Evaluation of irrigation and nitrogen management strategies for wheat production on the Darling Downs

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Abstract

Wheat is an important winter crop on the Darling Downs, Queensland, Australia, which is usually grown under dryland or deficit-irrigation conditions. Increases in grain prices, compared to cotton prices, and decreases in available irrigation water, have prompted interest in growing irrigated wheat, trying to maximize water use efficiency (WUE) and profits mainly using supplemental irrigation. As crops receive supplemental irrigation, rather than full irrigation, nitrogen (N) applications need to be adjusted accordingly. Local growers have questions about how to best manage irrigation and N applications to maximize WUE and profits. The objective of this study was to evaluate different irrigation- and N-management strategies to determine which would maximize WUE and economic returns for sprinkler-irrigated wheat. A replicated field experiment with four irrigation treatments (initiating irrigation at 50%, 60%, 70% or 85% depletion of available soil water in the crop root zone) and three N treatments (100, 150 or 200 kg N/ha) was conducted in 2008 at Kingsthorpe, Queensland. We found that increasing irrigation significantly increased crop yield, but decreased grain protein content. No response was observed from the N treatments due to high initial soil N content. Economic analysis showed that irrigation increased partial gross margins (GM) when calculated in terms of $/ha. However, irrigating at 60% depletion resulted in similar or higher GM compared with initiating irrigation at 50% depletion when compared in terms of $/ML of water inputs. Severely stressed treatments (starting irrigation at 70% and 85% depletion) resulted in the lowest gross margins, on both a $/ha and $/ML basis.

Key Words

Wheat, irrigation, nitrogen, water use efficiency

Introduction

Severe drought over the last decade in Australia has placed water as the main limiting factor affecting crop production. Therefore, maximising the beneficial use of water not only makes good economic sense but has also become a stewardship imperative to protect and conserve water resources. Many growers on the Darling Downs, Australia, have responded to water scarcity by changing from surface irrigation to sprinkler irrigation. Since these alternative irrigation systems do not have the capacity to refill the soil profile during one irrigation event, the management of irrigation needs to be adjusted. Local experience is currently lacking on how to manage irrigation using these new systems. Wheat is an important local crop, which is usually grown under dryland or deficit-irrigation conditions in rotation with summer cereals, cotton and pulse crops. Increases in grain prices, compared to cotton prices, and decreases in available irrigation water, have prompted interest in growing irrigated wheat, trying to increase yields and economic returns.

Since local farmers are usually water-limited rather than land-limited, they have a strong focus on maximising water-use efficiency (WUE), which they perceive as a way of maximising profits and saving water. Deficit irrigation, rather than full irrigation is often suggested as an effective way of increasing WUE (Ali and Talukder 2008), since full irrigation is more likely to waste water via runoff and deep drainage. However, local knowledge about what level of deficit irrigation growers should target and what irrigation strategies to follow is commonly lacking. Under deficit irrigation, N applications also need to be adjusted to account for reduced yield potential compared to that of fully-irrigated crops. Important considerations are both the rate and timing of N applications. The objective of this study was to evaluate different irrigation- and N-management strategies to determine which of them would maximize WUE and economic returns for sprinkler-irrigated wheat.

Methods

A field experiment with wheat was conducted at the Agri-Science Queensland research station near Kingsthorpe, Queensland, Australia, in 2008. The variety Lang was planted on 6 June following a cotton crop and was harvested, using a plot combine, on 11 November to determine yield and grain quality (grain protein). The experiment had four irrigation treatments, three N treatments and three replications arranged in a split-plot design with irrigation as the main plot and N as the split-plot. The irrigation treatments were: T50%, T60%, T70%, and T85%, which received irrigation when 50%, 60%, 70%, or 85%, respectively, of the total available water (TAW) in the crop root zone was depleted. The soil at this site can store about 140 mm of TAW in the top 90 cm. Therefore, since TAW increases daily following root growth (Allen et al. 1998), the maximum allowable depletion for the T50% treatment when the crop was fully grown was about 70 mm. Smaller depletions were allowed earlier in the season to account for shallower root depths. The focus of the irrigation treatments was to maximize WUE by avoiding wastage of water by runoff and deep drainage. Therefore, the soil profile was not refilled during each irrigation event, which is consistent with normal sprinkler-irrigation and deficit-irrigation practice. The main plots were irrigated individually with bore water using a solid-set sprinkler system. Partial-circle sprinkler heads were used to avoid irrigating adjacent plots. Irrigations were scheduled based on neutron probe soil water measurements taking about weekly at 10 cm depth increments. Three rain gauges were installed in each plot to measured irrigation application depths.

The N treatments were: N100, N150 and N200, which received a total of 100, 150 or 200 kg N/ha, respectively. N100 received all N at sowing. N150 received 100 kg N/ha at sowing and 50 kg N/ha at first node. N200 received 100 kg N/ha at sowing, 50 kg N/ha at first node and 50 kg N/ha at the awn peep growth stage.

A seasonal soil water balance was conducted to estimate seasonal total water use to the end of October (TWO) and to crop harvest (TWH). This water balance was conducted using the measured profile soil water at crop emergence and at the end of the season (end of October and harvest) and the measured rain and irrigation. TWO and TWH were both calculated because it was expected that rain in November would have little impact on crop yield. Irrigation water-use efficiency (IWUE = yield/irrigation) and gross production water-use efficiency (GPWUE = yield/total water) were also calculated.

Partial gross margins (GM) were calculated based on variable cost of irrigation and N inputs and the crop revenue considering both crop yield and protein content, assuming typical crop production costs and crop prices for Queensland. GM’s were calculated in terms of Australian dollars per hectare ($/ha), per megalitre (ML) of irrigation ($/ML Irrigation) and per ML of total water (rain + irrigation+ soil water) ($/Total ML).

Results and discussion

Crop yield and grain quality

Irrigation significantly affected yields, while nitrogen and irrigation x nitrogen (I x N) interaction did not (Table 1). As expected, yields increased with irrigation. In this study, no significant effect on yield was observed from N application, since soil N was plentiful for all treatments. Yields were relatively low due to crop stress for all treatments. Even the T50% treatment received some stress at about 100 days after sowing (DAS) due to a breakdown of the pumping system at that time, which highlights some of the risk involved in applying deficit-irrigation strategies. Yields were linearly related to irrigation depths and total water, which allowed us to extrapolate the expected yield under full irrigation (without stress) at about 500 g/m^2 (dry mass basis), which would have required about 250 mm of irrigation instead of the 197 mm applied to the T50% treatment. Table 1 also shows that irrigation significantly decreased grain protein content. The drier treatments resulted in lower yields, but the higher protein contents would attract a price premium, which could compensate some of the lost revenues from the lower yields.

Table 1. Wheat grain yields and protein content by irrigation and nitrogen treatments obtained in 2008 at Kingsthorpe

	Grain Yield (g/m^2, dry mass basis)				Grain Protein (%)			
Irrigation	100 kg N/ha	150 kg N/ha	200 kg N/ha	Mean	100 Kg N/ha	150 kg N/ha	200 kg N/ha	Mean
T50%	412.1	386.4	389.4	396.0a	14.71	14.70	15.17	14.86b
T60%	341.5	339.5	358.2	346.4b	15.43	15.47	15.53	15.48b
T70%	196.5	184.7	201.1	194.1c	18.47	19.43	18.63	18.84a
T85%	203.0	155.6	177.5	178.7c	18.73	19.97	19.97	19.48a
Mean	288.3	266.5	281.5	278.8	16.84	17.33	17.33	17.17
ANOVA (d.f)		Pr>F					Pr>F	
Irrigation (3)		<0.001					<0.001	
Nitrogen (2)		0.411 (ns)					0.22 (ns)	
I x N (6)		0.943(ns)					0.61 (ns)	

Means with the same letter are not significantly different using $LSD_{(0.05)}$.

d.f = degrees of freedom, ns = not significant

N=nitrogen, I= irrigation, LSD = least significant difference

Water-use efficiency

Water inputs and calculations of water-use efficiency indices (IWUE and GPWUE) by irrigation treatment are shown in Table 2. Yield increased almost linearly with total water. Each mm of additional TWoct and TWharvest produced an average of 1.63 and 1.67 g/m^2 of dry grain yield, respectively. It took about 206 mm of TWoct and 249 mm of TWharvest to produce the first grain yield increment under this environment. This included water needed to produce vegetative growth and any water losses (mainly from soil evaporation). GPWUE increased with irrigation while IWUE decreased with irrigation under the conditions of this study. The question then is which one of these indices growers should maximize. This can be answered by performing an economic analysis.

Table 2. Water inputs and wheat water use efficiencies obtained at Kingsthorpe during 2008 (using average yield of all N treatments).

Variable measured	Irrigation Treatment			
	T50%	T60%	T70%	T85%
Profile soil water at crop emergence (mm)	602.4	552.9	558.6	540.7
Profile soil water at end of October (mm)	501.94	446.27	472.51	445.31
Profile soil water at harvest (mm)	521.30	468.00	489.20	462.70
Profile soil water used by end of October (mm)	100.46	106.63	86.09	95.39
Profile soil water used by harvest (mm)	81.1	84.9	69.4	78.0
Irrigation (mm)	197.0	154.0	79.0	73.0
Rain by end of October (mm)	154.2	154.2	154.2	154.2
Rain by harvest (mm)	212.2	212.2	212.2	212.2
Total Water by end of October (TWO, mm)	451.66	414.83	319.29	322.59
Total Water by harvest (TWH, mm)	490.3	451.1	360.6	363.2
Dry grain yield (g/m^2)	396.0	346.4	194.1	178.7
GPWUE_o (yield/TWO) ($g/m^2/mm$)	0.88	0.84	0.61	0.55
GPWUE_h (yield/TWH, $g/m^2/mm$)	0.81	0.77	0.54	0.49
IWUE (yield/irrigation, $g/m^2/mm$)	2.01	2.25	2.46	2.45

GPWUE= gross production water use efficiency, IWUE =irrigation water use efficiency

Economic analysis

Figure 1 shows partial gross margins (GM) for the different irrigation treatments (average of all N treatments), taking into account both grain yield and grain quality, in terms of Australian dollars per hectare ($/ha), per megalitre (ML) of irrigation ($/ML Irrig) and per ML of total water (rain + irrigation+ soil water) ($/Total ML). The two driest treatments (T70% and T85%) always had the lowest gross margins in terms of $/ha, $/ML irrigation or $/Total ML compared to the two wettest treatments (T50% and T60%). In terms of $/ha, the GM increased from the driest to the wettest treatment, suggesting that if water is not limited, fully irrigating the crop rather than dryland or deficit irrigation is the best option from the purely economic point of view.

In terms of $/ML irrig, however, slightly higher GM was obtained with the T60% compared to the T50% treatment. Very similar GMs were also obtained from the T50% and T60% treatments in terms of $/Total ML. Also, the T60% treatment saved about 43 mm of water compared to the T50% treatment. These results could be due to less soil evaporation from the T60% treatment. Therefore, if water is limited, under the conditions of this study, the T60% treatment seems like a more feasible option compared to the T50% treatment from an economic and environmental stewardship prospective. However, it should be clear that the treatment with the highest GM in terms of $/ML (of irrigation or total water) will only be the best option if the water savings can be used to obtain additional income.

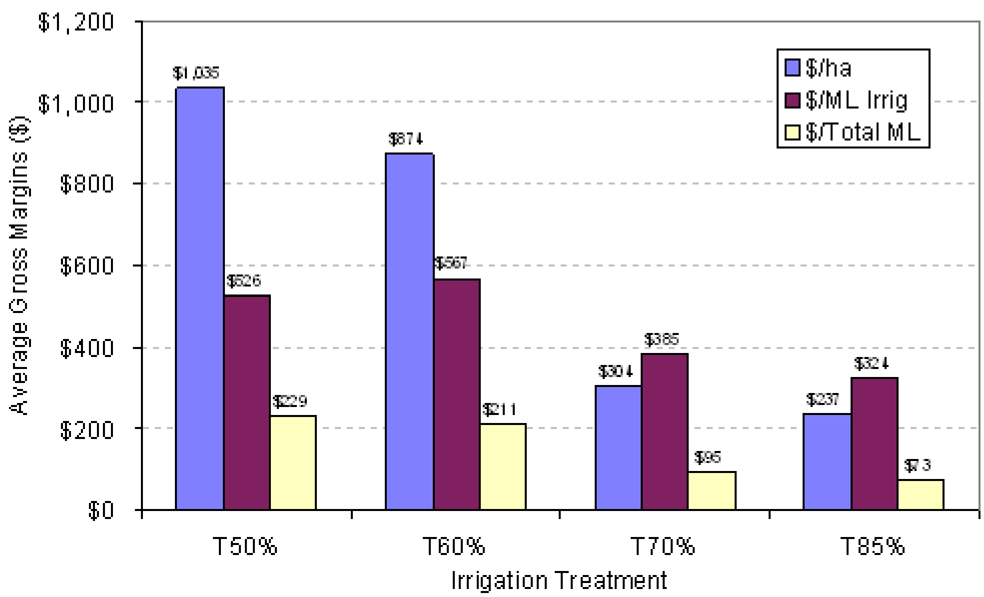

Figure 1. Average partial gross margins by irrigation treatments obtained for wheat at Kingsthorpe during 2008.

Conclusions

This study was conducted to evaluate different irrigation- and N-management strategies to determine which of them would maximize WUE and economic returns. Under the conditions of this study, we found no response to N applications, due to high soil N content. We also found that increasing irrigation significantly increased crop yield, but decreased grain protein content. Irrigation also increased GPWUE but decreased IWUE. Economic analysis showed that irrigation increased GMs in terms of $/ha. However, the T60% treatment had similar or higher GM compared with the T50% treatment when compared in terms of $/ML of water inputs. Severely stressed treatments (T70% and T85%) resulted in the lowest gross margins, both in a $/ha and $/ML basis. These results suggest that if water is limited, deficit irrigation could be a reasonable alternative to full irrigation.

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