Winter sown sorghum cropping systems

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Abstract
Lack of planting opportunities, water stress and high temperatures around flowering are major limitations to dry land sorghum (*Sorghum bicolor* L.) yield across Australia's Northern Grains Region. Sowing summer cereals into cool moist soil can increase the likelihood of crop establishment, reduce the impact of high temperatures and dry spells around flowering, and have large benefits at the cropping system level by increasing the chances of double cropping. Here we, i) used parameterised APSIM to identify sowing windows that fit the flowering of sorghum during low heat and water stress periods, ii) evaluated commercial sorghum hybrid cultivars in winter (July-August) sowing windows on-farms in northern New South Wales (NSW) and southern Queensland (Qld), and iii) quantify impacts of the practice on the cropping intensity. Results showed that i) the ideal flowering window across the region falls within two periods, October-November and March-April, ii) to achieve these target flowering windows, sorghum should be sown during July-August when soil temperatures are sub-optimal *ca*. 12°C in some regions; iii) sorghum seedlings are tolerant of frosts (0°C), iv) winter sowing did not cause yield penalties and v) that winter sown crops harvested before mid-December offered an 80% probability (80% of the years) for double cropping chickpea; this contrasts with a 20% probability (20% of the years) for a November sowing. We conclude that winter sowing of sorghum could reliably maintain high and more stable grain production and increase cropping intensity.

Key Words
Climate change adaption, Heat and water stress, Farming systems, GxExM

Introduction
Water stress and high temperature effects on grain set are increasingly limiting summer cereal production across Australia's Northern Grains Region. Sowing crops in winter is a potential option to avoid heat stress, however optimal combinations of genetic traits and crop management for early sown crops are unknown. The benefits of early sowing are not only expected to be on higher yields due to a reduced likelihood of heat stress at flowering, but also at the cropping system level, through an increased cropping intensity as result of an increased frequency of double cropping.
Previous research identified high yields but increased risk with early sorghum (*Sorghum bicolor* L.) sowing due to simulated frost damage and the influence of tillering on canopy size and subsequent water stress severity at flowering (Muchow, et al., 1994). However, winter sowing with modern genetics requires a re-evaluation as pre-flowering cold temperature thresholds for the new germplasm is not known, and the new germplasm is also lower tillering and more drought tolerant (Borrell, et al., 2014).
The amount of plant available water (PAW) stored in the soil at sowing, seedbed moisture content, the probability of in-crop rainfall and flowering heat stress are the primary biophysical drivers for the dryland sorghum planting decisions across North Eastern Australia. Here we postulate that (i) a narrow window of opportunity exists to plant a summer cereal crop into soil moisture in winter, as early as August on cold soils; and that (ii) early sown crops are likely to reduce the likelihood of heat stress at flowering and increase the opportunity of double cropping a winter crop after a short summer fallow.

Methods
Sites and trial management
Trial site locations in northern NSW (Breeza, Gurley and Mallawa) and southern Qld (Mount Moriah and Warra), were sown through August to November 2017 i) to reproduce a diverse range of frost, water, chilling and heat stress combinations based on ex-ante modelling, ii) for the option to irrigate as required and iii) the capacity to intensively manage and monitor the trials. Trials were sown on 1 m wide rows with a double disc opener precision planter. Starter fertiliser and nitrogen were be applied at sowing to achieve nutrient

unlimited growth for the locally adjusted yield target. Sites were managed to prevent pest, disease and weed competition.

Treatments

Commercial sorghum hybrid cultivars of contrasting maturity, tillering and staygreen were sown including Agitator, Archer, Buster, Cracka, G33, HGS114, Scorpio, Taurus and A66. Population densities of 3, 6, 9 and 12 plants m^{-2} were sown with the aim of achieving a diverse range of populations that can be statically compared between times of sowing treatments that are expected to have different emergence and establishment percentages. Sowing times targeted two early and one conventional control i.e. farmers practice sowing date. Yield measurements and multi-environment ASREML-R analysis followed the protocols from Clarke *et al.* 2018.

Cropping systems simulations

Lead farmers, agronomists, consultants, researchers and input suppliers were surveyed to identify winter sowing crop rotation scenarios in the context of known farm profit and risk drivers or research priorities. These scenarios were simulated with APSIM.

Results

Ex-ante simulation analysis of sowing date on flowering and yield potential

At Warra, Queensland, optimal ambient temperatures for sorghum flowering occur at the end of October and late February to early March (not shown). These results also show that sowing earlier maturing sorghum hybrids during July and August would be required to fit flowering during that optimum period.

Sowing time observations in on-farm field trial

The first time of sowing at Warra, Queensland was frosted (minimum ambient temperature at the canopy level < 2°C) 10 times between emergence and 3-expanded leaves without any visual damage to foliage showing that the vegetative tissue is more cold tolerant than previously reported (Fig. 1). Temperatures were cooler with a higher photo-thermal quotient for the first time of sowing compared to the second and third sowings. In-crop rainfall was close to the long-term median for each time of sowing but most rain fell around sowing or harvest for the spring sowings (11/10/2017 and 1/11/2017).

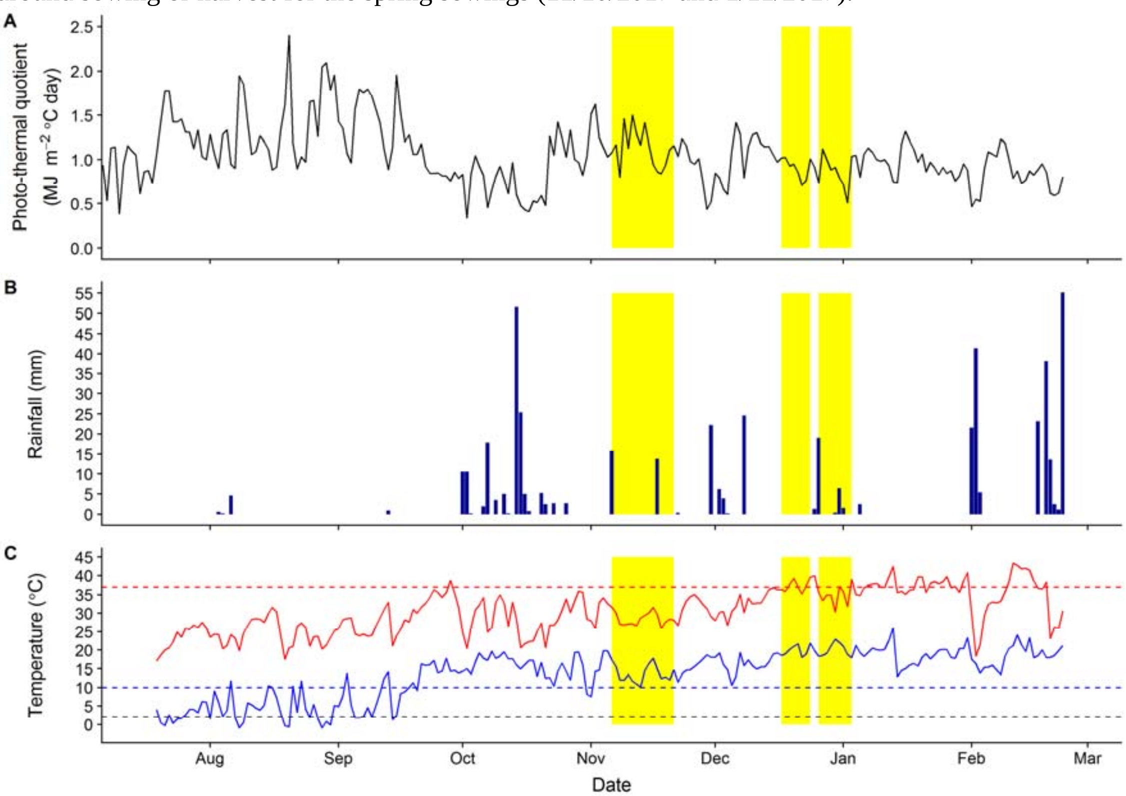

Figure 1. Photothermal quotient (A), rainfall (B) and ambient temperatures (C) at Warra, Qld for the 2017-2018 summer cropping season. The three yellow rectangles indicate flowering timing for each sowing date. Solid blue and red lines represent daily maximum and minimum temperatures, respectively. Dashed horizontal represent the reported minimum (blue) and maximum (red) temperatures stress thresholds at flowering and frost (black).

The earliest sown treatments flowered in November when damaging heat waves are frequent and that was much later than expected. However, Agitator and G33 were most frequently early flowering for the August sown trials but time to flowering was inconsistent across sites and sowing dates (data not shown).

Most importantly, grain yield was not penalised by sowing substantially earlier than current recommendations. Sowing date had no significant effect on yield within any site but Mount Moriah site sown on 8/8/2017 failed due to insufficient seedbed moisture (Fig. 2). There were significant interaction between hybrid and environment but none were consistently related to measured variables (Fig. 2).

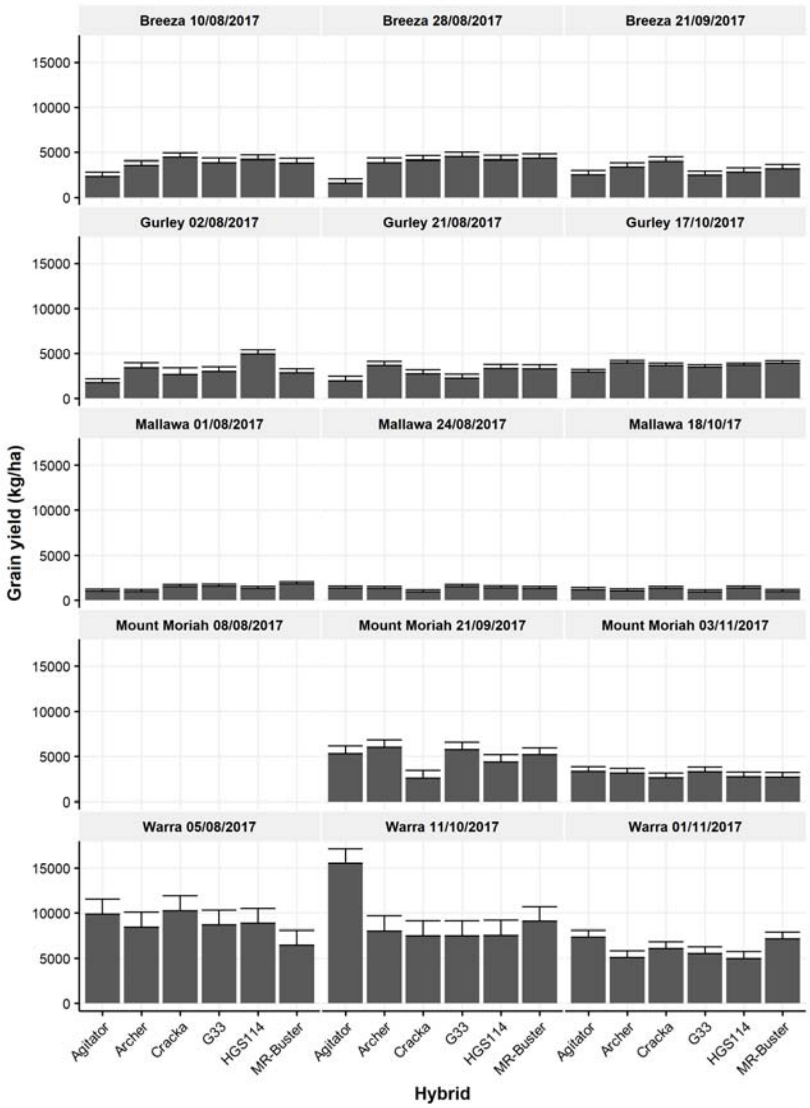

Figure 2. The effect of winter and spring sowing times on sorghum hybrid grain yields at Breeza, Gurley, Mount Moriah and Warra. Vertical bars indicate standard error.

Early sowing and copping intensity

Early sown sorghum crops mature and are potentially harvestable by mid-December. The subsequent summer fallow efficiency is relatively high due to the high level of crop residues on the soil surface during the highest rainfall period. Simulation analysis at Warra, Queensland also demonstrated that early sowing sorghum harvested on the 15th December increased the likelihood of double cropping chickpeas to 80% of years (Fig 4). Long fallows from wheat offer the highest frequency of planting opportunities for winter sown sorghum based on stored soil moisture thresholds and seed bed water content (not shown).

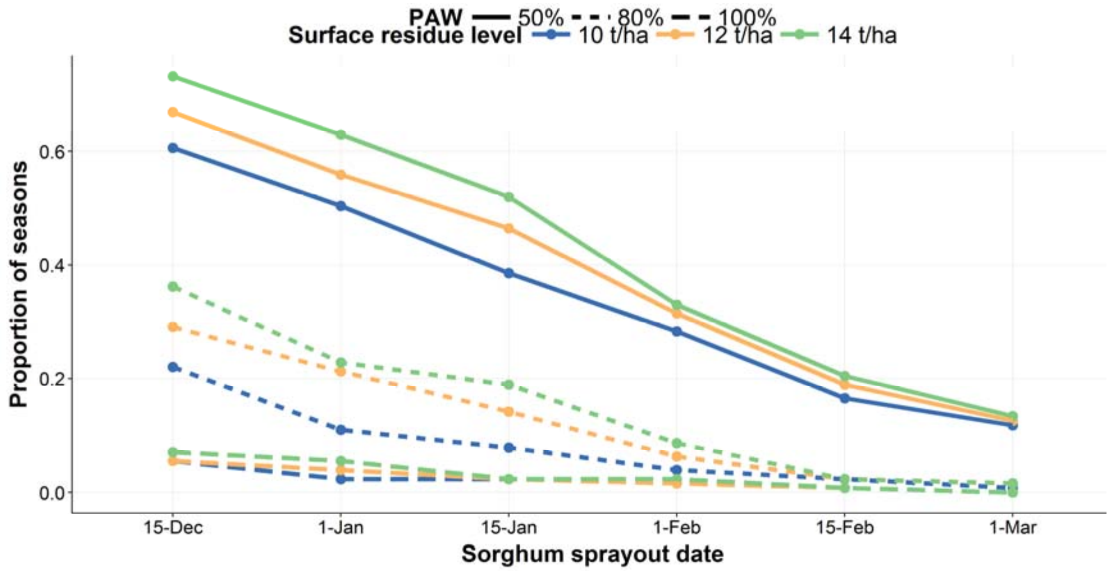

Figure 3. The simulated effect of sorghum harvest time (spray out) and sorghum crop residue level on double cropping chickpea frequency.

Conclusion

Based on this ex-ante modelling and one year of field trials, we propose that

i) Sorghum can be successfully sown earlier into colder seedbed than current recommendations,
ii) Seedlings are more frost tolerant than expected and lethal frost thresholds require further validation,
iii) Winter sown sorghum can be high yielding when crop management and genetics are matched to water availability, and
iv) Winter sowing increases the cropping system intensity due to more frequent double cropping i.e. sorghum – chickpea rotation.

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