Management strategies to improve water-use efficiency of barley in Tasmania

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Abstract

Tasmania's mild climate, long growing season and access to irrigation are amenable to the production of high-yielding cereal crops. For malting barley, the extended sowing window (winter to spring) and price premium makes it a flexible and potentially more profitable alternative to other grains in crop rotations. Barley is one of the few grain crops that can be sown late where waterlogging has prevented timely sowing of other crops or there has been a crop failure. However the shorter growing season and additional costs associated with irrigation and the lower yield potential of barley may reduce grower profits. Consequently there has been a trend towards earlier sowing to take advantage of winter rainfall, which however comes at the risk of greater frost damage at anthesis. Strategic nitrogen and irrigation management are also critical, so as to meet grain quality requirements for malting. Crop water-use efficiency (WUE) is an integrative measure of the impact these management strategies have on production, but there are few reports for WUE of barley in this environment. Grain yield was collated from field trials of barley conducted in Tasmania from 2008 to 2011 and WUE determined from crop simulation modelling. There was a good relationship between simulated and observed grain yield (r^2 = 0.83) and WUE ranged from 7 to 24 kg/ha.mm. The modelled impact irrigation management and time of sowing on predicted grain yield, WUE and quality are discussed.

Key Words

Water-use efficiency, barley, nitrogen fertiliser, high rainfall zone

Introduction

Tasmania is located in the high rainfall zone (HRZ) for grain cropping in Australia. The high rainfall and mild growing conditions with minimal heat stress and access to irrigation result in a long growing season and favour a high potential grain yield. Water-use efficiency (WUE) of other cereal crops, such as wheat, has been shown to be variable (Botwright Acuna et al., 2010a), due in part to constraints to yield such as excess water that either contributes to waterlogging on difficult subsoils or is lost by drainage, carrying mobile nutrients such as nitrogen. Strategic management of irrigation and nutrients has been reported to improve WUE and grain yield of this crop (Botwright Acuna et al., 2010a). In contrast, there are few reports for WUE of barley in this environment.

Barley is grown as winter and spring sown-crop in Tasmania for malting or feed, due to the absence of terminal drought at the end of the growing season and the shorter maturity of barley compared with winter wheat. Barley can provide growers with a flexible cereal in crop rotations compared with the range of grain, vegetable, seed and extractive crops grown in the state. Crop management is however critical to make the best use of strategic irrigation and nitrogen fertilizer to meet quality requirements for malting of between 9 to 11% grain protein. Growers typically apply irrigation preferentially during grain fill and, depending on water availability, at booting, with basal application of nitrogen followed by two split applications as topdressings. Crop water-use efficiency (WUE) is an integrative measure of the impact these management strategies have on production.

The aim of this work was to benchmark WUE in the long season and high rainfall environment of Tasmania and to evaluate the impact of strategic irrigation and split application of nitrogen and time of sowing on yield, WUE, grain quality and economic returns of barley.

Methods

Benchmarking WUE

Management and yield data for seven barley field trials, providing 24 data points, undertaken in Tasmania from 2008 to 2011 were collated and used to configure the APSIM farming system model (Keating et al., 2003). Sowing dates of the barley (cv. Gairdner) field trials ranged from June to October and around 25 kg N/ha was applied at seeding and a further 50 kg N/ha as a topdressing. The field trials received between 20 to 80 mm of irrigation and two were rainfed. Model soil parameters were chosen to represent the prevailing conditions at each site and long-term climate data was sourced from the Australian Bureau of Meteorology SILO website. Once satisfied that the model was reliably simulating barley yield across the sites, APSIM model output for key water balance elements were then used to estimate WUE [grain yield / (surface evaporation + transpiration + drainage + runoff)].

WUE sensitivity to N fertiliser and water supply

Further model scenarios were run to explore the response of predicted grain yield, WUE and quality to N and water supply. The scenarios were based on a field trial undertaken in the 2010-11 season at Cambridge in southern Tasmania, sown on 26 August 2010 to Gairdner barley with two 120 kg/ha applications of urea and 50 mm irrigation. Two management strategies were assessed, including response to i) N and irrigation and ii) time of sowing (TOS). For part i), nitrogen was applied basally and as two later topdressings at either juvenile, mid-tillering or at the start of floral initiation. Reflecting grower practice, irrigation was applied either at booting (GS45), grain fill (GS75) or both, or between stages GS45 -55 and GS70-75 when the water deficit exceeded 24 mm or the crop was rainfed. For part ii), a suite of model scenarios was set up to explore monthly sowings from April to October. Gairdner barley was sown on the 26th day of each month with N and irrigation management based on the optimum strategies determined in i). All model scenarios were run over a 30 year period from 1980 – 2010 to explore the impact of seasonal climate variability. Economic cost-benefit analyses of the scenarios were based on a malting barley grain price of $300/t, with costs of $245/ML for water plus delivery and $1.05/kg N fertiliser. Treatments were deemed economic when the extra revenue gained from yield increases exceeded the additional input costs.

Results and discussion

Benchmark WUE for barley

Yield of barley was greater than 4 t/ha, with the exception of one rainfed site in a drought year in 2008. Grain yield grouped into two clusters, most likely due to regional differences in annual rainfall between Cressy in northern Tasmania and the Coal River Valley in southern Tasmania, which on average receive 620 and 500 mm annual rainfall, respectively. Soil types, nitrogen and irrigation inputs were otherwise similar across the trial sites. Overall, there was a good relationship between observed and predicted grain yield for barley, which accounted for 82% of the variation (Figure 1). The high rainfall and use of irrigation in this environment meant that rainfed sites with low yield were under-represented in the data set, which favoured a higher r^2. Excluding the rainfed sites had a slight reduction in the overall r^2 (y = 1.0083x r^2 = 0.71).

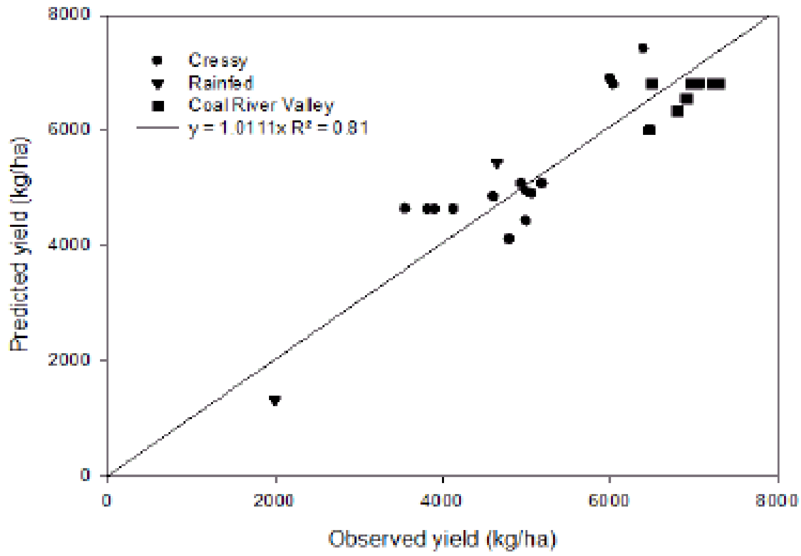

Figure 1. Observed vs. predicted yield for barley grown in Tasmania between 2008-2012. Symbols represent different regions in Tasmania.

Average predicted WUE was 17 kg/ha.mm and ranged from 7.7 to 24.3 kg/ha.mm. Runoff varied from 0 to 12 mm across sites and no drainage losses were predicted with the exception of 3 mm from a rainfed trial in 2009. WUE for barley were greater than that reported for wheat in Tasmania (Botwright Acuna et al., 2010a) and other Australian environments (Sadras and Angus, 2006), reflecting a shorter (and later starting) growing season, mild finishing conditions and minimal losses through drainage and runoff. Despite this, the average barley grain yield across all trial sites was only 4.7 t/ha, with a range of 1.8 to 6.0 t/ha, which is relatively low compared with other barley cultivars such as Triumph grown in field trials (10 t/ha) (Mendham and Russell, 1986). Gairdner continues to dominate the Tasmanian market for barley production as it meets the grain quality requirements of local brewers.

Strategies to improve WUE of barley in Tasmania

In contrast to previous WUE studies with wheat (Botwright Acuna et al., 2010a), there was no convincing relationship between modeled WUE of barley and cumulative N stress (y = -0.0765x + 17.233 R^2 = 0.04) or water stress (y = -0.0112x + 17.453 R^2 = 0.001; excluding the single drought year) for the Tasmanian benchmark dataset.

Simulated N stress levels were typically low across the benchmark trials, reflecting relatively high soil ambient levels at the commencement of each trial. As a consequence, the timing of topdress applications was found to have minimal effect on yield and WUE (results not shown). Rainfed barley had an average predicted yield and WUE of 3.6 (244 – 6870) t/ha and 14.2 (1.8 – 21.6) kg/ha.mm, respectively. Large variation in predicted yield and WUE was associated with drought or erratic rainfall events in 7 out of 30 years, in particular in 1995, 2006 and 2008. In addition, inadequate water relative to N supply resulted in predicted grain protein content exceeding that acceptable for malting in 14 out of the 30 years.

Table 1. Effect of irrigation timing relative to rainfed production on simulated yield, WUE and quality of barley from 1980 – 2010 at Richmond. Sown 26 August. Malting quality is grain protein of between 9 to 11.5%. Irrigation is based on either 25 mm applied at key stages of development, or deficit irrigation between stages GS45 -55 and GS70-75 when the water deficit > 24 mm.

Irrigation	Average yield change (kg/ha)	Yield change range (kg/ha)	Years with yield gain	Average WUE change (kg/ha.mm)	Yield change range (kg/ha)	Years with WUE gain	Years with malting quality	Years with economic gain
GS45	756	-1366 – 2180	24	1.6	-6.0 – 5.9	22	10	23
GS75	759	-310 – 1797	26	1.9	-2.3 – 6.8	22	14	23
GS45+75	1538	-1236 – 3213	28	3.3	-5.6 – 12.4	24	15	25
Deficit	2356	432 – 4229	30	4.3	-2.6 – 11.3	28	26	28

Irrigation management in Tasmania is typically strategic, with growers targeting key stages of development such as booting and grain fill to apply water, with only some adopting soil monitoring equipment and deficit irrigation practices. Table 1 shows little difference in predicted grain yield and WUE for one irrigation event of 25 mm at either booting (GS45) or grain fill (GS75), although there was a trend for improved grain quality with the latter option. In comparison, irrigation applied at both these stages of crop development doubled the average predicted gain in grain yield and WUE in 80% of years or more (Table 1). Not surprisingly, deficit irrigation (Table 1) had the most consistent increase in predicted grain yield and WUE in 93% of years or more. These results are consistent with field trials of barley undertaken in northern Tasmania where grain yield was greatest when irrigation was applied at booting with subsequent irrigation events tapered off during grain filling (Johnson et al., 2009). In addition, there was a large increase in the number of years that the crop met malting quality with deficit irrigation that translated into more years with an economic gain.

A second set of simulations were run to assess the impact of time of sowing (TOS) on grain yield, WUE and quality. Although barley can be sown as late as September in Tasmania, data in Table 2 shows that predicted grain yield and WUE were greatest with a June sowing. Economic gains were greatest with a May sowing, reflecting a reduced requirement for costly irrigation. On the other hand, growers would need to weigh up the increased risk of frost damage at flowering, particularly in inland regions, with earlier sowing times (Botwright Acuna et al., 2010b). There was little effect of TOS on malting quality, consistent with the results for deficit irrigation shown in Table 1.

Table 2. Effect of time of sowing on predicted yield and WUE of barley from 1980 – 2010 at Richmond, compared with the April sowing. Simulated crops were irrigated between stages GS45 -55 and GS70-75 when the water deficit > 24 mm.

Irrigation	Average yield gain (kg/ha)	Yield range gain (kg/ha)	Years with yield gain	Average WUE change (kg/ha.mm)	Yield change range (kg/ha)	Years with WUE gain	Average irrigation (mm)	Years with economic gain
April	6244	-	-	18.5	-	-	46	-
May	841	-1542 – 2124	29	0.5	-4.3 – 3.8	18	78	27
June	972	-1440 - 2430	26	0.7	-4.8 – 4.8	20	92	23
July	745	-2870 – 2705	22	0.4	-7.5 – 6.3	19	108	21
August	390	-2305 – 2077	21	0.0	-6.8 – 5.9	16	123	12
September	-263	-2902 – 2937	9	-0.6	-6.8 – 7.8	16	122	6
October	-849	-5065 – 2290	8	-1.4	-13.0 – 9.3	9	124	6

Conclusion

WUE was higher for barley compared with wheat in Tasmania, due to a shorter growing season and minimal losses due to waterlogging and runoff. Gains in predicted grain yield and WUE in most years were associated with strategic irrigation at both booting and grain fill, rather than either option alone. Furthermore, deficit-based irrigation not only improved predicted grain yield and WUE, but also grain quality. It would seem that an initial investment in soil monitoring technology and training would pay off for growers in terms of improved yield and quality. Finally, despite the option for growers to take advantage of the mild growing conditions to sow barley late so to provide improved flexibilty in farm management, yield and WUE were maximised with a June sowing.

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References

Botwright Acuna T., Lisson S., Dean G. (2010a) Benchmarking wheat water-use efficiency in Tasmania, in: H. Dove (Ed.), Food Security from Sustainable Agriculture: Proceedings of the 15th Agronomy Conference, 14 - 18 November 2010. Lincoln, New Zealand. pp. 4 pgs.

Botwright Acuna T.L., O'Leary G., Riffkin P.A. (2010b) Effect of time of sowing on phenology of cereals grown in a temperate environment in south-eastern Australia, in: H. Dove (Ed.), Proceedings of the 15th Australian Agronomy Conference, Australian Society of Agronomy, Lincoln, NZ. pp. 4 pgs.

Johnson P., Dean G., Howard R. (2009) Barley response to incremental irrigation, GRDC Research Updates for Higher Rainfall Growers: Profitable stockfeed grains in Tasmania, GRDC, Hadspen, Tasmania. pp. 30-31.

Keating B.A., Carberry P.S., Hammer G.L., Probert M.E., Robertson M.J., Holzworth D., Huth N.I., Hargreaves J.N.G., Meinke H., Hochman Z., McLean G., Verburg K., Snow V., Dimes J.P., Silburn M., Wang E., Brown S., Bristow K.L., Asseng S., Chapman S., McCown R.L., Freebairn D.M., Smith C.J. (2003) An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18:267-288.

Mendham N., Russell J. (1986) In pursuit of higher wheat and triticale yields in Tasmania, in: W. Gardner and L. O'Brian (Eds.), Wheat breeding for high rainfall areas, Victorian Crops Research Institute, Horsham, Victoria, August 12 - 13 1986. pp. 43-49.

Sadras V.O., Angus J.F. (2006) Benchmarking water-use efficiency of rainfed wheat in dry environments. Australian Journal of Agricultural Research 57:847-856.