Transformational agronomy by growing summer crops in winter: Winter sown sorghum

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Abstract
History shows that transformational changes in agriculture are rarely associated with the adoption of single innovations. It has been argued that transformative changes in agriculture have usually resulted from the incremental adoption of complementary technologies, and result in ongoing increases in yield from improvements from breeding and agronomy – though gains in productivity remain piece meal, insufficient and primarily confused with adoption processes. Here we propose that there is a role and need to design research that aims to be more transformative, likely to have larger than the ongoing or incremental gains, and that can be achieved in shorter periods of time. This argument is discussed by summarising the results of a four-year cross-agency research program conducted across Eastern Australia that tested crop designs of winter sown sorghum (WSS). The innovation is a systems adaptation with the potential to produce gains in productivity and farmer profits beyond what is the incremental or ongoing yield gain – though impact will still be dependent on adoption rates.

Keywords
Abiotic stresses, crop design, adaptation

Introduction
Yield gains in broadacre cropping can be attributed to genetic improvements from breeding (G), from the adoption of more productive agronomic managements (M), and from synergistic interactions across environments (E). In Australia for example, gains in sorghum yield have been estimated to be 2.1% per year (44 kg/ha/year) which is about twice as high as that for wheat (1.2% per year or 21kg/ha/year) (Potgieter et al., 2016). In sorghum, yield gains from improvements in agronomy can be traced back to the rapid adoption of reduced or no-tillage and the adoption of conservation agriculture principles, together with the use of modern sowing equipment that allowed for seed singulation, improved seed-soil contact and moisture seeking that produced more uniform canopies better able to outcompete weeds (Serafin, et al., 2019). Other drivers of yield improvement included farmers' better understanding of how to match nutrient supply, hybrid and plant population to site and expected seasonal conditions (Clarke et al., 2018; Rodriguez et al., 2018). In sorghum, improvements from breeding were attributed to the introduction midge resistance (Franzmann and Hardy, 1997), and stay-green traits, that provided yield benefits in the more marginal environments and seasons (Borrell et al., 2014). When these innovations are collated (incrementally or not), significant transformations of the production system can take place, in Australia and globally (Sadras et al., 2020). However, examples of research with potential to drive transformative changes, this is, larger than the ongoing incremental gains in crop productivity are not common. Probably the clearest framework to understand the need and role of transformational changes (adaptations) in agriculture relates to adaptation sciences under the pressure of climate change (Howden et al., 2007; Rickards and Howden, 2012) (Fig 1). In this regard the need to adapt to the increasing frequency and intensity of heat and water stresses around flowering in sorghum, presents an interesting case to explore options for non-incremental gains. This is, gains associated with sowing a summer crop in winter, and the cascade of implications on the number of sowing opportunities, the likelihood and intensity of heat and water stresses, the cropping intensity, the diversity of the cropping system, and even benefits to the livestock enterprises. Here these ideas are discussed by summarising the learnings from a current five year on-farm research program on winter sown sorghum conducted across eastern Australia since 2018.

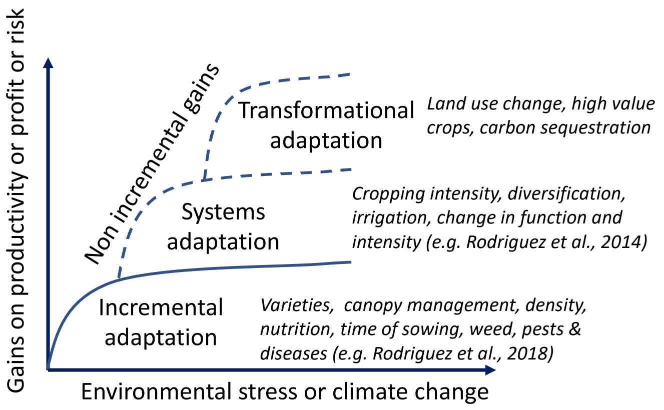

Fig 1. Adaptation pathways and conceptual gains in relation to increasing pressures from environmental stresses (adapted from Rickards and Howden, 2012).

Methods

The analysed multi environment trial data consists of eight trials per year over three years run from the Liverpool Plains, NSW to Central Queensland. All trials included a consistent factorial combination of three times of sowing (winter, spring and summer), four plant densities and six hybrids. All trials had three replicated blocks. The data presented here i.e. moisture corrected grain yields and % screenings are estimated means from a linear mixed model framework that used residual maximum likelihood, allowing for complex variance structures to be captured in the model including, but not limited to, heterogeneity of residual variance, experimental design terms and spatial field trend (for more details see Mumford et al., (2021) at this conference). Here, we also used APSIM to quantify cropping system benefits, and APSIM and BoM's ACCESS S1 for soil temperature and crop emergence predictions.

Results

Results from empirical experimentation showed that it is possible to establish sorghum in winter, into cooler soils, with no yield loss (Fig 2a), with a significant reduction in heat stress induced pollen sterility (Fig 3b), and increased transfer of water use to grain filling stages (Fig 3a) that resulted in reduced screenings (Fig 2b).

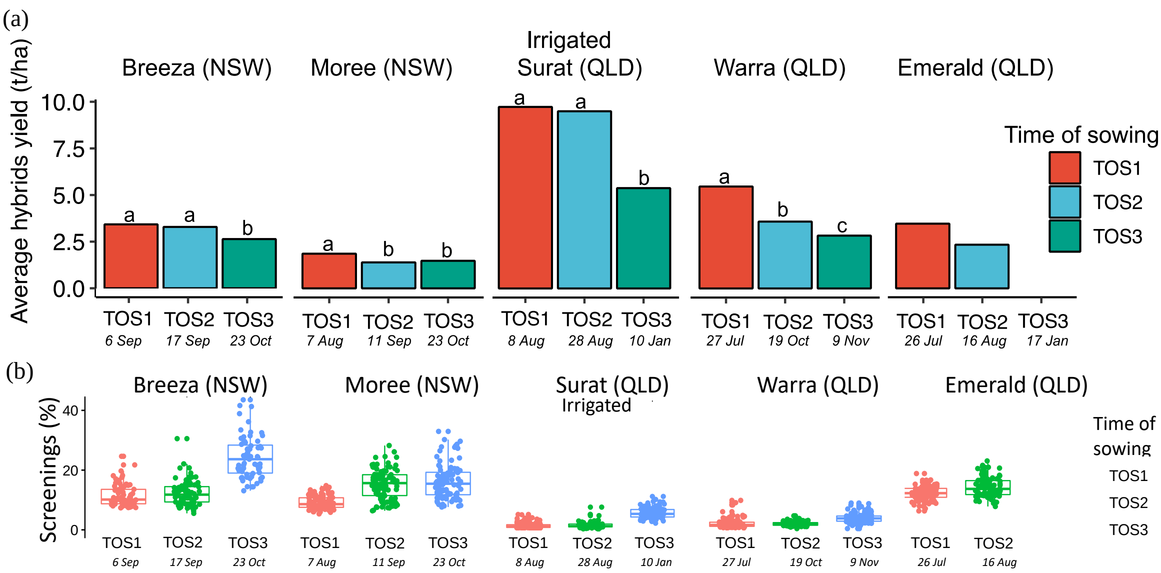

Fig 2. Estimated mean yields (a) and percent screenings (b) of sorghum crops sown in winter, spring and summer across eastern Australia between 2018-2019.

In the Bi-Plot analysis (not shown), the data points from the spring sowings were grouped and different environmental co-variates were related to different yield components within each season of sowing. The higher yields, values of seed set and grain weight in winter sown sorghum were associated to higher values of the normalised photothermal quotient (Rodriguez and Sadras, 2007), while the higher screenings in the summer sowing were related to the occurrence of more intense terminal stresses, represented by the simulated stress environment type and higher post flowering temperatures.

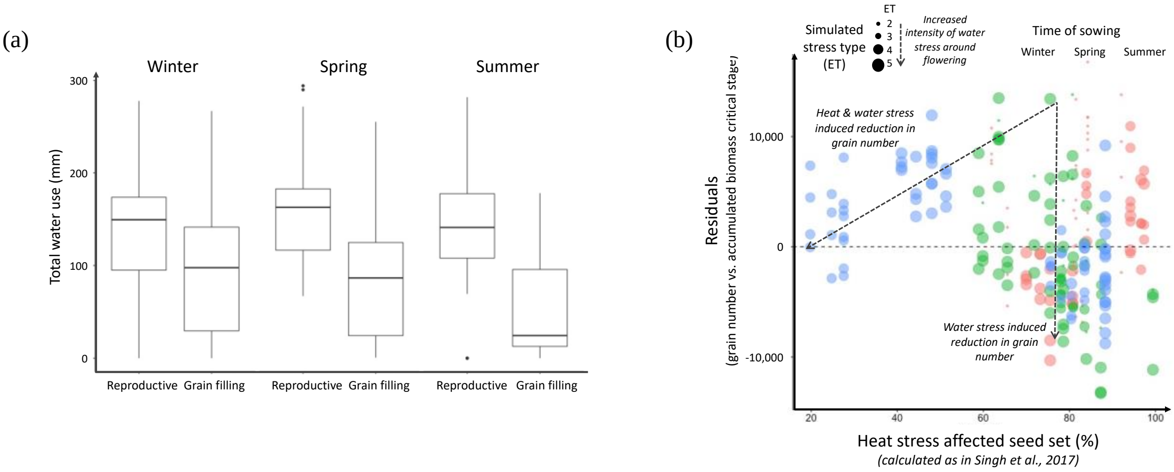

Fig 3. Simulated water use during reproductive (floral initiation to anthesis) and grain filling (anthesis to maturity) stages for winter, spring and summer sown sorghum (a), and (b) impact of heat stress and water stress on grain number formation for winter, spring and summer sowings on final grain number (residuals of the relationship between grain number and accumulated biomass between floral initiation and flowering), and the simulated associated water stress types for each treatment combination (ET, as in Hammer et al, 2014, i.e. 2 mild stress, 3, 4, 5 increasing severity of terminal stresses).

Cropping system benefits were also identified, with crop sequences including a winter sown sorghum dominating all simulated gross margin terciles in the Pareto frontier (Fig 4). The C–WS rotation dominated the middle and upper terciles, and the W-WS crop sequence was best performing in the first tercile, though the lowest variability (risk) and gross margins were obtained with the S-S crop sequence.

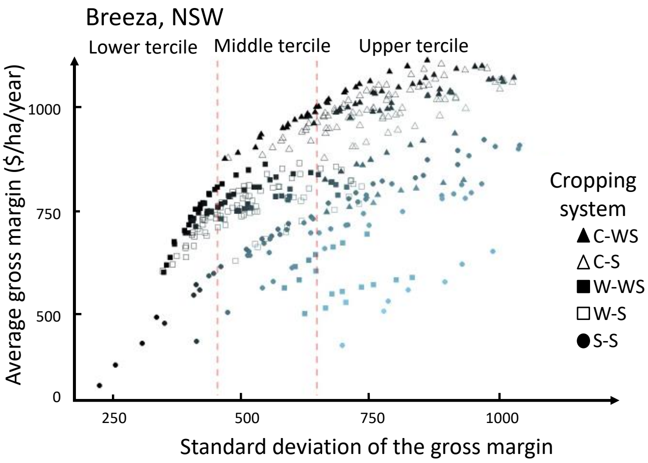

Fig 4. Trade-off between the cumulative gross margin and its standard deviation for a chickpea – winter sorghum (C-WS), chickpea – sorghum (C-S), wheat – winter sorghum (W-WS), wheat – sorghum (W-S) and sorghum-sorghum (S-S) rotation, at Breeza NSW (from Thomas et al., 2021).

Conclusions

The inclusion of winter sown sorghum in the crop sequence seems simple, though its implementation and consequences are not. This is, a sorghum crop sown in winter will have a long emergence period that will increase the likelihood of some seeds running out of soil moisture, and soil insects damaging seeds resulting in patchy plant stands with implications for weed competition and yield. On the upside, sowing sorghum in winter can be highly transformational. It will widen and increase the opportunities for managing ground cover and organic carbon inputs in regions where spring rainfall is highly variable; it will flower early and avoid heat and water stresses at flowering. Crops sown in winter will grow slowly during a time of the year of high radiation, lower temperatures and lower atmospheric drying demand that will increase the crop water use efficiency. Winter sown sorghum crops will substantially increase the chances of double cropping a winter crop after a short summer fallow or allow for the crop to be ratooned into a second harvest, particularly if irrigation was available.

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