Faculty of Health, Engineering and Sciences

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Improving water productivity of irrigated wheat in the northern grain production region of Australia

A dissertation submitted by

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Abstract

While cotton has traditionally been the dominant crop in irrigated broad-acre farming systems of subtropical Australia, high grain prices triggered a record area of irrigated wheat production in the winter of 2008. Unfortunately wheat yields were substantially lower than expected, probably due to widespread lodging (a disorder where crops fall over). And while irrigation water was plentiful for the 2008 season, the typical water availability for irrigated wheat production in the region involves water rather than land being the limiting factor to production.

Little research has been conducted on the potential yield, water use requirement or water productivity of irrigated spring wheat in the northern grain production region of eastern Australia, often referred to as the 'northern grains region'. Such information would allow growers to assess lodging-related yield losses, compare the profitability of irrigated wheat against alternative crops, and determine the irrigation strategies that maximise economic returns. Additionally, there is uncertainty within the region over which agronomic techniques can be used to minimise the risk of lodging without reducing grain yield.

The overarching question to be addressed by this study is therefore: *what are the agronomic practices required to achieve maximum water productivity in irrigated wheat, across the northern grain production region of eastern Australia?* Two specific hypotheses were investigated in answering this question: (1) *that lodging constrains irrigated wheat yields in the northern grains region, and agronomic techniques can be used to control lodging, and* (2) *that when irrigation water availability is limited, maximum whole-farm crop water productivity for wheat is achieved by partially irrigating a larger crop area rather than fully irrigating a smaller area.* These hypotheses were investigated in the context of spring-wheat production systems within the northern grains region, where water rather than irrigable area is generally the limiting factor to crop production.

The APSIM (Agricultural Production Systems Simulator) model was used to determine the potential yield and water use requirement of irrigated spring wheat, but first required validation against field data. Crop production data (e.g. biomass and grain yield) were collected from 21 wheat crops throughout the northern grains region in 2008 and 2009, and recorded crop conditions and inputs (e.g. weather data, sowing dates, irrigation) were used to parameterise APSIM simulations for each crop.

APSIM predicted biomass production satisfactorily in 2008 but substantially over-predicted grain yield of lodged fields. The mean difference (yield gap) between APSIM-estimated potential yield and farmer-realised yield was 0.9 t ha^{-1} in non-lodged fields, and 2.5 t ha^{-1} in lodged fields. The average effect of lodging was therefore estimated as a decrease in grain yield of 1.6 t ha^{-1}, the difference between the yield gap calculated for lodged and non-lodged fields. In 2009 commercial fields generally experienced little lodging, probably due to the use of in-crop nitrogen (N) application to control canopy development. APSIM generally under-predicted biomass production and yield in these fields, suggesting that the N uptake parameters in APSIM may require adjustment. However, observed yields from fields of a quick-maturing cultivar that experienced little lodging were simulated accurately when N was assumed to be non-limiting. Further simulations of fully irrigated, quick maturing wheat using 50 years of climate data at six representative locations found that the potential yield of irrigated spring wheat in the northern grains region was

approximately 8 to 9 t ha^{-1}, and average growing season evapotranspiration of such crops was approximately 490 to 530 mm, depending on location.

The canopy management techniques of in-crop N application and reduced plant population are widely used in rainfed wheat production in temperate climates. However they are untested on irrigated wheat in the subtropics, and may not reduce lodging risk in the northern grains region without simultaneously reducing yield potential. Irrigated small plot experiments were therefore conducted in 2009 and 2011 to examine the effect of alternative N timing and plant populations on lodging and yield for two cultivars, under well-watered conditions.

Low sowing N treatments exhibited moderate to severe vegetative N stress, having soil plus fertiliser N at sowing of less than 80 kg ha^{-1} (sometimes as low as 15 kg N ha^{-1}) and the majority of fertiliser N applied in-season. These low sowing N treatments had significantly less lodging and were the highest yielding, exhibiting yield increases of up to 0.8 t ha^{-1} compared to high sowing N treatments. Increasing plant population above 100 plants m^{-2} increased lodging and decreased yield in high N treatments, but did not always increase lodging in low N treatments. Increased LAI, biomass and tiller count at the end of the vegetative growth phase were correlated with increased lodging in both cultivars, although the strength of the correlation varied with cultivar and season. Optimal N regime varied slightly between the cultivars, indicating that the optimisation of canopy management techniques for irrigated spring wheat systems would require further investigation of genotype × management interaction. It was therefore determined that canopy management techniques can be used to simultaneously increase yield and decrease lodging in irrigated spring wheat in the subtropics, but should be implemented differently to the techniques used in temperate regions of Australia, where recommended plant population and sowing N rates are higher than those identified in the present study.

While full irrigation of wheat in 2008 was forecast to be profitable (before the impact of lodging was apparent), irrigation water availability for irrigated wheat growing in the northern grains region is usually limited, and water rather than land is typically the limiting factor to production. Previous studies in other regions indicate that deficit (i.e. partial) irrigation of wheat is often considered to have greater economic water productivity (EWP) under such circumstances. Unfortunately, the cost/revenue functions traditionally used to evaluate alternative irrigation strategies are not applicable across multiple environments, and such studies have not accounted for the intrinsic value of water stored in the soil at the end of the cropping season.

The APSIM model was therefore used to determine whether growing larger areas of deficit irrigated wheat is more profitable than full irrigation of a smaller area in the northern grains region, when water rather than land is the limiting factor. The analyses accounted for the value of stored soil water across the entire farm by simulating rainfed crop production on unirrigated land, and/or by assigning an economic value to stored soil water remaining at the end of the season. Whole-farm profitability was assessed for alternative economic analyses where different values (inexpensive vs. expensive) were assumed for both irrigation water and stored soil water. Optimal irrigation strategies were those considered to be the most risk-efficient, being closest to a 1:2 ‘line of indifference’ that identifies the two unit increase in risk (measured as standard deviation) acceptable to farmers in return for a unit increase in profit.

The results of the simulation study demonstrated that irrigation strategies involving deficit irrigation of larger areas of wheat generally had greater levels of

absolute profitability, and were typically more risk-efficient than smaller areas of fully irrigated wheat. When precipitation or stored soil water at sowing was increased, the most risk-efficient strategies were those that spread the water across a larger area at a reduced frequency of irrigation. However in a low rainfall environment when water was expensive and soil water was given the same economic value as irrigation water, fully irrigated wheat in conjunction with fallow land was found to be the most profitable and risk-efficient option. The importance of evaluating farm-management strategies using EWP (i.e. incorporating gross margins) instead of crop water productivity (grain yield per unit of water use) was evident, as re-ranking of farm-management strategies occurred between these alternative methods of calculating whole-farm EWP. Accounting for the intrinsic value of stored soil water and precipitation was fundamental to understanding the benefit of deficit irrigation strategies in water limited situations, as the larger crop area sown in conjunction with deficit irrigation strategies accessed much larger absolute volumes of soil water and precipitation. Future evaluations of deficit irrigation strategies should account for such considerations.

The results of this study therefore support the hypothesis that lodging constrains irrigated wheat production in the northern grain production region of eastern Australia, and that agronomic techniques can be used to control lodging. The study also supports the second hypothesis that maximum whole-farm water productivity is achieved by partially irrigating a larger area of wheat when water availability is limited, except in low rainfall environments where irrigation water is expensive and soil water is assigned an economic value equivalent to the irrigation water.

Certification of dissertation

I certify that the ideas, experimental work, results, analyses, and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award.

Signature of Candidate: ____________________ Date: __________

Signature of Supervisors:

Principal Supervisor: ____________________ Date: __________
(Professor Steven Raine)

Associate Supervisor: ____________________ Date: __________
(Professor Rod Smith)

External Supervisor: ____________________ Date: __________
(Dr Peter Carberry)

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Publications Arising

(Listed in Chronological Order)

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*This conference paper is a slightly modified version of Appendix A.

**This conference paper formed the basis of Chapter 4.

***This journal paper is an abbreviated version of Chapter 3.

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