Estimating water and N co-limitation levels of wheat using remote sensing technologies across upper Eyre Peninsula

RESEARCH

Fabio Arsego[1], Andrew Ware[2], C. Mariano Cossani[3] and Victor O. Sadras[3]

[1]SARDI, Minnipa Agricultural Centre/Port Lincoln, [2]SARDI Port Lincoln, [3]SARDI Waite

Looking for answers

Location
Minnipa Agricultural Centre, N10 paddock
Rainfall
2017 GSR: 141 mm
Yield
Potential: 1.2 t/ha (W)
Paddock History
2017: Medic pasture
2016: Wheat/Mace
Soil Type
Red sandy clay loam
Plot Size
5 m x 1.6 m x 3 reps

Location
Lock
Rainfall
2017 GSR: 191 mm
Yield
Potential: 2.8 t/ha (W)
Paddock History
2016: Kaspa peas and clover
2015: Barley
2014: Wheat
Soil Type
Grey sandy loam
Plot Size
5 m x 1.6 m x 3 reps

Key messages

- **It was possible to estimate N uptake and water content with remote sensing.**
- **Co-limitation of nitrogen and water was associated with wheat yield increases.**

Why do the trials?

In-season nitrogen applications are challenging for South Australian growers. Due to the high economic risks of extra nitrogen (N) fertilisation, growers miss opportunities to reach maximum attainable yields due to underestimation of optimum fertiliser requirements. Recent studies have proven the positive relationship between the simultaneous limitation of yield (co-limitation) by water and nitrogen, attainable grain yield and water use efficiency. Therefore, growers can reduce management risks and maximise their profit by matching nitrogen requirements with water availability (co-limitation of water and nitrogen levels) during the season.

Spectroradiometry is a type of remote sensing (RS) technology that allows estimation of the nutritional content and stress condition of the crop in a non-destructive way. This tool can be applied to measure in-season co-limitation nitrogen and water levels, assisting growers to make more informed in-season nitrogen decisions. This approach has the potential to minimise economic risks during poor seasons while maximising profit in favourable ones.

The current study aims to validate the 2017 season co-limitation results, and test the remote sensing prediction of water and nitrogen RS status of the crop in different locations of the Eyre Peninsula.

How was it done?

Field research trials were established across a range of environments with different water availability on Eyre Peninsula with experimental plots at Minnipa, Cummins and Lock. A complete randomised block design with three replicates was used with four genotypes, two N rates and two water availabilities in all locations. Treatments consisted of 60 kg/ha nitrogen with rainfed conditions, and extra nitrogen (100 kg/ha applied at GS31) and water (50 mm/plot applied at GS31). Genotypes consisted of well adapted wheat varieties that have been used during the last 50 years; Halberd (1969), Spear (1984), Mace (2007) and Scepter (2015). Weeds, pests and diseases were managed following practices used for National Variety Trials (NVT).

Soil samples were obtained to estimate water content and N at anthesis and maturity stages. Samples were obtained to a soil depth of 60 cm due to soil structure. Water use was calculated considering water inputs from soil and rainfall.

Stress and co-limitation indices were calculated following the method of Cossani et al. (2010). Nitrogen and water stress indices (NSI and WSI) were calculated following the formulas: NSI=1-((harvested biomass N (N uptake) (kg/ha))/ ((maximum attainable yield (t/ha) x nitrogen reference requirements (kg N))) and WSI=1 - ((rainfall from sowing to anthesis/maturity(mm)+irrigation(mm)-water content in the soil at anthesis (mm)/maturity(mm))/(maximum attainable yield (t/ha)/WUE reference requirements)). NSI and WSI were used to derive total, maximum stress indices and co-limitation. Co-limitation indices tending to 1 meant an equilibrium between stress, while co-limitation indices closer to 0 indicate unbalance between limitations.

Spectral data was collected at the same time as soil sampling using a SR-3500 spectroradiometer from Spectral Evolution with 25^o (field of view) bare fiber optic. Spectral data were pretreated with standard normal variate, moving average smoothing and Savitzky-Golay derivation. Partial least square regression (pls) was then used to calculate the relationship between pretreated spectral data and nitrogen and water data.

Results

Grain yield

In Minnipa, low rainfall conditions (122 mm from sowing to maturity) affected the overall crop yield performance to an average yield of 1.2 t/ha. Lock had better rainfall conditions (215 mm from sowing to maturity) resulting in an overall crop yield of 2.8 t/ha. Highly significant ($P<0.001$) variation for grain yield was found across extra water treatments, varieties, environments and growth stages. Significant interactions were observed between varieties and environments ($P<0.001$), and between environments and growth stage (Z65 and Z70). No significant variability and interaction was detected for extra nitrogen application, as previously observed in Minnipa 2016. This result may suggest the varieties performance may depend on a better adaption to nitrogen use and responsiveness to extra water application with a significant impact of environment and growth stages. Scepter and Mace were equally the best performing varieties in both sites (Table 1). At Lock, Scepter and Mace yielded an average of 3.55 t/ha with an extra 50 mm of irrigation reaching a yield advantage of 0.5 t/ha. In Minnipa, both varieties had an average yield of 1.67 t/ha with the extra 50 mm of irrigation at stem elongation and 0.6 t/ha of yield advantage. In Minnipa rainfed conditions, Scepter yielded an average of 1.14 t/ha, while Mace was 1.04 t/ha. The lower yielding varieties were Spear in Lock (average grain yield 1.73 t/ha) and Halberd in Minnipa (0.73 t/ha) in rainfed conditions.

Table 1. Grain yield averages (t/ha) across varieties, treatments and environments.

Environment	Treatment	Variety	Mean grain yield (t/ha)±SE
Lock	Irrigated	Halberd	2.53 ± 1.19
Lock	Rainfed	Halberd	1.73 ± 0.69
Lock	Irrigated	Spear	2.81 ± 2.34
Lock	Rainfed	Spear	2.38 ± 1.35
Lock	Irrigated	Mace	3.55 ± 1.73
Lock	Rainfed	Mace	2.97 ± 1.57
Lock	Irrigated	Scepter	3.55 ± 1.43
Lock	Rainfed	Scepter	3.11 ± 1.36
Minnipa	Irrigated	Halberd	1.1 ± 0.97
Minnipa	Rainfed	Halberd	0.96 ± 1.20
Minnipa	Irrigated	Spear	1.18 ± 0.86
Minnipa	Rainfed	Spear	0.73 ± 0.64
Minnipa	Irrigated	Mace	1.66 ± 0.21
Minnipa	Rainfed	Mace	1.05 ± 0.36
Minnipa	Irrigated	Scepter	1.68 ± 0.95
Minnipa	Rainfed	Scepter	1.14 ± 1.16

Partial least square regression (pls) was used to calculate the relationship between pretreated spectral data and nitrogen and water data Across all remote sensing (spectroradiometry) calibrations for water and nitrogen content at maturity, the R^2 was greater than 0.93 (Figure 1a-b). These values suggested the regression was good with no overfitting on the calibration models. Minnipa had similar calibration curves (Figure 1a, maturity) to Lock (Figure 1b, maturity). At both sites, water content data tended to cluster at maturity (Figure 1a-b), maybe due to leaves starting to senesce. The resulting reflectance predictions of water and nitrogen were then added in the WSI and NSI formulas as water content at maturity (mm) and harvested biomass N (kg/ha) at maturity.

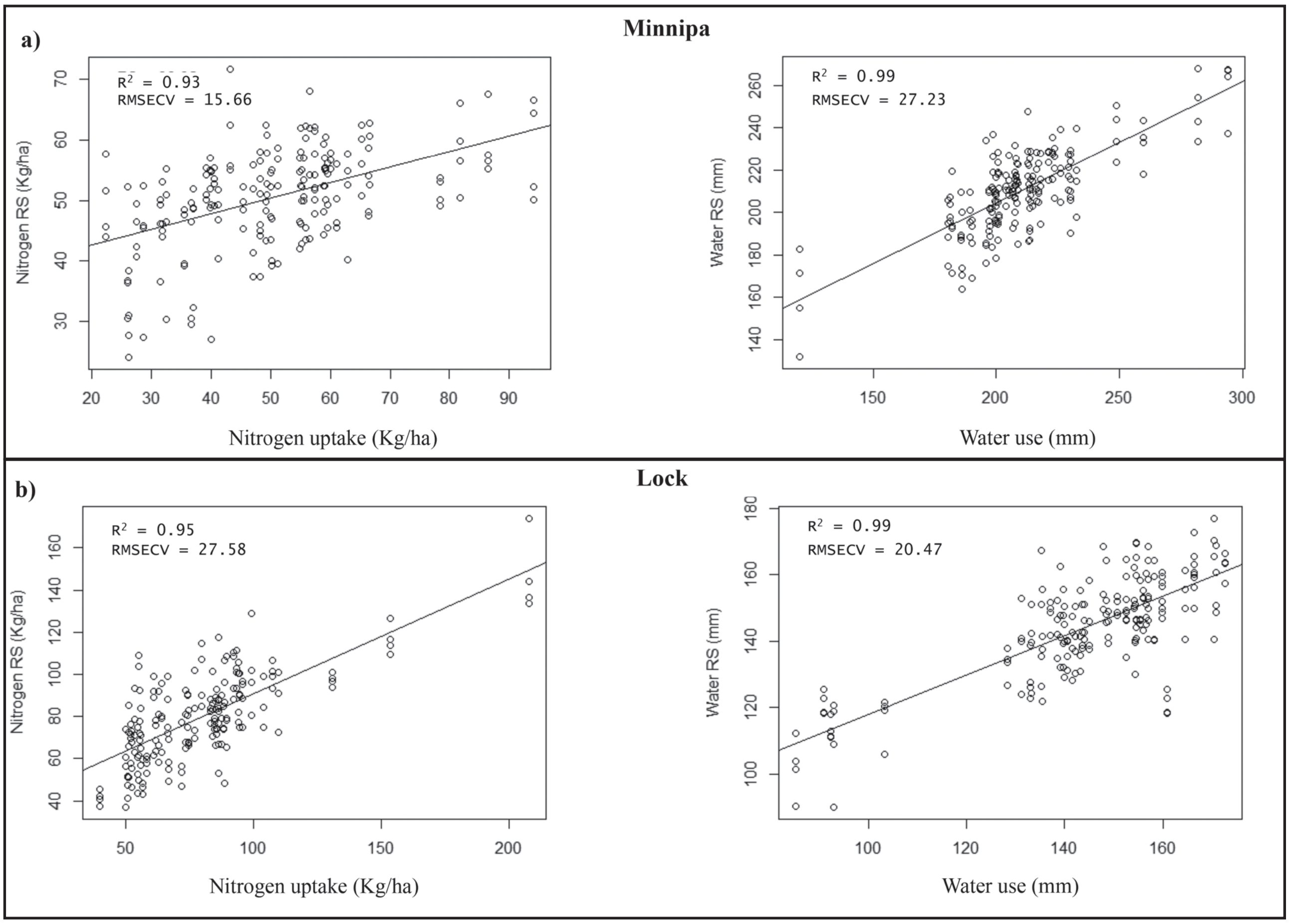

Figure 1a and b. Calibration lines of water and nitrogen RS predictions vs. actual values at Minnipa (a, maturity) and Lock (b, maturity). The RMSECV (Root mean square error of cross validation) is a measure of deviation between actual and predicted data.

Nitrogen and water content RS predictions vs oven dried method

Water and nitrogen remote sensing predictions were plotted against the actual water and nitrogen values taking into effect the environments and corresponding treatments (Figure 2a-b). As a result, water data seemed to have the best fit (R^2=0.97, SE=6.03, Figure 2a) compared to the nitrogen treatment (R^2=0.75, SE=10.97, Figure 2b).

An ANOVA test was performed to look at the relationships between variables. In both trials, significant variability ($P<0.001$) was found across water and nitrogen measurements. Lock had also significant ($P<0.01$) variation in nitrogen treatments ($P<0.001$), while Minnipa had significant ($P<0.001$) differences in water treatments. These results suggest that remote sensing can predict water content and nitrogen, however, treatments and variety detection were affected by the environment.

Co-limitation indices traditional methods vs. RS

At maturity, co-limitation indices and biomass (kg/ha) were calculated for each cultivar at both trials (Figure 3a-c and Figure 4a-c). In Lock, positive significant relationship ($P<0.001$) have been found between grain yield (kg/ha) and co-limitation indices at both water (R^2=0.72, SE=544.5) and nitrogen treatments (R^2=0.64, SE=619.3). Interestingly, remote sensing predictions at both trials had a better fit for nitrogen treatment (R^2=0.64, SE=613) compared to the actual measurements (Figure 3b). In Minnipa, significant relationships ($P<0.001$, R^2=0.29) between co-limitation indices and grain yield were found only under water treatment (Figure 3a).

What does this mean?

Lock results were in line with the Minnipa 2016 co-limitation experiment and confirmed the positive relationship between co-limitation indices and yield. Nitrogen and water measurements of remote sensing and traditional methods were highly correlated at both stages and environments. However, remote sensing was not capable of detecting differences between varieties and treatments in a consistent way across environments.

Remote sensing technology has a great potential for estimating water and nitrogen content in wheat instead of applying traditional methods, however, further studies need to address environment confounding effects and lack of genotypic variability.

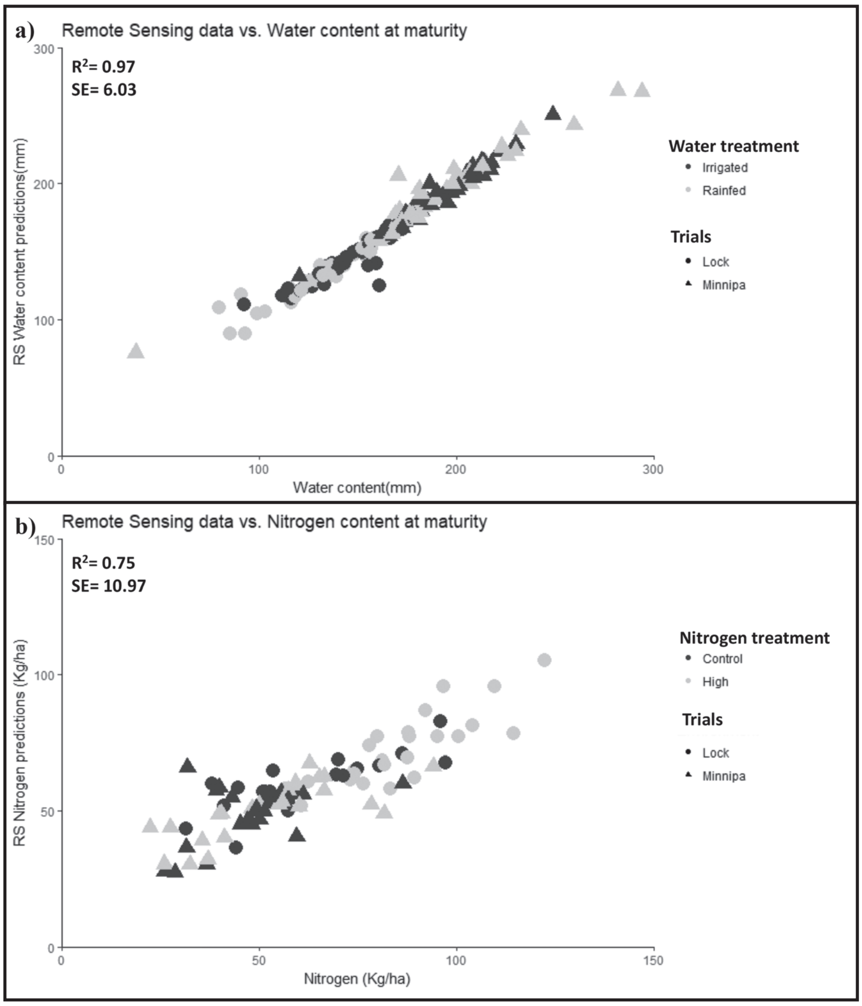

Figure 2a and b. Relationships between traditional and RS methods for assessing water (a, mm) and nitrogen (b, kg/ha) content.

Acknowledgements

The present project is part of the bilateral investment initiative between SARDI and GRDC. Special thanks to Jake Hull, Stuart Modra and Ian Burrows for providing the field trials in Minnipa, Lock, and Cummins. Thank you to Brenton Spriggs, Sue Budarick, Blake Gontar, Dave Holmes, Ashley Flint and Jake Giles for their collaboration with field activities.

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

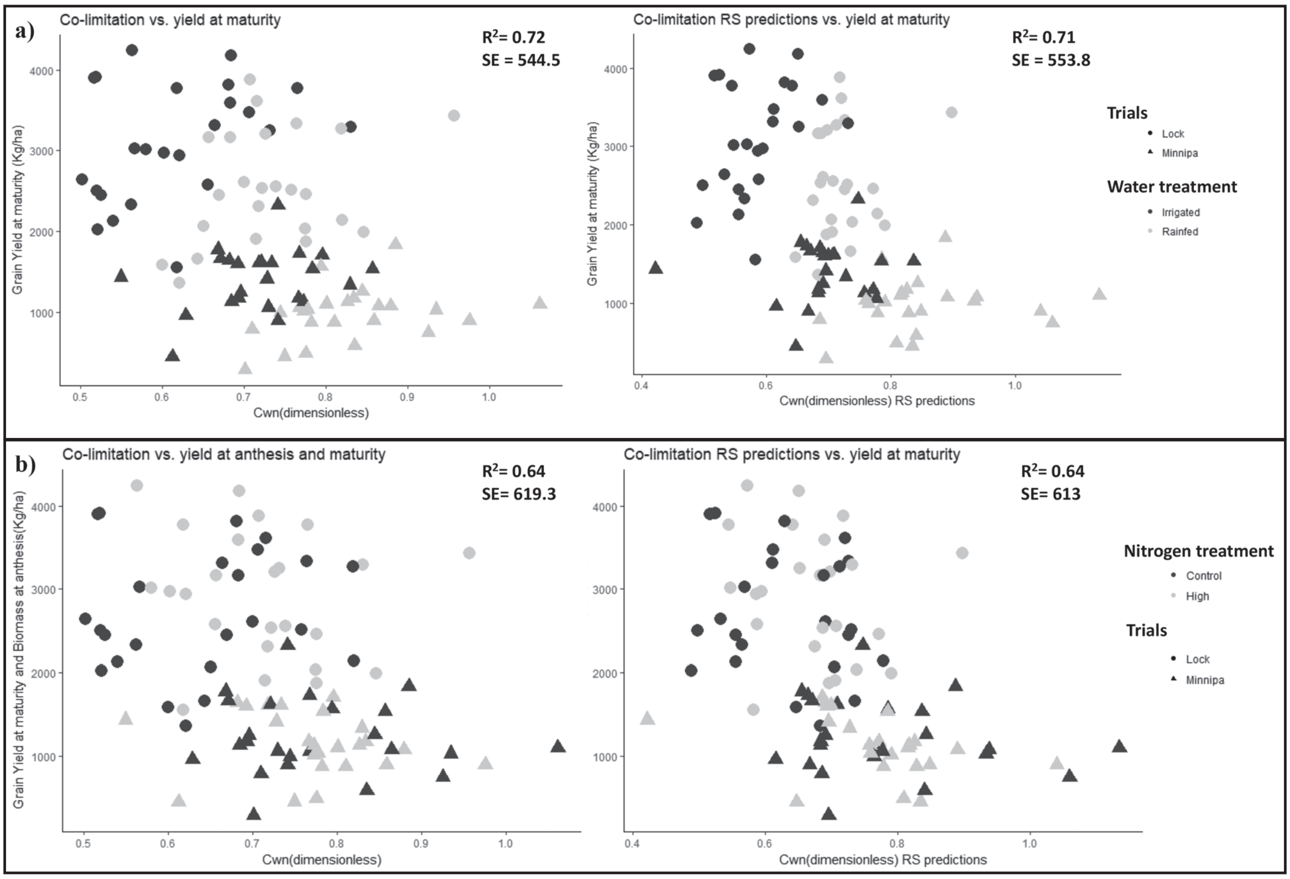

Figure 3a and b. Comparing traditional and RS methods for assessing co-limitation indices and grain yield relationships at maturity in Lock and Minnipa.