Benchmarking wheat water-use efficiency in Tasmania

Tina Botwright Acu?a[1], Shaun Lisson[2] and Geoff Dean[3]

[1] Tasmanian Institute of Agricultural Research, PMB 54, Hobart Tas 7001 Email Tina.Acuna@utas.edu.au
[2] CSIRO Sustainable Ecosystems, PMB 54, Hobart Tas 7001
[3] Tasmanian Institute of Agricultural Research, Mt Pleasant Research Laboratories, PO Box 46, Kings Meadows, Tas 7249

Abstract

Water-use efficiency (WUE) in the high-rainfall zone of Tasmania can be extremely variable, as a result of environmental and agronomic constraints to grain production that limit yield potential. Emerging developments in Tasmanian grain cropping, such as the expansion of low-pressure overhead irrigators and increased access to low-cost, plentiful irrigation sources in some areas, will have a strong influence on WUE. This paper reports on desktop modelling studies to benchmark wheat WUE and to explore the sensitivity of WUE to changes in management practice. Management and yield data for 34 wheat trials were used to configure and validate the APSIM farming system model. Model output for key water-balance elements were used to estimate 'attainable' and potential WUE. Maximum potential WUE is ~20 kg/ha.mm, which aligns with previous studies of wheat WUE elsewhere in southern Australia. Attainable WUE ranges from 58% to 100% of potential WUE. Further model scenarios were run to explore the response of WUE to nitrogen and irrigation management.

Key Words

Water-use efficiency, wheat, high rainfall zone, APSIM modelling

Introduction

Improved water-use efficiency (WUE) is one strategy to potentially increase grain yield and there have been considerable research efforts of late in this area, particularly in dry regions (e.g. Sadras and Angus 2006). Furthermore, there has been a trend away from modelling of WUE based on the concepts of French and Schultz (1984), to more integrative approaches that account for soil moisture (Angus and van Herwaarden 2001) and other water-balance components. The high-rainfall zone (HRZ) for agricultural production of cereal crops in southern Australia has an annual rainfall of between 450 to 900 mm and includes Tasmania, southern Victoria and parts of southwest Western Australia. WUE in these environments can be extremely variable, as a result of environmental and agronomic constraints to grain production that limit yield potential (Riffkin and McNeil 2006; Zhang et al. 2005). In particular, the drainage term in the water-balance equation can be high and is an obvious point of distinction from lower-rainfall regions. A further complication is the increased likelihood of leaching of applied nitrogen which, together with deep drainage, can reduce both grain yield and WUE in these high-rainfall environments. The objectives of this paper were to benchmark current levels of WUE for wheat under Tasmanian conditions and to evaluate the response of WUE to various management practices and their potential to close the attainable versus potential WUE 'gap'.

Methods

Benchmarking WUE

Management and yield data for 34 wheat field trials undertaken in Tasmania from 1982 to 2009 were collated and used to configure the APSIM farming system model (Keating et al. 2003). Sowing dates of the wheat (cvs. Mackellar or Tennant) field trials ranged from May to September and around 25 kg N/ha was applied at seeding and a further 50 kg N/ha as a topdressing. Around half of the field trials received between 24 to 60 mm of irrigation; two received a maximum of 160 mm and the remainder were rainfed. Model soil parameters were chosen to represent the prevailing conditions at each site and long-term climate data were obtained from the Australian Bureau of Meteorology SILO website (Bureau of Meteorology 2010). Once satisfied that the model was reliably simulating wheat yield across the sites, APSIM model outputs for key water-balance elements were then used to estimate 'attainable 'and 'potential' WUE [grain yield / (SE + T + Drainage + Runoff)]. Here, potential WUE is determined by climate and is free of nutrient and biological constraints. Attainable WUE is additionally constrained by nitrogen supply.

WUE sensitivity to N and water supply

Further model scenarios were run to explore the response of WUE to irrigation and nitrogen management practices and the potential to close the attainable versus potential WUE 'gap'. Analysis was based on a field trial undertaken in the 2009-10 season at Cressy in Northern Tasmania. The control treatment was sown on 18 May 2009 to Mackellar wheat with 23 kg N/ha and 5 mm irrigation. A further two 23 kg N/ha applications of urea were applied as topdressings later in the season (i.e. total N applied of 70 kg N/ha) plus an extra 15 mm of irrigation in November (i.e. total irrigation of 20 mm). A range of additional scenarios were configured covering different irrigation rates (60 and 120 mm), N rates (70, 140, 210 kg N/ha) and various combinations of N and irrigation rates (Table 1). 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 feed-wheat grain price of $200/t, with costs of $145/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

The performance of the model to predict grain yield was acceptable across a range of environment and management systems (obs = 0.92 pred – 0.02, R^2 = 0.85) (data not shown). Maximum WUE_{TE} calculated as the ratio between yield and seasonal ET for the benchmark dataset was 33 kg/ha.mm, where E = 200 mm (data not shown), which is considerably larger than the 22 kg/ha.mm reported in lower-rainfall environments (Sadras and Angus 2006). This value, however, does not account for drainage and runoff, which can be considerable in a high-rainfall environment. Maximum potential WUE was thus determined to be around 20 kg/ha.mm (Figure 1). Furthermore, there was substantial variability in potential WUE and a significant gap between attainable and potential WUE in the majority of environments (Figure 1).

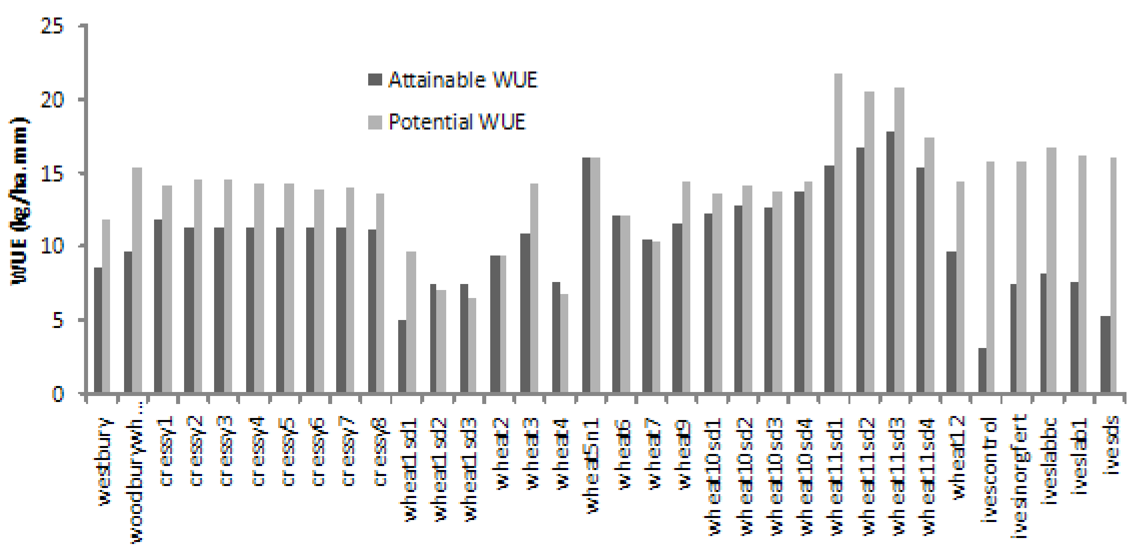

Figure 1. Simulated attainable and potential WUE for the benchmark dataset

The trend for WUE to increase with decreasing N stress indicated that N supply and demand dynamics were an important driver of WUE in Tasmania (Figure 2). The correlation between modelled seasonal crop N stress and WUE for the 2009-10 season, in which rainfall exceeded decile 9, was very high (R^2 = 0.85, data not shown). Consequently in a wet year, N supply will be a key driver of yield and WUE in Tasmania. The importance of N in Tasmania is also supported by the gap between potential and attainable WUE at some sites (Figure 1). The corresponding relationship between crop water stress and WUE, showed a weaker relationship (R^2 = 0.13, data not shown).

WUE sensitivity to N and water supply

Results from the various nitrogen and irrigation scenarios are summarised in Table 1. Increasing the irrigation by 60 mm resulted in an average yield gain of 602 kg/ha and an increase in WUE of 0.4 kg/ha.mm cf. the control, with 15/30 years generating both an economic yield gain and an increase in WUE (Figure 3a). A further increase in irrigation by 120 mm led to a small increase in average yield but had no effect on average WUE. The frequency of seasons with gains in both yield and WUE declined to 8. As expected there are larger gains in WUE achieved from irrigation in drier years.

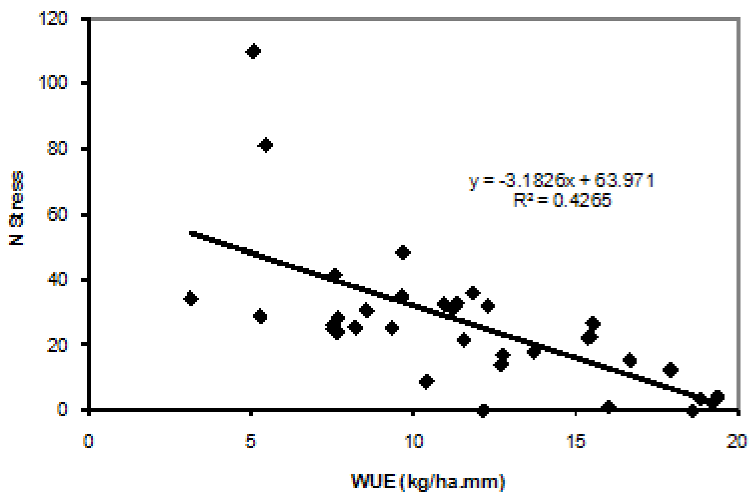

Figure 2. Accumulated seasonal crop N stress versus WUE for the benchmark dataset

Increasing the total N rate from 70 kg N/ha (control) to 140 and 210 kg N/ha (unchanged irrigation of 20 mm), resulted in yield gains of 437, 660 and 782 kg/ha, respectively. Corresponding gains in WUE were 0.6 (Figure 3b), 0.9 and 1.1 kg/ha.mm. The frequency of gains in both yield and WUE ranged from 17/30 (+70 kg N/ha) to 11/30 (+210 kg N/ha). Increasing both irrigation and applied N resulted in much larger and more consistent gains in both yield and WUE. For example, average yield and WUE gains of 2119 kg/ha and 2.4 kg/ha.mm were reached with an additional 120 mm irrigation and 210 kg N/ha of fertiliser with positive gains in both occurring in 24/30 years (Figure 3c).

Table 1. WUE and yield response to irrigation and N treatments across the period from 1980 to 2010. Data in brackets are the seasonal range of yield or WUE change

Extra irrigation	Extra N	Average yield	Years with yield	Years with economic	Average WUE change	Years with WUE	Years, economic

(mm)	(kg/ha)	change (kg/ha)	gain	yield gain	(kg/ha.mm)	gain	WUE gain
60	0	602 (0-1917)	20	15	0.4 (-0.7-2.8)	15	15
120	0	817 (0-3224)	20	8	0.4 (-2.0-6.3)	13	8
0	70	437 (-125-1058)	28	17	0.6 (-0.2-1.8)	28	17
0	140	660 (-313-1750)	27	13	0.9 (-0.6-2.6)	23	13
0	210	782 (-545-2325)	24	11	1.1 (-1.1-3.6)	22	11
120	70	1577 (601-3482)	30	14	1.3 (-0.7-6.3)	25	14
120	140	2119 (575-4039)	30	22	1.9 (-0.0-6.1)	30	22
120	210	2535 (481-4394)	30	24	2.4 (-0.2-6.0)	29	24

Conclusion

In Tasmania the maximum WUE_{TE} for wheat is around 33 kg/ha.mm. This is higher than published data for water-limited environments (Angus and van Herwaarden 2001; Sadras and Angus 2006), yet is consistent with the hypothesis of (Sadras and Rodriguez 2007) that southern regions with greater seasonal rainfall may have a high $WUE_{TE,}$ as a result of the longer growing season and mild climate. Potential WUE, which takes into account losses due to runoff and drainage, had a maximum value of around 20 kg/ha.mm and was variable as a result of constraints of climate, soil attributes and water availability. At most sites there was a gap between attainable and potential WUE, which could be addressed by improved crop management. Modelled scenarios showed that yield, WUE and economic returns could be improved by applying additional N fertiliser with strategic irrigation, thus avoiding co-limitation (Sadras 2004) of these inputs. The results serve to highlight that in high-rainfall cropping areas such as Tasmania, N supply is a key driver of yield and hence WUE. There may be scope to increase N use in Tasmania, which seems to be relatively low compared with other high-rainfall environments overseas. Validation of the modelled scenarios and further field trials will be required to better understand the complexities of yield formation and efficient use of inputs in this high-rainfall environment.

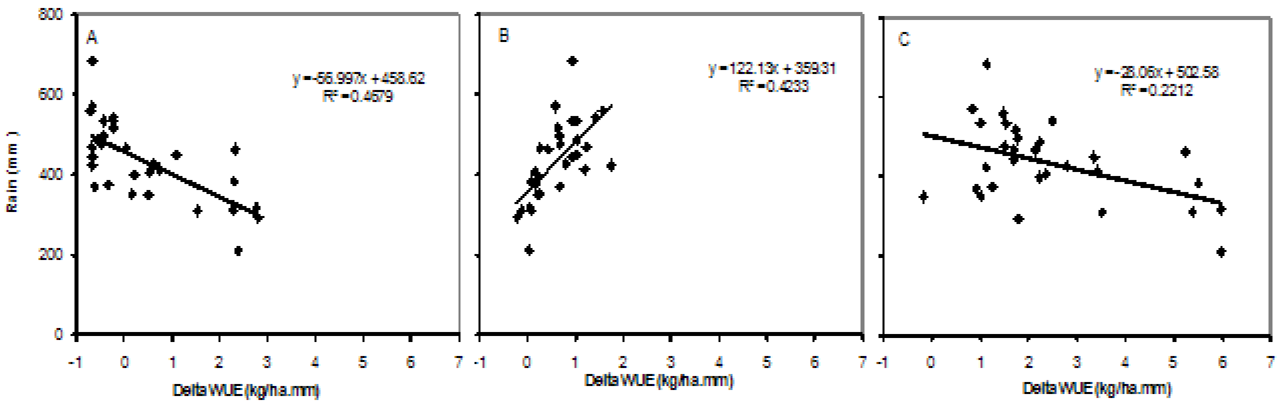

Figure 3. Seasonal rainfall vs. WUE difference from 1980 to 2010 between treatments receiving A) 80 mm vs. 20 mm irrigation per season; B) 140 kg N/ha vs. 70 kg N/ha per season, and; C) 140 mm irrigation + 280 kg N/ha vs. 20 mm irrigation + 70 kg N/ha.

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