Water use efficiency is improved by storing more water before planting

Andrew Erbacher[1], Lindsay Bell[2], Jayne Gentry[3], David Lawrence[3], Jon Baird[4], Mat Dunn[4], Darren Aisthorpe[3] and Greg Brooke[4]

[1] Department of Agriculture and Fisheries, 22-26 Lagoon St, Goondiwindi, Queensland, 4390, Email: andrew.erbacher@daf.qld.gov.au

[2] CSIRO Agriculture and Food, 203 Tor St, Toowoomba, Queensland, 4350

[3] Department of Agriculture and Fisheries, Queensland (Toowoomba and Emerald)

[4] Department of Primary Industries, New South Wales (Tamworth, Narrabri and Trangie)

Abstract

The efficiency of soil water accumulation during fallow periods, and the availability of that soil water for use by crops are key drivers of northern farming system productivity and profitability. In 2015 seven farming systems experiments were established from central Queensland to central New South Wales to answer the question; Can system performance be improved by modifying farming systems in the northern grains region? To assess this soil water dynamics were monitored under different farming systems, along with soil nitrogen, pathogens, crop biomass, grain yield and variable costs, as measures of system performance.

Analysis of soil water accumulation during the fallows and its subsequent use by sorghum, wheat and chickpea crops, showed a cost to all crops for converting biomass to grain yield. This cost was least for chickpea (50 mm), followed by wheat (100 mm) and highest for sorghum (150 mm), and should be deducted from crop water use to calculate water-use-efficiency (WUE). The WUE was lowest for pulse crops (10 kg/mm), but sorghum and wheat returned the same WUE (17 kg/mm).

Northern growers typically store plant-available-water (PAW) in the fallow as a buffer against variable quantity and timing of in-crop rainfall. Crops produced a better than average WUE when planted with at least 60 mm PAW in a high in-crop rainfall season, or 120 mm of PAW with low in-crop rainfall.

Keywords

Water-use-efficiency (WUE), sorghum, wheat, chickpea, plant-available-water (PAW)

Introduction

The efficiency of soil water accumulation during fallow periods, and the availability of that soil water for use by crops are key drivers of northern farming system productivity and profitability. Fallow water is stored and used as a buffer for more reliable grain production in highly variable rainfall patterns. Thomas *et al.* (2007) showed crop yields in Queensland and northern New South Wales had a fallow dependency (*i.e.* proportion of transpired water from fallowed plant-available-water (PAW)) of 26% to 82%, therefore it is likely that increasing stored water will have proportional increase in yield.

In March 2015, experiments were established at seven locations in a partnership between CSIRO, Queensland Department of Agriculture and Fisheries (DAF) and New South Wales Department of Primary Industries (NSW DPI), supported by Grains Research and Development Corporation (GRDC) to answer the question; Can system performance be improved by modifying farming systems in the northern grains region? These experiments are comparing farming systems and crop sequences designed to meet emerging challenges with a large factorial experiment at Pampas near Toowoomba, and six to nine locally relevant systems studied at Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie (red & grey soils). A common set of farming system strategies were employed to examine how changes in the farming system impact on multiple aspects of the farming system (see Bell et al. 2017).

These sites represent a range of climatic conditions, soil types, nutritional status and paddock history. A system with best commercial practices (Baseline) for each location was compared to alternative systems with higher or lower crop intensity, higher crop diversity, higher legume frequency, higher nutrient supply and higher fertility through the addition of organic matter. The rules around each of these systems have driven crop sequences with a range of different crops and planting and growing conditions at each site. Of particular interest here is the comparison of systems with different cropping intensities, which vary the amount of PAW accumulated prior to planting a crop and will therefore have a greater reliance on stored PAW contribution to crop water use. The *Baseline* (moderate intensity) is planted with 60% plant available water capacity (PAWC), *Higher intensity* is planted with 30% PAWC and *Lower intensity* is planted with 80% PAWC.

Methods

System water use efficiency of crop sequences is driven by the efficiency of fallows (i.e. the proportion of rain falling during the fallow that accumulates in the soil to be available for the next crop) and how efficiently the subsequent crops can convert the accumulated soil water and in-crop rainfall into grain or product.

Soil sampling at the sites was conducted prior to planting each crop and again after harvest to measure soil water, nitrogen and pathogens (Predicta® B). With this soil sampling process, we tracked soil water accumulation in fallows and use by the subsequent crop. With crop data (biomass and grain yield) and weather data collected onsite, we are able to calculate fallow efficiency (FE; = ΔSoil water / Rainfall), crop water use (= ΔSoil water + in-crop rainfall), and crop water use efficiency (WUE; = grain yield / Crop water use) for individual crops and therefore their impact on the farming system.

We have monitored crop water use, water use efficiency and subsequent fallow water accumulation for over 300 different crops to explore how soil water accumulates and is used over different crop sequences. The relationships between biomass and grain yield to PAW at planting, crop water use (WU) and WUE over five years were analysed across the major crops of wheat (67), sorghum (56) and chickpea (45). Minor crops were excluded from the analyses.

Biomass and grain yield was plotted against crop water use and fitted with a linear regression; the slope being the average WUE. Similarly, grain WUE was calculated for individual crops and the 25% of crops with the highest WUE were fitted with a linear regression to calculate the potential WUE.

Results

Crop biomass WUE

The relationship between biomass (total above-ground dry matter at physiological maturity) and crop water use (*i.e.* $PAW_{planting} – PAW_{harvest} + Rainfall_{incrop}$) shows all crops have an intercept at zero and the slope of these linear relationships gives us the WUE_{DM} for these three crops (Figure 1). The most efficient are the wheat with a WUE_{DM} of 29.3 kg/mm, followed by sorghum with a WUE_{DM} of 23.3 kg/mm. Physiological differences between C3 and C4 grasses (i.e. temperate wheat and tropical sorghum) suggest the reverse trend, with C4 grasses reported to have higher WUE of transpired water than C3 grasses (Steduto & Albrizio 2005). However, as this data includes all crop water use (both transpiration and evaporation), the lower WUE of sorghum is likely due to greater evaporative losses and/or evaporative cooling by the sorghum in the hotter growing conditions of summer. The chickpea crops had the lowest WUE_{DM} of 18.0 kg/mm, as would be expected of a legume compared to grasses.

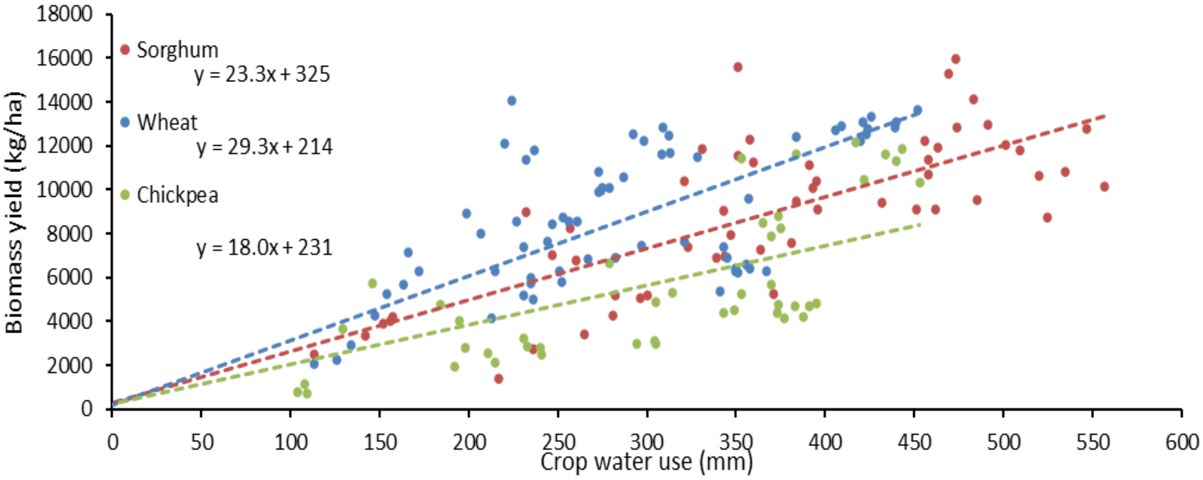

Figure 1. Predicted WUE_{DM} using maturity biomass yield of sorghum, wheat and chickpea crops against the amount of water used (PAW + rainfall).

Grain WUE

In contrast to biomass, the relationship between grain yield and crop water use showed these crops had clear shifts in the intercepts indicating that there are critical water requirements before grain yield is accumulated (Figure 2). These intercepts were ~50 mm for chickpea, ~100 mm for wheat and ~150 mm for sorghum. The slopes of these trendlines provide a water use efficiency (WUEgrain), calculated by first deducting the intercept (50 mm, 100 mm or 150 mm) from the total crop water use.

Despite the 50 mm difference in initial water demand, wheat and sorghum had similar average WUEgrain (17.3 and 17.0 kg/mm, Figure 2a). This suggests that once the initial demand is met, these winter and summer cereals were able to produce grain yield with similar efficiency.

Chickpea had both lower initial water demand and lower WUE. The indeterminate reproduction of chickpea could contribute to this as they have a lower demand prior to grain-fill, but continually produce additional biomass while they produce more flowers and pods, whereas cereals invest resources in building biomass before converting to grain yield. Other factors in chickpea's lower WUE may be the need to support the symbiotic relationships that allow legumes to produce nitrogen and the higher nitrogen concentration of the grain. In fact, the relationship between grain N removal (kg N/ha) and crop water use is very similar for wheat and chickpea (data not shown).

WUE of the best crops (Figure 2b) compared to WUE of all crops (Figure 2a), suggests potential to improve the grain WUE of sorghum by 3 kg/mm, wheat by 6 kg/mm and chickpea by 3.6 kg/mm. Importantly, the range of performance occurred across the full range of seasonal grain yields. This suggests other factors, such as disease, nutrients, agronomy, heat/cold stress, are reducing the yield potential of many crops.

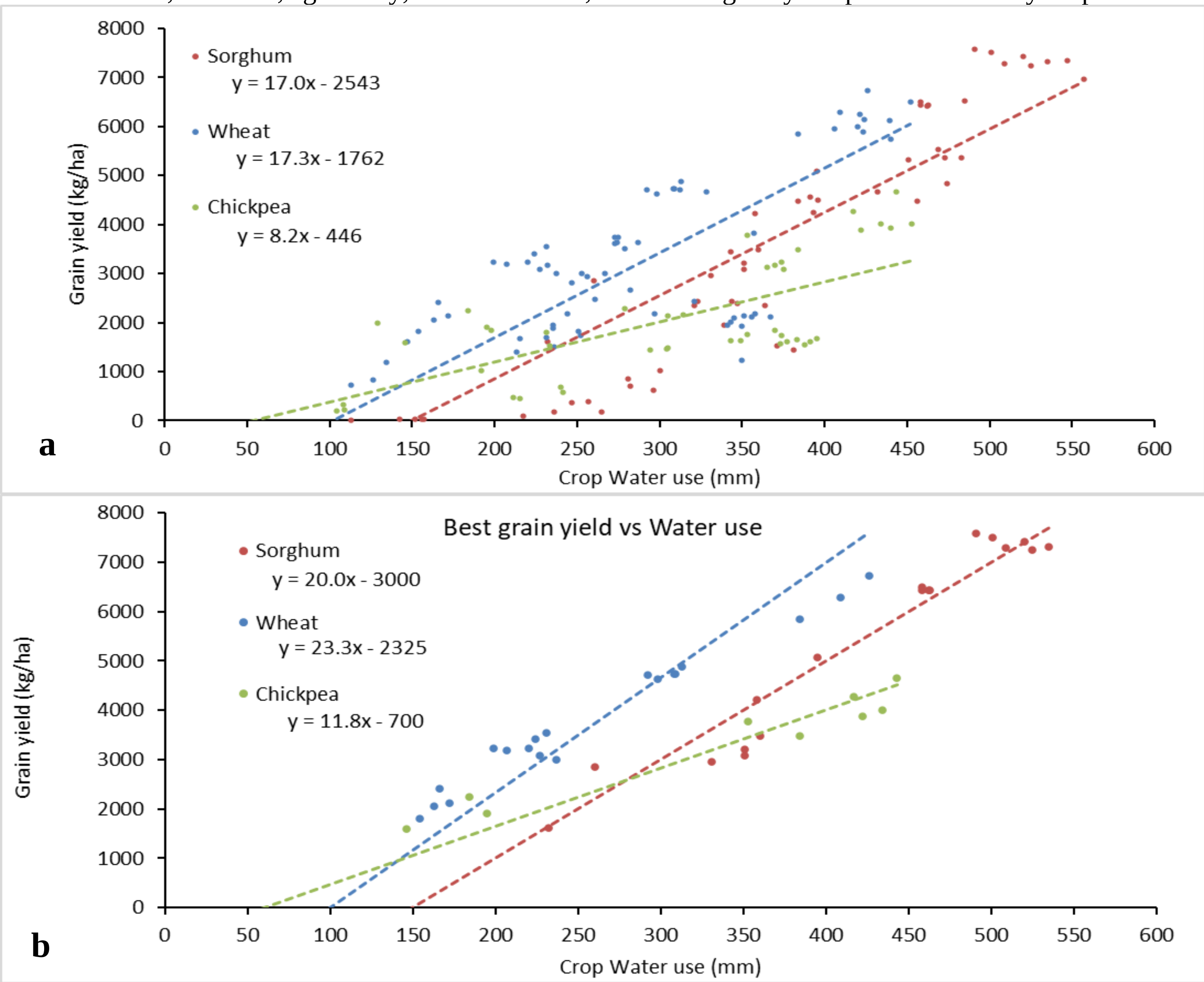

Figure 2 Grain yield of sorghum, wheat and chickpea crops with different amounts of crop water use. Figure 2a includes all crops and Figure 2b is the top 25% for WUE ('best'). The slope of the trendlines represent the WUE.

Soil water at planting as a driver of crop WUE

We have demonstrated WUE as an indicator of the link between grain yield and crop water use. In the northern grains region the value of PAW is well recognised and is a management tool growers can use to influence crop availability and therefore grain yield. As such we looked at the relationship between PAW at planting and WUE of each crop (Figure 3).

Crops with low PAW at planting have a much higher reliance on quantity and timeliness of in-crop rainfall. In this data all crops with less than 60 mm PAW at planting demonstrated lower WUE. When planted with 60 to 120 mm PAW there was an even spread of high and low WUE (across all three crop types), suggesting this is sufficient buffer to support the crops between in-crop rainfall events, but these crops had a greater chance of failure (low WUE and grain yield) when in-crop rainfall was low.

The optimum PAW at planting for each of the three crops is slightly different. Chickpea crops with the best WUE had 70 mm to 170 mm of PAW at planting, the best wheat crops were planted with 110 mm to 160 mm PAW and the best sorghum crops were planted with more than 120 mm PAW, with no downside to more PAW at planting.

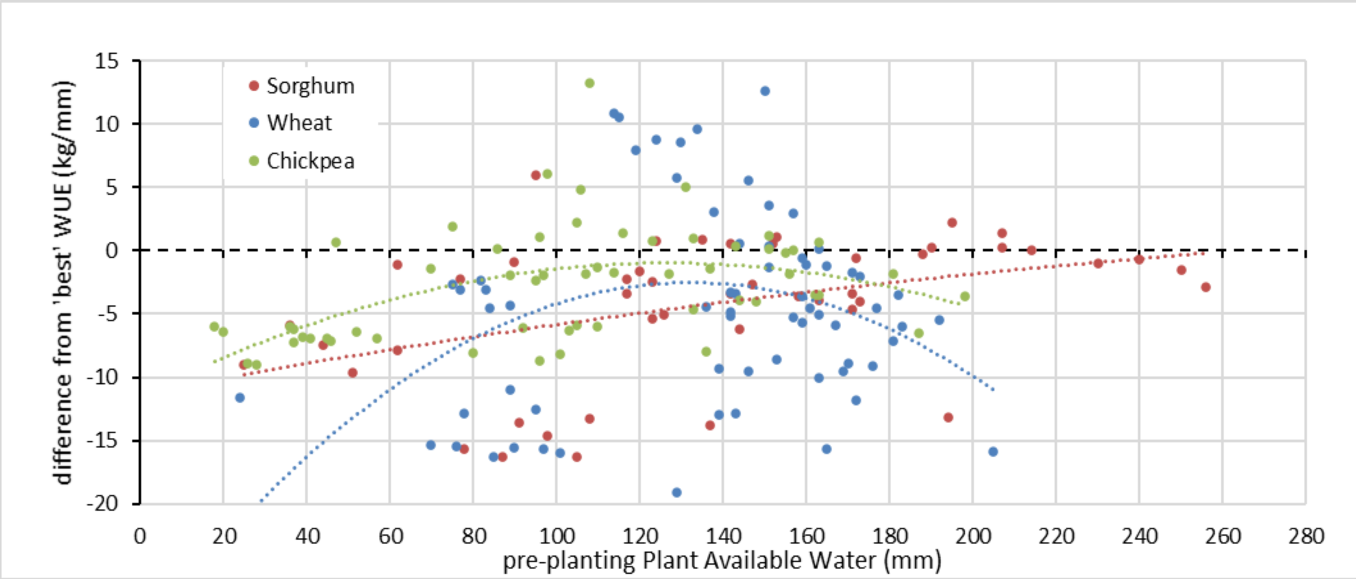

Figure 3. Difference from 'best' WUE, determined in Figure 2b, of sorghum, wheat and chickpea crops with different amounts of PAW at planting.

Conclusion

In a dryland farming system, water is often the biggest limitation to production. From the first five years of the Northern Farming Systems experiments we can see some clear trends that influence the capacity of crops to convert available water into biomass and grain. Cereal crops (wheat and sorghum) have been more efficient at converting water (both stored PAW and rainfall) into biomass than chickpea. Sorghum is also less efficient in producing biomass than the wheat, likely due in part to the hotter growing season conditions increasing evaporative losses in-crop.

In all of these crops there is a crop water use cost in converting crop biomass into grain yield, as such it is appropriate to subtract this value from the crop water use prior to calculating water use efficiency. Chickpeas were the lowest, because they largely accumulate yield and biomass simultaneously, whereas the cereal crops produce biomass early, then redirect resources to reproduction. Sorghum used more water than wheat crops, likely because of the hotter growing conditions.

When comparing water use efficiency of grain yield, sorghum and wheat performed similarly, and both greater than chickpea. However, gross margins were not considered in this analysis, so the higher value of chickpea may produce different outcomes in a $/mm comparison.

By comparing the WUE outcomes to the best achieved WUEs we demonstrated the advantage of storing at least 60 mm of PAW prior to planting chickpeas, 110 mm for wheat and 120 mm for sorghum. In dryer environments or seasons with less in-crop rainfall, PAW provides a greater contribution to total crop water use so delaying planting until there is more than 120 mm of PAW will further reduce the risk of crop failure.

Acknowledgements

The research undertaken as part of this project (CSA00050, DAQ00192) is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC. We would also like to thank all the farm and field staff contributing to the implementation and management of these experiments and the trial co-operators and host farmers.

References

Bell L.W, Klepper K, Gentry J, Lawrence D.N, Verrell A and McMullen G (2017). A paradigm shift in farming systems experimentation: deploying a rule-based approach. In: Proceedings of the 18th Australian Society of Agronomy Conference, Ballarat, Vic. (http://www.agronomyaustraliaproceedings.org/)

Steduto P & Albrizio R (2005). Resource use efficiency of field-grown sunflower, sorghum, wheat and chickpea II. Water use efficiency and comparison with radiation use efficiency. Agricultural and Forest Meteorology 130 (2005) 269–281

Thomas, G.A, Titmarsh, G, Freebairn, D.M & Radford, B. (2007). No-tillage and conservation farming practices in grain growing areas of Queensland - A review of 40 years of development. Australian Journal of Experimental Agriculture - AUST J EXP AGR. 47. 10.1071/EA06204.