Key constraints to irrigated wheat yields in the southern Murray-Darling basin.

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Abstract
Grower surveys indicate there is a 2 t/ha yield gap between expected "average" and "best ever" yields of irrigated wheat in the irrigation areas of the southern Murray-Darling Basin. This project aimed to determine the major reasons for this discrepancy. Sixty four commercial wheat crops were monitored over a three year period (2014-2016) across a range of soil types and irrigation systems. The results of this monitoring showed that 64% of irrigated wheat crops in southern NSW and northern Victoria are not achieving close to their water-limited yield potential. Four key yield constraints were identified: waterlogging, drought stress, late sowing and wide row spacing. Better paddock drainage, more timely and better scheduled irrigations, sowing early in the window, and matching row spacing to the target yield, are the key messages for irrigators.

Key Words
Drought stress, waterlogging, sowing time, row spacing, wheat, irrigation

Introduction
The average annual gross value of irrigated cereal (grain) production was $370 million over the three years from 2015 to 2017 and 50-60% of this came from the irrigated areas of the southern Murray-Darling Basin (SMDB) (Australian Bureau of Statistics 2018). Commercial irrigated wheat yields of 8 t/ha are possible in this region (Figure 1) and advisory materials show how to achieve this yield level (Fisher et al. 2014). However, a grower survey conducted in 2014 (North *et al.* 2017) showed expected "average" irrigated wheat yields are considerably lower (5–6 t/ha) and that a 2 t/ha yield gap exists between expected "average" and "best ever" yields. The objective of this project was to determine the reasons for this discrepancy and identify key management strategies to overcome yield limitations.

Methods
Sixty-four commercial wheat crops were monitored over a three-year period (2014–2016) across a range of soil types and irrigation systems in the irrigation areas and districts of the SMDB (Figure 1).

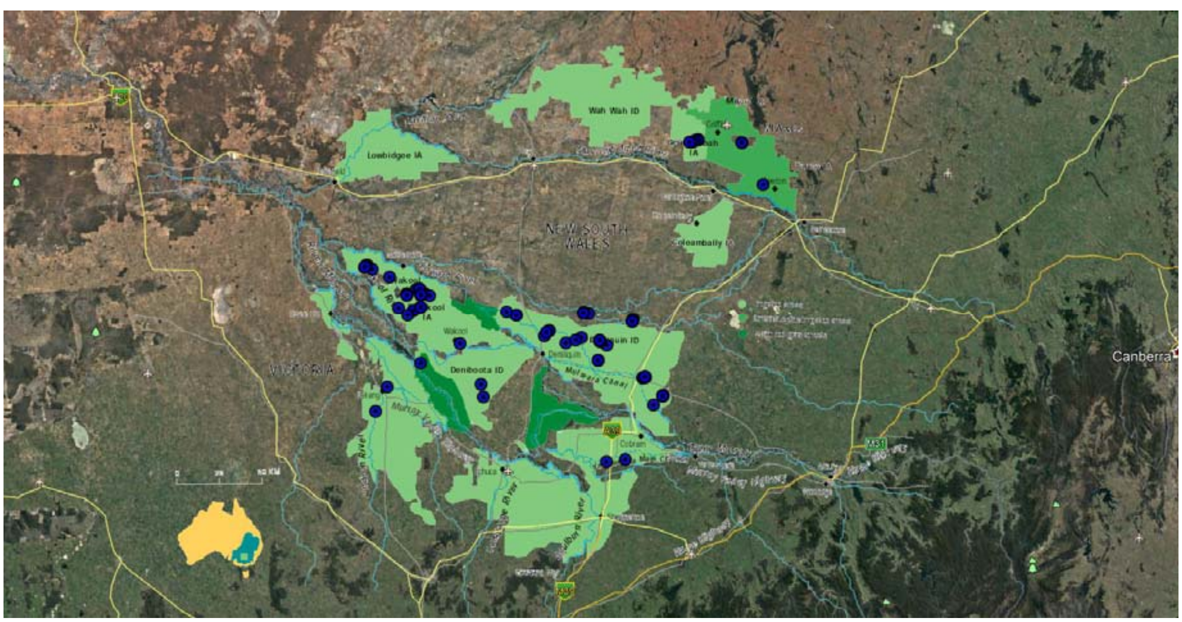

Figure 1. The location of the sites where commercial wheat crops were monitored in 2014-2016 with respect to the irrigation areas and districts of the southern Murray-Darling Basin. Base map: Google Earth™. Irrigation area map: Murray Darling Basin Authority.

Soil water (matric) potential (ψ_m) sensors were installed at each site to monitor the occurrence and duration of waterlogging and drought stress. Sites were visited at least twice (at the end of tillering and at anthesis) to record crop development, the presence or absence of disease, weeds, and waterlogging/drought stress. At physiological maturity, three quadrat cuts (1 m^2) were taken in representative parts of the crop within a 10 m radius of the soil moisture monitor site to measure yield components (number of tillers per m^2, grains per spike and grain weight) and grain yield. Paddock inputs and header yield data were collected from cooperators at the end of each season.

Two yield potentials were calculated for each crop:

1. The physiological yield potential – based on average photothermal quotient (PTQ) over the 30 day period before anthesis (Peake & Angus 2009).
2. Water-limited yield potential – based on the French and Schultz (1984) equation.

These two yield potentials were calculated in order to indicate the limits for achievable wheat yields in the monitored crops.

Multiple linear regression and backward step-wise regression were used to examine correlations between grain yield and total, growing season applied water (rain + irrigation); total applied nitrogen; sowing rate; and row spacing. Correlations between grain yield and soil type and irrigation system were also examined. The stress-day index concept (Hiler and Clarke 1971) was used to examine the effect of waterlogging and drought stresses on yield and yield components.

Results and Discussion

Yields from the 64 commercial crops ranged between 2 t/ha and 8.5 t/ha. Only one crop in the three years had a yield over 8 t/ha. There was no correlation between yield and either soil type or irrigation system type. Nor was there a significant linear correlation between yield and applied nitrogen, sowing rate or row spacing. There was a significant positive correlation between yield and total applied water ($R^2 = 0.54$, $P < 0.001$).

Plotting grain yield against total, growing season applied water for each year, together with the average and minimum physiological yield potential and the water-limited potential (Figure 2), shows:

- Average physiological potential yield varied each year, being 10.0 t/ha, 9.9 t/ha and 8.5 t/ha in 2014, 2015 and 2016 respectively. One crop in 2015 and two in 2016 achieved yields close to the minimum physiological potentials calculated in those years.
- Twenty-three of the 64 crops monitored (i.e. 36%) achieved close to their maximum possible yield, with yields greater than 80% of the water-limited yield potential.

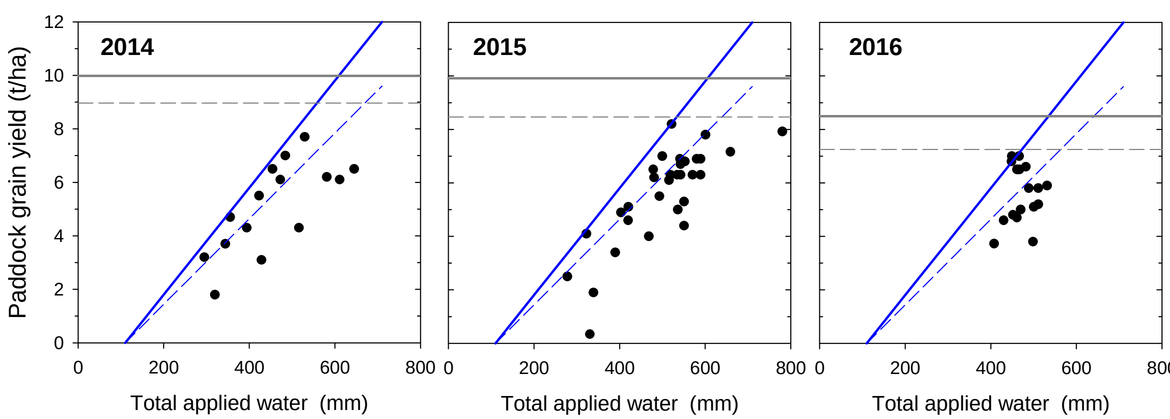

Figure 2. Plots of paddock grain yield (t/ha) on total, growing season applied water (rain + irrigation) (mm) for the commercial wheat crops monitored in 2014 (15 crops), 2015 (31 crops) and 2016 (18 crops).

Note: Horizontal lines show the average (solid grey) and minimum (dashed grey) physiological potential (Peake & Angus 2009) for the crops monitored each year calculated from temperature and solar radiation in the 30 days prior to flowering for each crop. The diagonal black lines define the water-limited yield potential (thick blue line) and 80% of the water-limited yield potential (thin, dashed blue line).

Physiologically potential yields were calculated for each year of the period 1997 to 2016 using Rawson's (1998) equation and average PTQ for the 30 days prior to a mid-flowering date in week 40 (end September and start of October). Long-term median physiological yield potential for wheat in the irrigated regions of the SMDB was found to range from 9 t/ha in the western Murray and the Murrumbidgee, to 9.7 t/ha in the eastern Murray, but it varied annually between 6–7 t/ha and 11–12 t/ha. On average, the current best practice benchmark irrigated wheat yield of 8 t/ha (Fisher *et al.* 2014) was not physiologically achievable in 25% of years during the period examined. This was certainly the case for many crops in 2016 when cloud in spring limited solar radiation and resulted in a lower physiological potential (Figure 2), despite abundant rainfall. Clear skies in 2015 resulted in a higher physiological yield potential and good conditions in spring allowed one irrigated crop to achieve near this potential. In contrast, hot weather in early October 2014 (i.e. anthesis) meant no crop achieved close to its physiological potential that year.

Examination of the soil water potential and yield component data revealed waterlogging and drought stress to be responsible for a major reduction in two key yield components:

1. Cumulative days waterlogged ($\psi_m > -6$ kPa at 5 cm depth) from 40 to 20 days before anthesis accounted for 46% of the variation in tiller density in 2016 (Figure 3 left).
2. Cumulative days waterlogged from 40 to 20 days before anthesis plus cumulative days drought stressed ($\psi_m < -100$ kPa at 5 cm depth AND < -60 kPa at 30 cm depth) from 20 days before 10 days after anthesis accounted for 66% of the variation in grains/m^2 in 2014 and 2015 (Figure 3 right).

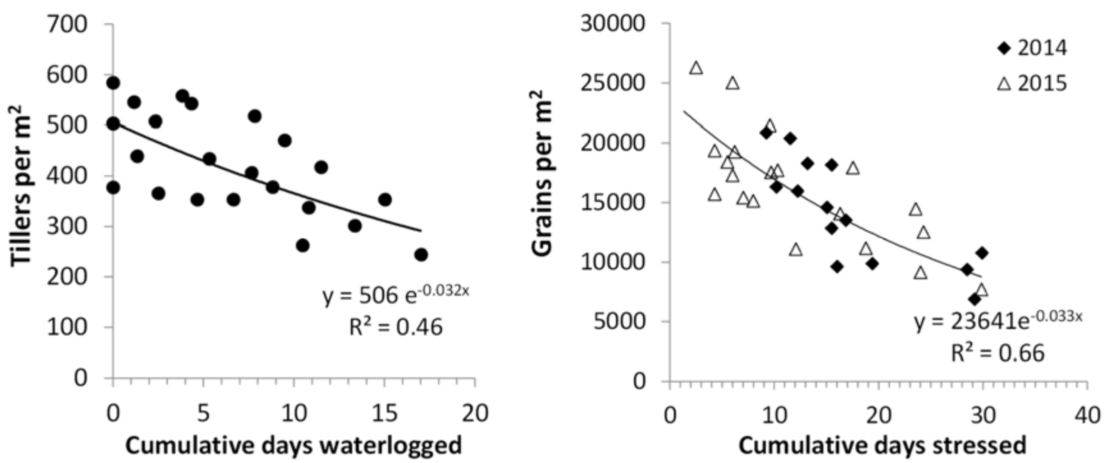

Figure 3. The relationships between tillers per m^2 and cumulative days waterlogged 40–20 days before anthesis in 2016 (left); and grains per m^2 and cumulative days waterlogged 40–20 days before anthesis and drought stressed from 20 days before10 days after anthesis in 2014 and 2015 (right).

The different response in 2016 was due to the exceptionally wet conditions during that season. This led to waterlogging in late August–early September, but negated the need to spring irrigate as crops had sufficient soil water to avoid water-stress leading up to, and after, anthesis. This was not the case in 2014 and 2015 when crops that were not irrigated on time had periods of drought stress.

Two other yield-reducing factors were identified: sowing date (Figure 4 left) and row spacing. All 23 of the well managed crops were sown in May and all within the recommended sowing window of the 10 varieties in the group. For these crops, where crop inputs reflected target yields and the effect of drought and waterlogging stress was minimal, sowing at the end of May resulted in a 1 t/ha lower yield than sowing at the start of May (Figure 4 left). This represented a yield loss of 3% per week (given a 7 t/ha crop sown at the start of May), which is slightly less than the 4–7% yield drop indicated by Matthews and McCaffery (2019) for each week delay in sowing after the optimum sowing time recommended for a variety.

With respect to row spacing, no crop achieved more than 7 t/ha if sown in rows more than 0.23 m apart (Figure 3 right). This confirms trial results that show plant populations which have a within-row distance between plants less than 2.5 cm have either a neutral or negative impact on yields (Poole and Hunt 2014).

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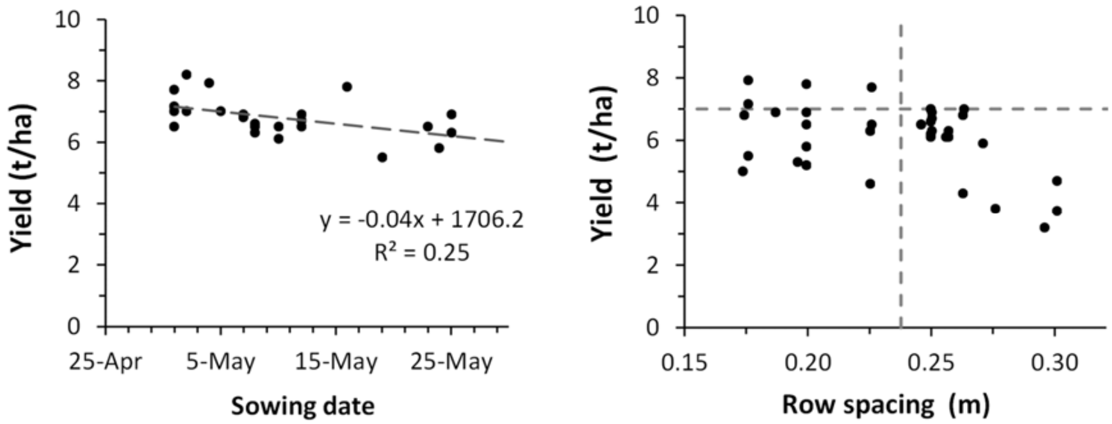

Figure 4. The relationship between wheat yield (t/ha) and sowing date for the sub-group of well managed crops in 2014, 2015 and 2016 (left); and between wheat grain yield (t/ha) and row spacing (m) for all 64 of the monitored crops (right). The grey dashed horizontal and vertical lines indicate a yield of 7 t/ha and a row spacing of 0.24 m respectively

Conclusions

Commercial irrigated wheat crops in the SMDB can attain yields close to their physiological potential. However, yields are primarily determined by the amount of water a crop receives, which accounted for 54% of the variation in observed grain yields. While the amount of irrigation water applied to a crop is a commercial decision, a major proportion (64%) of the crops that were monitored should have produced higher yields from the depth of water that was applied to them. Better paddock drainage, more timely and better scheduled irrigations, sowing early in the window, and matching row spacing to the target yield (i.e. not sowing in rows > 0.23 m for a 7+ t/ha yield target), are the key advisory messages to have come out of this project.

Acknowledgements

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