# High yielding wheat in the northern region: impact of nitrogen fertilisation on grain yield and quality in modern cultivars

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## Abstract
Season to season variability in grain yields is the main factor determining farmers' conservative investment strategies in dryland cropping. Yield differences among wheat cultivars and its responsiveness to resource availability are usually related to grain number per $m^2$. The experience from Australia suggests that part of the low yields in dryland conditions might be due to low N availability, and that water use efficiency, yield, and grain quality could then be significantly improved by increasing N fertilizers rates. In this study, grain yield and quality were characterised for two recently released cultivars known to contrast for protein content. Crops were grown at Gatton, Queensland, under rainfed and irrigated conditions, and with three N levels. The aim of this study was to determine and quantify differences in yield and grain quality between different modern wheats grown in contrasting N and water conditions. Yield was significantly related to total dry biomass at maturity. Cultivar Suntop achieved higher biomass and yield than Spitfire beyond the treatments imposed, while Spitfire had a significantly greater percentage of grain protein than Suntop.

## Key words
*Triticum aestivum* L, water, nitrogen, protein content, grain number, tillering.

## Introduction
Yield and grain protein content are traits of primary importance for the industry (e.g. Groos et al., 2003) and can be maximised by matching canopy development to seasonal conditions through management of sowing date and density, crop configuration, nutrient supply, and varietal selection. In the northern region, water stress dominates wheat production (Chenu et al., 2011) so that greatest crop productivity involves maximising the amount of water captured by the crop while optimising its distribution between pre- and post-flowering stages. However, against the notion of managing crops to maximise water use efficiency in low rainfall environments, prevailing high nitrogen to grain price ratios require that emphasis be given to the trade-off between water use efficiency and nitrogen utilisation efficiency (Sadras and Rodriguez, 2010). Here, we discuss how water and nitrogen levels influence yield and protein content for two major newly released wheat cultivars.

## Materials and methods
### *Growing conditions*
An experiment was carried out under field conditions at Gatton Research Station (27º 33' 08.23'' S, 152º 19' 40.78'' E; altitude 91 m.) Queensland. Two wheat cultivars (Suntop and Spitfire) contrasting for grain protein content were planted on 2nd July 2014 and grown under rainfed and irrigated conditions in a split plot experiment, where the main blocks were defined by water regime and sub-blocks by cultivars and increasing levels of N supply (Table 1). Rainfed and irrigated crops received no fertilization (treatment N0), 150 kg N $ha^{-1}$ (N150) or 300 kg N $ha^{-1}$ (N300) at sowing (urea fertilization). Each of the six different growing conditions (Gc; Table 1) was replicated three times. All in all, there were 36 plots (six rows per plot oriented in a north-south direction). Diseases and insects were prevented or controlled by spraying recommended fungicides and insecticides at the doses suggested by their manufacturers. Weeds were removed by hand and controlled by spraying selective herbicides.

### *Measurements and analyses*
At anthesis, a linear metre of plants was harvested and then the total number of plants and tillers counted. Within each sample, 6 plants were randomly selected as a subsample and separated in main shoot and tillers. At maturity, 2 linear metres were hand harvested, and grain yield and its main components determined. An analysis of variance and some regression analyses were performed to study the relationships between traits of interest.

**Table 1. Initial conditions and treatments**

| | | | | | Experimental treatments | | | Gowing |
|---|---|---|---|---|---|---|---|---|
| Sowing date | Soil Type | Initial soil water[a] (mm) | Initial soil N[b] (kg N $ha^{-1}$) | Plant density (plants $m^{-2}$) | Water regime[c] (mm) | Fertilization[d] (kg N $ha^{-1}$) | Cultivars | conditions labels (Gc) |
| 2-Jun-14 | Black Vertosol (Lawes) | 206.6 | 70.8 | 150 | Rainfed | 0 | Suntop Spitfire | Gc 1 |
| | | | | | | 150 | Suntop Spitfire | Gc 2 |
| | | | | | | 300 | Suntop Spitfire | Gc 3 |
| | | | | | Irrigated | 0 | Suntop Spitfire | Gc 4 |
| | | | | | | 150 | Suntop Spitfire | Gc 5 |
| | | | | | | 300 | Suntop Spitfire | Gc 6 |

[a] Calculated as plant available water.
[b] Mineral N ($NO_3$-N + $NH_4$-N).
[c] Periodic drip irrigations throughout the growing season, one a fortnight to decile eight. Accumulated rainfall: 108.4 mm
[d] N as urea was applied at sowing.

## Results

In this trial, the main source of variation affecting yield and most of its major determinants was N availability (Table 2). However, cultivars also differed significantly for most studied traits, and water × nitrogen interaction had an order of magnitude higher to that of the cultivar effect on grain weight.

**Table 2. Means and mean square values for yield, above ground dry biomass, harvest index, protein content and main yield components.**

| | | Yield (g $m^{-2}$) | Biomass (g $m^{-2}$) | Number of grains ($m^{-2}$) | Number of grains ($spike^{-1}$) | Number of spikes ($m^{-2}$) | Grain weight (mg $grain^{-1}$) | Harvest index | Protein (%) |
|---|---|---|---|---|---|---|---|---|---|
| **Water regime** | | | | | | | | | |
| Rainfed | | 379.0 a | 939.4 a | 12588.1 a | 35.1 a | 343.0 a | 31.3 b | 0.41 a | 11.2 a |
| Irrigated | | 434.2 a | 1032.3 a | 11574.9 a | 36.0 a | 306.9 a | 37.6 a | 0.42 a | 10.4 a |
| **Cultivars** | | | | | | | | | |
| Spitfire | | 365.2 b | 846.3 b | 10542.8 b | 32.7 b | 304.2 b | 35.0 a | 0.43 a | 11.3 a |
| Suntop | | 455.3 a | 1136.3 a | 13680.9 a | 38.5 a | 345.8 a | 34.0 a | 0.40 b | 10.2 b |
| **Cultivar x Nitrogen** | | | | | | | | | |
| Spitfire | N0 | 150.0 c | 369.8 c | 4099.0 c | 24.7 c | 165.1 c | 36.6 a | 0.41 b | 8.5 e |
| | N150 | 461.5 b | 1039.4 b | 13368.7 b | 36.0 b | 372.2 b | 34.6 ab | 0.44 a | 12.3 b |
| | N300 | 474.9 b | 1129.5 b | 14106.6 b | 37.5 b | 375.2 b | 33.8 bc | 0.42 ab | 13.1 a |
| Suntop | N0 | 211.7 c | 522.3 c | 5895.3 c | 34.1 b | 170.9 c | 36.6 ab | 0.41 b | 8.7 e |
| | N150 | 595.8 a | 1467.9 a | 17550.0 a | 40.2 ab | 436.7 a | 34.2 b | 0.40 b | 10.4 c |
| | N300 | 523.2 ab | 1333.5 a | 16569.2 a | 41.0 a | 404.5 ab | 31.6 c | 0.39 a | 11.5 b |
| **Source of variation** | **d.f.** | | | | | | | | |
| Block ( B) | 2 | $403.0^{NS}$ | $3812.8^{NS}$ | $855501.7^{NS}$ | $1.9^{NS}$ | $718.8^{NS}$ | $2.7^{NS}$ | $<0.01^{NS}$ | $0.2^{NS}$ |
| Water (W) | 1 | $33591.3^{*}$ | $104433.0^{NS}$ | $4581418.6^{NS}$ | $4.6^{NS}$ | $6645.9^{NS}$ | $310.9^{*}$ | $<0.01^{NS}$ | $2.9^{NS}$ |
| B x W | 2 | $1741.0^{NS}$ | $7698.0^{NS}$ | $4735774.9^{NS}$ | $1.2^{NS}$ | $2227.3^{NS}$ | $5.8^{NS}$ | $<0.01^{NS}$ | $0.3^{NS}$ |
| Cultivar (C) | 1 | $56772.6^{***}$ | $586760.1^{***}$ | $66979575.0^{***}$ | $277.2^{***}$ | $9466.2^{*}$ | $6.6^{NS}$ | $<0.01^{*}$ | $10.9^{***}$ |
| Nitrogen (N) | 2 | $405847.8^{***}$ | $2308673.7^{NS}$ | $394469301.0^{***}$ | $318.4^{***}$ | $191657.9^{***}$ | $42.8^{***}$ | $<0.01^{*}$ | $40.7^{***}$ |
| W x C | 1 | $16186.0^{*}$ | $102934.8^{*}$ | $7132972.3^{NS}$ | $11.4^{NS}$ | $3235.1^{NS}$ | $24.4^{*}$ | $<0.01^{NS}$ | $0.6^{NS}$ |
| W x N | 2 | $11664.7^{NS(c)}$ | $59232.6^{NS}$ | $2091185.5^{NS}$ | $17.0^{NS}$ | $2339.9^{NS}$ | $58.0^{***}$ | $<0.01^{NS}$ | $1.6^{NS(b)}$ |
| C x N | 2 | $6352.6^{NS}$ | $62187.7^{NS(a)}$ | $4398658.7^{NS}$ | $28.1^{*}$ | $2481.4^{NS}$ | $3.9^{NS}$ | $<0.01^{NS}$ | $3.3^{**}$ |
| W x C x N | 2 | $24.0^{NS}$ | $1313.1^{NS}$ | $413510.6^{NS}$ | $10.0^{NS}$ | $25.8^{NS}$ | $3.3^{NS}$ | $<0.01^{NS}$ | $0.18^{NS}$ |
| Error | 19 | 3528.9 | 19135.3 | 3713439 | 7.1 | 1523.2 | 3.8 | 0.02 | 0.44 |

The asterisks stand for the level of significance of the mean squares: * P<0.05; **P<0.01; ***P<0.001; NS not statistically significant
(a) Level of significance of the mean square HxPop interaction P=0.0593. (b) Level of significance of the mean square WxN interaction P=0.0504
(c) Level of significance of the mean square WxN interaction P=0.0586

Yield was positively and significantly related to total dry biomass at maturity ($r^2$= 0.91; P<0.001; Fig. 1) The different cultivars and treatments resulted in a wide range of yields, which ranged from 113 to 613 g $m^{-2}$ (oven dry; Fig. 1, left panel). The largest effect was the nitrogen availability (Table 2). The yield of the different cultivars differed significantly as well. Cultivar Suntop achieved higher biomass and yield than Spitfire in all treatments (Table 2 and Fig. 1 left panel).

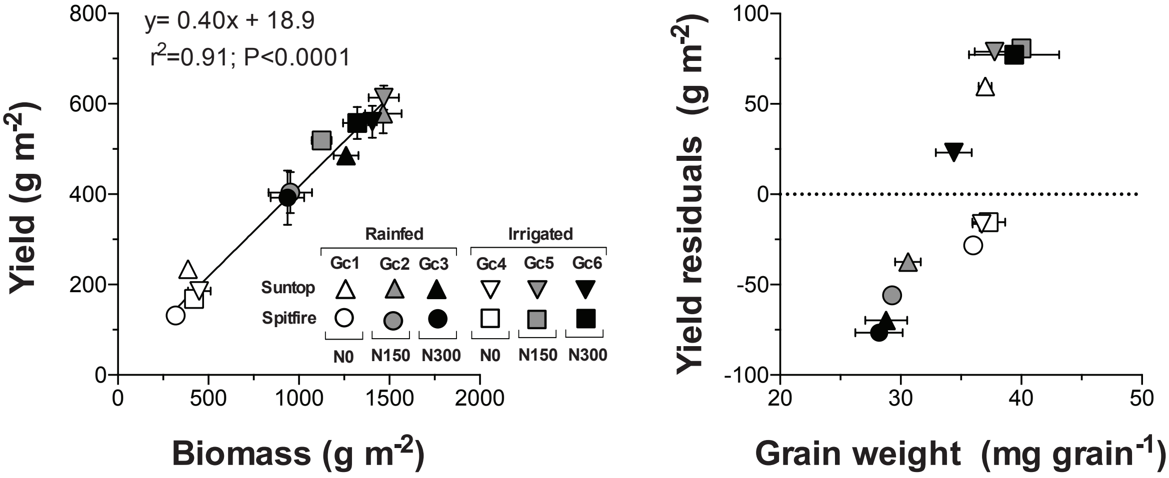


**Figure 1. Relationship between yield and total biomass at maturity (left panel), and yield residuals and grain weight (right panel) during 2014 growing season, for two wheat cultivars and six growing conditions (Gc1-Gc6) at Gatton Research Station. Symbols correspond to six different growing conditions: Gc1 - Gc3: Suntop and Spitfire (triangles and circles, respectively) with 0, 150 and 300 kg N ha$^{-1}$ (open, grey and black symbols, respectively) under rainfed conditions. Gc4- Gc6: Suntop and Spitfire (inverted triangles and squares, respectively) with 0, 150 and 300 kg N ha$^{-1}$ (open, grey and black symbols, respectively) under irrigated conditions. Bars correspond to *SEM.***

The high yield of Suntop was correlated to a high number of grains. Suntop had more grain per m$^2$ than Spitfire as a result from (i) a higher spike number per m$^2$ as consequence of a higher tillering, and (ii) more grains per spike (Table 2). Under rainfed condition, the lower the level of fertilization the higher the grain weight, while under irrigated conditions, fertilization resulted in bigger grains (Fig. 1 right panel).

Spitfire had a significantly greater percentage of grain protein than Suntop in all fertilized conditions (Fig. 2). Significant cultivar x N interactions were also observed when N fertilisation was applied (N150 and N300) (Fig. 2 left panel and Table 2). While in most conditions, the high protein level of Spitfire was related to a relatively low yield (dilution effect), under high N (N300) and water (irrigated) availability, Spitfire achieved a high yield together with a high protein content (Fig. 2 right panel). By contrast, the yield of Suntop was reduced by the highest fertilisation level (N300) compared to a more moderate level (N150) in both the rainfed and the irrigated treatments.

In the case of unfertilized treatments (values within dotted circle in Fig. 2, right panel) there was a strong yield reduction as a consequence of a severe N stress (Fig. 2 right panel).

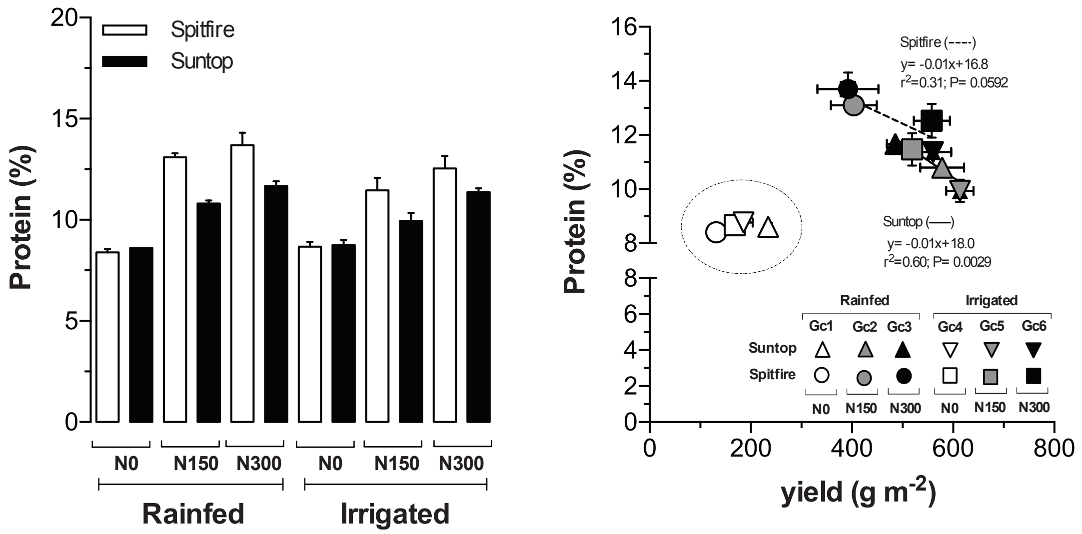


**Figure 2. Left panel: grain protein content under different N fertilization (0, 150 and 300 kg N ha$^{-1}$) and water availability for Spitfire and Suntop in 2014 at Gatton. Right panel: relationship between grain protein content and yield. Bars correspond to *SEM.***

## Discussion

Significant differences were observed when we compared grain yield and protein content of Spitfire and Suntop. The main differences between these two wheat cultivars were related to biomass production, yield and grain protein content. The fact that genotypic differences in yield were closely related to their biomass highlights that it is likely to improve yield through increasing biomass rather than its partitioning This was in line with what Ferrante et al. (2012) found when they subjected wheat to different N and water availabilities. This is, in turn, rather relevant as further gains in harvest index are limited (though still possible; Foulkes et al., 2011).

Results also provide evidence of the benefit from properly targeting levels of nitrogen supply to seasonal conditions and expected yields (e.g. over fertilization of Suntop resulted in reduced yield). In addition, there was a trade-off between being efficient for producing yield and for having high grain protein percentage.

In conclusion, the results of this comparison of wheat cultivars provide empiric evidence of the advantage to get more grains, and produce more biomass to increase yield potential.

## Acknowledgements

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