Transformational agronomy by growing summer crops in winter: Crop establishment in cold soils

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Abstract
Winter sown sorghum reduces the impact of heat and water stresses around flowering and increases cropping intensity, though, achieving uniform plant establishment remains challenging. Sowing sorghum in winter will require crops to uniformly germinate and emerge in soils which are cooler than the recommended >16ºC minimum daily temperature, during the driest time of the year. Prolonged emergence periods and reduced total emergence can decrease canopy uniformity with negative impacts on yield, crop management and cropping system intensity. Acceptable establishment percentages (>80%) were achieved for some site by seedlot combinations, though large differences in establishment rate between seedlots were observed. The differences in seedlot emerge rate were related to final establishment. This calls for seed vigour testing, novel seed production technologies, management of seedbed hydrothermal conditions and breeding programs for cold tolerance.

Keywords
Cubic spline, seed quality, Sorghum bicolor

Introduction
Water and heat stress during flowering are the primary limitations to sorghum production across Australia's northern cropping region. Planting sorghum earlier than recommended offers farm managers the opportunity to avoid these stresses but risk of uneven crop maturity and low establishment rates potentially out way benefits.

Genetic and cultural options for improving sorghum establishment in cold soils is a topical subject for biofuel options in Europe and the manage heat stress internationally with mixed success. Germplasm with significantly improved tolerance to low temperatures during germination and emergence was identified but establishment rates in the target environment remain less than commercially acceptable (Ostmeyer *et al* 2020). Several seed priming techniques cheaply and effectively improve crop establishment but they substantially reduce seed shelf life and interactions with essential seed fungicide, insecticide and herbicide safener coatings prevent widespread use (Farooq et al 2019). Polymer films increase soil temperature and maintain seedbed moisture for accelerating crop establishment but their costs are prohibitive (Tang *et al* 2020).

Identifying superior quality hybrid seedlots from existing commercial germplasm that rapidly and uniformly emerge at sub-optimal temperatures before they are sown is as yet unrealized. The term seed vigor is used to describe all the traits that contribute to rapid and uniform establishment in the target environment. To the best of our knowledge the diversity and attributes of sorghum vigor for early sown sorghum in the cool dry springs of northern Australia are not characterised.

Here we screen hybrid-seedlots in farmers' fields to identify the diversity in emergence at low temperatures and describe the seed characteristics that related to high establishment proportion.

Methods
Sorghum field trial was sown at Nangwee in 2020 (Black Vertisol) to evaluate winter sown sorghum systems agronomy. Treatments were designed to generate a range of chilling stress intensities during establishment and heat and water stress intensity combinations during sorghum flowering. These treatments included a range of commercial sorghum hybrid cultivars with different maturities sown at 4 plant population densities (3, 6, 9, and 12 plant m-2) in 3 sowing windows denoted TOS1 (6th August), TOS2 (11&12th September), and TOS3 (6th October). Seed were sown into at least 30mm depth of moist soil and 8am soil temperatures for the 7 days following sowing were 13, 17 and 21°C for TOS1, 2, and 3, respectively.

Crop emergence was monitored with bi-weekly plant counts on the same $2m^2$ quadrant. Plants were considered emerged if any part of the plant had broken through the soil surface.

The proportion of emerged plants was calculated by dividing plant counts by the number of seeds sown in the respective quadrant. Data was logit transformed and the randomized split-plot block design trial (TOS and irrigation levels formed main plots) was analyzed by ASREML with cubic spline curves over time.

Results and discussion

The cumulative proportion of emerged seedlings was greater and faster with irrigation and as sowing time was delayed from August (TOS1), to September (TOS2) and October (TOS3) at the Nangwee 2020 site (Data not shown). Regardless of sowing time, water regime and population some hybrids 2, 3 and 4 were faster to emerge (Fig 1). Early sowing decreased the final proportion of emerged seedlings and the proportion of emerged seedlings declined after peaking for the slowest hybrid seedlots even without frosts (e.g. Hybrid seedlot 5; Fig 1). Ferraris (1992) similarly found a linear relationship between rate of emergence and establishment at suboptimal temperatures for sorghum in Mywybilla clay (Black Vertisol). Rapid emergence is associated with large embryo in wheat and could be a target trait for early sown sorghum (Moore and Rebetzke 2015).

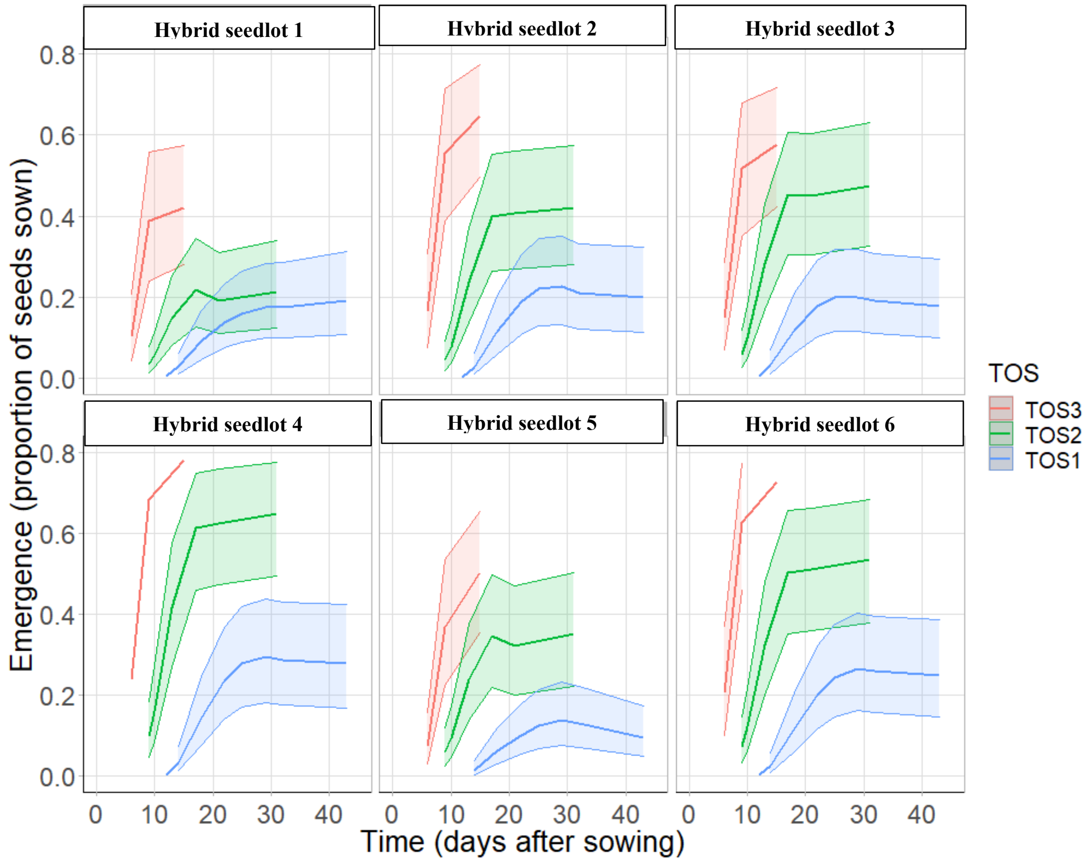

Figure 1. Inverse logit back transformation of the predicted means and 95% confidence interval for the effect of time of sowing on sorghum emergence over time.

Conclusion

Seedbed drying during the prolonged emergence period caused by low soil temperatures associated with early sowing reduce seedling emergence and contributes to seedling death. Seed quality testing should consider characterise rate of germination as well as the proportion of seeds germinated at low temperatures to identify seedlots suitable for early sowing. Screening for large embryo may identify germplasm adapted to early sowing.

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