Is increased Radiation Use Efficiency in Sorghum related to increased Height?

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Abstract

Sorghum yield is known to correlate with height in breeding populations and some recent studies have found enhanced radiation use efficiency (RUE) in a tall (single dwarf) sorghum hybrid, which may explain the correlation. The experiments reported in this paper were undertaken to investigate whether plant height *per se* was related to radiation use efficiency in sorghum. Two field experiments were conducted with mutant lines differing only in one height gene – conventional triple dwarfs and their mutated (taller) double dwarfs. In experiment 1, a significant increase in biomass due to higher RUE was observed for the tall mutant in one genetic background but not in the other. In experiment 2, however, the same genotype showed significantly increased biomass with the tall mutant form, but this was caused by enhanced light interception rather than difference in RUE. Hence, at this stage it was not possible to draw a clear conclusion about the possible relationship between RUE and height in sorghum. The question remains unresolved and is the subject of on-going study.

Media summary

Enhanced efficiency in converting radiation to biomass was discovered in a tall sorghum. By studying single gene height mutants we have not yet been able to resolve if this is directly linked to differences in height.

Key words

Near-isogenic, reverse mutation, light interception, single-gene, Dw3.

Introduction

Data from sorghum breeding trials, conducted by the Queensland Departement of Primary Industries over 15 years have shown that the yield of F1 hybrids is correlated with plant height (Jordan, Tao et al. 2003) (Fig. 1).

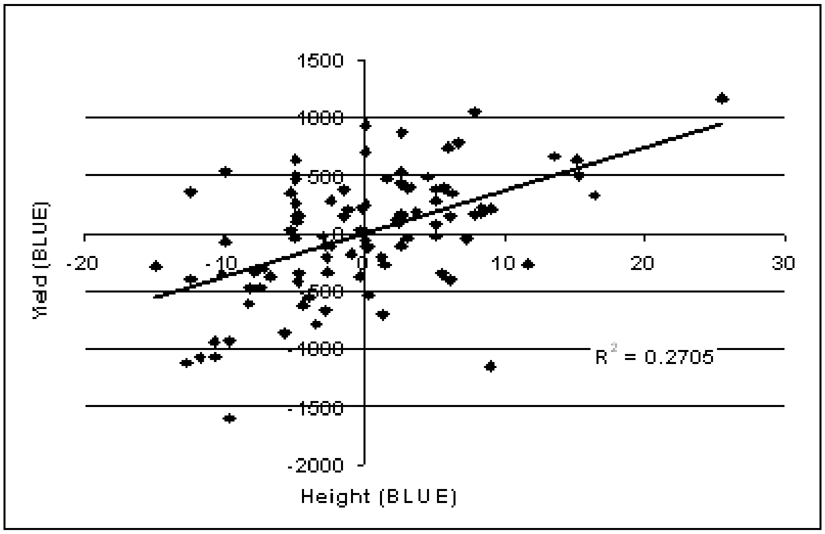

Figure 1. Correlation between yield and height for 99 F1 sorghum hybrids. Data are Best Linear Unbiased Estimates (BLUE) from analysis of 48 trials over 15 years.

In addition, recent detailed field experiments comparing a tall (single dwarf) Indian sorghum hybrid (CSH13R) with a short (triple dwarf) Australian commercial hybrid (Buster) discovered significantly higher radiation use efficiency (RUE) in the tall hybrid (Fig. 2) (Hammer, unpublished). This finding was consistent over a number of experiments. RUE is usually defined as the slope of the relationship between accumulated biomass and accumulated intercepted radiation and therefore is a measure of the efficiency of conversion of radiation to biomass at the crop scale.

The experiments reported in this paper were undertaken to investigate whether stem height *per se* was related to radiation use efficiency and whether increased RUE was the cause of the observed correlation of yield with height.

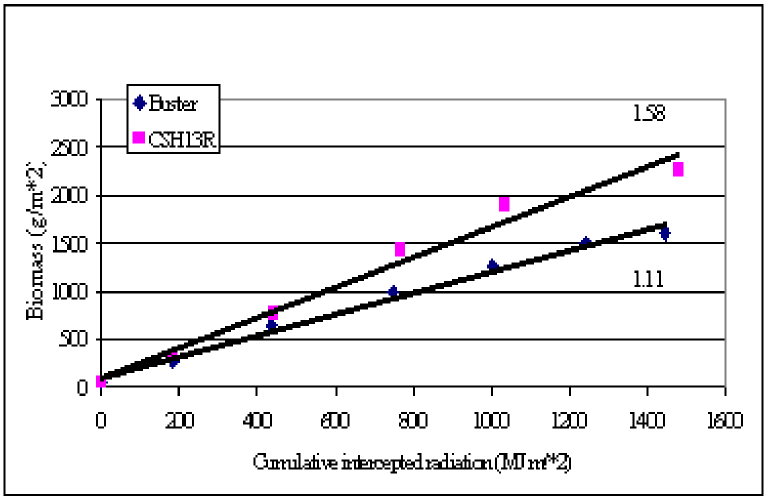

Figure 2. Above ground biomass vs cumulative intercepted total radiation for a tall (CSH13R) and a short (Buster) sorghum hybrid. The slopes of the respective lines indicate the RUE (g/MJ).

Methods

Production of near-isogenic lines differing in height

Near-isogenic lines differing in height were produced for the sorghum lines 31945-2-2, 55637 and 55343-1 by utilising spontaneous reverse mutations from 3dwarf to 2dwarf genotypes. These reverse mutations occur at a high frequency in sorghum due to an unstable dwarfing gene (Dw3) that mutates back to the original tall allele (Quinby and Karper 1954). The resultant pairs of lines were thus isogenic except for one height gene. The tall mutants were denoted by addition of TM to the line descriptor. All three pairs of lines were hybridised by crossing with A23171, to give pairs of hybrids differing only in one height gene, in addition to the pairs of inbred lines.

Field experiments to measure RUE

Two experiments were sown at Hermitage Research Station (Lat. 28? 12' S, Long. 152?06' E 470m above see level) in southeastern Queensland. Experiment 1 was sown 24th October 2001 and experiment 2 on the 5th November 2002. The soil was a strongly cracking and self-mulching alluvial clay with a high montmorillonitic clay content (McKeown 1978) that was well drained. Both experiments were fertilised and irrigated to provide non-limiting nutrient and water conditions.

Experiment 1 consisted of the pairs of lines based on 31945-2-2 and 55637, as well as the pairs of hybrids, A231717/31945-2-2 and A23171/55637, plus the female parent line B23171 in a randomised complete block design with three replications. Experiment 2 also contained the pairs of lines based on 31945-2-2 and 55637, but insufficient seed of the pairs of hybrids was available for their inclusion in this experiment.

In both experiments, plots were eight rows wide with 0.75 m row spacing. Plots were 15m long in experiment 1 and 20m long in experiment 2. The 4 central rows were used for detailed measurements while the 2 rows on either side were left as guard rows. The row orientation was approximately North to South. Two further guard rows (Sorghum cv. Buster) were planted between all plots along their longer side as a buffer zone to prevent shading effects from neighbouring plots differing in height. Tube solarimeters (type TSL, Delta-T Devices Ltd., Burwell, Cambridge, England) were installed in each plot early in crop development to measure crop radiation interception. The solarimeters were coupled to a data logger (CR10X, Campbell Scientific Inc., Logan, UT). A scan rate of 5 minutes was used and radiation measurements were averaged and recorded hourly. A reference tube solarimeter was installed above the crop canopy and the measurements taken below the canopy were expressed as the fraction of incoming radiation intercepted by the canopy. A nearby meteorological station provided total daily solar radiation, which was used to calculate actual canopy radiation interception on a daily basis. Before placement in the canopy, all solarimeters were installed in situ above the canopy for a period of a week for calibration against the reference tube. All solarimeters were kept clean and free from condensation at all times.

Biomass harvests were taken at floral initiation, anthesis and maturity in experiment 1, while more frequent harvesting was conducted in experiment 2 (every 2 weeks). Main culm and tiller numbers were determined and plant material from a representative sub-sample was partitioned into green leaves, senesced leaves, stems and panicles. Green leaf area was determined with an electronic planimeter (DIAS image analysis system, Delta-T Devices Ltd., Burwell, Cambridge, England). Main culms and tillers were measured separately.

The increments in biomass and cumulative intercepted radiation (fraction intercepted by the crop multiplied by daily solar radiation) were determined for each plot and time period so that RUE could be calculated from their ratio. Canopy light extinction coefficient (k) was calculated using the function:

$$LI = 1 - \exp^{(-k*LAI)}$$

where LI is the fraction of light intercepted by the canopy and LAI is leaf area index (m^2 leaf m^{-2} ground). In fitting this equation data on light interception and leaf area were pooled for all measurements throughout the growing season. Phenological data (days to flower, days to physiological maturity and leaf number) were collected to ensure that the mutants did not differ in rate of development.

Results

In experiment 1, a significant increase in pre-anthesis RUE was observed for the tall mutant of the 31945-2-2-genotype in both the inbred line and hybrid (Table 1). The increased RUE resulted from a significantly greater biomass increment while LAI at anthesis (data not shown) and intercepted radiation were not significantly different.

Table 1. Analysis of variance for the pre-anthesis period for experiment 1. Cumulative intercepted radiation in MJ m^{-2}, biomass increment in g m^{-2}, RUE in g MJ^{-1}. RUE values followed by the same letter are not significantly different at the 0.05 probability level. K is the canopy light extinction coefficient.

Genotype	Cumulative Interception	Biomass Increment	RUE		k
31945-2-2	483	518	**1.09**	*d*	0.43
31945-2-2 TM-2	512	720	**1.41**	*ab*	0.42
55637	446	644	1.45	*ab*	0.40
55637 TM-2	517	698	1.36	*abc*	0.44
23171/31945-2-2	545	664	**1.22**	*bcd*	0.43
23171/31945-2-2 TM-2	583	857	**1.47**	*a*	0.46
23171/55637	552	752	1.36	*abc*	0.39
23171/55637 TM-2	592	849	1.43	*ab*	0.44
B23171	500	643	1.29	*bc*	0.46
significance	***	***	**		n.s.
lsd (0.05)	*47.4*	*74.8*	*0.17*		

In experiment 2, however, while the same genotype (i.e. 31945-2-2) showed significantly increased biomass with the tall mutant form, on this occasion intercepted radiation was also significantly greater.

While LAI did not differ significantly between the mutants (data not shown), the increased interception was derived from a greater canopy light extinction coefficient. The mutant pairs did not differ significantly in RUE but the line 55637 had higher RUE than 31945-2-2.

Table 2. Analysis of variance for the pre-anthesis period for experiment 2. Cumulative intercepted radiation in MJ m^{-2}, biomass increment in g m^{-2}, RUE in g MJ^{-1}. RUE values followed by the same letter are not significantly different at the 0.05 probability level. K is the canopy light extinction coefficient.

Genotype	**Cumulated Interception**	**Biomass Increment**	**RUE**		**k**
31945-2-2	557	709	1.28	b	0.24
31945-2-2 TM-2	**627**	**818**	1.31	b	0.33
55637	562	883	1.57	a	0.24
55637 TM-2	**640**	907	1.43	ab	0.33
significance	***	***	**		***
lsd (0.05)	*64.3*	*97.9*	*0.18*		*0.0327*

The values found for RUE in this study were generally consistent with values reported previously for sorghum hybrids (Muchow and Davis 1988). Apart from the initial (unpublished) study with hybrid CSH13R, to our knowledge, there have been no reports of genetic variation in RUE in sorghum and nor reports of any effect of increased height on RUE. However, as the results of the two experiments in this study did not give consistent results among the mutant lines, no clear conclusion can be drawn about the possible relationship between RUE and height. The significant increase in biomass accumulation and RUE measured for the tall mutant of 31945-2-2 in the first experiment was not duplicated in the second experiment. The enhanced biomass increment for this mutant line in the second experiment was related to differences in canopy light extinction (k), not RUE. Differences in k are often associated with canopy architecture. The tall mutants had significantly higher k values than the dwarf lines in the second experiment, but values were generally lower than for the first experiment. It is possible that effects on canopy architecture, e.g. differences in tillering resulted in these inconsistencies between the two experiments. Further study into the cause of the observed RUE difference and the alleged link with plant height is underway.

Conclusion

It was not possible to draw a clear conclusion that height *per se* was related to radiation use efficiency in sorghum. The two experiments with single gene mutants gave inconsistent results. The question remains unresolved and is the subject of on-going study.

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