# Improving wheat growth and nitrogen-use efficiency under waterlogged conditions

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## Abstract

Soil moisture content has a significant impact on nutrient availability in wheat. Excessive soil moisture due to waterlogging can severely reduce nutrient availability through substantial dilution of nutrient concentrations and leaching of mobile nutrients like nitrogen (N). Nitrogen-use efficiency (NUE) may be improved by using controlled-release fertilisers (CRFs) and appropriate timing of N fertiliser application. This study investigated whether timing of N application and source of applied N can alleviate the adverse effects of waterlogging on wheat growth and improve NUE. The experiment was designed as a split-plot with irrigation regime and N fertiliser application as main-plot and subplot factors and three replicates. The irrigation regime included: rainfed, irrigated and waterlogged while N fertiliser application had nil N, single-applied urea, split-applied urea and CRF treatments. At harvest, tiller number, ear number, grain yield and harvest index were determined. Nitrogen-use efficiency, its components and grain protein content were also determined. The results showed that waterlogging and N fertiliser application had a significant effect ($P < 0.05$) on tiller number, ear number, grain yield and NUE. The CRF had the highest grain yield for all irrigation regimes, with 9.2 t/ha, 9.4 t/ha and 6.8 t/ha for the rainfed, irrigated and waterlogged respectively. There were significant variations ($P < 0.05$) in NUE between different irrigation regimes and N fertiliser treatments. The CRF had the highest NUE for all irrigation regimes. Under waterlogged conditions, the CRF improved NUE by 17% and 27% more than single- and split- applied urea respectively.

## Keywords

Enhanced-efficiency fertilisers, high rainfall zone, conventional urea, *Triticum aestivum,* duplex soil.

## Introduction

Nitrogen fertiliser application plays a significant role in improving plant growth and development under waterlogged conditions. Nitrogen fertiliser applied as foliar sprays or top-dressed, can increase grain yield through a combination of changes to root and shoot growth including increase in plant height, tiller number and spikelet number. For instance, Robertson et al. (2009), showed that N fertiliser applied after waterlogging can increase grain yield by ~20%. Nonetheless, conventional N fertilisers are easily lost through leaching, denitrification, immobilisation, volatilisation and surface runoff during waterlogging (Mathers et al. 2007), all of which can reduce nitrogen-use efficiency (NUE). With the increasing environmental and health concerns associated with N fertiliser 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 (Cai et al. 2011). Controlled-release fertilisers (CRFs) often referred to as enhanced-efficiency fertilisers 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. Furthermore, most N is top-dressed after waterlogging, which can be difficult under field conditions as the soil moisture content is often too high for efficient mechanisation. The evaluation of the potential of N fertiliser application in reducing the adverse effects of waterlogging under field conditions has received little attention. This study investigated whether timing of N application and source of applied N can alleviate the adverse effects of waterlogging on wheat growth and improve NUE. We compared wheat growth responses and yield components under different irrigation regimes and nitrogen treatments and quantified NUE, its components and grain protein content under different irrigation regimes.

## Methods

The study was conducted at Cressy Research and Demonstration Station 45 km south of Launceston, Tasmania. The site is located $41^0 72$'S, $147^0 08$'E and 150 m above sea level, with a duplex soil that is prone to waterlogging. A split-plot design included irrigation regime (rainfed, irrigated and waterlogged) and N application (nil N, single-applied urea, split-applied urea and CRF, poly-S coated Agrocote®) as the main-plot and subplot factors with three replicates. The rainfed treatment received 351 mm of rain during the experimental period whilst the irrigated block in addition to the natural rainfall, received 25 mm of water twice a week until the mid-grain filling phase using an overhead centre pivot irrigator. Waterlogging was instigated at tillering (GS20) for 28 days using a drip irrigation system to ensure the water level was kept above the soil surface. Nitrogen fertiliser was applied at a rate of 90 kg N/ha, and the 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. The rate applied was based on the yield potential and the starting soil mineral N content.

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 30 mm and a seed rate of 125 kg/ha with 150 mm row spacing in plots 8 m long and 1.8 m wide. The rainfed and irrigated blocks were formed into 12 raised beds each using a commercial bed former with a depth of 300 mm and a furrow width of 300 mm. The waterlogged block consisted of 12 flat (unbedded) plots. At sowing, a starter fertiliser with no nitrogen (N: P: K: S: Ca; 0-6-17-7-13) was applied at a rate of 250 kg/ha. During waterlogging, the change in the depth of the water table was monitored using small diameter (50 mm) PVC tubes (piezometers) installed to a depth of 1 m. The depth to the water table was recorded manually using a sampler and tape measure.

At harvest (GS91), plants within a 0.3 $m^2$ quadrat were hand harvested and processed for tiller number and ear number. The ears were dried, threshed and grains weighed for grain yield. The straw and grain were ground through a 0.5 mm sieve using a Thomas-Wiley Laboratory Mill and analysed for percent N content using a Thermo Finnigan EA 1112 Series Flash Elemental Analyser. Nitrogen concentration was analysed for only the rainfed and waterlogged urea and CRF N treatments. The N content was used to compute N uptake efficiency (NupE) (ratio of total plant N to N supplied), N utilisation efficiency (NutE) (ratio of grain N to total plant N), and grain protein content (GPC) (%N x 5.83). Total N uptake was calculated as (grain yield x %N in the grain + straw yield x %N in the straw)/100. Nitrogen use-efficiency (NUE) (ratio of grain yield to N supply), and harvest index (ratio of grain yield to total-above ground biomass) were also determined. Nitrogen supply in this study refers to the amount of mineral fertiliser applied and pre-crop or in-crop mineralisation was not included. Data were analysed using two-way ANOVA to determine treatment effects and interactions using GenStat 17th edition. Treatment means were deemed significant at 5% least significant difference (LSD).

## Results

The depth to the water table varied from 140 to 200 mm during waterlogging; it was maintained in the top 300 mm of the rhizosphere. The depth to the water table for the rainfed varied from 580 to 880 mm. Yield attributes including tiller number, ear number and wheat grain yield were significantly affected by the irrigation regime ($P = 0.001$) and N fertiliser application ($P < 0.05$) (Table 1) but no significant interaction occurred between irrigation regime and N fertiliser application ($P > 0.05$). The rainfed regime had the highest number of tillers compared with respective N treatments of the irrigated and waterlogged. Nitrogen fertiliser application improved tiller number, with single-applied urea of the rainfed having the highest number of tillers (692 tillers/$m^2$). The CRF had the highest number of tillers for the irrigated (639 tillers/$m^2$) and waterlogged (526 tillers/$m^2$). Similarly, ear number was improved by N fertiliser application; the CRF still had the highest number of ears for the irrigated (603 ears/$m^2$) and waterlogged (477 ears/$m^2$) while single-applied urea (686 ears/$m^2$) had the highest number of ears for the rainfed.

Wheat grain yield increased in response to N fertiliser application under all irrigation regimes. The waterlogged plants had the lowest grain yield compared with their respective N treatments for the rainfed and irrigated. The CRF had the highest grain yield for all irrigation regimes with 9.2 t/ha, 9.4 t/ha and 6.8 t/ha for the rainfed, irrigated and waterlogged respectively. The urea treatments had an average of 8 t/ha for both the rainfed and irrigated, and 5.3 t/ha for the waterlogged. The CRF increased grain yield by an average of 1.5 t/ha compared with both urea treatments under waterlogged conditions. There was a significant interaction between irrigation regime and N application ($P = 0.04$) for the harvest index (HI) (Figure 1). The waterlogged plants had the highest HI for all N treatments compared with their respective N treatments for the rainfed and waterlogged. Both urea and CRF treatments had higher HI than nil N treatments of the rainfed and irrigated.

Nitrogen-use efficiency was significantly affected by irrigation regime ($P = 0.001$) and N fertiliser application ($P = 0.036$) (Table 1). The waterlogged plants had the least NUE for all respective N treatments under the rainfed and irrigated regimes. The CRF had the highest NUE for all irrigation regimes; over all, the irrigated regime had the highest NUE for both urea and CRF treatments. Under waterlogged conditions, CRF improved NUE by 17% and 27% more than single- and split- applied urea respectively. There were no significant variations between N treatments for the different NUE components assessed (NupE and NutE) and GPC (Table 2). The irrigation regime had a significant effect on NupE, NutE and GPC ($P < 0.05$). The rainfed had higher NupE than the waterlogged for all N treatments while the waterlogged had higher NutE for all N treatments compared with the rainfed. The GPC was relatively similar for both the rainfed and waterlogged.

**Table 1. Yield attributes and NUE at harvest under different irrigation regimes and nitrogen treatments.**

| Source | Tiller number ($m^{-2}$) | Ear number ($m^{-2}$) | Grain yield (t/ha) | NUE (g/g) |
|---|---|---|---|---|
| Rainfed | 650 | 609 | 7.2 | 91.7 |
| Irrigated | 584 | 566 | 8.0 | 94.7 |
| Waterlogged | 395 | 372 | 5.2 | 63.9 |
| l.s.d. | 68.4 | 63 | 1.0 | 13.5 |
| | | | | |
| Nil N | 467 | 426 | 4.6 | - |
| Single-applied urea | 536 | 524 | 7.2 | 79.8 |
| Split-applied urea | 563 | 541 | 6.9 | 76.7 |
| CRF | 607 | 571 | 8.5 | 93.9 |
| l.s.d. | 79 | 73 | 1.2 | 13.5 |

**Table 2. Nitrogen-use efficiency components and grain protein content at harvest under different irrigation regimes and nitrogen treatments.**

| Source | NupE (ratio) | NutE (ratio) | GPC (%) |
|---|---|---|---|
| Rainfed | 2.57 | 0.75 | 12.6 |
| Irrigated | - | - | - |
| Waterlogged | 1.33 | 0.80 | 9.6 |
| l.s.d. | 0.56 | 0.05 | 2.4 |
| | | | |
| Nil N | - | - | - |
| Single-applied urea | 1.73 | 0.79 | 10.4 |
| Split-applied urea | 1.78 | 0.78 | 11.4 |
| CRF | 2.34 | 0.76 | 11.5 |
| l.s.d. | 0.70 | 0.06 | 2.9 |

## Discussion

Waterlogging adversely affects wheat growth and development. The formation of perched water tables on the subsoil clay causes excess water within the crop root zone, depleting soil oxygen and substantially diluting nutrient concentrations. This decreases the availability of essential plant nutrients, leaving plants with marked nutritional deficiency symptoms. Such symptoms include chlorosis, which accelerates premature leaf senescence thereby decreasing the plant canopy, photosynthetic capacity and resultant biomass. This accounts for the low tiller number, ear number and yield observed under waterlogged conditions. Moreover, under stressful conditions, plants channel their resources (photoassimilates) to key plant organs such as the grains and maintenance of vital physiological processes for survival. This improves their productivity as can be noted with the higher harvest indices and N utilisation efficiency observed under waterlogged conditions. On the other hand, N fertiliser application improved wheat performance under all irrigation regimes. Nitrogen is a vital macronutrient for plant growth, with a significant proportion allocated to the chloroplasts for synthesis of components for the photosynthetic apparatus. Although waterlogging is still a major abiotic constraint to wheat production, N fertiliser application could improve wheat yield. The timing of N application and source are important. Applying full amount of the required fertiliser at sowing helps plants to withstand the adverse effects of transient and intermittent waterlogging through enhanced vegetative growth. Nitrogen uptake increases leaf chlorophyll content and photosynthetic capacity, which propels vegetative growth (tillering and canopy size and duration), resultant grain yield and biomass.

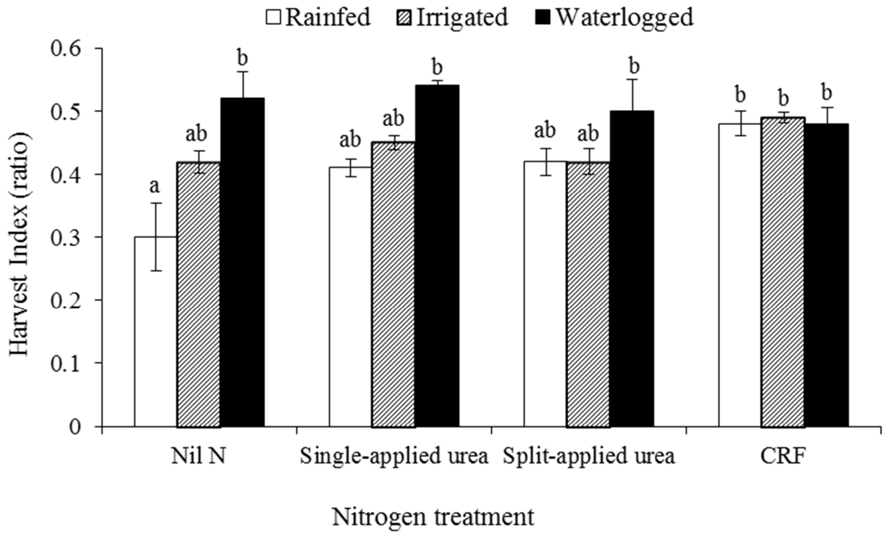

**Figure 1. Harvest index (HI) for the different nitrogen treatments under different irrigation regimes. Treatments with the same letter are not significantly different ($P > 0.05$).**

Nonetheless, the efficiency of N fertiliser is usually reduced by waterlogging when significant amounts are lost through leaching and denitrification. This reduces N uptake subsquently decreasing tiller production, ear formation, grain yield and NUE of the affected plants. Top-dressing urea after waterlogging and during stem elongation improved wheat performance of the split-applied urea treatment under different irrigation regimes. It boosted secondary tiller production, which increased the number of fertile tillers, sustained canopy duration and accelerated the production of photoassimilates translocated to the grain compared with the straw thus increasing its HI. The CRF sustained N supply by synchronising N release with crop demand (Chen et al. 2008), which improved wheat growth, yield attributes and NUE components.

## Conclusion

Using CRFs may improve wheat growth and NUE under rainfed and waterlogged conditions though there might be no significant yield advantage 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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