Unmanned Aerial Vehicles for Nitrogen Management of Corn (*Zea mays* L.): A Framework for Predicting Spatial and Temporal Variability of N Requirement.

Jacob Nederend[1], Dr. Bill Deen[1], Dr. Hugh Earl[1], Dr. Aaron Berg[2]

[1]Department of Plant Agriculture, University of Guelph

[2]Department of Geography, University of Guelph

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Introduction

Corn nitrogen (N) demand varies temporally and spatially across a field, making successful prediction of fertilizer rate a challenge. Annual variability of the most economic rate of N (MERN) is related to seasonal precipitation, thus complicating estimation of in-season fertilizer rates [1]. Vegetative indices (VIs) calculated from spectral reflectance of corn canopies acquired using ground sensors have successfully predicted corn N response, however, they are constrained by limited sensitivity to N status until the V8 leaf stage, low spatial resolution, and time consuming data acquisition[2]. Unmanned aerial vehicles (UAVs) mounted with multispectral sensors can rapidly acquire reflectance measures at high spatial resolution, however, the sensitivity of these sensors to N status and ability to predict N requirement is unknown. The objective this study was to determine the sensitivity of four UAV-derived VIs to N status and response on a delta yield (Δyield) basis.

Materials and Methods

Site description and treatments

- Long-term N trial in continuous corn (2008-2016): Elora Research Station, ON, Canada
- Well drained London silt loam
- Randomized split-block
  - Main plot: two application timings of pre-plant and sidedress
  - Split plot: N rate
- Pre-plant N response treatments selected for UAV observation
  - 0, 28, 57, 115, 188, and 230 kg ha^{-1}

Observations

- UAV surveys at V6, V8, V10 with SenseFly eBee fixed-wing UAV
- 2 Filter-modified consumer digital cameras (Canon S110, Canon, Ohta-ku, Japan) on separate flights
  - Approximately 2.3cm/pixel ground sampling distance
  - Camera centre wavebands (nm): 1) 625, 560, 850; 2) 715, 505, 455
- Ground-based measurements
  - Trimble GreenSeeker (Trimble Inc., Sunnyvale, CA), grain yield

Image Processing and Data Analysis

- Images from separate flights aligned and orthomosaics generated in Pix4dmapper v2.2.25 (Pix4D, Lausanne, Switzerland)
  - Digital numbers converted to reflectance using built-in radiometric calibration tool and ground-based images of 99% reflective Spectralon panel (ASD Inc., Boulder, CO)
  - VIs (Table 1.) calculated using raster calculator
- Plot-level VI means extracted using ArcGIS 10.3 (ESRI, Redlands, CA)
  - Transformed to relative values using 230 kg ha^{-1} as non-limiting reference
- Data analyzed using SAS v9.4 (SAS Institute, Cary, NC)
  - N response determined using PROC NLIN
  - VI linear regressions conducted using PROC GLM
  - α=0.05 for all analyses

Table 1. Vegetative indices and associated reflectance (R) calculations determined in post-processing

Vegetative Index	Formula
Normalized Difference Vegetative Index (NDVI)	$(R_{NIR}-R_{red})/(R_{NIR}+R_{red})$
Green Chlorophyll Index (CI)	$(R_{NIR}/R_{Green})-1$
Soil Adjusted Vegetation Index (SAVI)	$(R_{NIR}-R_{red})(1+L)/(R_{NIR}+R_{red}+L)$
Enhanced Vegetative Index (EVI)	$2.5(R_{NIR}-R_{red})/(R_{NIR}+6R_{red}7.5R_{Blue})$

Results

- MERN at N:corn price ratio of 6 was equal to 190 kg N ha^{-1}, producing 12160 kg ha^{-1} grain yield (Fig. 1)
- Rate of N required to reach plateau yield of 12227 kg ha^{-1} was 212 kg N ha^{-1}
- GreenSeeker NDVI was more closely related to Δ yield than any UAV-derived VI at all development stages except V6 (Fig. 2)
- NDVI was a better predictor of Δ yield than all other UAV-derived VIs (Fig. 2)
- SAVI was most related to Δ yield at V6 (R^2=0.31679) but was a poor predictor at later stages (data not shown)

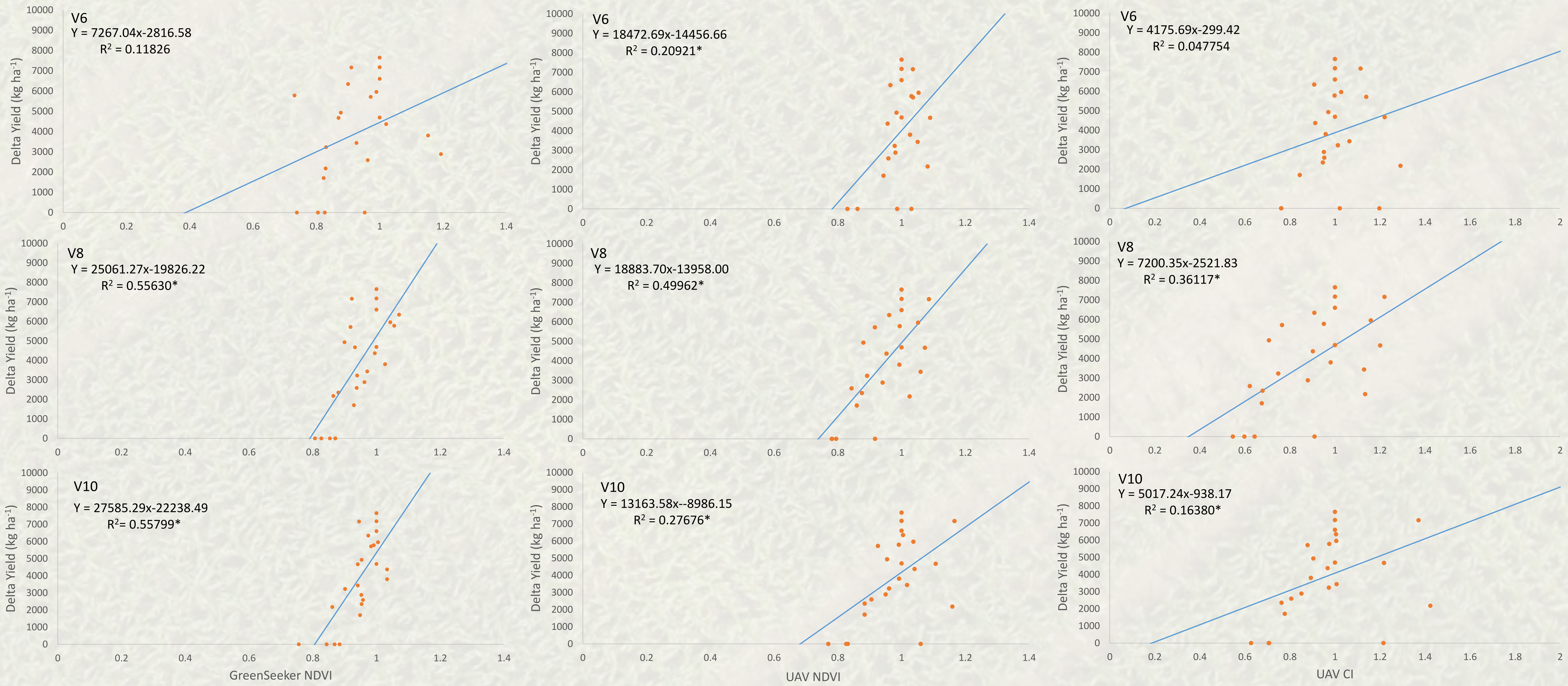

Figure 2. GreenSeeker NDVI (left), UAV-derived NDVI (centre), and UAV-derived CI (right) versus delta yield at three leaf stages for corn with six different rates of N. Orange points represent individual observations. * denotes significance at P ≤ 0.05.

Figure 1. Quadratic plateau model depicting N response function for six N rates. The most economic rate of N was 190 kg N ha^{-1} based upon a N:corn price ratio of 6. Fertilization rate at plateau yield was 211 kg N ha^{-1}.

Conclusions

- Active GreenSeeker technology outperforms passive UAV sensors even with radiometric calibration of multispectral imagery
- Calibration procedures using multiple reflectance standards may yield more accurate reflectance spectra
- Future research will be conducted using image calibration procedures tailored to field campaign instead of proprietary software
- Prediction models using additional variables such as soil-N, tissue-N, and climatological data in addition to canopy reflectance may improve determination of N requirement

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References

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