Can we optimise N applications for grains using spatial estimates of N sufficiency?

E M Perry[1,2], G J Fitzgerald[2,3], A F Colaço[4], A Clancy[3], and R G V Bramley[4]

[1] Agriculture Victoria, Department of Jobs, Precincts and Regions, 1 Taylor Street, Epsom, VIC, 3551,
Email: eileen.perry@agriculture.vic.gov.au
[2] The University of Melbourne, Parkville, VIC, 3000, Australia
[3] Agriculture Victoria, Department of Jobs, Precincts and Regions, 110 Natimuk Rd, Horsham, Victoria 3400
[4] Centre for Agricultural Innovation, School of Agriculture and Food, Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, VIC 3010, Australia.
[5] CSIRO – Agriculture and Food, Waite Campus, Locked Bag 2, Glen Osmond, SA 5064, Australia.

Abstract

The Canopy Chlorophyll Content Index (CCCI) using sensor information combined with a physically measured dilution curve (Canopy Nitrogen Index; N% vs biomass) allows sensed data to be more directly linked to crop growth and development. Paddock-scale experiments were run for three years in rainfed wheat and barley in southern Australia, utilising N reference strips designed to capture the spatial variability. These datasets were used to establish an N dilution curve. CCCI, calculated from ground-based active optical sensing data, was combined with estimates of above ground biomass (AGB) from time series of Sentinel-2 imagery to estimate plant N% and N uptake based on the established N dilution curve. The estimates of AGB and plant N% across all sites were compared with direct measurements, resulting in R^2 values of 0.75 and 0.64, respectively. Estimated N uptake values at each sample site, paired with the estimated biomass from the equivalent N rich strip point (target biomass), were used to compute the N required to match the target N uptake.

Keywords

Remote sensing, spatial measurements, NDVI time series, crop sensors.

Introduction

Remotely sensed indices based purely on spectral information to estimate canopy N content have been developed for many years but mapping canopy N at key phenological stages to inform N fertiliser decisions is improved if the relationship between canopy N% and biomass is known (Fitzgerald et al. 2010). The Canopy Chlorophyll Content Index (CCCI) using sensor information combined with a physically measured dilution curve (Canopy Nitrogen Index; N% vs biomass) allows sensed data to be more directly linked to crop growth and development. Using only sensed data at a key physiological stage (e.g., growth stage 30-31) when fertiliser decisions are made, a relationship can be developed based on a pre-established dilution curve. This allows a grower to apply sufficient N to achieve the desired growth and biomass based on canopy N% using only sensed data. The broad framework for an N sufficiency approach is presented in Colaço et al. (2021) in these proceedings.

Methods

Datasets used

Nitrogen fertiliser strips at 0, 1, and 2 times the paddock rates were incorporated in a 119 ha paddock planted to wheat (2018) and barley (2019), and a 235 ha paddock planted to wheat (2020) all located near Nhill VIC. Target sampling locations were selected to represent the soil variability within the fertiliser strips at 27, 27 and 30 points for the three years. Likewise, data from 2018-2020 acquired from a 64 ha paddock located near Tarlee SA (described in Colaço et al. 2021) was also analysed with 21 target sampling sites for each year. Plant N%, above ground biomass (AGB), and active optical measurements (Holland Scientific Crop Circle ACS-470, ACS-430; Lincoln NE USA) were acquired during the crop stem elongation at all sampling locations in each trial. The active optical measurements were used to compute the Canopy Chlorophyll Concentration Index (CCCI; Fitzgerald et al. 2010).

AGB from satellite time series NDVI

Sentinel-2 satellite imagery Normalized Difference Vegetation Index (NDVI) time series were used to estimate AGB for each 10m pixel at the date of the active optical measurements. The methods employed are described in Perry et al. 2021.

Estimation of canopy N and N uptake

The estimation of canopy N based on this approach requires the establishment of functions to relate vegetation indices (e.g., CCCI) to Canopy Nitrogen Index (CNI), and estimates of AGB to back calculate plant N%. First, we establish the N dilution curve, which describes the relative amount of plant N% for a given AGB, based on direct measurements of AGB and plant N%. This proportion of plant N%, termed the CNI, is described in Fitzgerald et al. (2010). The upper and lower bounds of the dilution curve are fitted manually using exponential equations. Second, we establish the relation between CNI from direct measurements of plant N% to CCCI from active optical measurements using a linear equation.

Results

Establishing the N dilution curve bounds

Plant N% and dry matter measurements for the VIC and SA paddocks were used to determine the upper and lower limits of the N dilution curve, as shown in Fig. 1. The fitted equations were determined as:

$$\%N_{max} = 1.359+EXP(1.746+(-0.001892*AGB\ g/m^2)) \quad [1]$$

$$\%N_{min} = 0.305+EXP(1.372+(-0.009187*\ AGB\ g/m^2)) \quad [2]$$

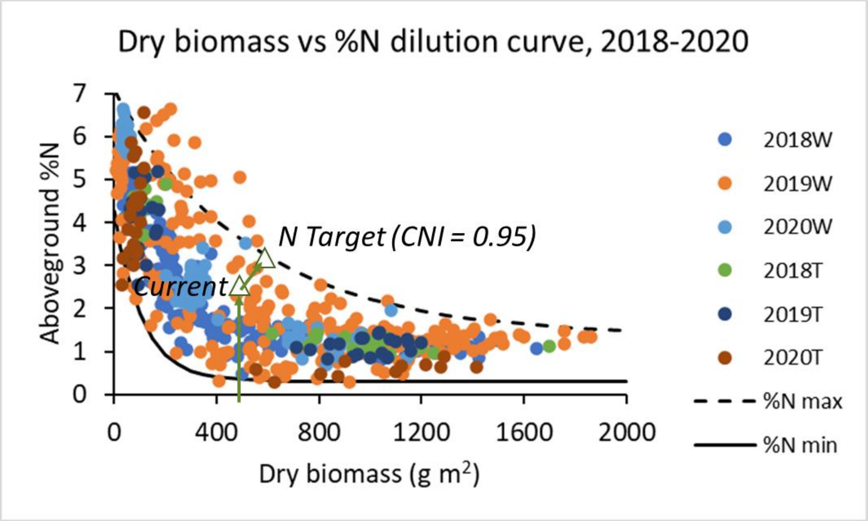

Figure 1. The N dilution curve determined for the combined VIC (W) and SA (T) datasets (wheat and barley), showing the N_{min} and N_{max} bounds used to compute CNI.

Relating CNI to active optical CCCI

CCCI was computed for each dataset using bounds for that data, following Fitzgerald et al. (2010). All the datasets, excluding the 2019 Woorak VIC data, resulted in the relationship shown in Fig. 2. The 2019 VIC data resulted in a distinctly different slope and intercept value, and therefore was excluded from the remaining analyses.

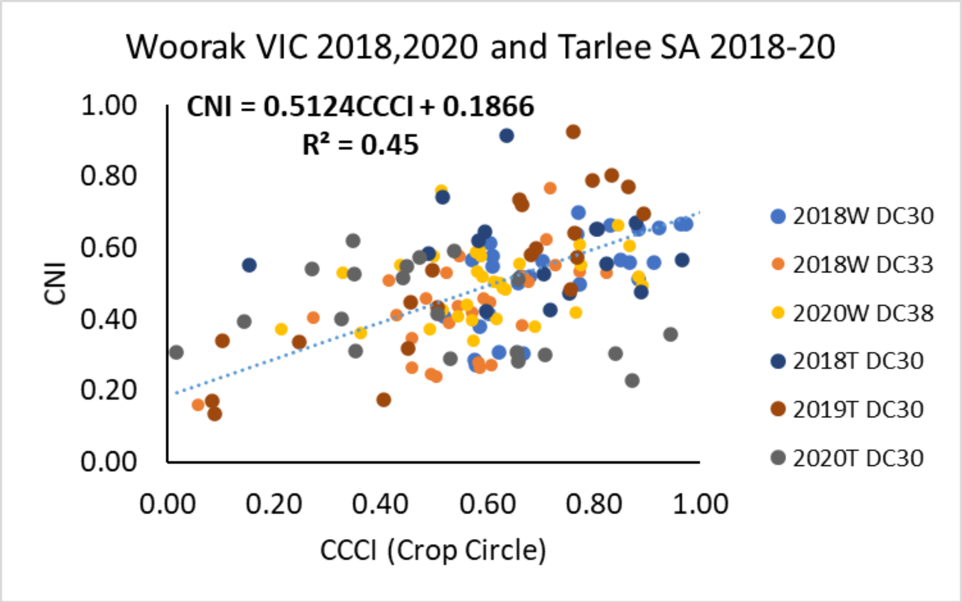

Figure 2. Relating CNI from direct biomass sampling to the active optical CCCI for the VIC (W) and SA (T) datasets.

Estimating Canopy N and N uptake from CCCI
AGB was computed from cumulative NDVI based on the relationship:

$$\text{AGB kg ha}^{-1} = -1658.3 + 116.5*\text{summed NDVI} \qquad [3]$$

The AGB was estimated for the date of the active optical measurement, at each sample site within the paddock. The CNI was calculated from the active optical CCCI measurements based on the relationship shown in Fig. 2. Plant N% was then calculated from the CNI and biomass estimates:

$$N\% = CNI*(N_{max} - N_{min}) + N_{min} \qquad [4]$$

where N_{max} and N_{min} were determined from the estimated AGB using Eq. 1 and 2. Figure 3 shows the resulting estimated AGB and plant N% for each measurement site, plotted against the corresponding measured values for all sites. N uptake was then determined by multiplying the plant N%, divided by 100, with the corresponding AGB values.

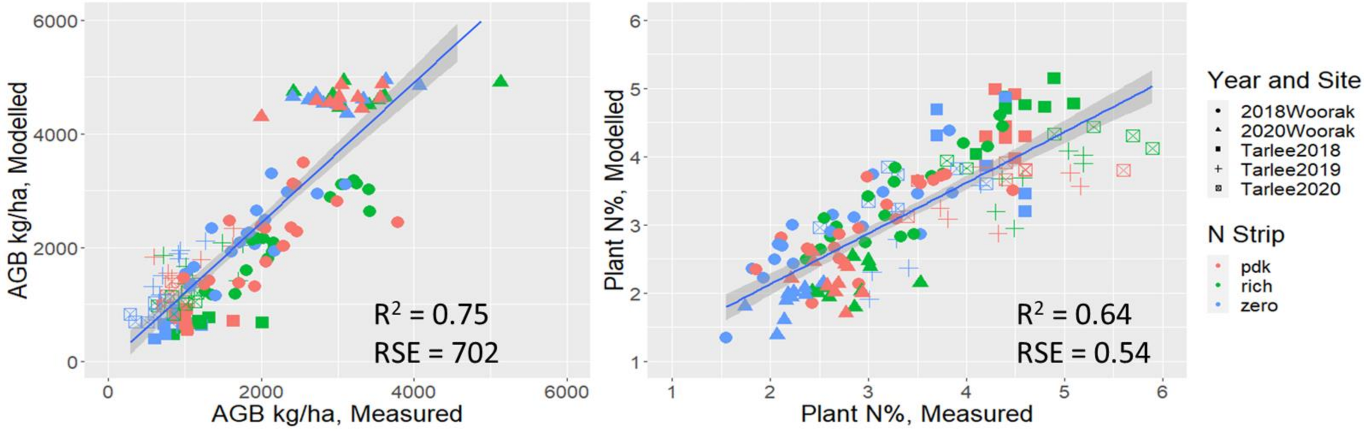

Figure 3. AGB (left) and plant N% (right) estimated from active optical CCCI and Sentinel-2 time series graphed against measured values for VIC (2018, 2020) and SA (2018-2020).

Discussion and Conclusions

The estimated N uptake can be used to determine a fertilizer requirement, based on the framework presented in Colaço et al. 2021. N requirement is defined as the difference between the estimated N uptake for any given point, and the corresponding target N uptake. This is represented by the arrow from ‘Current’ to ‘N Target’ in Fig. 1. The target N uptake is determined from the estimated biomass for the N rich strip point which best corresponds to the current point, and specifying a CNI value of 0.95. We determined the required N for all sample sites using this framework. The mean N uptake values for each fertilizer level (rich, paddock and zero) at each site and growth stage are presented in Table 1.

Table 1. Estimated N requirements N kg ha^{-1}, by site, growth stage, and N strip

Strip	2018 Woorak GS30	2018 Woorak GS33	2020 Woorak GS38	2018 Tarlee GS31	2019 Tarlee GS31	2020 Woorak GS30
Zero	32	59	79	14	55	33
Paddock	30	55	65	8	36	22
Rich	23	47	67	7	36	17

In terms of application for Australian dryland grains, this approach could potentially be implemented in various strategies. The approach would require the grower to establish N strips (zero and N rich) that capture the soil variability within the paddock. The estimate of AGB from satellite imagery could be computed a few days before the active optical sensing. The AGB and CNI from active optical sensors could be used to generate an N requirement map (Colaço et al. 2021), which could be simplified by management zones. It may be possible to perform the required N application on the go, if the placement of the N rich strips allowed measurements prior to the remaining paddock.

One of the remaining research questions is how well the relationship between CCCI and CNI (Fig. 2) holds for paddocks outside of the calibration data. We plan to evaluate this with the application of the established relationships to datasets from additional paddocks with direct sampling and active optical measurements taken during stem elongation.

One alternative to the use of CCCI from active optical data is to determine NDVI and NDRE from the same Sentinel-2 imagery used for AGB. This would offer the opportunity to assess N entirely from remotely sensed data, and to retrospectively assess N status where active optical data isn’t available. We plan to evaluate the relationship between CCCI from Sentinel-2 with CNI determined from direct measures to assess the stability of the relationships between CCCI and CNI across paddocks and years.

Acknowledgements

This research was funded by the Grains Research and Development Corporation (GRDC) and Agriculture Victoria.

References

Colaço AF, et al. (2021). A framework for sensor-based nitrogen management using nutrient dilution and sufficiency. Presented at the 20th Australian Society of Agronomy Conference, Toowoomba, QLD. (https://www.agronomyconference.com/).

Fitzgerald G, Rodriguez D, O’Leary G (2010). Measuring and predicting canopy nitrogen nutrition in wheat using a spectral index—The canopy chlorophyll content index (CCCI). Field Crops Research, 116 (3), 318-324. https://doi.org/10.1016/j.fcr.2010.01.010.

Perry EM, et al. (2021). Above ground biomass and growth across paddocks from space for characterising soil constraints and N availability. Presented at the 20th Australian Society of Agronomy Conference, Toowoomba, QLD. (https://www.agronomyconference.com/).