New Tools for Real Time N Sensing of Cereal Crops

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Abstract

Rapid, non-destructive assessments of plant N has the potential to support in-season N applications, reduce pre-sowing N applications, support variable rate application within paddocks, and reduce fertilizer costs and greenhouse gas emissions. Previous research has shown an improvement in estimation of N deficiency detection in wheat by using vegetation indices that incorporate a red-edge band (centred at approximately 720 nm) over methods based on only red and near infrared wavelength bands. The previous research was based on reflectance measurements with passive optical sensors, such as portable reflectance spectrometers, and primarily small plot data. New technology is available to provide canopy reflectance measurements in the red, red-edge and near infrared wavelengths using active sensors. Recently, the active optical Crop Circle ACS 470 sensor was commercially introduced allowing the operator to install filters to collect three different wavelengths regions. Additionally, new RapidEye satellite imagery offers images using the same wavelength regions as the active optical sensors. In the current research, we evaluate methods using red-edge measurements for different sensor types and scales of measurements. Initial results using active sensors show a high degree of correlation between indices with and without the chlorophyll red-edge. The response to plant N for active optical sensors is different from that using passive light sensors, which were shown in previous research to saturate with increased biomass. Based on initial results, agronomists and other users of these technologies should be aware that the response to plant N and biomass does depend on sensor type.

Key Words

Active optical sensors, vegetation indices, chlorophyll red-edge, remote sensing, proximal sensors

Introduction

Remote and proximal sensing of plant N has the potential to support in-season N applications, reduce or eliminate pre-sowing N applications, support variable rate application within paddocks, and reduce fertilizer costs and greenhouse gas emissions. There is a legacy of research with passive sensors leading to the recognition of the importance of reflectance measurements in the chlorophyll red edge (near 720-730nm) for improving the sensitivity to canopy chlorophyll density (e.g., Perry and Roberts 2008, Rodriguez et al. 2006). More recently, Fitzgerald et al.(2010) have demonstrated improvements of N estimates from passive sensors by linking the biophysical relationship between plant biomass and canopy N (N dilution curves) and by expression of plant N on an area basis (e.g., kg/ha) basis rather than plant concentration (percent).

Active optical sensors which use an internal light source and operate independent of sky conditions have replaced passive optical systems for ground based measurements. They are mainly being used in a qualitative way, relative to in-paddock N rich strips or to delineate the paddock into zones (e.g., Raun et al. 2001). The current research reported within this paper focuses on new work to improve estimates of canopy N from active sensors.

Methods

Sensor Measurements

Active optical measurements were made using the Crop Circle ACS 470 (Holland Scientific, Lincoln, NE USA) operated approximately 1.5 m above the soil surface (approximate ground sample diameter of 0.8m) handheld for plot work, or mounted to a motorbike or tractor to map entire paddocks. Passive optical measurements were made with a portable spectrometer (ASD Field Spec FR; ASD Inc, Boulder CO USA) at a height 2 m above the soil surface to produce a ground sample diameter of approximately 1 m within plots. The newly launched RapidEye satellite AG imagery (Brandenburg an der Havel, Germany) was acquired when sky conditions allowed during the growing season (August – October). The imagery was delivered radiometrically corrected, georeferenced, and re-sampled to 5 m. Atmospheric corrections were made using the ACORN6 program (Imspec LLC, Palmdale CA, USA), converting the radiance values to reflectance. The red, red-edge, and near infared bands were used to compute the vegetation indices in this study.

Scales of Field Trials

The spectrometer and active optical sensor measurements were made on a winter wheat trial with 6 m x 30 m plots located near Horsham VIC (36? 44' 0" South, 142? 34' 0" East). The plot treatments included pre-drill and in-season N applications at various rates from zero to 100 kg/ha. RapidEye satellite imagery and active optical sensor measurements were also acquired for six barley and wheat paddocks located near Inverleigh VIC (38? 6' 0" South, 144? 3' 0" East).

Determination of Vegetation Indices

Vegetation indices were calculated from the passive and active sensor measurements. The Normalized Difference Vegetation Index (Rouse et al. 1974) was determined as

$NDVI = (Refl_{NIR} – Refl_{Red})/(Refl_{NIR} + Refl_{Red})$ (1)

The Normalized Difference Red-Edge (Clarke et al. 2001) was determined as

$NDRE = (Refl_{NIR} – Refl_{Red\text{-}edge})/(Refl_{NIR} + Refl_{Red\text{-}edge})$ (2)

The Canopy Chlorophyll Content Index (CCCI; Clarke et al. 2001, Barnes et al. 2000) is a combination of NDVI and NDRE determined by fitting of the passive sensor measurements as described in Fitzgerald et al. 2006.

Results

The research approach was to apply the same techniques developed for passive sensors to the active optical sensors, and evaluate the results. However, comparison of indices determined from the 2009 datasets indicates that the passive and active optical sensor measurements aren't comparable. Part of the improvement in N estimation demonstrated in previous research stems from the use of the CCCI, by combining NDVI which is sensitive to percent cover with NDRE that is more sensitive to chlorophyll content. But the 2009 results indicate that the NDVI and NDRE measurements were highly correlated for the active optical sensors as seen in Figure 1. This precludes the determination of the CCCI.

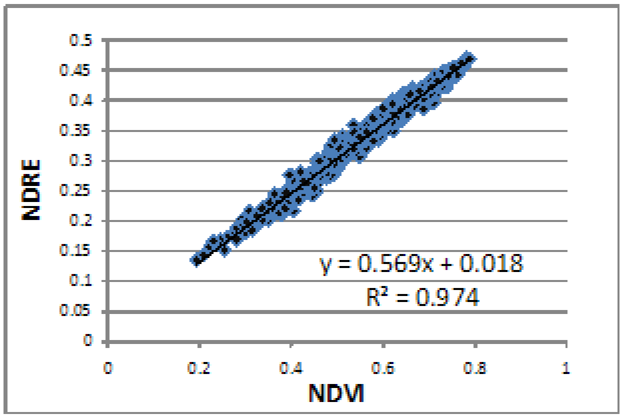

Figure 1. Active optical measurements made for a large plot trial throughout the 2009 growing season (n=513). The vegetation indices show a high degree of correlation between the NDVI, which is sensitive to percent canopy cover, and the NDRE, which is based on the chlorophyll red-edge wavelengths. This suggests that NDRE, and the derived CCCI, will not offer any additional response to canopy chlorophyll content or canopy N.

Passive optical measurements were made for the same wheat N trial when sky conditions allowed, and the passive and active optical measures of NDVI could be directly compared. Figure 2 was generated from a coincident set of active and passive measurements made at GS (Growth Stage) 39, showing the treatment means and standard errors (n = 2 or 4 for each treatment level) for the index values measured with each sensor. For the spectrometer (passive sensor) measurements, the NDVI values increased from 0.8 to just over 0.9, with a fairly flat response to the treatment effect (increasing applied N). By contrast, the Crop Circle active sensor NDVI measurements range from under 0.4 to just over 0.6, with a much greater response to increasing N. When the CCCI is determined from the passive measurements, the response to increased N greatly improves, as we would expect from previous research, and is more similar to the response using the Crop Circle active sensor NDVI measurements.

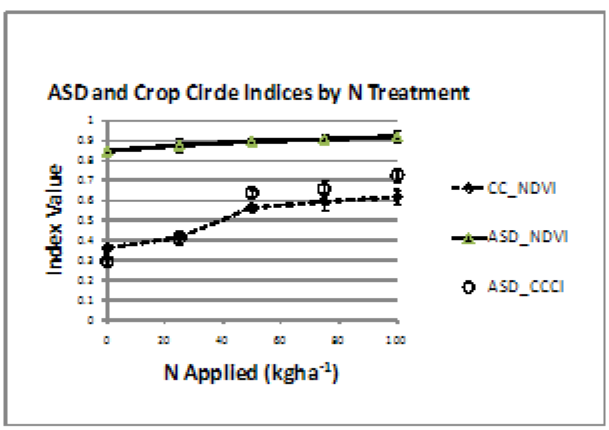

Figure 2. Comparison of indices measured with a passive sensor and an active sensor for wheat at Z39. NDVI measured with an ASD spectrometer (ASD_NDVI) shows less response to increasing applied N than does NDVI from the active sensor (CC_NDVI). The passive sensor response to N treatment is improved using a combination of NDVI and NDRE (ASD_CCCI); the improved response is similar to the active sensor NDVI.

Near coincident passive and active optical measurements were also made using the RapidEye imagery and a tractor-mounted Crop Circle sensor to map whole paddocks. Figure 3 shows results for a wheat paddock at GS 30 and GS 65. The NDVI values are greater for the passive systems, although the standard deviations are similar between sensors, and the spatial patterns appear similar.

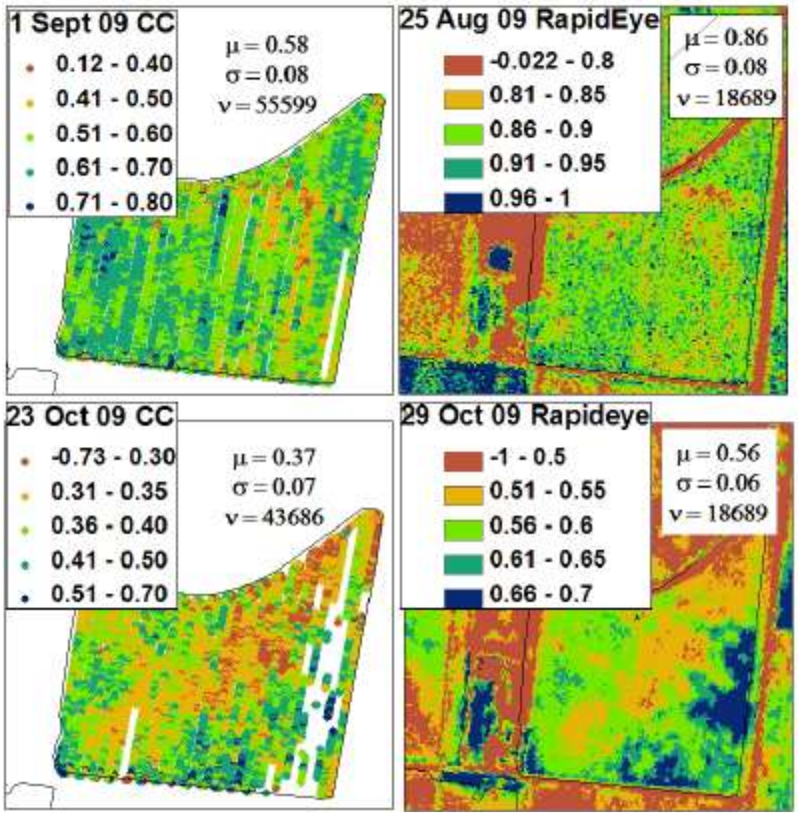

Figure 3. NDVI measured from a tractor-mounted Crop Circle active optical sensor (left panels), and RapidEye (passive optical) imagery (right panels) for winter wheat near Inverleigh VIC. The legends show mean (?), standard deviation (σ), and N (ν) for each dataset. The NDVI values near GS 30 (top panels) and GS 65 (bottom panels) are larger for the passive systems, although the standard deviations are similar between sensors, and the spatial patterns appear similar.

Conclusion

Results to date indicate that active and passive optical sensors don't produce equivalent vegetation index values. Datasets from 2009 demonstrate consistently lower values for NDVI from active optical sensors than for passive optical sensors, and highly correlated values for NDVI and NDRE, which is based on the chlorophyll red-edge. This has implications for the approach developed with passive sensor systems to quantify canopy N using the CCCI, or other indices based on the chlorophyll red-edge. Research is need to determine whether NDVI (or other indices) from active sensors can be related to the N dilution curves, linking the biophysical relationship between plant biomass and canopy N.

RapidEye imagery may be used to determine canopy N for whole paddocks following the techniques demonstrated by Fitzgerald et al. 2010, which were largely developed and evaluated with plot-level data. However, canopy biomass is needed to extract N from the N dilution curve used by that approach. Active optical sensors have the potential to provide spatial and temporal quantification of biomass (expressed as mass per area). Results from 2009 (not shown) indicate a strong relationship between NDVI from the active sensors and percent cover of the wheat crops. Crop height may be related to the measured reflectance of an individual band, as the reflectance is proportional to the distance from the sensor to the target. Research is needed to determine if this information can be combined to determine robust values of canopy biomass.

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