Improved water-use efficiency of rainfed and irrigated farming systems in Tasmania

Summary
This project has benchmarked water-use efficiency (WUE) for wheat and barley using existing and historical data through participatory research, development and extension (RD&E) with grain growers. This has involved crop simulation approaches and identified the production (nitrogen (N) management, time of sowing), hydrological (irrigation, loss of unproductive water through deep drainage and run-off) and environmental impacts (diverse soil types, waterlogging) of constraints to improved WUE in the high rainfall zone (HRZ) farming system of Tasmania (Tas). Delivery of best-bet water management options to grain growers in this region can improve WUE by 10%.

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Conclusions
Yield, water use and water-use efficiency (WUE) in the high rainfall zone of Tasmania is highly variable due to environmental and agronomic constraints to grain production that limit yield potential. Computer simulation modelling using APSIM was used benchmark wheat WUE for 27 wheat experiments and to explore the sensitivity of yield, water use and WUE to changes in management practice in a high rainfall environment. WUE was defined as grain yield divided by the sum of evapotranspiration, drainage and runoff. The upper limit for WUE was around 30 kg/ha.mm in excess of 180 mm evaporation, which is 16% larger than previous estimates at this southerly latitude for wheat. This is higher than published data for water limited environments, but consistent with the hypothesis that southern regions with greater seasonal rainfall may have a high WUE (TE) because of the longer growing season and mild climate. At most sites, there was a gap between attainable and potential WUE of up to 58%, which could be addressed by improved crop management. Modelled scenarios showed that yield (up to 33%) WUE (up to 18%) and economic returns (80% of years) could be improved by applying additional N fertiliser with strategic irrigation - avoiding co-limitation of these inputs. The results serve to highlight that in high rainfall cropping areas, such as Tas, N supply is a key driver of yield and, therefore, WUE.

Working with leading growers, a range of management strategies were implemented at four sites, which had contrasting soil and climatic features, to explore their effect on yield and WUE and demonstrate outcomes to the community. Responses to N management and strategic irrigation were mixed, depending on the site, seasonal variation in rainfall and fertiliser product, which reflected the benchmarking outcomes. In general, irrigation during grain fill increased yield but at the expense of WUE. Some sites experienced high levels of background N, particularly at Cambridge, while others at Tunbridge did respond to applied fertiliser, but only on a clay soil, which had higher soil water content compared to the sand. Sites sown immediately after a pasture phase had complicated N dynamics that were responsive to additional N only when conditions were dry. This suppressed stubble breakdown and release of N. There was some evidence for an initial lag in N release at the start of the season with controlled-release (CR) fertiliser, while under waterlogged conditions these products gave a yield benefit compared with standard fertilisers only when the latter was applied in a single dose at the start of the season. There were no other yield penalties associated with these products, although the existing price compared with standard fertilisers is likely to be prohibitive to widespread adoption by growers for lower-value crops.

Management units were identified using a combination of sensor technologies at a site with a commercial variable-rate irrigator at Tunbridge, which demonstrated that differences in grain yields and WUE were associated with soil type and water holding characteristics. Finally, a series of field trials at Hagley were undertaken with plant-growth regulators (PCRs) to evaluate their potential to improve yield. Results have shown that chlormequat® applied alone at mid-tillering (growth stage (GS) 24) increased grain yield by 7% in most years and reduced height, but not to the extent of chlormequat + trinexapac-ethyl ®. In contrast, trinexapac-ethyl applied at GS30 did not substantially reduce height, but increased yield in one out of four trial years.

Recommendations

Benchmarking WUE

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1. Maximum potential WUE for wheat and barley are 30kg/ha/mm and 24kg/ha/mm, respectively.
2. French and Schultz (1984) type approaches underestimate WUE in high-rainfall environments because they do not account for unproductive losses of water through drainage and run-off. Instead, WUE has been estimated using crop simulation modelling approaches as grain yield/[surface evaporation + transpiration +runoff + drainage]

**Crop management strategies to improve grain yield and WUE**

There is a gap between attainable and potential WUE for wheat in the majority of Tas environments considered in this study. This gap can be closed:

1. Growers can achieve improved WUE by optimising N and irrigation management. For N, this includes splitting N applications and considering alternative sources of N fertilisers, at least in environments prone to waterlogging. For irrigation, two strategic applications of water improve WUE of barley, compared with a single event, and a better option is to invest in soil moisture monitoring equipment, which will permit deficit-based irrigation - shown to improve grain yield and WUE across seasons in most years.
2. Grain yield of barley following perennial ryegrass increased with applied N, most likely because it was tied up in stubbles at the start of the season and unavailable for plant growth.
3. Root depth of cereals is deeper (approx. 1m) than many growers realise. Access of roots to nutrients and water at depth needs to be taken into account when calculating nutrient budgets and this reinforces the need for growers to consider using soil moisture monitoring to schedule irrigation and make the most use of available water.
4. Growers should consider implementing site-specific crop management under variable rate irrigation. Managing soils to their soil moisture holding capacity, and tendency for waterlogging with appropriate nutrition, can improve yield and WUE - shown here on a site that contained contrasting sand and clay soils.
5. Chlormequat and trinexapac-ethyl applied in combination at early stem elongation (GS30) reduces plant height and hence lodging risk but in these trials does not increase yield. Chlormequat applied alone at mid-tillering (GS24) and early stem elongation (GS30) increases grain yield in most years and reduces height, but not to the extent of chlormequat + trinexapac-ethyl combined. Trinexapac-ethyl applied at GS30 treatment does not substantially reduce height but did increase yield in one out of four trial years. Plant growth regulators are substantially less effective when applied during and immediately after waterlogging.

**Outcomes**

**Economic outcomes**

Benchmarking of wheat and barley showed that predicted potential WUE was around 30 kg/ha/mm. Scenario analysis using Agricultural Production Systems Simulator (APSIM) modelling identified a gap between potential and attainable WUE of between 58% and 100%. N supply was identified as a key driver of WUE in Tas, however N uptake is co-limited by water supply and, therefore, management strategies need to take into account both these inputs. Long-term analysis using simulation modelling showed that increasing N supply and strategic irrigation improved predicted grain yield and WUE in 80% and 97% of years. Furthermore, economic modelling showed that this scenario led to an economic gain in 80% of years. 

Plant growth regulator studies during a four-year period showed that chlormequat and trinexapac-ethyl applied in combination at early stem elongation (GS30) reduced plant height and lodging risk, but did not increase yield. Trinexapac-ethyl applied at GS30 treatment does not substantially reduce height, but did increase yield in one out of four trial years.

**Achievements/Benefits**

**Benchmarking WUE**

Historical and new datasets originating from the project were used to benchmark WUE for wheat and barley across the key production areas of Tas. WUE in the high rainfall zone (HRZ) of the state can be extremely variable because of environmental and agronomic constraints to grain production that limit yield potential. Emerging developments in Tas grain growing, such as the expansion of low pressure overhead irrigators and increased access to low cost, plentiful irrigation sources in some areas, has a strong influence on WUE.

For wheat, desktop modelling studies were used to benchmark WUE and explore the sensitivity of WUE to changes in management practice and climate change. Management and yield data for 27 wheat trials were used to configure and
validate the APSIM model. Model output for key water balance elements were used to estimate attainable and potential WUE. The upper limit for WUE was around 30kg/ha.mm in excess of 180mm evaporation, which is 16% larger than previous estimates at this southerly latitude for wheat. Attainable WUE ranged from 58% to 100% of potential WUE and was limited by nitrogen (N) supply and the loss of unproductive water. Further model scenarios were run to explore the response of WUE to N and irrigation management, which highlighted co-limitation of these inputs - they were an important driver of grain yields and WUE. In a future with climate change, grain yield and, therefore, WUE are predicted to increase in response to warmer temperatures and increased atmospheric CO₂ concentration.

For barley, the extended sowing window and price premium for malting makes this crop a flexible and potentially more profitable alternative to other grains. Barley can be sown late where waterlogging has prevented timely seeding or there has been a crop failure. But when sown late, the shorter growing season and additional costs (associated with irrigation and the lower yield potential of barley) were shown to reduce grower profits. Strategic N and irrigation management are critical to meet grain quality requirements for malting. Based on grain yield results collated from field trials - 2008-2011 - and historical rainfall figures, WUE ranged from 7kg/ha/mm and 24kg/ha/mm.

APSIM simulation was used to estimate WUE because this approach could account for all elements of the crop/water balance. Routine estimation by agronomists and growers would require the use of decision support tools, such as Yield Prophet®, which was used alongside APSIM in each of the field trials.

But growers and agronomists showed little to no interest in adopting Yield Prophet® because of time constraints, inability to model waterlogging effects and an increasing preference for dual-purpose cereal production over grain only.

**Crop management strategies to improve WUE of wheat and barley**

Results of the benchmarking studies showed there was considerable variation in WUE and a gap between attainable and potential yield that could be addressed through nutrient and irrigation management strategies. Results of the benchmarking were presented at a workshop attended by 12 leading local growers in March, 2009, to facilitate the design of field trials - undertaken from 2009 to 2012 - to demonstrate an improvement in WUE of 10%. Four trial sites were chosen that represented a range of climate and soil types, including Hagley (Ferrosol 830mm annual rainfall), Cressy (Sodosol, 630mm), Tunbridge (Dermosol, 480mm) and Cambridge (Sodosol, 500mm).

**Cambridge - nitrogen and irrigation management of barley**

Field trials at Cambridge were undertaken under a commercial centre pivot with uniform application of water. Irrigation treatments were imposed by ceasing irrigation at a range of crop development stages, typically during grain filling. All field trials were undertaken using Gairdner barley. The trials evolved in response to new fertiliser products and included soil type and crop sequence as treatments.

The trial in 2009 evaluated irrigation timing. Irrigation ranged from 17mm to 72mm and grain yields were approx. 4t/ha with WUE of 18kg/ha/mm. There was no benefit from additional irrigation in this season because of the full soil profile and hence the crop being free from water stress. An important observation was that roots were detected to a depth of 1m, which is deeper than the 0.5m widely regarded by growers and agronomists as typical in Tas. This observation formed the basis of further research undertaken by M Matuszek in his PhD studies (GRDC code GRS155).

In 2010, the field trial focused on irrigation x N rate x brassica or pasture sequence, published in the 2011 Southern Farming Systems (SFS) results book. Local growers also participated in a field walk at the site. N availability limited crop growth, yield and WUE of barley, depending on the previous crop or pasture and the timing of fertiliser application.

Growth of the barley crop, following the pasture sequence, appeared to be limited by the amount of available soil N, most likely because the tie-up of N in stubbles released too late in the season to improve grain yield. This was clearly seen and quantified using multi-spectral images from an unmanned aerial vehicle (UAV). In contrast, yield and WUE of barley, following forage rape, was unresponsive to increased rates of applied N and were, instead, constrained by available soil moisture and lodging. Grain yield and WUE could be improved by changing the timing of N fertiliser applications to better match crop demand. WUE of the barley crop was approx. 22kg/ha/mm, reflecting the shorter growing season compared with wheat and no loss to drainage or run-off at this site.

In 2011 and 2012, field trials included soil type x N rate x source + irrigation. There was growing interest in the potential of new controlled release (CR) fertiliser products in annual crop production. Depending on the formulation, these products slowly
release N through a process modulated by ambient temperature or moisture. In Tas, these products may be of benefit under waterlogged conditions should they promote post-waterlogging recovery without leaching of N. Field trials were undertaken in contrasting environments at Cambridge, in the south, under relatively dry conditions and at Cressy, in the north, under waterlogged conditions. Collaboration between the Tasmanian Institute of Agriculture (TIA) and the national project led by CSIRO contributed data to APSIM simulation modelling of these products. For the Cambridge site, results were confounded by high levels of background N, but did indicate there was no yield or WUE penalty associated with use of controlled release polymer products, compared with conventional fertiliser. Data were used to demonstrate N dynamics of the slow release compared with standard products and identified a slight lag at the start of the season in N release in the polymer.

An additional benefit to growers from the Cambridge field trials was demonstrated through APSIM modelling of N dynamics and time of sowing. In some years, the growers were sowing their barley crops as late as September. APSIM modelling was used to demonstrate the yield, WUE and economic penalty associated with this practice, which was optimised with a May sowing.

**Cressy - N and irrigation management of wheat**

A selection of irrigation by N trials was undertaken with wheat and barley at Cressy on Sodosol, widely used for irrigated agriculture in the northern midlands. They are prone to waterlogging because of low relief and poor drainage. The inclusion of natural waterlogging in the trial has been problematic because it reduces the yield potential and increases the variation across the site. The trials evaluated the benefits of flowering to grain fill irrigation from 2009-2012, and standard vs controlled release DAP (fertiliser) in 2011-12.

During the four years, there was little to no response of grain yield to late irrigation - GS61 to GS85 - except in 2012 when continuing irrigation to GS77 gave a 23% yield increase, but slightly reduced WUE from 14.5kg/ha/mm to 13.2kg/ha/mm. In 2009, the overall WUE was low, ranging from 9.2kg/ha/mm to 10.2kg/ha/mm, because of poor water utilisation under waterlogged conditions. In 2010, average WUE was 13.4kg/ha/mm when the site experienced moderate to severe waterlogging. The spring barley of 2011 gave an average WUE of 13.8kg/ha/mm.

The CR N trial in 2011 was planned to be a winter wheat, but excessive rain in June prevented sowing until October when barley was the only option. As a result, there was no waterlogging and the benefits of the CR product to alleviate waterlogging stress could not be evaluated. There was a small early benefit to the CR DAP, but by crop maturity the standard DAP yielded 4.5% higher. This is attributed to an incomplete release of the CR product from the short spring season. In 2012, winter wheat was sown in June and experienced mild to moderate waterlogging during winter. There was a significant 25% yield decline from applying all N as standard DAP at sowing, compared with N as the CR.

**Hagley - plant growth regulators and wheat**

Plant growth regulators (PGRs) are widely used in Tas to control lodging of winter wheat grown with high rates of applied N fertiliser. There is some evidence from research conducted by chemical companies that timely applications of growth retardants may increase yield and WUE, irrespective of whether lodging has occurred.

Trials evaluated the individual and combined effects of two growth regulators: chlormequat# (trade names include Cycocel®, CCC-720®, Errex 750TM) and trinexapac-ethyl# (trade name Moddus®#) on height, yield and, where possible, WUE of winter wheat. Trials were conducted in commercial fields at Hagley from 2009-2012, with chlormequat or trinexapac-ethyl applied at GS24, GS30 or GS34. PGR treatments applied at GS30 showed height reductions in most years. The greatest reduction in height of 22% was achieved with chlormequat + trinexapac-ethyl applied at GS30 and GS34 in 2009. Neither the single nor double trinexapac-ethyl applications applied alone at GS24 reduced height. In 2009, a single application of trinexapac-ethyl at GS30 increased yield (10%), but this was not repeated in any other year. In contrast, chlormequat applied alone at mid-tillering (GS24) increased grain yield in most years (e.g. 7% in 2012) and reduced height (7%), but not to the extent of chlormequat + trinexapac-ethyl combined. In 2010, a very wet year at the time of applications, no significant reductions in height were achieved. Overall, the results indicate that generally chlormequat applied alone at GS24 had the greatest increase on yield. Note that estimating WUE of wheat treated with PGRs is complicated by structural changes in plant architecture not accounted for in the APSIM model. These results have been published as a fact sheet (Merry et al, 2013b) and in the SFS Results Book (Merry et al, 2013a).

**Tunbridge - crop sequence and N and irrigation management under variable rate irrigation**
A trial site was established under rain-fed conditions in Tunbridge in 2009 with canola, wheat, barley, field peas and a ryegrass pasture, with four replications. Grain yield and predicted WUE using APSIM was used in the benchmarking study. In 2010, this trial was scheduled to enter a barley crop phase. The trial was sown on time, but experienced significant pest damage from cockchafers. The trial was resown, but establishment remained low and the ryegrass population was such that it was abandoned. In 2011, additional measures were put in place for pest management and the trial sown on time. Within a one-week period, a single rainfall event of 70mm compromised stand establishment; the majority of crops sown in the region were likewise damaged. At this point, by mutual agreement with the grower, it was decided to abandon the trial site.

In the meantime, there had been significant adoption of variable rate irrigation (VRI) by Tas growers. This technology is well-suited to the introduction of site-specific crop management, which growers have been a little slower to adopt because of constraints in efficiency and cost of equipment. Growers typically block out unproductive land (e.g. waterlogged, wheel ruts) and make some allowances for differences in soil type, rather than employing remote sensing approaches. In 2012, the trial site at Tunbridge was moved to another location with known differences in soil types, which was mapped for elevation - electromagnetic (EM) 38 and normalised difference vegetation index (NVDI). A field trial was located in two management zones with contrasting soil types showing 14% improved tiller production at anthesis and 13% grain yield on clay, compared with the sandy soil. The 2012 growing season was drier than usual and improved grain yield on the clay soil was associated with higher soil water content and deeper roots (90cm compared with 50cm) than the sand. Higher rates of applied N fertiliser on the sand did not improve yield because water was limiting.

Results of this research were presented to local growers and agribusiness at a field walk, which had a theme around water management of crop, and a written report included in the 2012 SFS Results Book. Feedback from participants at the field walk showed that only half used soil moisture monitoring and that they planned to use these approaches in the future to optimise water supply to make better use of less productive land and upgrade to variable rate with more mapping.

Other research

Alternative fertiliser products

Together with the CSIRO national coordination project, the opportunity arose to evaluate the potential of CR products to improve WUE. CR products are more commonly used in grain production systems in North America and the turf industry in Australia. In Tas, CR was specifically targeted as a potential management strategy to improve post-waterlogging recovery and to minimise fertiliser burn at sowing. Results at Cressy and Cambridge under high and medium rainfall conditions, respectively, have shown that while there is no yield penalty associated with the product, neither was there much difference in WUE or grain yield. At twice the price of urea, it is prohibitive to wider adoption by growers, but it may be an option for higher-value crops, such as poppies.

Variable rate irrigation (VRI)

Adoption of variable rate irrigation (VRI) by Tas growers has increased during the course of the project. VRI in combination with site-specific crop management offers a real opportunity for Tas growers to improve crop productivity and sustainability through remote sensing. In the final year of the project, an opportunity arose to run a demonstration trial at a property in Tunbridge with known soil variability, plus susceptibility to waterlogging in wet years. Results demonstrated a yield benefit of up to 14% to growers through higher rates of N on a clay soil compared with sand.

Honours scholarship - effect of irrigation and N supply on WUE of barley (D Heys, UHS10228)
This research reported on the growth, yield and N response of barley using various fertiliser treatments, including CR DAP fertiliser. The CR product showed increased emergence and early growth compared with standard DAP fertiliser because of the decreased toxicity effects on the roots of the germinating seedling. Yield at 12% moisture for spring-sown Macquarie barley was (4.3%) less for barley sown with CR than when sown with standard DAP. The CR did not release enough N through the growing period (particularly after GS65) which resulted in N being unutilised in the soil after harvest. Under waterlogging, the CR produced more ground cover than the other fertiliser treatments, but was significantly less than post-waterlogging topdressing treatments. Topdressing N after the waterlogging event resulted in more ground cover at 122 days after sowing. Further studies that evaluate the yield and dry matter production of these products will reveal whether the CR product is beneficial for barley growth after a waterlogging event.

**PhD scholarship - the effect of crop rotation and irrigation on WUE and soil health of grain crop production in TAS (M Matuszek, GRS155)**

This project aims to understand the interactions between soil moisture, strength and cracking of duplex subsoils and how these influence yield, WUE and root growth of barley and how irrigation can be used to manipulate these factors. The trials are modelled in APSIM with detailed crop, root and soil data collected during two seasons. Because of significant inconsistencies between the observed and simulated results, the project aims to make changes to the APSIM model in relation to root exploration factors to improve simulated yield of cereals on duplex soils under Tas conditions. The overall hypothesis of the project is that irrigation can be used to increase root depth of barley and, therefore, increase yield and WUE because of greater water availability.

**Additional information**


