Effect of water availability and nitrogen source on wheat growth and nitrogen-use efficiency

Eseeri Kisaakye [1], **Tina Botwright Acuña [1]**, Peter Johnson [2], Sergey Shabala [1]

[1] School of Land and Food, University of Tasmania, Private Bag 54 Hobart, Tasmania,7001, Eseeri.Kisaakye@utas.edu.au
[2] Tasmanian Institute of Agriculture, University of Tasmania, PO Box 46 Kings Meadows, Tasmania, 7249

Abstract
Soil moisture content has a significant impact on soil nutrient availability. Excessive soil moisture due to waterlogging can severely reduce nutrient availability through denitrification, leaching and restricted root growth, which impairs nutrient uptake by plants. This reduces nitrogen (N) uptake and utilization by plants thereby decreasing nitrogen-use efficiency (NUE). Controlled-release fertilizers (CRFs) can improve NUE through synchronisation between N supply and crop demand. A study was conducted to investigate whether timing of N application and source of applied N can alleviate the adverse effects of waterlogging on wheat growth and improve NUE. A split-plot design experiment with irrigation regime as main-plot factor and nitrogen application sub-plot factor was setup. Irrigation regimes included waterlogged and rainfed; nitrogen treatments included: nil N, single-and split-applied urea and CRF. Wheat growth and yield attributes were monitored during stem elongation and anthesis. Grain yield and NUE were determined at harvest. The study findings showed that waterlogging significantly ($P<0.05$) decreased tiller number, ear number and NUE for all nitrogen treatments. Although split-applied urea had a higher number of tillers and ears than single-applied urea under waterlogged conditions at harvest, there was no significant yield advantage under both irrigation regimes. The CRF increased grain yield by 1t/ha compared to both single- and split- applied urea of the waterlogged treatment. CRF also improved wheat NUE by 7% and 10% under rainfed and waterlogged conditions respectively.

Key words
Triticum aestivum; duplex soil; enhanced-efficiency fertilizers; yield components; nitrogen fertilizer and high rainfall zone.

Introduction
Water availability plays a significant role in crop growth development; however, excessive soil moisture content has detrimental effects. In Tasmania an estimated 23% of the soils are duplex and susceptible to waterlogging (Cotching et al. 2009), causing wheat grain yield losses of *c*. 30-50% (Zhou 2010). These yield losses are usually as a result of reduced tiller and grain number, restricted root growth, reduced dry matter accumulation, premature leaf senescence and production of sterile florets.

Nitrogen (N) fertilizer application is said to play a significant role in improving plant growth and development under waterlogged conditions. Various studies have shown that N, applied as foliar sprays or top-dressed, can increase grain yield by around 20% through a combination of root and shoot growth including plant height, tiller number and spikelet number (Pang et al. 2007; Robertson et al. 2009; Swarup & Sharma 1993). Nonetheless, conventional N fertilizers are easily lost through leaching, denitrification, immobilization, volatilization and surface runoff during waterlogging (Mathers et al. 2007), which reduces nitrogen-use efficiency (NUE). With the increasing environmental and health concerns associated with N fertilizer use in agriculture there is need to maximise NUE. Timing of N application influences N loss and split N application is often recommended over single N application. Controlled-release fertilizers (CRFs) often referred to as enhanced-efficiency fertilizers have also been reported to be a viable option for improving NUE through synchronisation between N supply and crop demand (Chen et al. 2008). However, most work under waterlogged conditions has focused on the conventional N sources such as urea with no deliberate intention to explore the potential of CRFs. Also, attempts to evaluate the potential of N fertilizer application in reducing the adverse effects of waterlogging under field conditions have received little attention. This study investigates whether timing of N application and source of applied N can alleviate the adverse effects of waterlogging on wheat growth and improve NUE.

Materials and methods

The study was conducted at Cressy Research and Demonstration Station 45km south of Launceston. The site is located $41^0 72$'S, $147^0 08$'E and 150m above sea level. The site soil is duplex in nature posing significant problems to agricultural use. The area receives an average annual rainfall of 626mm; making it one of the high rainfall zones (HRZs) in Australia. A split-plot design with irrigation regime (waterlogged and rainfed) and N application (nil N, single-applied urea, split-applied urea and CRF) as the main-plot and subplot factors with three replications was used. Waterlogging was instigated at tillering (GS20) for 28 days using a drip irrigation system setup to ensure the water level is kept above the soil surface. Nitrogen fertilizer was applied at a rate of 90kg/ha; urea (46-0-0) and CRF (39-0-0) were used. Single-applied urea and CRF had full amounts applied once at sowing while split-applied urea had 40% applied at sowing and the remaining 60% top-dressed at GS32 after waterlogging.

Wheat (*Triticum aestivum*) cv. Revenue dressed with fungicide "Real" (Triticonazole and Cypermethrin) was sown early June 2014. The crop was drilled at a depth of 30mm at a seed rate of 125kg/ha with a 150mm row spacing in plots 8m long and 1.8m wide. The rainfed block was formed into 12 raised beds using a commercial bed former with a depth of 300mm and a furrow width of 300mm. The waterlogged block consisted of 12 flat (unbedded) plots. At sowing, a starter fertilizer with no nitrogen (N: P: K: S: Ca; 0-6-17-7-13) was applied at a rate of 250kg/ha. During waterlogging, the raise in the depth of the water table was monitored using small diameter (50mm) PVC tubes (piezometers) installed to a depth of 1m. Three piezometer tubes were randomly installed in the rainfed and waterlogged blocks at 6m spacing. The depth of the water table was recorded manually using a sampler and tape measure.

Plants were monitored for specific growth stages (Zadoks et al. 1974). At stem elongation (GS32) plants within a $0.3m^2$ quadrat were hand harvested, 12 plants were randomly selected and processed for tiller number, green leaf area and total above ground dry matter (AGDM). At harvest, plants within a $0.3m^2$ quadrat were hand harvested and processed for tiller number and ear number. The ears were dried, threshed and grains weighed for grain yield. NUE was calculated as a ratio of grain yield to N supply. Nitrogen supply in this study refers to the amount of mineral fertilizer applied. Data was analysed using two-way ANOVA to determine treatment interactions using GenStat 17^{th} edition. Treatment means were deemed significant at 5% LSD.

Results

The depth of the water table varied from 140 to 200mm during waterlogging; it was maintained in the top 300mm of the rhizophere (Figure 1). The rainfed treatment which received at total of 351mm of rainfall during the experimental period (BOM 2015) had its depth of the water table vary from 580 to 880mm.
At GS32, there was a significant interaction between irrigation regime and N fertilizer application for tiller number (P = 0.019), leaf area (P = 0.044) and total AGDM (P = 0.041). Waterlogging significantly decreased tiller number, leaf area and total AGDM for all nitrogen treatments in comparison with the rainfed treatments (Table 1). No significant differences were observed between N treatments for all parameters measured under waterlogged conditions. However, under rainfed conditions, significant differences were noted with CRF being greater than the control (nil N) for tiller number (9.1 cf 5.1), leaf area (321 cf $115cm^2$) and total AGDM (2.6 cf 1.5g). No significant differences were observed between CRF and conventional urea treatments for all measured parameters.

At harvest, significant differences (P<0.05) in irrigation regimes were marked with low tiller number, ear number and NUE for the waterlogged plants (Table 2). Nitrogen fertilizer application however, improved tiller number, ear number, grain yield and NUE of the waterlogged plants (Table 2). The CRF increased grain yield by 1t/ha compared to both single- and split- applied urea of the waterlogged and improved wheat NUE by 7% and 10% under rainfed and waterlogged conditions respectively.

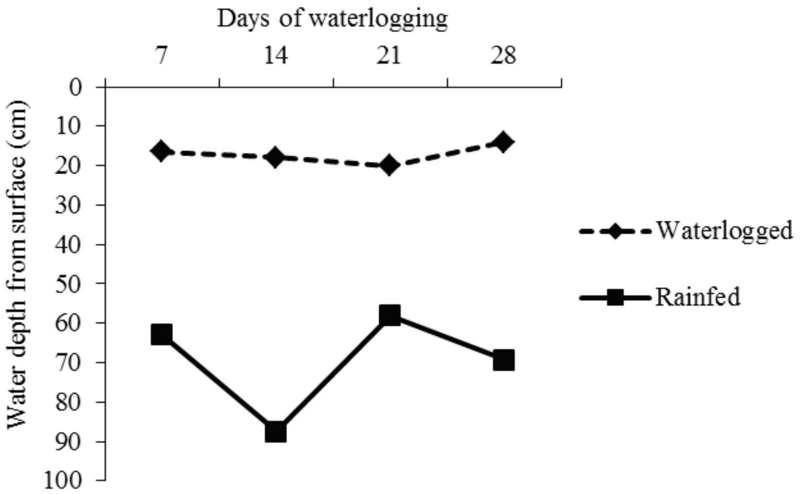

Figure 1. Level of the water depth from the surface during waterlogging.

Table 1. Growth attributes at stem elongation under different irrigation regimes and nitrogen levels.

GS32	Irrigation regime	Nitrogen level	Parameter		
	Rainfed		Av tiller number / plant	Av leaf area/plant (cm^2)	Av AGDM/plant (g)
		Nil N	5.1a	115ab	1.5b
		Single-applied urea	8.0b	241bc	2.4c
		Split-applied urea	7.8b	234bc	2.3bc
		CRF	9.1b	321c	2.6c
	Waterlogged				
		Nil N	3.8a	4a	0.4a
		Single-applied urea	4.2a	13a	0.6a
		Split-applied urea	3.9a	11a	0.5a
		CRF	4.4a	22a	0.6a

*Treatments followed by the same letter are not significantly different (*P*>0.05).

Table 2. Growth and yield attributes at harvest under different irrigation regimes and nitrogen levels.

GS91	Irrigation regime	Nitrogen level	Parameter			
	Rainfed		Tiller number/ m^2	Ear number/m^2	Grain yield (t/ha)	NUE (g/g)
		Nil N	604cd	492bc	3.8ab	-
		Single-applied urea	692d	686d	7.7bcd	85.3ab
		Split-applied urea	647d	627cd	7.8cd	87.2ab
		CRF	657d	632cd	9.2d	102.7b
	Waterlogged					
		Nil N	280a	272a	3.6a	-
		Single-applied urea	351ab	336ab	5.6abc	61.7a
		Split-applied urea	424abc	403ab	4.9abc	55.2a
		CRF	526bcd	477bc	6.8abc	75.0ab

*Treatments followed by the same letter are not significantly different (*P*>0.05).

Discussion

Waterlogging adversely affected wheat growth and development. The low tiller number, ear number, leaf area and total AGDM of the waterlogged plants could be attributed to the decreased availability of essential plant nutrients leaving plants with marked nutritional deficiency symptoms. Waterlogging also decreases root biomass through root death, which impairs the ability of plants to forage for the already limited resources (Pang et al. 2007). The low AGDM and grain yield is possibly due to premature leaf senescence, reduced tiller and grain number and production of sterile florets. On the other hand, N fertilizer application improved wheat performance under rainfed and waterlogged conditions. Nitrogen is a vital macronutrient for plant growth with 75% of the total leaf N allocated to the chloroplasts for synthesis of components for the photosynthetic apparatus particularly RuBisCo, that plays a significant role in CO_2 assimilation (Hirel et al. 2007). The improvement in leaf area, tiller number, ear number, grain yield and AGDM under both irrigation regimes may be due to increased N uptake, which increases leaf chlorophyll content and photosynthetic capacity. This propels vegetative growth (tillering and canopy size and duration), resultant grain yield and biomass. The role of N availability particularly in the form of NO_3^- ions in alleviating the consequences of waterlogging was emphasised by Drew (1991); NO_3^- ions can replace molecular O_2 as a terminal acceptor thereby sustaining respiration and cell survival during anoxia through dissimilatory NO_3^- reduction. However, the efficiency of N fertilizer application is usually reduced by waterlogging when significant amounts are lost through volatilization, denitrification and leaching. This might be responsible for the low tiller and ear numbers, grain yield and NUE of waterlogged N fertilizer treatments. The higher growth and yield attributes, and NUE for CRF than single-and split-applied urea for both irrigation regimes can be related to it's ability to synchronise N release with crop demand (Chen et al. 2008).

Conclusions

Although waterlogging is still a major abiotic constraint to wheat production, N fertilizer application could improve wheat yield. The timing of N application and source are important. Applying full amount of the required fertilizer at sowing helps plants to withstand the adverse effects of transient and intermittent waterlogging through enhanced vegetative growth.Using CRFs may improve wheat growth and NUE under rainfed and waterlogged conditions though there might be no significant yield advantange over conventional urea to warrant investment. Nonetheless, there is need to evaluate different CRF products available for their potential in broadacre cropping and understand the processes involved in improving NUE and how they can be enhanced to maximise their productivity.

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References

BOM 2015, Bureau of Meteorology, viewed 10th February 2015, <http://www.bom.gov.au/climate/averages/tables/cw_091306.shtml>.

Chen, D, Suter, H, Islam, A, Edis, R, Freney, J & Walker, C 2008, 'Prospects of improving efficiency of fertiliser nitrogen in Australian agriculture: a review of enhanced efficiency fertilisers', *Soil Research*, vol. 46, no. 4, pp. 289-301.

Cotching, W, Lynch, S & Kidd, D 2009, 'Dominant soil orders in Tasmania: distribution and selected properties', *Soil Research*, vol. 47, no. 5, pp. 537-548.

Drew, MC 1991, 'Oxygen deficiency in the root environment and plant mineral nutrition', *Plant Life under Oxygen Deprivation*, pp. 303-316.

Hirel, B, Le Gouis, J, Ney, B & Gallais, A 2007, 'The challenge of improving nitrogen use efficiency in crop plants: towards a more central role for genetic variability and quantitative genetics within integrated approaches', *Journal of Experimental Botany*, vol. 58, no. 9, pp. 2369-2387.

Mathers, NJ, Nash, DM & Gangaiya, P 2007, 'Nitrogen and phosphorus exports from high rainfall zone cropping in Australia: Issues and opportunities for research', *Journal of environmental quality*, vol. 36, no. 6, pp. 1551-1562.

Pang, J, Ross, J, Zhou, M, Mendham, N & Shabala, S 2007, 'Amelioration of detrimental effects of waterlogging by foliar nutrient sprays in barley', *Functional Plant Biology*, vol. 34, no. 3, pp. 221-227.

Robertson, D, Zhang, H, Palta, JA, Colmer, T & Turner, NC 2009, 'Waterlogging affects the growth, development of tillers, and yield of wheat through a severe, but transient, N deficiency', *Crop and Pasture Science*, vol. 60, no. 6, pp. 578-586.

Swarup, A & Sharma, D 1993, 'Influence of top-dressed nitrogen in alleviating adverse effects of flooding on growth and yield of wheat in a sodic soil', *Field Crops Research*, vol. 35, no. 2, pp. 93-100.

Zadoks, J, Chang, T & Konzak, C 1974, 'A decimal code for the growth stages of cereals', *Weed research*, vol. 14, no. 6, pp. 415-421.

Zhou, M 2010, 'Improvement of plant waterlogging tolerance', in S Shabala & S Mancuso (eds), *Waterlogging signalling and tolerance in plants*, Springer-Verlag, Berlin, pp. 267-285.