ASSESSMENT OF RED-EDGE BASED VEGETATION INDICES DERIVED FROM UNMANNED ARIAL VEHICLE FOR PLANT NITROGEN CONTENT ESTIMATION

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A paper from the Proceedings of the

14th International Conference on Precision Agriculture

June 24 – June 27, 2018

Montreal, Quebec, Canada

Abstract. *Unmanned Aerial Vehicles (UAVs) have become increasingly popular in recent years for agricultural research. High spatial and temporal resolution images obtained with UAVs are ideal for many applications in agriculture. The objective of this study was to evaluate the performance of red edge based vegetation indices (VIs) derived from UAV images for quantification of plant nitrogen (N) content of spring wheat, a major cereal crop worldwide. This study was conducted at three locations in Idaho, United States. A quadcopter UAV equipped with a red edge multispectral sensor was used to collect images during the 2016 growing season. Flight missions were successfully carried out at Feekes 5 and Feekes 10 growth stages of spring wheat. Plant samples were collected on the same days as UAV image data acquisition and were transferred to the lab for N content analysis. Different VIs including Normalized Difference Vegetative Index (NDVI), Red Edge Normalized Difference Vegetation Index ($NDVI_{red\ edge}$), Enhanced Vegetation Index 2 (EVI_2), Red Edge Simple Ratio ($SR_{red\ edge}$), Green Chlorophyll Index (CI_{green}), Red Edge Chlorophyll Index ($CI_{red\ edge}$), Medium Resolution Imaging Spectrometer (MERIS), Terrestrial Chlorophyll Index (MTCI) and Red Edge Triangular Vegetation Index (core only) ($RTVI_{core}$) were calculated for each flight event. At Feekes 5 growth stage, red edge and green based VIs showed higher correlation with plant N content compare to the red based VIs. At Feekes 10 growth stage, all calculated VIs showed high correlation with plant N content. Empirical relationships between VIs and plant N content were cross-validated using test data sets for each growth stage. At Feekes 5, the plant N content estimated based on $NDVI_{red\ edge}$ showed one to one correlation with measured N content. At Feekes 10, the estimated and measured N content were highly correlated for all empirical models, but the model based on CI_{green} was the only model that had a one to one correlation between estimated and measured plant N content. The observed* *high correlations between red edge based VIs derived from UAV and the plant N content suggests the significance of red edge based VIs deriving from UAVs for within-season N content monitoring of agricultural crops such as spring wheat.*

Keywords. *Unmanned Aerial Vehicles and Systems (UAV), Vegetation Indices (VIs), Red Edge Spectral Band, Plant Nitrogen Content, Wheat*

ASSESSMENT OF RED-EDGE BASED VEGETATION INDICES DERIVED FROM UNMANNED ARIAL VEHICLE FOR PLANT NITROGEN CONTENT ESTIMATION

Unmanned aerial vehicles (UAVs) are remote sensing systems that can capture crop reflectance in the VIS-NIR region of spectrum and assess CL and N concentration. The UAVs, which have recently gained tractions in number of studies, acquire ultra-high spatial resolution images by flying at low altitudes (Maes et al., 2017; Pádua, 2017). Operational advantages such as low-cost systems, high flexibility in terms of flight planning and acquisition scheduling, and imaging below cloud cover make UAVs an appropriate tool to study crop biophysical parameters including N concentration (Simelli and Tsagaris,2015). To date, no studies on comparing red edge based VIs from the UAV data for wheat canopy CL or N concentration estimation have been reported. The main goal of this study was to evaluate the performance of UAV based VIs in estimating plant N concentration at canopy scale. Specifically, we analyzed and statistically compared the performance of different red edge based VIs from UAV data to estimate spring wheat plant N concentration. The experimental studies were conducted at five locations in Idaho during 2016 growing season. Hard red spring wheat (cv. Cabernet) was planted using a Hege 500 series drill at Rupert and Ashton, and soft white spring wheat (cv. Alturas) was planted at Parma using H&N Equipment research plot drill, at a density of approximately 106.5 kg seeds ha^{-1}. Row spacing was set at 17.78 cm using double disk openers. The plots were 1.52 wide by 4.27 m long, and then reduced to 3.05 m using glyphosate and tillage. Granular urea (46-0-0) was surface broadcasted immediately after planting at five different rates (0, 84, 168, 252, and 336 kg N ha^{-1}). Each treatment was replicated four times in a randomized complete block design, resulting in a total of 20 plots at each location. A quadcopter UAV 3DR Solo (3D Robotics, Inc., Berkeley, CA) shown in Figure 2 was selected to carry camera payloads to acquire ultra-high-resolution imagery. A MicaSense Red Edge™ 3 Multispectral Camera (MicaSense, Inc, Seattle, WA) with an integrated Global Positioning System (GPS) with an accuracy of 2-3 meters, mounted on the UAV was used to obtain the imagery. The camera was mounted on a Gimbal and as the camera's weight was similar to GoPro camera's weight, there was no need to add balance weight. The MicaSense Red Edge™ 3 has a Downwelling Light Sensor (DLS) (MicaSense, Inc, Seattle, WA), which measures the ambient light during a flight for each of the five bands and records this information in the metadata of the images captured by the camera. The gain and exposure settings are automatically optimized for each capture and each band to prevent blurring or over-exposure, which results in properly exposed images. The UAV images were captured within 2.0 hours of solar noon with flight duration ranging from 15 to 20 minutes in sunny and cloud free conditions. Two flight missions performed at each location to coincide with Feekes 5 and Feekes 10 spring wheat growth stages resulted in six flight missions per season. Acquired multispectral images were imported to Micasense Atlas software (MicaSense, Inc, Seattle, WA) for mosaicking, georeferencing and radiometric calibration. Micasense Atlas has a partnership with Pix4D mapper

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image analysis software (Pix4D SA, Lausanne, Switzerland) to create aligned, mosaicked and georeferenced images from multispectral data captured with the MicaSense red edge camera. To obtain a representative plant sample, aboveground biomass was destructively sampled at Feekes 5 and Feekes 10 growth stages by cutting three randomly selected plants in the middle of each plot immediately after each UAV flight event. Plant samples were dried in the oven for 72 hours at 80°c and then were transferred to the lab for N content analysis. Samples' N content analysis was performed using the AOAC method 990.3 (http://www.aoac.org, 2018) at Brookside Laboratories, Inc (New Bremen, OH, USA) with extended uncertainty of ± 5 %. The UAV reflectance data were used for calculating eight VIs, many of which have been proposed as surrogates for canopy N concentration estimation. The VIs tested include the Normalized Difference Vegetation Index, NDVI [30], the Red Edge Normalized Difference Vegetation Index, $NDVI_{red\ edge}$ (Gitelson and Merzlyak,1994), the Enhanced Vegetation Index 2, EVI_2 (Huete et al, 2002), the Red Edge Simple Ratio, $SR_{red\ edge}$ (Gitelson et al., 2005), the Green and Red Edge Chlorophyll Indices, CI_{green} and $CI_{red\ edge}$, respectively (Gitelson et al., 2005), the MERIS Terrestrial Chlorophyll Index, MTCI (Dash and Curran, 2004), and the Core Red Edge Triangular Vegetation Index ($RTVI_{core}$) (Nicolas etal., 2010) (Table 1). For each study plot, a region of interest (ROI) was manually established by choosing the central two rows and mean of each VI value corresponding to that plot was extracted. The study plots were randomly divided into test and training data sets. For the training data sets, simple regression analysis was performed to find the best relationship fit between N concentration and each UAV based VI. The determination coefficient (R^2) and Root Mean Squared Error (RMSE) were used to evaluate the predictive accuracy of each model. These parameters are widely used to evaluate the performance of empirical models. In the next step, the test data set was used to evaluate the performance of developed model in the previous step. Predicted values of N concentration were plotted versus corresponding values of N concentration measured in the lab. The performance of regression models in estimating N for the training data set were evaluated by calculating the R^2 and RMSE. In addition, Student's t-tests were used to determine if the slope and the intercept of the regressions were significantly different from 1 and 0, respectively. If the values of slopes were not significantly different from 1 and the values of intercepts were not significantly different from 0, then it was concluded that the regression was not significantly different from the 1:1 line, and the empirical model could accurately predict N concentration. We used the training data set for establishing separate plant N content predictive models using UAV based VIs for Feekes 5 and Feekes 10 separately. The training data set includes a wide range of plant N content values due to differences in N application rates.

Tables and Figures

Table 1. Vegetation indices (VIs) tested in this study to estimate nitrogen (N) content.

Vegetation Index	Equation
Normalized Difference Vegetation Index (NDVI)	(NIR − Red)/ (NIR + Red)
Red Edge Normalized Difference Vegetation Index ($NDVI_{red\ edge}$)	(NIR − Red Edge)/ (NIR + Red Edge)
Enhanced Vegetation Index 2 (EVI_2)	2.5 × (NIR − Red)/(NIR + 2.4 × Red + 1)
Red Edge Simple Ratio ($SR_{red\ edge}$)	(NIR)/ (Red Edge)
Green Chlorophyll Index (CI_{green})	(NIR/Green) − 1
Red Edge Chlorophyll Index ($CI_{red\ edge}$)	(NIR/Red Edge) − 1
Medium Resolution Imaging Spectrometer (MERIS) Terrestrial Chlorophyll Index (MTCI)	(NIR − Red Edge)/ (Red Edge + Red)
Core Red Edge Triangular Vegetation Index ($RTVI_{core}$)	100(NIR – Red Edge) − 10(NIR − Green)

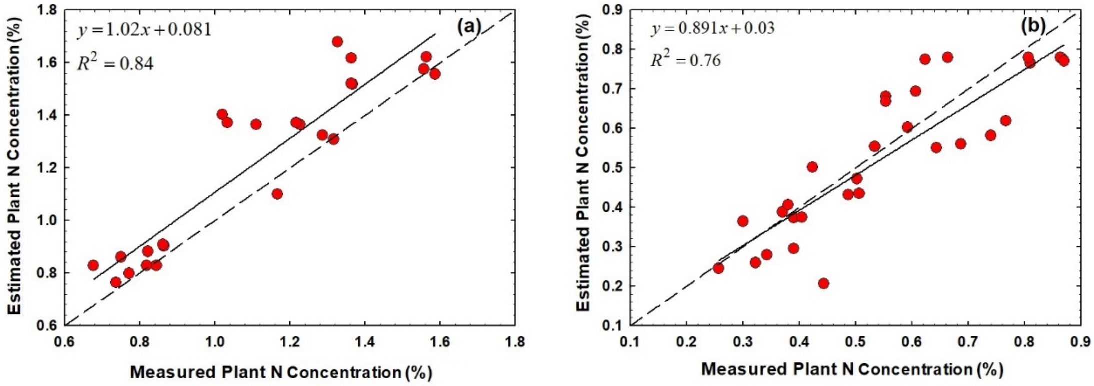

Figure 1. Cross validation of developed algorithms based on (a) $NDVI_{red\ edge}$ at Feekes 5 and (b) CI_{green} at Feekes 10 in estimating plant N concentration of wheat crop in test data sets.

Conclusion or Summary

Remotely sensed VIs have been extensively used to quantify wheat crop N status. The UAV technology appears to provide a good complement to the current remote sensing platforms for N monitoring in wheat by capturing low-cost, high resolution images. These UAV technologies can bring a unique perspective to N management in wheat by providing valuable information on wheat N status. Time, labor and money can be saved using UAV data in crop monitoring. Results presented in this paper show that high resolution images acquired with UAVs are a useful data source for in-season wheat crop N concentration estimation. At Feekes 5 growth stage, red edge and green based VIs had higher correlation with plant N concentration compared to red based VIs because red edge based VIs can reduce the soil background effect on crop reflectance. At Feekes 10 growth stage, all calculated VIs showed high correlation with plant N concentration, and there were no significant differences between red and red edge based VIs' performance. At this stage, crop canopy has been fully developed, and soil reflectance did not have strong effect on the reflectance of research plots. At Feekes 5, the plant N concentration estimated based on $NDVI_{red\ edge}$ showed 1:1 correlation with N concentration measured in the lab. At Feekes 10, the estimated and measured N concentration were highly correlated for all developed models, but the model based on CI_{green} was the only model that had a 1:1 correlation between estimated and measured plant N concentration (Figure 1). The observed high correlation between UAV based VIs with plant N concentration indicates the applicability of UAV for in-season data collection from agricultural fields.

Acknowledgements

This study was supported in part by the Idaho Wheat Commission.

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