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Aerial multispectral imagery for high-throughput mapping of spatial soybean yield potentials.

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Introduction

Timely mapping of grain yield at pre-harvest stages can be critical for the producers to implement appropriate crop management decisions. Conventionally, yield is measured at harvest by combines equipped with yield monitoring systems. Although this data is useful to understand high and low performing areas within the fields and plan for amendments in the future, it does not enable execution of any crop management decisions either at earlier crop growth stages or at pre-harvest. Additionally, such yield monitoring systems can be highly expensive and are restricted for providing yield measurements only once for the growing season. Evaluating yield potentials at earlier crop growth stages can help growers to implement crop input management such as pesticides, fertilizers, fungicide, and irrigation applications (Klompenburg et al., 2020), while at pre-harvest stages would help them to manage harvest, storage and other post-harvest resources, insurance, cash-flow budgeting, and estimate sales and market value among others (Chandel et al., 2021). In such pursuit, mapping yield potentials before harvest has been deemed essential (Klompenburg et al., 2020).

Advent of non-invasive sensing techniques have enabled estimation of crop biomass, nutrient, health, and yield potentials of the crop at pre-harvest stages. Such sensors range from hand-held, ground-based, drone-based, to satellite-based. Hand-held sensors offer restricted sampling and measurements while satellite-based systems are often hindered by cloud covers and restricted resolution.

Drones and spectral imaging for yield mapping

Drones are unoccupied aerial vehicles that have seen significant advancements in the past two decades for agricultural operations, especially crop health mapping and application of pesticides. Crucial mapping applications include detection and assessments of biotic and abiotic stresses, biomass, and yield potentials. Drones equipped with spectral/imaging cameras can provide detailed (up to mm of resolution) and high-throughput data, and thereby the potential for prompt crop management. Aerial imaging enables understanding and management of spatial variations within the fields, which is not often possible with manual scouting or intensive plant/soil analysis. Most importantly, drone imaging missions can be conducted on-demand and quickly when crop assessments are deemed critical. Imaging for agricultural crops has evolved over time and typically includes visible or RGB, Hyperspectral, Multispectral, Fluorescence, and Thermal range among others (Chandel, 2023). Vegetation indices are the most widely used features of spectral imagery for crop analysis. Some of the popular indices include, but are not limited to, Normalized Difference Vegetation Index (NDVI), Green-NDVI, Normalized Difference Red-Edge Index (Ranjan et al., 2019; Chandel et al., 2021). Typically, the higher the magnitudes of these vegetation indices, the higher biomass content, and yields. This article summarizes a recent exploration on drone-based multispectral imagery to estimate grain yield potentials of soybean. Similar updates on various other crops of interest will also be published as progress is made on this subject.

Soybean trials and data collection

Trials were conducted at the Tidewater Agricultural Research and Extension center in Suffolk, VA (Fig. 1). Plots were 4-rows, 30-ft long with fungicide treatments applied to the two center rows of each plot. Plots were arranged in a randomized complete block design with four replications per treatment for a total of 108 individual plots. A drone was flown in mission-mode over the trial plots at vegetative stage-R6 (October 18, 2022) at an altitude of 25 m above ground. This mission captured high resolution (@ 1 cm/pixel) multispectral image snapshots (in Blue, Green, Red, Red-Edge, and Near-infrared wavelength ranges, Drone: DJI Phantom 4 Multispectral). The imaging was conducted near solar (± 2h) noon period for high quality crop feature retrieval. The drone also has a skyward facing light sensor to measure solar radiation intensity while imaging. This measurement is important as it is used to correct any inconsistencies in spectral signatures occurring due to sunlight fluctuations. The plots were harvested on December 5th, 2022, using a plot combine and yield was recorded using an on-board yield monitor.

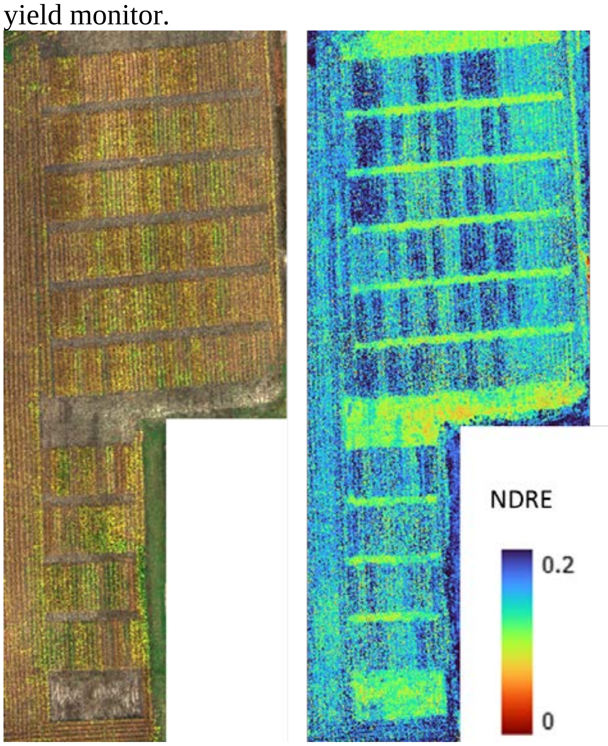

Figure 1. An aerial multispectral imagery derived vegetation index map of the soybean trials showing spatial variation in canopy vigor.

Spectral imagery processing

Multispectral imagery snapshots were initially stitched in a mapping software platform (Pix4D mapper) to generate orthomosaic maps for each corresponding wavelength sensor (i.e., Blue, Green, Red, Red-Edge, and Near-Infrared). These maps were then exported into Geographical Information System software (QGIS) to extract a total of 24 vegetation index feature maps (Chandel et al., 2021). From these maps, feature values were extracted for each trial plot (Total 108) using a combination of shapefiles and zonal statistics toolbars in the software. These values were then contrasted with actual yield recorded at harvest using statistical correlation (r) and regression coefficients (R^2). These statistical analyses were conducted to observe the significance of yield potential mapping using drone-based spectral imaging.

Results

Among the derived spectral features, the regression plots revealed that NDRE (Normalized Difference Red-Edge Index, $R^2 = 0.56$, Fig. 2) had the highest accuracy for soybean yield estimation, followed by GRVI (Green-Red Vegetation Index, $R^2 = 0.54$), GCI (Green Chlorophyll Index, $R^2 = 0.54$), and GNDVI (Green-NDVI, $R^2 = 0.54$), among others. NDVI showed relatively lower accuracy ($R^2 = 0.07$).

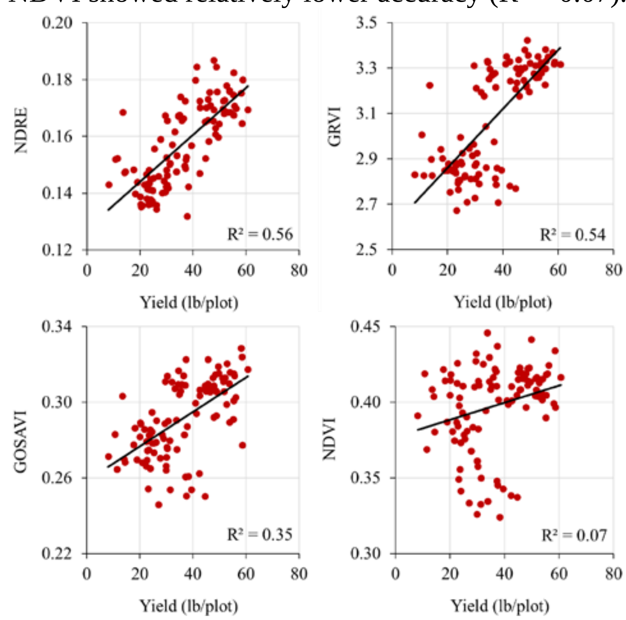

Figure 2. Sample regression plots for selected vegetation indices showing accuracy of soybean grain yield estimation.

Similar to regression analysis, correlation analysis also revealed the highest value for NDRE (r = 0.75, Fig. 3), followed by GRVI (Green-Red Vegetation Index, r = 0.74), GCI (Green Chlorophyll Index, r = 0.74), and GNDVI (Green-NDVI, r = 0.73), among others i.e., highest accuracy for soybean grain yield estimation. Among the evaluated vegetation indices, MNLI (Modified Non-Linear Index) had the lowest accuracy (R^2 = 0.02, r = 0.15). Figure 3 shows the correlation coefficients (representing accuracy) for estimating soybean grain yield potentials using raw reflectance and vegetation indices. NDRE showed highest accuracy because it is capable of detecting variations in crop vigor and biomass even in advanced or denser stages. GOSAVI also had decent accuracy for yield estimations (R^2 = 0.35, r = 0.59) but relatively lower than with previously reported corn yield estimations (Chandel and Langston, 2023). Reasons for this could be the structural and density differences between the soybean and corn crops at different growth stages. NDRE has also been reported to be a more reliable estimator of soybean nitrogen and phosphorous status and requirements for precision fertilizer applications compared to NDVI. Figure 4 shows pixelated soybean grain yield projections derived using best performing vegetation index i.e., NDRE.

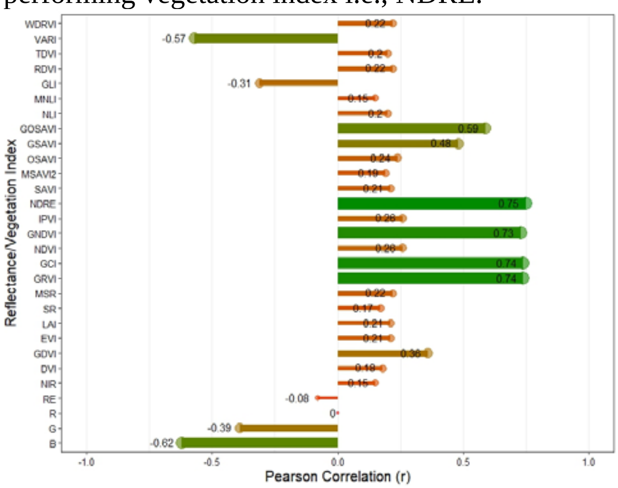

Figure 3. Correlation coefficients representing accuracy of extracted spectral reflectance and vegetation indices for soybean grain yield estimation.

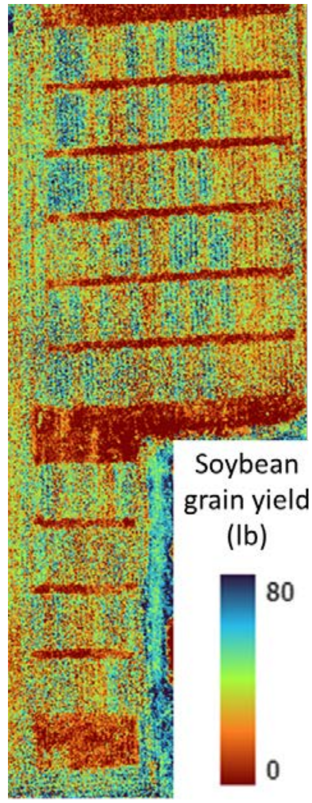

Figure 4. Sample spatial soybean grain yield projection map derived using NDRE spectral feature. Higher intensity of blue color represents higher grain yielding areas.

Conclusions and future scope

Drone-based spectral imaging is capable of estimating soybean grain yield projections faster and more efficiently than the yield monitors in combines. Such spatial estimations if done early in the season could help growers to identify lower performing areas of the field. This will guide them to adopt prompt, precise, and cost-effective crop management operations (e.g., irrigation, fertilizer, or fungicide applications) in the same season or before/during the next cropping season. Pre-harvest yield estimates would help in better planning and allocation of harvest, storage, and sales resources for higher profitability and crop value. Using the findings reported in this study, our group is working to identify the earliest time stamp in the season when accurate spatial yield projections could be made so that further precision in disease management, fertilizer applications, or irrigation could be established.

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2023 ENTO-527NP