial and temporal environmental variability encountered across the production region, seed companies can be expected to breed and supply broadly adapted genotypes. Such a genotype will have a β value close to unity and above average yields in both low and high yielding environments. It is clear that hybrids fitting these characteristics are available to sorghum producers, especially when compared to the industry standard hybrid (Figure 1). There also exists a niche market for specialised hybrids adapted to very high yielding sites created by levels of stored soil moisture, irrigation and positive seasonal outlooks. There are hybrids with β > 1 and above average yields particular to high yielding environments suited to such niche conditions available to Australian sorghum producers (Pac2 and G56; Figure 1).

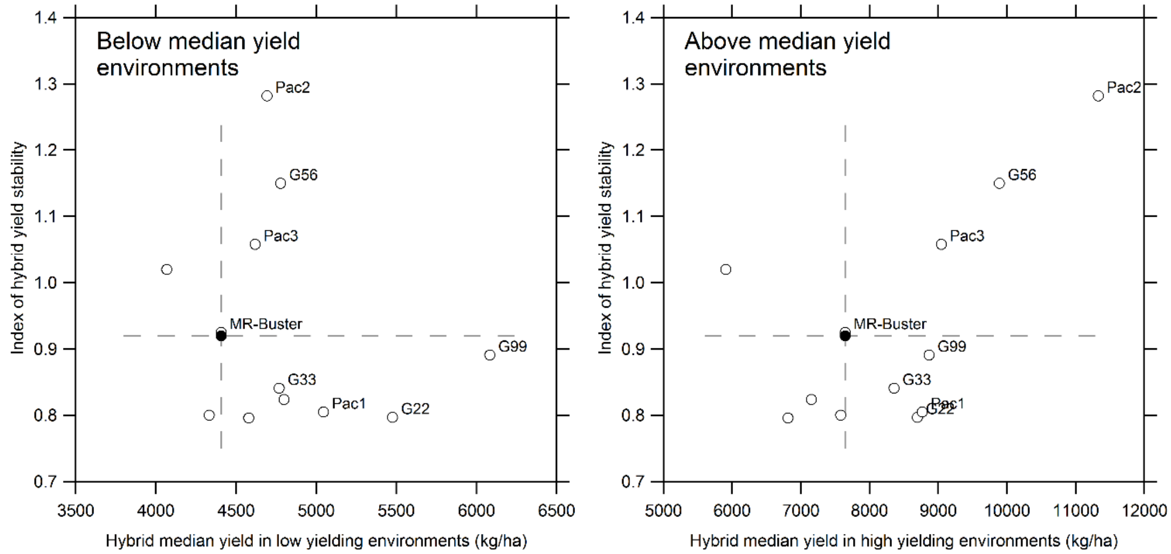

Figure 1. Characterisation of commercial sorghum hybrids by their yield potential in low yielding (< 6.0 t/ha) (left panel), and high yielding (> 6.0 t/ha) (right panel) environments. The dashed lines place hybrids in relation to the industry standard, MR-Buster (black circle). Hybrids that yielded less than MR-Buster are not named.

Genotype by management (crop design) across high and low yielding environments

The decision tree identified G and M factors that correlate with observed yield in both low and high yielding environments (Figure 2). The M factor the decision trees repeatedly identified as important was row configuration, whereby skip row configurations yielded relatively poorly. This suggests that the environments tested were sufficiently non-limiting to realise the benefit of skip row over solid row configurations (Whish et al. 2005). Hybrid characteristics (G) appear stronger determinants of yield in low relative to high yielding environments, particularly those hybrids that typically yielded less than MR-Buster. Very high plant density was identified as a potential contributor to somewhat poorer yields in high yielding environments. Given that sorghum yields are generally considered insensitive to plant density due to compensation amongst yield components, such as tillering and grain number (Wade and Douglas 1990), this finding may instead reflect the particular combination of sites and treatments with a higher proportion of high plant density treatments. This highlights the scope for potential bias in the output of the decision tree whereby the unbalanced set of trials that comprise the MET (Table 1) increase the likelihood that recursive partitioning over-fits the data.

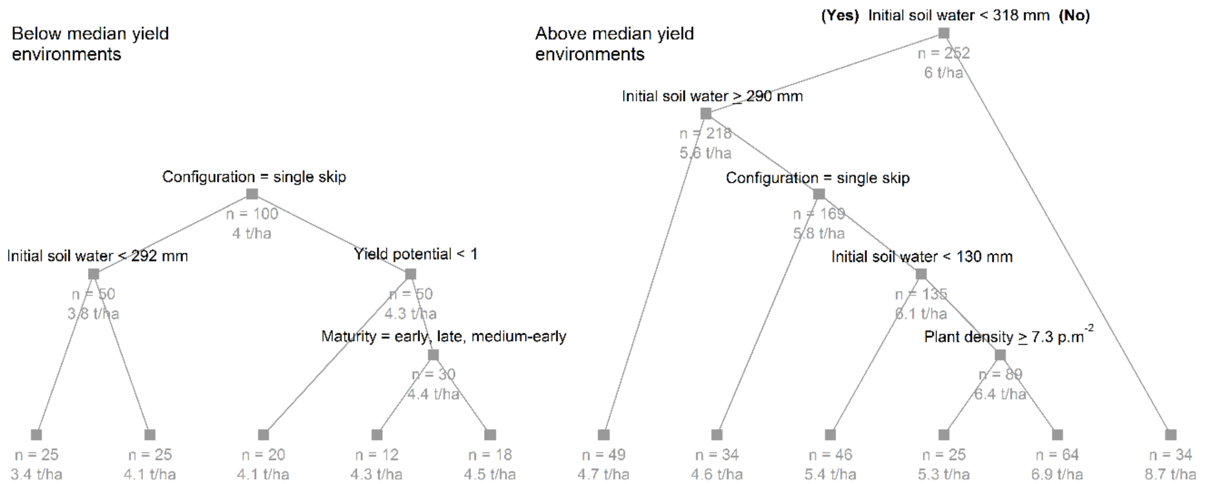

Figure 2. Decision trees for commercial sorghum hybrid yields across a Queensland MET. Indicated for each node are the number of G x M treatments represented and the mean yield (t/ha).

Conclusions

Queensland sorghum growers have access to a set of hybrids that differ in their maturity type, propensity to tiller, yield stability and yield potential. The performance of these hybrids and their interaction with management contrast in important ways between low (< 6.0 t/ha) and high (> 6.0 t/ha) yielding environments. Irrespective of the environment yield; in this case between 4 – 12.0 t/ha, wide row configurations always yielded less than solid configurations. In high yielding environments initial soil moisture was highly effective at identifying the most productive environments in the MET, with plant density playing a lesser role. Hybrid yield potential was the most important genotype attribute in low yielding environments. Our results indicate that in sorghum, what really matters is not just agronomy, but to understand how to match the combination of hybrid and agronomy to site and seasonal conditions.

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