Transformational agronomy by sowing grain sorghum in winter: Sorghum root growth and function

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Abstract
Water stress and extreme heat at flowering are common stresses limiting yield in sorghum across the Northern Grains Region. To avoid these stresses farmers could sow sorghum, a summer crop, into cold soils in winter. Though little is known about the impacts of cold soils on root growth and function (water uptake). Here we report results from the first year of on-farm trials run over two seasons (2019-20 and 2020-21) at Cecil Plains QLD. The trial consisted of three sowing times (winter, spring, and summer) and two levels of irrigation (rainfed and supplementary irrigation). A single hybrid was sown (MR Buster) at a single plant population (9 pl m^{-2}). At flowering, in each time of sowing, soil cores were taken, washed and roots scanned to determine root a range of root parameters and dry weights. During the first year of trials results showed significant differences in root growth and root architecture between times of sowing, with winter sown sorghum having significantly smaller total root length values (cm) ($P<0.01$), a smaller root surface area (cm^2) ($P<0.05$), and smaller total root length to root dry weight ratio (cm g^{-1}) ($P<0.05$). There was also a significant interaction between time of sowing and irrigation for shoot dry weight ($P<0.05$). Even though the rooting system of winter sown sorghum appears to be smaller (relative to the shoots), no implications on final grain yield were observed. Results from the second season of trials is being analysed.

Keywords
Early sown sorghum, Heat stress, Drought stress, Adapting to climate change

Introduction
Water stress and extreme heat at flowering are common abiotic stresses limiting yield in sorghum production across the Australia's northern grains region (Clarke et al., 2018; Singh et al., 2015). Recent results (Ortiz-Boeda, et al., 2021) indicate that ongoing climate change is making these stresses more intense and frequent increasing the vulnerability of farming and the urgency to adapt agricultural practices. While breeding appears to be fixated in a long-haul search for heat tolerance mechanisms, agronomy can deliver immediate solutions to avoid the overlap between times of the year of high likelihood of the stress and sensitive crop stages (Prasad et al., 2017). Early sowing sorghum is one of the options. Sorghum crops sown in late winter or early spring are more likely to flower before yield-limiting summer heat waves. However, for the practice to be scaled out, information on how cold is too cold to sow summer crops in winter is still needed. Sorghum crops sown into cold soils can be expected to grow slowly during a cooler, lower atmospheric demand, and higher photothermal quotient environments, that will affect the dynamics of crop water use, at least until air temperatures increase during mid and late Spring. However, little is known on the impact of cold soils on the growth, architecture, and function of the rooting system. Here we present results from the first year (of a two-year research) in which we aim to answer whether sowing sorghum into cold soils in winter will affect root growth and architecture. The study provides the first evidence, to relate root growth across winter-, spring-, and summer-sown sorghum crops.

Methods
Root growth and architecture were assessed for three times of sowing and two levels of water availability (dryland and irrigated), over two seasons (2019 and 2020). Only results from the first season are presented here. The three sowing times (TOS1, TOS2 and TOS3) corresponded to winter, spring, and summer sowing times, and aimed to achieve contrasting soil and ambient temperatures during vegetative and reproductive growth. In 2019, TOS1 was sown on 9 August, TOS2 was sown on 11 October, and TOS3 was sown on 10 November. Two water regimes were implemented with a drip irrigation system. A single hybrid (MR Buster) was sown at 9 pl m^{-2}. The treatments were set up in a split plot design with TOS as the main plot, and each plot was replicated three times. An automatic weather station recorded weather and soil temperatures. At flowering for each time of sowing, shoots were sampled for dry weights, and soil coring was used to sample the rooting system. A narrow tubular soil auger (44 mm diameter) was used that reached a depth of 1.3 m. The soil core was partitioned into nine depth intervals of 0-0.3, 0.3-0.5, 0.5-0.8, 0.8-1, and 1-1.3m. Two soil cores

(sub-samples) were taken directly above the plant after the shoots were harvested for dry weight determinations. Soil samples were then collected in zip lock bags and transported in Eskies from the field for processing and short-term storage. Root samples were separated from soil in root washing facilities. Soil cores were soaked in water with a water softening powder. The solution was rinsed over a sieve and the roots were collected with tweezers and stored in a 60-70% ethanol solution at -5°C. A digital scanner (Epson Expression XL 10000) was used to generate images of root samples for analysis. Root length, root diameters, root area and root volumes were derived from the scanned images using WinRHIZO® software, Regent Instruments Inc., Quebec, Canada (Trachsel et al., 2011). The results of the two sub-samples were averaged to provide a single plot level value. Results on grain yield are dry basis and expressed in t/ha; shoot dry weight are expressed in g per plant; and root parameters were bulked across all sampled layers. This is, total root length, volume, and root area, are expressed in units per volume of soil sampled i.e. 1.3m cores of 44mm diameter taken on top of the plant stump after the sampling of the shoots. All statistical analyses were performed using the advanced residual maximum likelihood (AS-REML) model in the R environment described in Butler et al., (2017).

Results

The results from the first season of trials showed statistically significant interactions for final grain yield, and shoot dry weight at flowering, between the time of sowing and the irrigation treatments ($p<0.05$) (Table 1). Significant main effects of the time of sowing were also observed on root parameters at flowering. This is, root length, root area and the ratio between root length and shoot dry weight (Table 1).

Table 1. Results from the linear mixed model using advanced Residual Maximum Likelihood (REML) on yield, shoot and root parameters for a sorghum crop (MR Buster) sown at three times of sowing (TOS) in winter, spring and summer, at 9pl/m2 at two levels of irrigation in Cecil Plains Qld during the 2019 season.

Trait	Mean	Significance	df	p
Grain yield (t/ha)	1.41	Interaction TOS by Irrigation	2	0.03
Total shoot dry weight (g/pl)	13.5	Interaction TOS by Irrigation	2	0.030
Root dry weight 0-1.3m (g/sample)	0.131	No significant effects		
Root to shoot ratio	0.010	No significant effects		
Root length 0-1.3m (g/sample)	632.1	TOS main effect	2	0.001
Root area 0-1.3m (cm2/sample)	46.1	TOS main effect	2	0.021
Root volume 0-1.3m (cm3/sample)	0.28	No significant effects		
Root length to shoot ratio (cm/g)	46.3	TOS main effect	2	0.023

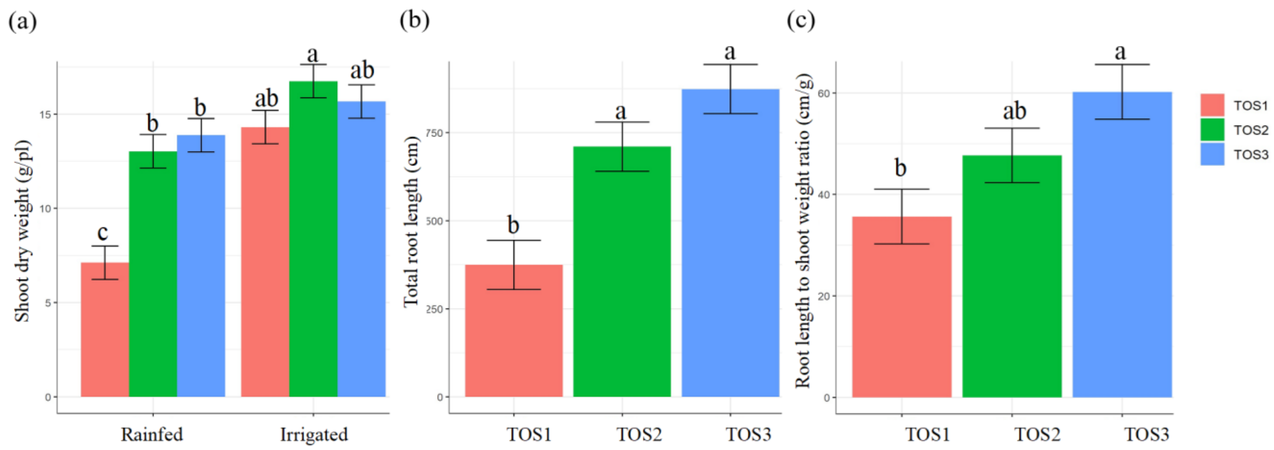

Figure 1. Effect of time of sowing and irrigation on shoot dry weight (g/pl) (a); total root length (cm/sample 0-1.3m) (b); and the ratio between total root length and shoot dry weight (cm/g) at flowering, for sorghum (MR Buster) crops sown at 9pl/m2 in winter (TOS1), spring (TOS2) and summer (TOS3), at Cecil Plains, Qld Australia.

Even though shoot dry weights were smaller for the rainfed and winter sown crops, time of sowing was the only factor affecting root parameters, with winter and spring crops showing smaller rooting systems. Total root length was proportional to the shoot dry weights (Figure 2a), though different relationships ($P<0.05$) were observed between the winter and the spring and summer sowings (see also Table 1 and Figure 1). This is, smaller values of root length were observed in the winter sown crop per unit of shoot dry weight – an indicator of the balance between the capacity of the crop to access underground and aboveground resources. Even though the lower values of root length per unit of shoot dry weight in the earlier sown crops, such a "root length – shoot size unbalance" (Figure 2a), was not affect the final grain yield (Figure 2b).

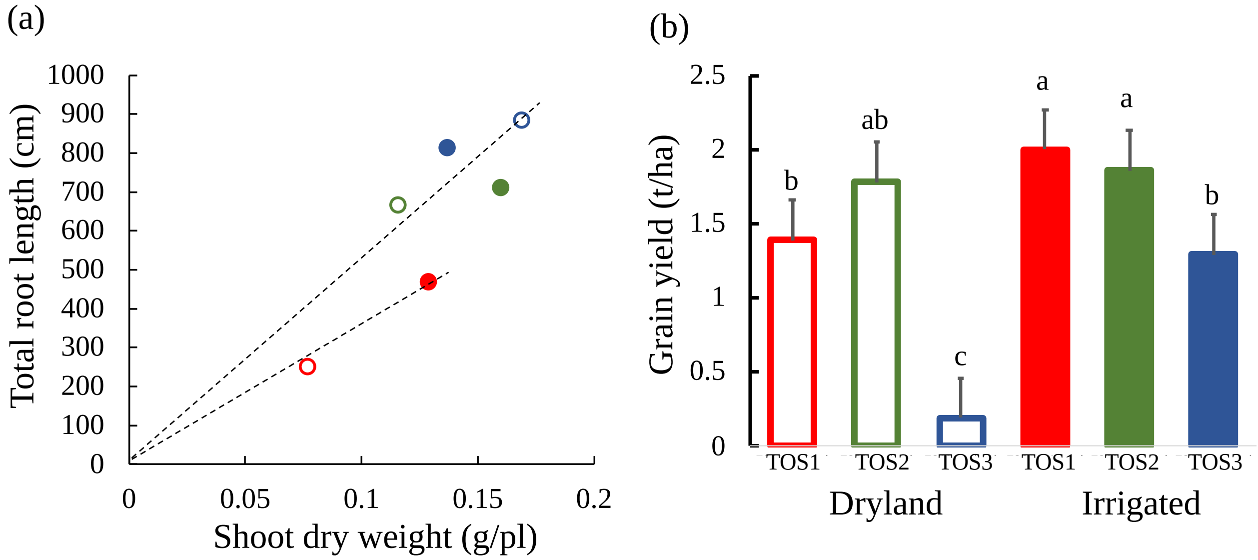

Figure 2. Effect of time of sowing and irrigation on the relationship between shoot dry weight (g/pl) and total root length (cm/sample 0-1.3m) at flowering for sorghum grown in Cecil Plains Queensland (a); and final grain yield (b), sown in winter (TOS1, red), spring (TOS2 green) and summer (TOS3 blue), at two levels of irrigation, dryland (open circles and bars) and irrigated (filled circles and bars), at Cecil Plains, Qld Australia. The dotted lines in (a) were fitted by hand to represent the significant differences observed on the relationship, as shown in Table 1 and Figure 1c.

Conclusion

Results from a single season of trials have shown that sowing summer crops (sorghum) in winter, reduced the size of the shoots and roots. An unbalance in the allocation of growth resources between roots and shoots was observed in the winter sown crop. The level of crop investment in root length per unit of shoot dry weight was smallest in the winter sown crop, followed by the crop sown in spring, and highest for the summer sown crop. Results also showed that, irrespective of the level of irrigation, grain yields were highest for the winter and spring sown crops, compared to the summer sown crop. These results are aligned to the observations by Rodriguez et al., (2021 – this conference) that the avoidance of heat stress, and the transfer of water use from vegetative to reproductive stages in winter and spring sown sorghum are key factors in determining the final yield of early sown sorghum.

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