Water stress negatively impacts reproductive success in chickpea and lentil

M. Fernanda Dreccer[1], Victor Sadras[2], Jeremy Whish[1], Allan Peake[1], Lachlan Lake[2], Mary Anne Awasi[1], Tony Swan[1], Richard Maccallum[3], Helen Bramley[4], Kerry Bell[5], Mel Bullock[1], Laura Goward[1], Josie Clark[4], Sarah Baxter[3], Karen Brangwin[3], Loretta Clancy[1], Brook Anderson[1], Brett Cocks[1]

[1] CSIRO Agriculture and Food, Email: fernanda.dreccer@csiro.au
[2]South Australia Research and Development Institute
3 New South Wales Department of Primary Industries
4 University of Sydney
5 Dept. of Agriculture and Fisheries, QLD

Abstract
We studied the impact of water supply on yield formation in pulses interrogating data from the National Variety Trials (NVT) and field experiments. Analysis of NVT chickpea trials combined with APSIM modelling showed that the water supply/demand ratio after flowering could discriminate high from low yielding trials across regions. Using shading to limit resource capture in the field, the critical period for yield was confirmed as ca. 100°Cd and 200 to 300°C after flowering in the South (South Australia) and the North (SE QLD) respectively. This was further investigated in chickpea and lentil in a range of environments resulting from combining four locations, rainfed vs irrigated in three sowing dates. Rainfed crops had an earlier onset of key reproductive stages (budding, flowering, podding) and lower leaf number. Differences in yield across environments were explained by seed number. Seed number under terminal stress was associated with growth rates between the onset of podding and maturity, pointing to pod set as a vulnerable stage. GxExM packages aiming at managing the risk of water stress at podding, should improve the balance between vegetative and reproductive growth.

Keywords
Pulses, Yield, Critical Period, Water Stress, Phenology, Desi Chickpea, Kabuli Chickpea, Lentil

Introduction
The yield of chickpea and lentil can be highly variable in response to different environmental and management conditions. In this paper we integrate information obtained from NVT data to detailed trials to ask key questions about which crop stage is more vulnerable to water stress in chickpea and lentil, the magnitude of the impact and the processes affected. Understanding when yield formation is at its most vulnerable during the crop cycle and what it responds to is the first step to design effective GxExM options.

Methods
NVT trial analysis
We analysed 157 chickpea trials in the Northern, Southern and Western regions (2009 – 2013) together with other crops (Dreccer et al., 2018). We used APSIM (Holzworth et al., 2014) to predict flowering for a mid-maturity variety and the water supply/demand ratio, which integrates initial soil water, rainfall and crop demand. The higher the ratio, the lower the water stress.

Shading trials
We extended the study by Lake and Sadras (2014) in the South to the North, to test under higher temperatures. Two adjacent trials were sown at the CSIRO Gatton Research Station on 23-05-2019 (TOS1) and 13-06-2019 (TOS2) with cultivar HatTrick. Main treatments were shaded in 7 day intervals or control, with or without N application post flowering.

Water limited experiments
At four locations (Gatton (SE QLD) and Narrabri (northern NSW), Condobolin (central NSW) and Greenethorpe (southern NSW)), trials were run in 2019 with two levels of water supply, three sowing dates and three adapted cultivars per crop, desi and kabuli chickpea and lentil (Table 1). Data from the extremes of the latitudinal transect, Gatton and Greenethorpe, are presented in this paper.

Table 1. Locations and treatments. * indicates sentinel varieties, with more detailed observations

		Gatton	Narrabri	Greenethorpe	Condobolin
Time of sowing	TOS 1	22/5/2019	16/5/2019	30/04/2019	06/5/2019
	TOS 2	10/6/2019	29/5/2019	21/5/2019	27/5/2019
	TOS 3	25/6/2019	02/7/2019	11/06/2019	17/6/2019
Irrigation	Rainfed (mm)	85	80	15	140
	Irrigated (mm)	200	170	105	295

Results

Can we use NVT data to identify sensitive stages of yield to water stress?

Using NVT data, we identified differences between winter crops in their vulnerability periods. In chickpea, water stress was able to discriminate high from low yielding trials from ca. 300-400°Cd after flowering, consistently across regions. This contrasted with wheat, where water stress could discriminate trials with contrasting yield from late tillering depending on the region (Figure 1).

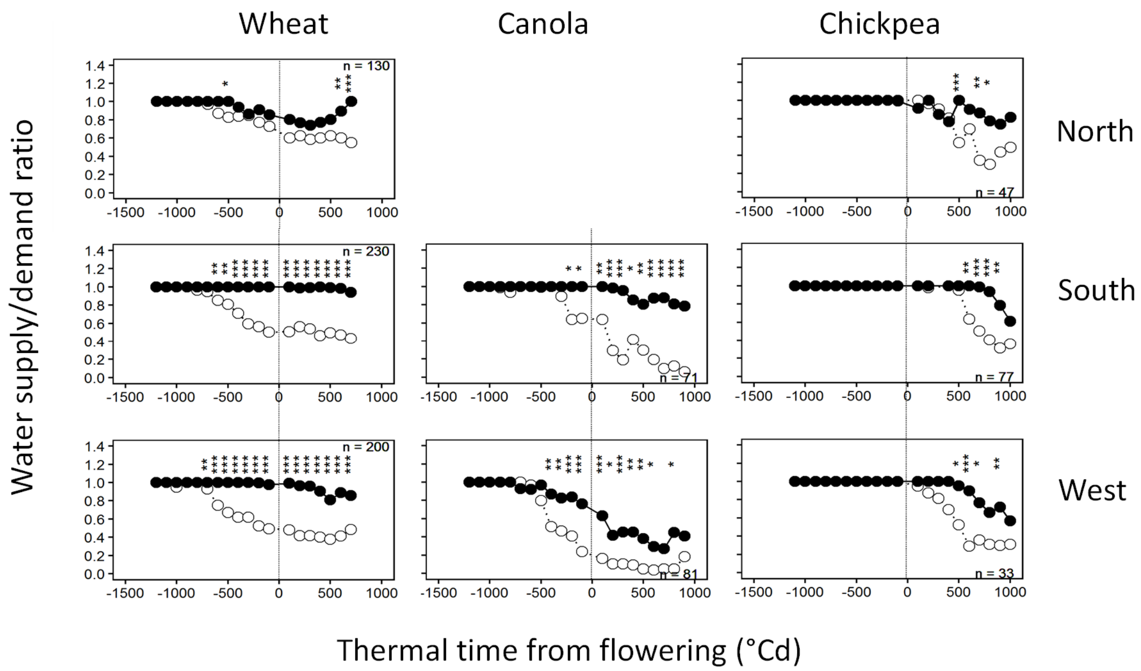

Figure 1. Simulated water supply/demand ratio associated with high (90th percentile, black symbols) and low (10th percentile, white symbols) yielding wheat, canola and chickpea in NVT as a function of thermal time centered at flowering (x=0°Cd). P<0.0001 (***), P < 0.01 (**) and P < 0.05 (*).

What is the timing of the critical period in chickpea? Are there differences between southern and northern growing environments?

To answer this question, we compared results from Lake and Sadras (2014) in South Australia with trials at Gatton, QLD. Yield decrease in response to shading relative to the control was pronounced after flowering. However, the critical period was centred around 100°Cd vs. 200-300°Cd after flowering in the South vs. North (Figure 2). The smaller reduction in QLD compared to SA is likely related to the different shading duration, 7 and 14 days respectively and higher radiation levels. Reductions in relative yield were matched by reductions in relative seed number, while seed weight was largely unaffected.

Is phenology affected in water limited crops?

Crop phenology was affected by water supply both in terms of occurrence of reproductive stages and production of leaves. Rainfed crops had generally earlier budding, flowering and/or start of podding, as shown for chickpea and lentil in Figure 3. Leaf number was lower in rainfed crops and the difference was established after flowering.

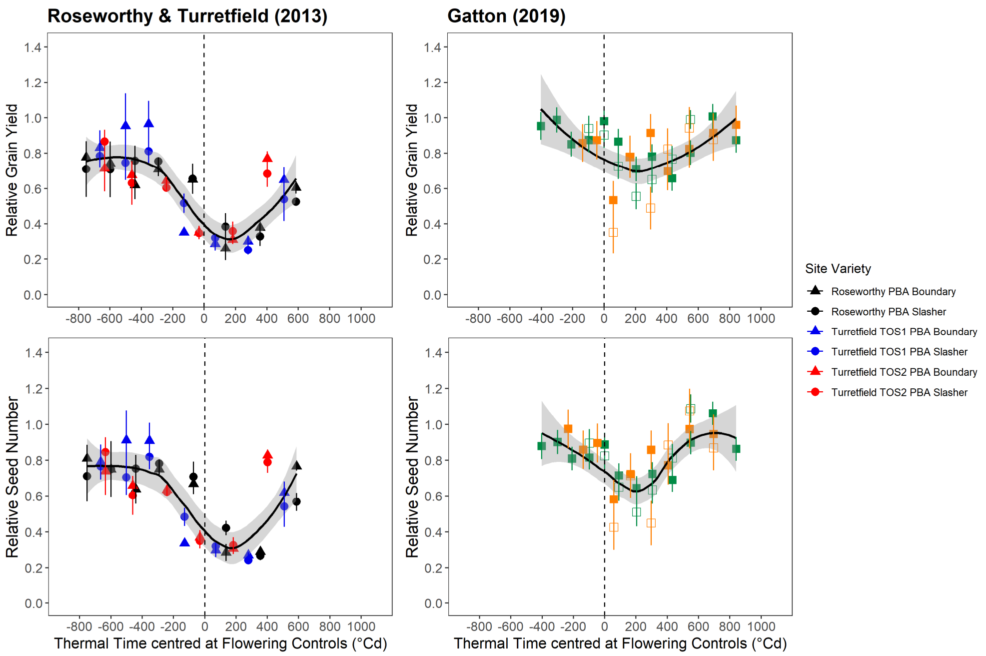

Figure 2. Yield and seed number relative to the unshaded control in SA (2013) and QLD (2019) as a function of thermal time from flowering (vertical dashed line).

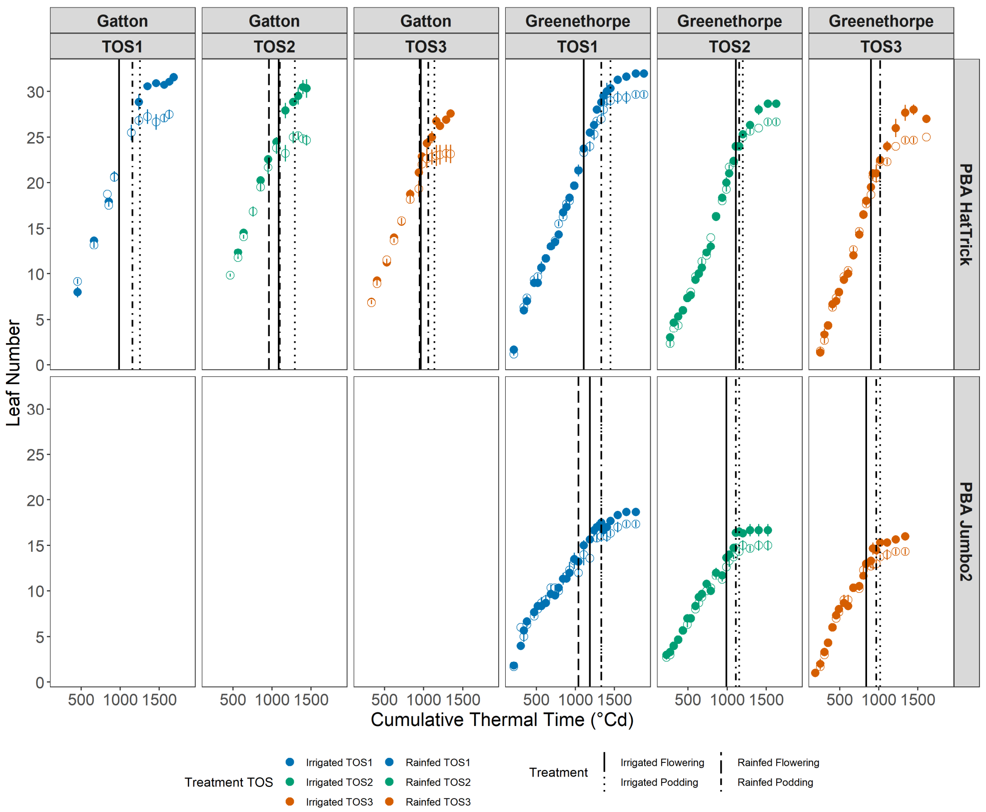

Figure 3. Leaf number in the main shoot of desi chickpea PBA HatTrick and lentil PBA Jumbo2. Vertical lines indicate flowering and podding in first and second sowing dates.

Which processes underpinning yield were more impacted by water supply?

Crops sown earlier or with higher water supply had higher yields associated with higher biomass production. By contrast, harvest index either increased or decreased with water stress and sowing date depending on location. Yield was strongly associated to seed number per unit area, across crops and environments (Figure 4), predominantly driven by pod number. A preliminary attempt to relate growth and yield components indicates that for desi chickpea in Gatton, the growth rate between podding and maturity was a good integrator and predictor of seed number (SN /m^2 = 2218.5 GR Pod-Mat (g/m^2/°C)+176.27, R^2=0.94, n=18).

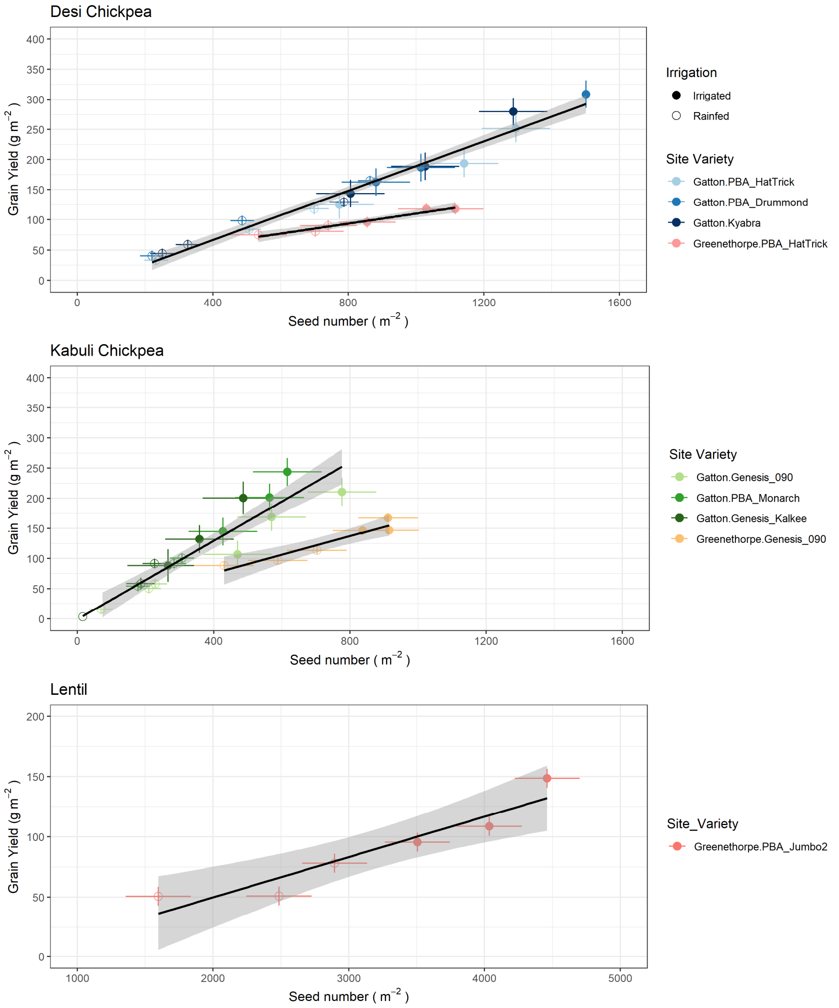

Figure 4. Grain yield vs seed number per unit area in Desi and Kabuli chickpeas and Lentils in three sowing dates at two water supply levels in Gatton and Greenethorpe 2019.

Conclusion

We have shown, using multiple years of large trial networks and detailed field trials, that the stage between pod set and initial pod growth is highly vulnerable to water stress. The next step is to develop GxExM solutions that, considering soil characteristics and climate variability, can manage the risk of water stress during this period to maximise seed number, yield and profit for Australian farmers. These are likely to be based on a better balance between vegetative and reproductive growth.

Acknowledgements GRDC for support in various projects involved in this paper

References

Dreccer, M.F., Fainges, J., Whish, J., Ogbonnaya, F.C. and Sadras, V.O., 2018. Comparison of sensitive stages of wheat, barley, canola, chickpea and field pea to temperature and water stress across Australia. Agric. For. Meteorol., 248(Supplement C): 275-294.

Holzworth, D.P. et al., 2014. APSIM – Evolution towards a new generation of agricultural systems simulation. Environmental Modelling & Software, 62: 327-350.

Lake, L. and Sadras, V., 2014. The critical period for yield determination in chickpea (Cicer arietinum L.), 168, 1–7 pp.