SUAVS TECHNOLOGY FOR BETTER MONITORING CROP STATUS FOR WINTER CANOLA

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ABSTRACT

The small-unmanned aircraft vehicles (sUAVS) are currently gaining more popularity in agriculture with uses including identification of weeds and crop production issues, diagnosing nutrient deficiencies, detection of chemical drift, scouting for pests, identification of biotic or abiotic stresses, and prediction of biomass and yield. Research information on the use of sUAVS have been published and conducted in crops such as rice, wheat, and corn, but the development of support tools associated with this technology is still under progress. One main example on the use of the sUAVS technology is portrayed herein for winter canola. Research studies were performed in Manhattan, Kansas at the Kansas State University –Department of Agronomy-, in a joint effort pursued by the Crop Production and Ecology and Agriculture Spatial Analysis Laboratory groups. Winter canola acres are gradually rising in the southern Great Plains region. Optimum nutrient management, specifically related to the right rate of nutrient to be applied, should be pursued to maximize crop production. The main issue faced by the scientific community is that the lack of information about nutrient management for canola. This study has as a main objective to: 1) determine biomass and nutrient accumulation for winter canola; 2) establish correlations between these parameters and blue NDVI and canopy temperature; and 3) determine the predictable value of blue NDVI and canopy temperature in assessing crop production issues and final canola yield. At flowering, blue NDVI presented a high correlation in predicting the whole-plant biomass under diverse mass levels. As expected, the canopy temperature map collected via sUAVS showed a trade-off relationship with whole-plant biomass, suggesting an optimum plant temperature value for maximizing solar radiation capture and efficiency in conversion (measured as final biomass). Both blue NDVI and canopy temperature, determined by the use of the sUAVS, predicted very well biomass status on canola. This information might help guide future nutrient prescriptions at the site-specific level. For the future, preparation of support decision tools are needed in order to quantify the "real" contribution of this technology in assisting key stake-holders for facilitating the decision-making process.

Keywords: winter canola, SUAVS, blue NDVI, canopy temperature, biomass.

INTRODUCTION

The use of new technologies for assessing and predicting crop nutrient status and final yield were gradually increasing during recent years. Understanding the final application and implementing support decision tools are still part of the missing pieces of the sUAVS discipline puzzle. Therefore, this research project pursued an interdisciplinary and critical collaboration between diverse scientific research groups with the ultimate goal of assessing correlations between plant traits and their predictors (e.g. blue NDVI and canopy temperature) and developing functions that can provide guidance on the potential uses of this technology in crop production for assisting key stakeholders in the decision-making process.

SUAVS and Applications

The small-unmanned aircraft vehicle systems (sUAVS) technology is becoming more popular in agriculture with uses including detection of small weed patches (Hardin et al., 2007), monitoring crop biomass (Hunt 2005; Swain et al., 2010), diagnosing N nutrition for crops (Hunt 2005; Swain et al., 2007), and estimation of leaf area index and water stress detection (Berni et al., 2009). Research on sUAVS technology has been conducted in rice, wheat, and corn; however very little information has been published on the use of this technology in canola. The Crop Production Group together with the Ecology and Agricultural Spatial Analysis Laboratory (EASAL) and the Precision Ag laboratory are currently investigating potential applications related to the use of this new technology at the on-farm and small-research plot scales. Among several potential benefits in using this technology, is the digital characterization of in-season crop status (e.g. biomass and nutrient) for determining the potential applicability in using this technology for detecting crop production issues and predicting final yields.

Canola Nutrient Management

Optimum nutrient management, using the 4Rs approach, right rate, time, placement and source should be pursued in order to maximize canola yield production. Following that rationale, nutrient uptake and removal values are critical for diagnosing plant nutrient programs for canola, more precisely for phosphorus (P) and potassium (K) nutrients. The main issue faced by the scientific community is that the lack of available public- or private-sector information about nutrient management for canola. In addition, less is known related to the crop nutrient dynamic, content and distribution within the plant (different fractions) as the growing season progresses (at exception for N). This peculiar issue is aggravated by the rapid progress experienced in the genetic component during the last years, from which more canola hybrids (and less proportion of open pollinated materials) are currently employed by producers. Balanced nutrition largely influences winter survival, consequently impacting yields. In general, winter canola presents a high requirement for N, P, and S. As regarding N management, precise N rate applications are critical for winter survival. Too much N can increase fall growth (“luxury vegetative growth”) which increase the susceptibility to lodging and diseases (*Phoma* sp.), extent the growth period, and reduce the oil content; while, too little can diminish the capacity of the plants to overwinter.

Biomass and Nutrient Dynamics during the Crop Growing Season

In canola, pod and final number of seeds are primarily defined around the critical period bracketing flowering. Thus, the biomass and nutrient accumulation from the end of the flowering until maturity will decide the seed weight (grain-filling period). As related to the N nutrition level, the amount of N taken up before flowering time can vary from 50 to 80% as compared with the total accumulated at the end of the growing period. Phosphorous uptake during the early vegetative stages is rapid, as similar to the K uptake evolution. By the end of the season, P harvest index is around 75 to 80% (seed P content) as compared to the entire aboveground canopy. For sulfur, uptake can be close to 50% around flowering with a S harvest index by the end of the season around 40 to 60% (seed S content related to the entire plant – except for the root system).

Remote Sensing Component

The sUAVS platform is becoming an essential component of the remote sensing discipline and, in overall, for the precision Ag technology. The information obtained via utilization of sUAVS is relatively inexpensive and allows for high-resolution of digital photography when compared with the satellite imagery technology. At the present times, there are several research groups investigating the potential uses of sUAVS in the agricultural discipline. Still, there has been few studies quantifying and connecting the use of this new technology in predicting in-season crop production issues. One potential predictor of the crop status is the blue NDVI parameter. Investigation in diverse crops and countries allowed to determine a certain degree of correlation between crop mass and nutrient status as compared with the NDVI map. Nonetheless, research studies estimating thermal infrared map via sUAVS are currently scarce. Among some examples in the use of the TIR technology for remote sensing purposes involved: 1) determination of reflectance and temperature imagery for vegetation (Berni et al., 2009), 2) parameterizing of land surface moisture conditions (Soer, 1980), 3) simulation of landscape energy exchange (Quattrochi, 1999), 4) inference of soil water and vegetation cover (Carlson, 1994), 5) determination of evapotranspiration (Caselles, 1992), and 6) assessment of urban heat (Lo, 1997).

The research goal for this study is to: 1) determine biomass and nutrient accumulation for winter canola; 2) establish correlations between these parameters and blue NDVI and canopy temperature; and 3) determine the predictable value of blue NDVI and canopy temperature in assessing crop production issues and final canola yield.

MATERIALS AND METHODS

Experimental location

The canola was planted September 20, 2013 at the Ashland Bottoms experimental field, Kansas State University, Manhattan (KS). For the purpose of this investigation, only one winter canola variety was study for the biomass and nutrient uptake determinations. The final stand density varied depending on the plot and the winter survival rate.

Biomass measurement

Biomass was determined close to the flowering time, 206 days after planting time (April 25, 2014). For biomass determination, "bio-crates" were constructed and placed in the field with the purpose of collecting not only the green material, but also all the dropped leaves and senescent plant tissues. A total of 4 bio-crates were placed on the canola experiment, one per each replication. At the moment of taking biomass sampling, actual stand density was measured for properly accounting for and then adjusting the potential differences in plant density across replications. After harvested, final wet weight of all canola fractions were recorded at the field- and after drying down, dry weight was obtained for calculating the final moisture content for each plant fraction. Each individual plant was cut and fractionated into leaf and stem tissues (flowering time). Each fraction was separately chopped and dried to constant weight at 60° C. Nutrient concentrations will be determined in all biomass samples in order to calculate the final nutrient content.

In addition to the bio-crates, at flowering sampling time, four sampling quadrats (0.5 m × 0.5 m) were distributed in the canola field with consideration of gradient of biomass. All biomass information was measured two days after the imagery acquisition.

Reflectance

Before the winter period, early-season reflectance measurements were taken in the canola field employing a ASD Inc. FieldSpec HandHeld 2 Pro. Single nm resolution from 325-105 nm.

Color Infrared (CIR) and Thermal Infrared (TIR) data

The color infrared imagery was collected using a DJI s800 evo hexcopter as a platform. A modified Canon point-shot S100 CIR digital camera (LDP-LCC MaxMax) was used to collect imagery data. This modified CIR digital camera records reflected sunlight in the blue, green and near infrared (NIR). This set of imagery was collected at approximately 50 m above the ground.

The TIR data was collected in parallel to the CIR information. A DRS Tamarisk®640 thermal camera was employed for collecting the TIR information. Cameras for CIR and TIR collection were installed side by side to the platform. Thermal infrared videos were stored in the camera. A matlab code was written to extract the images from thermal infrared videos.

Digital image processing

The CIR images were converted into TIFF documents, and then imported into PhotoScan Professional software by AgiSoft to generate a georectified orthomosaic for the entire area captured by the image. A pixel averaging method was used to compute the average brightness values from all overlapping images to help reduce the effects of the bidirectional reflectance distribution function, which is strong within low-altitude wide-angle photography. An orthomosaic was generated for images collected at the same altitude. Radiometric calibration was performed on orthomosaic image to convert the raw brightness value to relative reflectance using the average pixel brightness value of the standard reflectance target. Since the imagery was collected on a clear day close to solar noon, we also assumed little variation in atmospheric scattering between times of overflights.

The blue-NDVI (BNDVI) was computed for the CIR orthomosaic using the calibrated blue and NIR reflectance. The BNDVI equation used was:

$$BNDVI=(NIR-Blue)/(NIR+Blue)$$

The pixel samples within the quadrats were extracted using the AgPixel software (http://www.agpixel.com/). The AgPixel export command was used to extract the Blue and NIR brightness values of each sample into an Excel spreadsheet so the radiometric correction could be performed and mean BNDVI values for each quadrat could be calculated.

The thermal video taken from a DRS Tamarisk®640 was framed to still images in Joint Photographic Experts Group (JPEG) format. PhotoScan Professional software by AgiSoft was employed to export a thermal orthomosaic. The brightness values of the thermal orthomosaic were converted to temperature in Celsius using a linear equation.

RESULTS AND DISCUSSION

The canola biomass evolution, adjusted by the plant density, is presented in Figure 1. Rapid growth was documented after the winter period, with high plant growth rate (PGR) during the period bracketing flowering (+- 12 days around flowering).

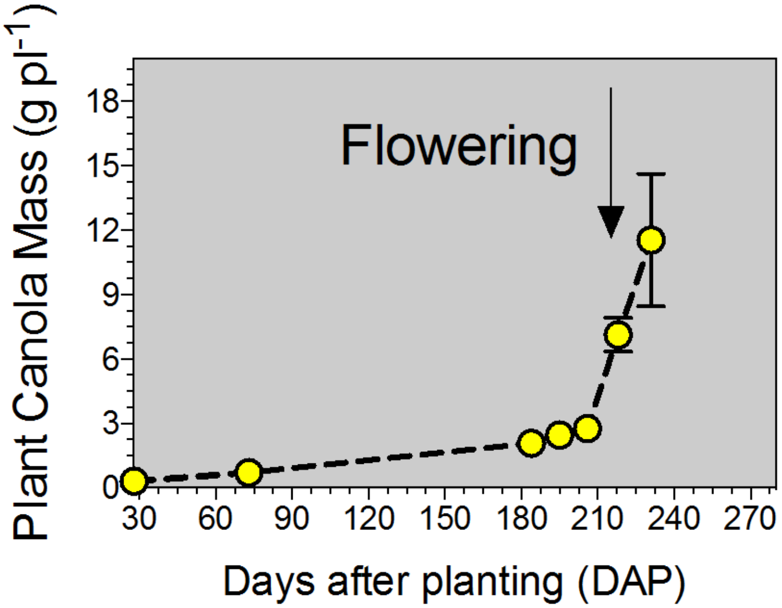

Figure 1. Per plant canola biomass evolution, expressed in grams per plant, as presented in days after planting time.

From the remote sensing perspective, a color infrared (CIR) orthomosaic picture from the canola research experiment was produced (Figure 3). This image allows visualizing differences in stand population and plant distribution within the experiment.

Figure 2. Color infrared (DRS Tamarisk®640 thermal camera) map for the canola field, the redder the area the more vegetated the ground.

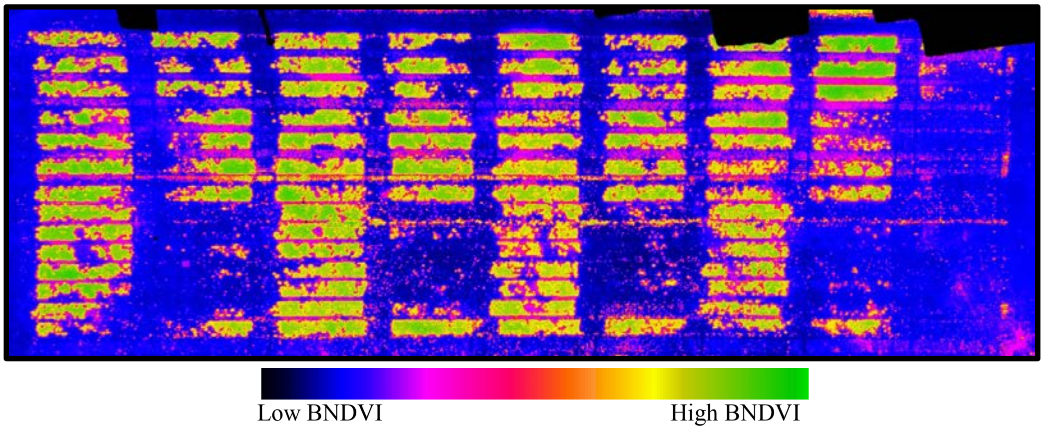

Figure 3. Blue NDVI (BNDVI, modified Canon S100 CIR digital camera) map for the canola field, as the color green intensity increases the higher is the canola mass.

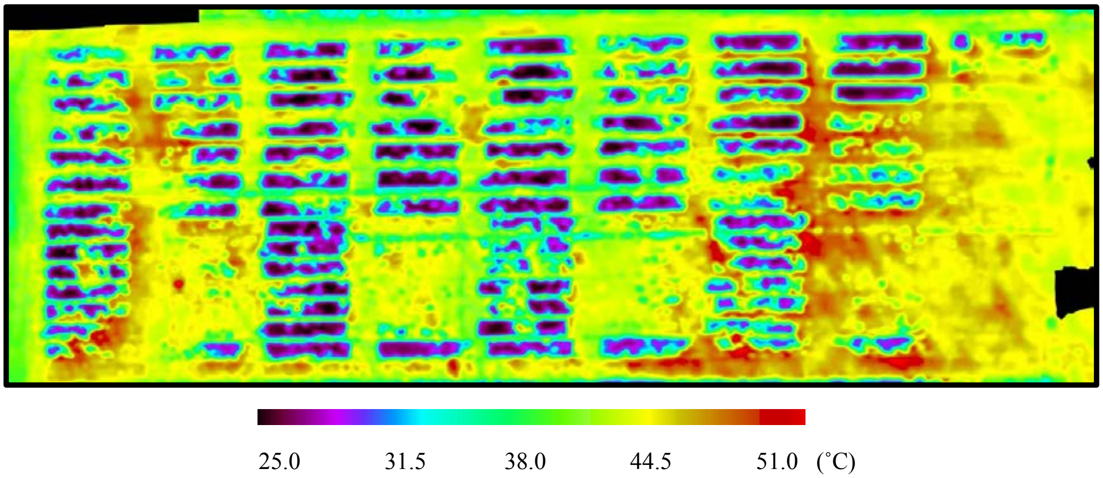

Figure 4. Colorized temperature map over canola field, depicting differences in canopy temperature among replications measured with the sUAS (04/25).

Both the BNDVI and TIR maps showed a close degree of correlation between biomass and canopy temperature in canola (Figures 3 & 4). Higher temperature was related to bare soil and poor plant stands. A potential application for the use of BNDVI and canopy temperature is for "phenotyping" and screening diverse germplasm (hybrids/ varieties) for biotic and abiotic stresses.

The canola biomass collected at flowering stage was highly and positively correlated with the BNDVI, increasing this last parameter as the plant mass increased (Figure 5A). For the canopy temperature factor, canola biomass was negatively associated, but presented a non-lineal relationship. The model fitted for this association is similar to the association documented between photosynthesis and temperature at the leaf-scale for corn (Figure 6). A similar canopy or leaf temperature threshold was established ranging from 30 to 35 °C, point after which photosynthesis or canola biomass (capture and converted radiation) presented a constant declination trend as temperature raises.

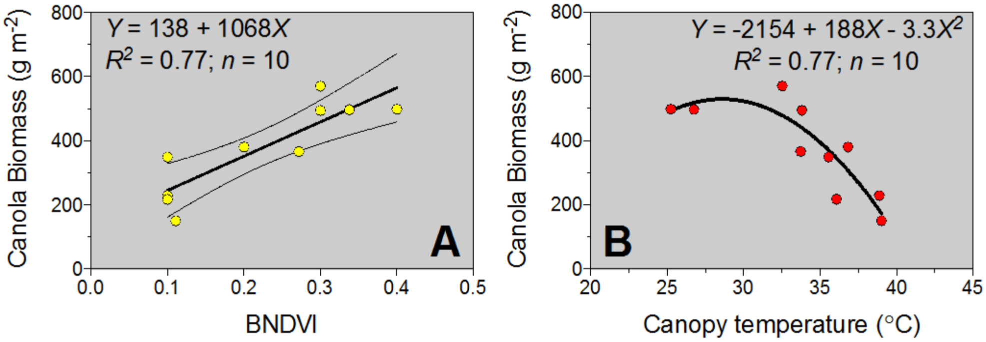

Figure 5. Canola biomass and blue NDVI (A) and biomass and canopy temperature (B) associations at flowering stage.

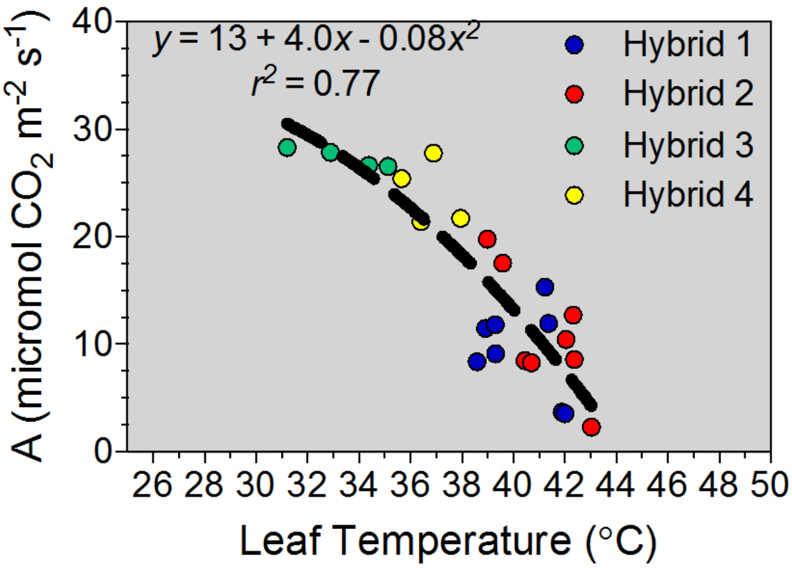

Figure 6. Photosynthesis and leaf temperature association in corn before flowering stage (Roth, Ciampitti, Vyn, 2013).

In addition to the previous association with biomass, BNDVI was negatively related to canopy temperature, with higher plant temperature as the BNDVI declines –related to poor plant stand and biomass- (Figure 6).

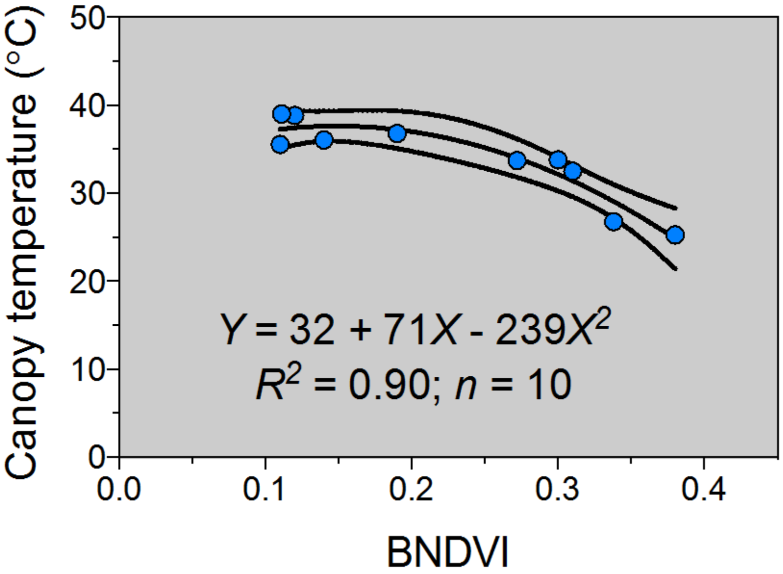

Figure 7. Association between canopy temperature and BNDVI for canola determined at flowering stage.

A multiple regression analysis was performed with the goal of testing if the TIR and CIR parameters were able to improve canola biomass estimation. The equation resulted from this test was:

Biomass = -0.021 x Temp + 0.00058 x BNDVI + 498

where biomass is expressed in g m^{-2}, Temp is expressed in Celsius and BNDVI in relative units. This model accounts for 81% of the variation presented in the biomass prediction, slightly increasing the explanation when these two variables were included in the model.

Lastly, as related to the individual plant fractions BNDVI was related with all biomass components with higher degree of correlation for the stem fraction (R^2 = 0.79), and with similar proportion of the biomass accounted by both the leaf and flower plant structures (R^2 = 0.69). One important point to highlight is that the best-fitted model was not lineal but a quadratic response, which presents an association with more biological meaning. Similar behavior was presented between the biomass plant fractions evaluated in this research and the thermal imagery.

For stand vigor purposes, the reflectance obtained early before the winter period was compared with a visual rating obtained from measurements gathered at the field-scale. An investigation of the canola reflectance properties depicted that the shape and magnitude (variation, maximum and minimum values) of the reflectance trait is highly dependent on the plant to soil visible ratio. Thus, as the biomass increases, the higher the influence of photosynthetic pigments on the curve (Figure 8); while with more soil the flatter the line becomes. As related to individual wavelengths, both visible color (mainly blue) and near infrared were highly correlated with stand and vigor ratings. Blue or UV has the highest correlation (~78%) with the rest of the visible region still having an r coefficient above 70 (Figure 9). In summary, combining blue + NIR with an NDVI may be useful for quantifying stand quality early in the season and could have implication in the final yield attained by the crop.

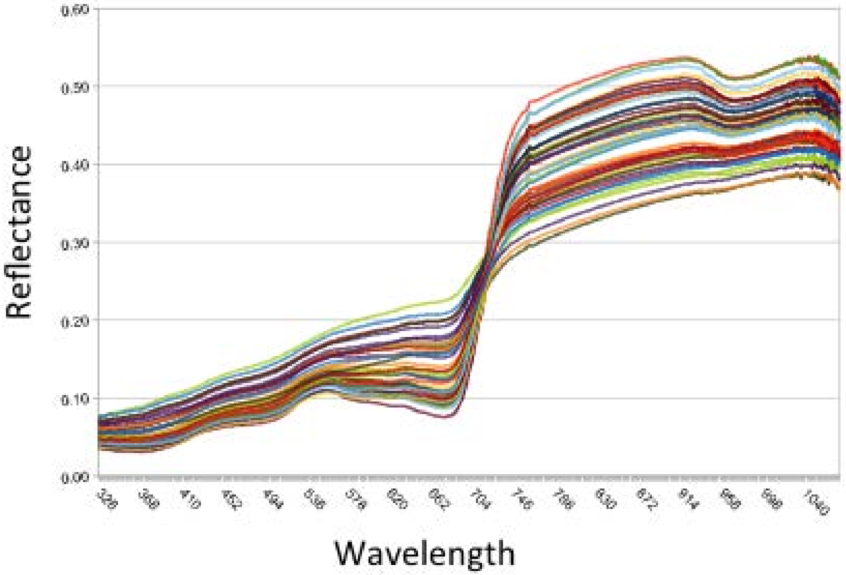

Figure 8. Relationship between reflectance and wavelength for early season stand of winter canola.

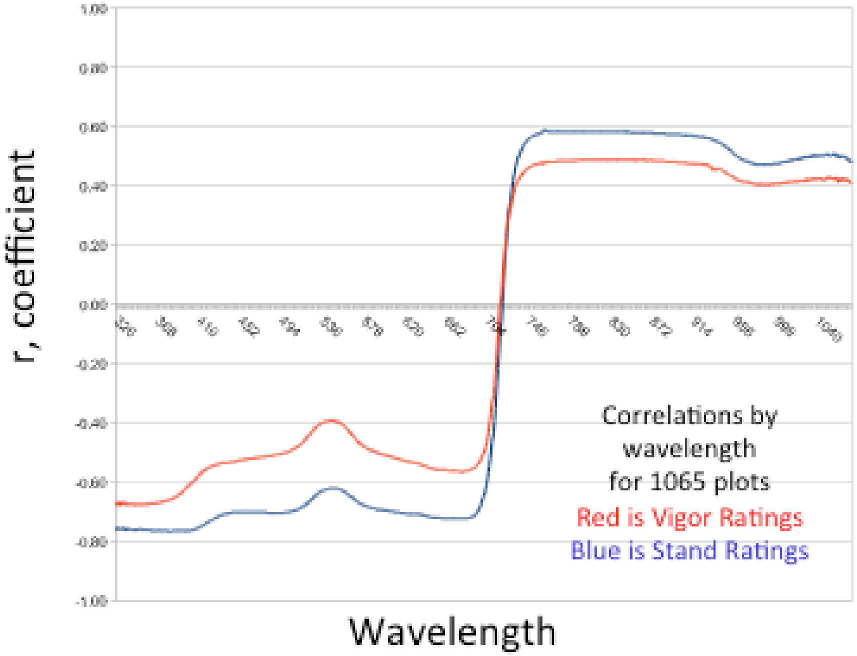

Figure 9. r coefficient and wavelength for early season stand of winter canola, red line represents the vigor ratings and blue the stand ratings.

CONCLUSIONS

The BNDVI values derived from sUAS with modified Canon S100 digital cameras were correlated with the canola biomass. In addition, the thermal imagery collected with sUAS and a DRS Tamarisk®640 thermal camera was highly correlated with the in-season canola biomass. The combined use of both BNDVI and thermal imagery can constitute a feasible option for increasing the in-season prediction of crop biomass. The creation of an index combining both parameters might also demonstrate some potential in predicting final grain yield utilizing information collected before or at the flowering stage.

REFERENCES

Berni, J., P.J. Zarco-Tejada, L. Suárez, and E. Fereres. 2009. Thermal and narrowband multispectral remote sensing for vegetation monitoring from an unmanned aerial vehicle. Geoscience and Remote Sensing, IEEE Transactions on, 47:722-738.

Blum, A., Mayer, J., & Gozlan, G. 1982. Infrared thermal sensing of plant canopies as a screening technique for dehydration avoidance in wheat. Field Crops Research, 5:137-146.

Carlson, T. N., Gillies, R. R., & Perry, E. M. 1994. A method to make use of thermal infrared temperature and NDVI measurements to infer surface soil water content and fractional vegetation cover. Remote Sensing Reviews, 9:161-173.

Caselles, V., Sobrino, J. A., & Coll, C. 1992. On the use of satellite thermal data for determining evapotranspiration in partially vegetated areas. International Journal of Remote Sensing, 13:2669-2682.

Hardin, P.J., M.W. Jackson, V.J. Anderson, and R. Johnson, R. 2007. Detecting squarrose knapweed (Centaurea virgata Lam. Ssp. Squarrosa Gugl.) using a remotely piloted vehicle: A Utah case study. GIScience & Remote Sensing 44:203–219.

Holzapfel, C. B., Lafond, G. P., Brandt, S. A., Bullock, P. R., Irvine, R. B., Morrison, M. J., & James, D. C. 2009. Estimating canola (Brassica napus L.) yield potential using an active optical sensor. Canadian Journal of Plant Science, 89:1149-1160.

Hunt, E.R., M. Cavigelli, C.S.T. Daughtry, J.E. McMurtrey, and C.L. Walthall. 2005. Evaluation of digital photography from model aircraft for remote sensing of crop biomass and nitrogen status. Precision Agriculture 6:359–378.

Hunt Jr, E. Raymond, et al. 2005. Evaluation of digital photography from model aircraft for remote sensing of crop biomass and nitrogen status." Precision Agriculture 6:359-378.

Lo, C. P., Quattrochi, D. A., & Luvall, J. C. 1997. Application of high-resolution thermal infrared remote sensing and GIS to assess the urban heat island effect. International Journal of Remote Sensing, 18:287-304.

Metternicht, G. 2003. Vegetation indices derived from high-resolution airborne videography for precision crop management. International Journal of Remote Sensing, 24:2855-2877.

Nansen, C. Fertiliser strategies, drones and apps–New approaches to pest management.

Quattrochi, D. A., & Luvall, J. C. 1999. Thermal infrared remote sensing for analysis of landscape ecological processes: methods and applications. Landscape ecology, 14:577-598.
Reynolds, M. P., Singh, R. P., Ibrahim, A., Ageeb, O. A. A., Larqué-Saavedra, A., & Quick, J. S. 1998. Evaluating physiological traits to complement empirical selection for wheat in warm environments. Euphytica, 100:85-94.
Sheng, H., Chao, H., Coopmans, C., Han, J., McKee, M., & Chen, Y. 2010. Low-cost UAV-based thermal infrared remote sensing: platform, calibration and applications. In Mechatronics and Embedded Systems and Applications (MESA), 2010 IEEE/ASME International Conference on (pp. 38-43). IEEE.
Soer, G. J. R. 1980. Estimation of regional evapotranspiration and soil moisture conditions using remotely sensed crop surface temperatures. Remote Sensing of Environment, 9:27-45.
Swain, K.C., H.P. Jayasuriya, and V.M. Salokhe. 2007. Suitability of low-altitude remote sensing images for estimating nitrogen treatment variations in rice cropping for precision agriculture adoption. Journal of Applied Remote Sensing 1:013547.
Swain, K.C., S.J. Thomson, and H.P. Jayasuriya. 2010. Adoption of an unmanned helicopter for low- altitude remote sensing to estimate yield and total biomass of a rice crop. Transactions of the ASABE 53:21–27.
Yang, C., Everitt, J. H., & Bradford, J. M. 2006. Comparison of QuickBird satellite imagery and airborne imagery for mapping grain sorghum yield patterns. Precision Agriculture, 7:33-44.
Zhang, Chunhua, and John M. Kovacs. 2012. The application of small unmanned aerial systems for precision agriculture: a review." Precision Agriculture 13:693-712.