Co-limitation in wheat crops of Eyre Peninsula as a way to better understand N and water economy

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Location: Minnipa Agricultural Centre, paddock N5S
Rainfall
Av. Annual: 325 mm
Av. GSR: 241 mm
2016 Total: 391 mm
2016 GSR: 268 mm
Yield
Potential: 3.60 t/ha (W)
Actual: 4.93 t/ha
Paddock History
2015: Legume pasture
2014: Barley
2013: Wheat
Soil Type
Red sandy clay loam
Plot Size
10 m x 1.6 m x 3 reps
Yield Limiting Factors
Water availability, hot temperatures

Key messages

- **Wheat yields increased with the level of water and N co-limitation explored.**
- **Higher yield in modern cultivars was partially associated with higher co-limitation.**
- **The higher yield of modern cultivars was related to use efficiency rather than to capture of water and N.**
- **Grain yield increased with increasing N uptake per unit of water used.**

Why do the trial?

Within Eyre Peninsula, as in other Mediterranean environments, grain yields of cereal crops are variable, and in many cases, this is due to under-fertilisation. Previous modelling and field experiments showed the need for higher rates of fertilisation in south-eastern Australia. Research into interactions between water and N, with simulation models and empirical data, has proved that yield, as well as water-use efficiency, is positively related to the degree of co-limitation between water and N [1, 2]. In other words, yield and water use efficiency increase when the stress produced by water has similar intensity to the stress produced by N. The understanding of how resources co-limit and its genotypic variability in wheat crops of Eyre Peninsula is a key step for improving the water use efficiency and to reduce yield gaps.

This trial is part of a new project which addresses research and development gaps on the interactions between water and nitrogen in Australian cropping systems identified in GRDC scoping study DAS00157. The novelty of this project is a new tool to estimate the actual water and nitrogen stress and co-limitation in the season. The new tool will complement existing tools and provide opportunities to adjust N availability in the season, thereby reducing farmers' risk and increasing chances of capturing the benefits of wetter seasons. Results are expected to be applicable to the medium to low rainfall areas of south-eastern and western Australia. The current project is focused on management of nitrogen fertiliser under uncertain conditions as related to variable rainfall and changing agronomic practices.

The aim of the current trial was to evaluate the impact of water and N co-limitation on grain yield of wheat under different N and water availability and to assess the genotypic variability in the main parameters.

How was it done?

A field experiment combining four wheat genotypes released in different decades, two N rates, and two water availabilities was set up at Minnipa Agricultural Centre. The genotypes were chosen to represent at least the last 50 years of agriculture and were Halberd (1969), Spear (1984), Mace (2007) and Scepter (2015). Nitrogen rates were control (12 kg N/ha applied at sowing) and 120 kg N/ha split in two applications before Zadocks growth stage 31. The two water treatments consisted of a rainfed crop and a 25 mm irrigation at the beginning of stem elongation; we used 13 cm spaced drip irrigation lines parallel to the crop rows. The sowing density was targeted at 180 plants/m^2, and rows spaced at 27 cm. Prior to sowing we applied MAP at a rate of 120 kg/ha. Weeds, pests and diseases were controlled following the practices used for National Variety Trials (NVT).

Soil water content was measured gravimetrically at sowing and maturity to 1 m depth, and water use calculated as the difference in soil water plus in-season rainfall. Water use efficiency ($WUE_{Biomass\ or\ yield}$) was calculated as the ratio between total biomass (kg/ha) or grain yield (kg/ha) and water use (mm).

Nitrogen uptake was measured for each experimental unit and N use efficiency was calculated. The levels of water and N stress were calculated using the method of Cossani *et al* (2010) with locally derived parameters. The stress indices range from 0 (no stress) to 1 (maximum stress) for both water and N. Nitrogen stress index and water stress index were used to calculate total stress index (T_{WN}), maximum stress index (M_{WN}) and co-limitation.

A co-limitation index (C_{WN}) tending to 1 when the magnitude of the limitation by water and nitrogen were similar. Therefore, values closer to 1 indicate better balance between N and water stress, while closer to 0 indicate either water or N stress was dominant. Yield potential was estimated at 6.35 t/ha.

Results

Environmental conditions (soil, rainfall, and temperatures) were outstanding for crops in Minnipa. There was 27% more rainfall from April to October than the average. An additional benefit of temperatures from August to November was also observed with a lower minimum (20%), and lower maximum temperatures (5%) than the average of Minnipa.

Grain yield

Grain yield of wheat increased with the year of release of the cultivar at a rate of approximately 24 kg/ha per year (Figure 1). The addition of 25 mm of water increased grain yield by approximately 0.3 t/ha. However, there was a genotype x water availability interaction showing a higher response to extra water supply for the modern cultivars in comparison with the older lines. On the other side, N did not produce any significant response in grain yield. The highest yield was observed for Scepter (4.8 t/ha) with the extra-supply of water, while the lowest yield was obtained by Halberd (3.3 t/ha) (Figure 1). Grain yield was mainly related to grain number per square meter (R^2=0.80 $P<0.001$), but also to the thousand kernel weight (R^2=0.54 $P<0.01$).

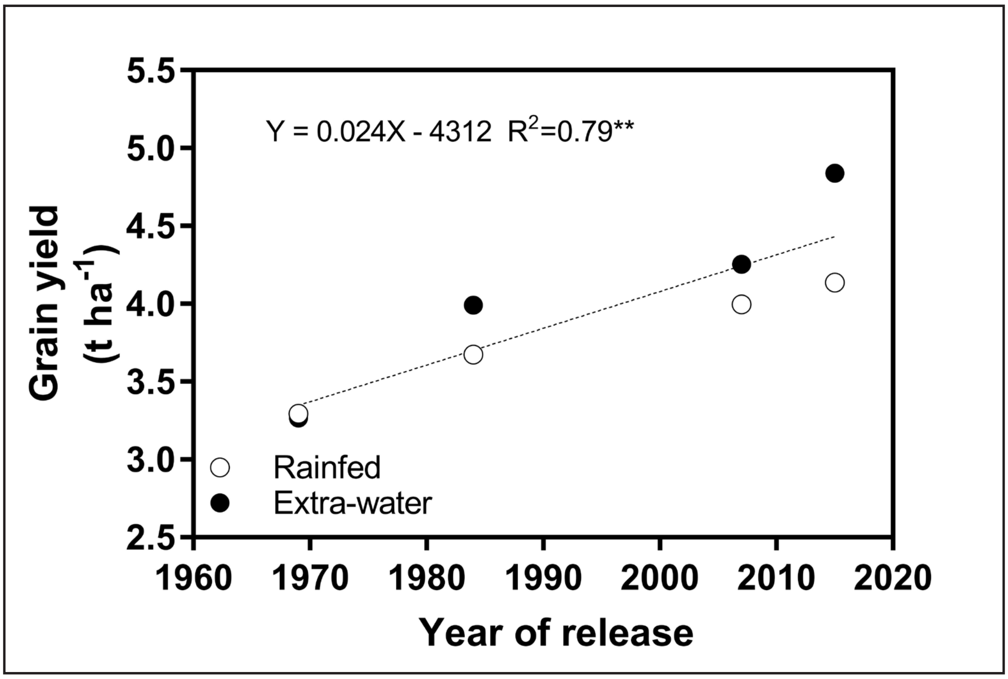

Figure 1 Grain yield as a function of the year of release for all 4 cultivars evaluated. Closed dots represent treatment with 25 mm of extra water, while clear dots represent rainfed conditions
*** Indicates a level of statistical significance of P <0.01*

Cereals

Efficiency in the use of water and nitrogen

Water use efficiency (kg_{grain}/ha/mm) ranged between 10.8 and 17.5 kg_{grain}/ha/mm for all cultivars and conditions, and was affected by water availability x cultivar interaction. Scepter was the most responsive cultivar to the extra-water supply. Similar to grain yield, water use efficiency increased with the year of release of the cultivars at a rate of 0.11 kg_{grain}/ha/mm/year. The highest water use efficiency was observed for Scepter with extra water supply (17.2 kg_{grain}/ha/mm) which was approximately 50% more efficient in using water than Halberd. Intermediate water use efficiency values were found for Spear (13.2 kg_{grain}/ha/mm) and Mace (15.4 kg_{grain}/ha/mm).

Nitrogen use efficiency (NUE) ranged from 12.5 to 21.4 kg_{grain}/kg $N_{available}$ with the N, and differed between cultivars. Similarly to grain yield and WUE, NUE increased with the year of release (Figure 2) at a rate of 0.087 kg_{grain}/ha/kg $N_{available}$/ha/year. In this case, there was a general increase in NUE as a consequence of higher water availability (16.7 kg_{grain}/kg $N_{available}$ vs 15.0 kg_{grain}/kg $N_{available}$ for extra water and rainfed treatments, respectively). As expected, N treatment affected NUE by decreasing it when more N was applied (14.2 kg_{grain}/kg $N_{available}$ vs 17.6 kg_{grain}/kg $N_{available}$ for fertilised and unfertilised treatments, respectively).

Furthermore, there was an increase (R^2 = 0.88) in N utilization efficiency (kg_{grain} /kg $N_{uptaken}$) with the year of release at a rate of approximately 0.13 kg_{grain}/kg $N_{uptaken}$/year. These results indicate that once N is uptaken, modern lines are more efficient in producing yield than old lines.

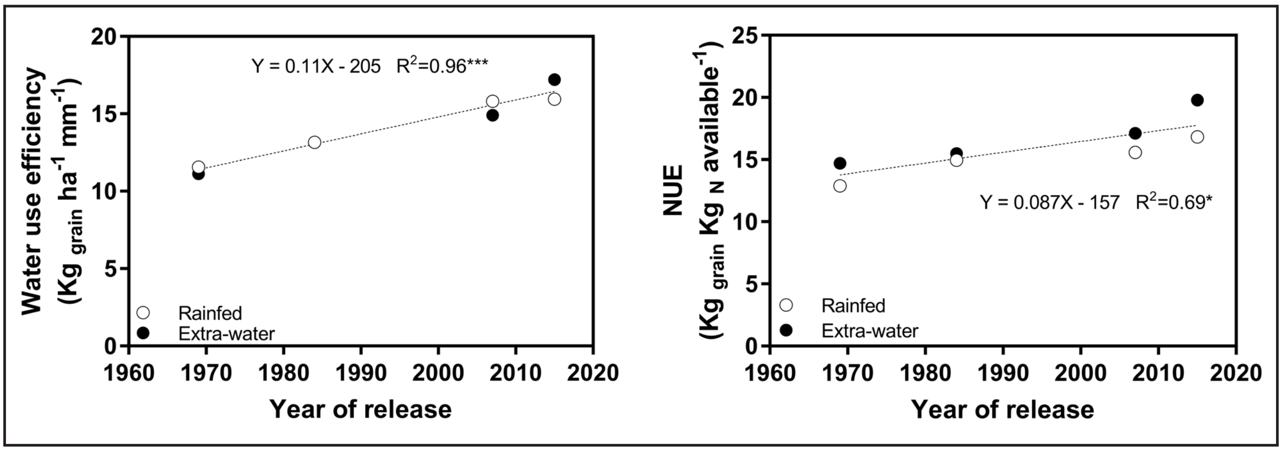

Figure 2 Water use efficiency and nitrogen use efficiency as a function of the year of release for all 4 cultivars evaluated. Closed dots represent treatment with 25 mm of extra water, while clear dots represent rainfed conditions

, **, or * Indicate a level of statistical significance of P <0.05; P<0.01; P<0.001, respectively*

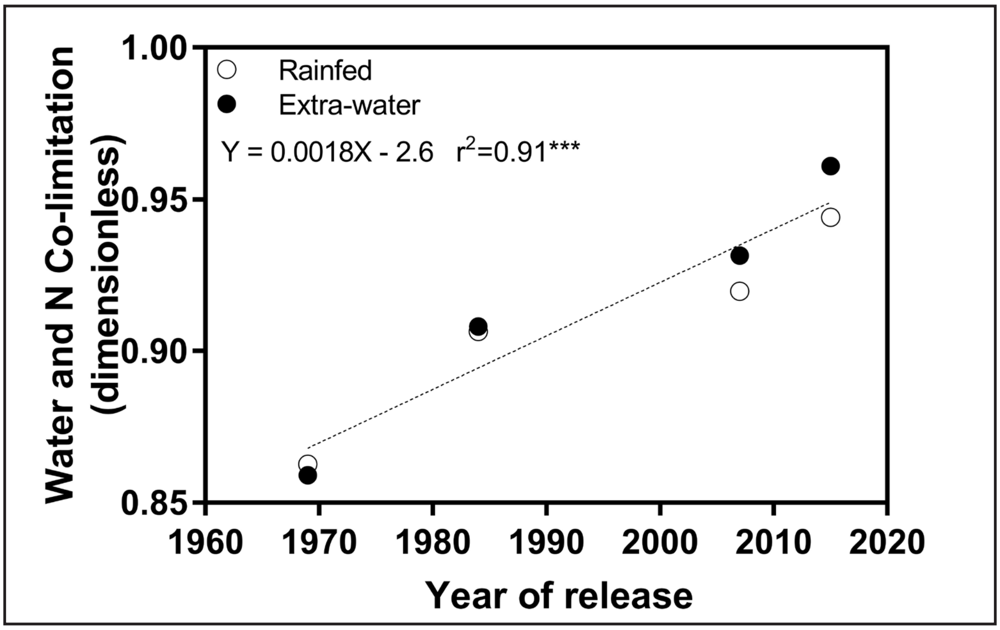

Figure 3 Water and N co-limitation as a function of the year of release for all 4 cultivars. Closed dots represent treatment with 25 mm of extra water, while clear dots represent rainfed conditions

**** Indicates a level of statistical significance of P<0.001*

Given the high N in the soil and high rainfall during the growing season, co-limitation range was narrow, between 0.79 and 0.96, indicating balanced stress of water and N. Following the same pattern observed for grain yield, the best balance between N and water stress was obtained by Scepter (0.95) while the poorest balance was observed for Halberd (0.86).

Interestingly, and in line with the resource use efficiency, the water and N co-limitation was higher in the modern cultivars than in the old cultivars (Figure 3). There was a positive correlation between grain yield and water and N co-limitation (R^2=0.95 P<0.001). N and water co-limitation was also positive related to water use efficiency (Figure 4, upper panel). These results are in line with previous research for South Australia and for Spain.

Similarly to the results observed with water use efficiency, N use efficiency (kg_{grain}/kg $N_{available}$) and N utilization efficiency (kg_{grain}/kg $N_{uptaken}$) were positively related to water and N co-limitation (Figure 4 middle and bottom panel). Results agree with previous work carried out by SARDI researchers that demonstrated that breeding for yield has improved the nutrition economy of wheat.

In general, modern cultivars tended to uptake more N per each mm of water used (Figure 5). There were no significant differences between both modern cultivars (Mace, Scepter), while differences between old cultivars indicated a higher capacity to uptake N per each mm of water used for Spear than for Halberd. The higher capacity to uptake N per each mm of water used was also positively related to the grain yield (R^2=0.82 P<0.05) and to harvest index (R^2=0.76, P<0.05). Results are in line with recently published results for Australia which demonstrates that modern cultivars have higher N uptake per unit root biomass in comparison with old cultivars [3].

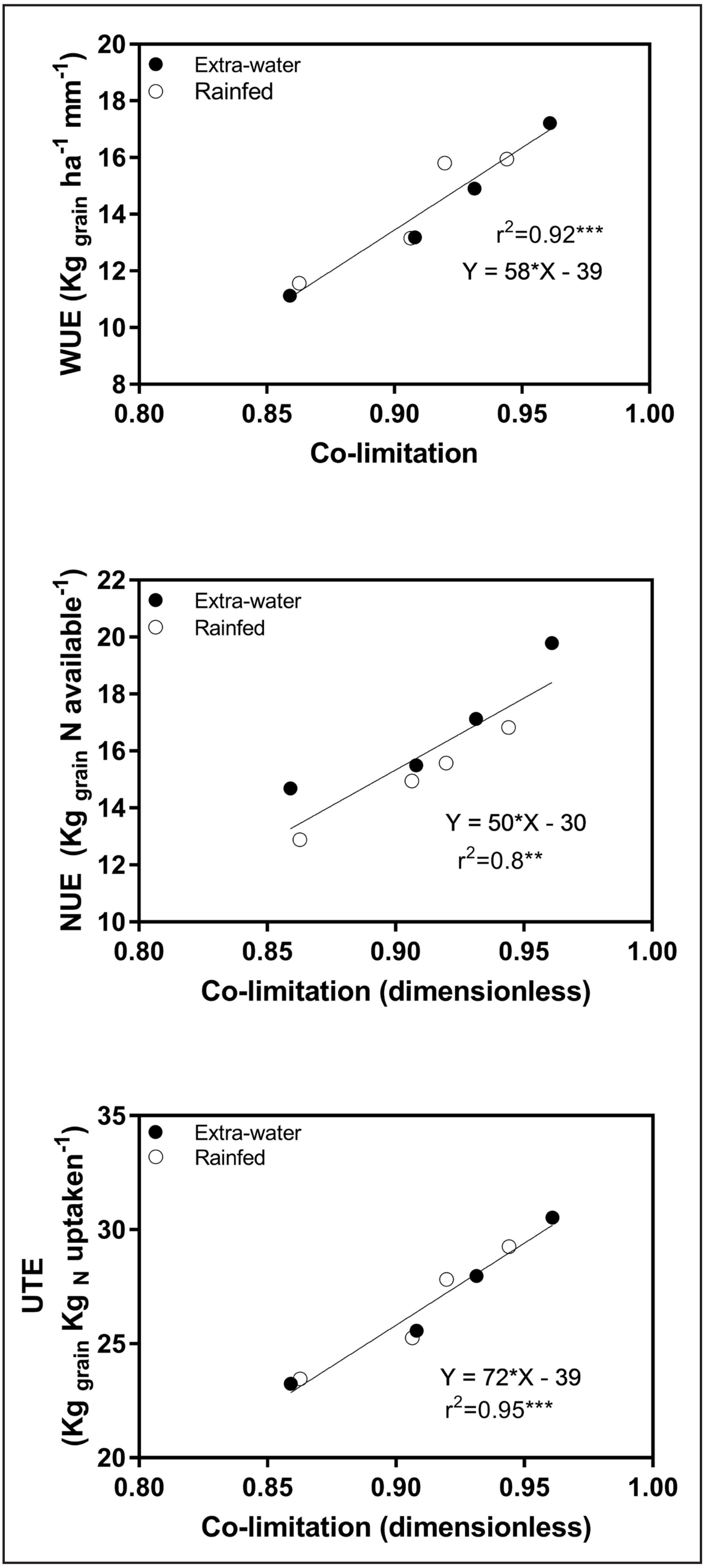

Figure 4 Water use efficiency (WUE), nitrogen use efficiency (NUE), and nitrogen utilization efficiency (UTE) as a function of water and N co-limitation for all 4 cultivars. Closed dots represent treatment with 25mm of extra water, while clear dots represent rainfed conditions

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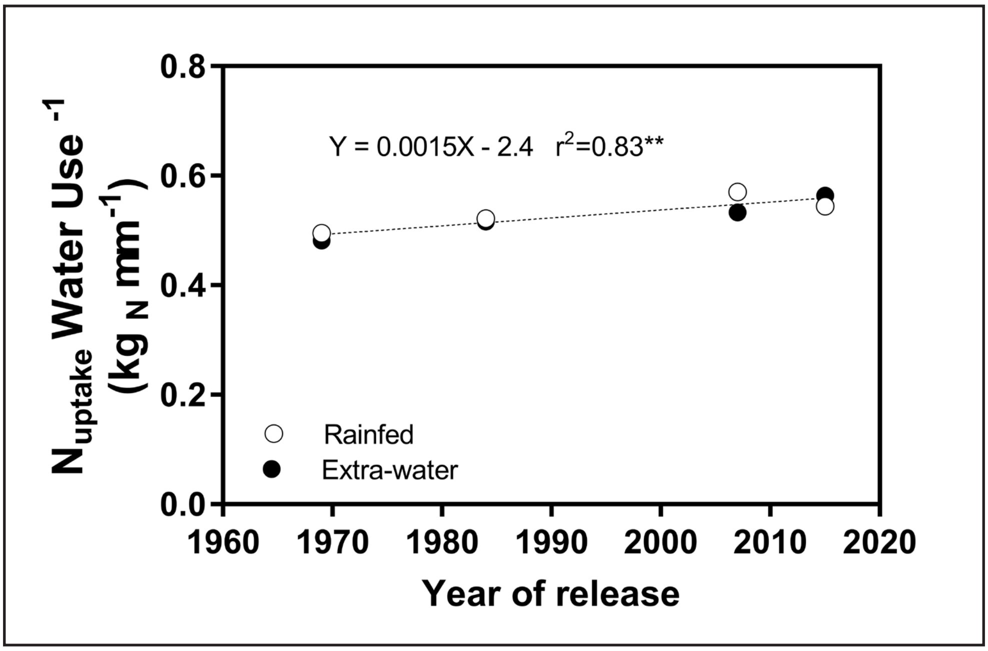

Figure 5 N uptake per mm of water used as a function of the year of release for all 4 cultivars. Closed dots represent treatment with 25 mm of extra water, while clear dots represent rainfed conditions
*** Indicate a level of statistical significance of P<0.01*

What does this mean?

Results of the first experimental year, 2016 agreed with previous results in Spain and Australia underlining the importance of properly matching N to water availability. The grain yields, WUE, NUE and UTE were higher where a balance between stress of N and water was achieved. Additionally, the experiments indicate a genetic progress through breeding in terms of the capacity of plants to balance their stress, by improving the efficiency in N uptake for each mm of water used. These results reinforce the concept and importance of developing tools to estimate the co-limitation of resources. These tools could help farmers to improve the yields by better matching N to actual water stress levels. Such kinds of tools should be based on plant status, soil conditions (water and N) and probability of rainfall.

This preliminary analysis, together with previous literature, suggests an improvement in the root system by eliminating a redundancy in deeper soil layers. That reduction was associated to a higher water use efficiency of modern cultivars in comparison to the old cultivars.

Further research is needed to investigate to what extent roots can be further trimmed to improve the water use efficiency by reducing yield gaps.

Acknowledgements

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