Exploring tractor mounted hyperspectral system ability to detect sudden death syndrome infection and assess yield in soybean

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Abstract. *Pre-visual detection of crop disease is critical for both food and economic security. The sudden death syndrome (SDS) in soybeans, caused by Fusarium virguliforme (Fv), induces 100 million US$ crop loss, per year, in the US alone. Field-based spectroscopic remote sensing offers a method to enable timely detection, but still requires appropriate instrumentation and testing. Soybean plants were measured at canopy level over a course of a growing season to assess the capacity of spectral measurements to detect Fv infection by inoculated vs control plots. A dual field-of-view, two-spectrometer (400 to 1630 nm) system named Piccolo Doppio, provided an efficient method for the collection of plant reflectance by eliminating the need for frequent reference standard measurements. This system was used on a tractor to obtain canopy reflectance eight times during the 2016 growing season in Arlington WI. Partial least squares discriminant analysis (PLSDA) was applied to the spectroscopic data to discriminate between Fv-inoculated and control plots. Best performance was during the early reproductive stages, spectrally discriminating Fv infection prior to visual canopy symptoms with total accuracy of classification of 88% for calibration, 79% for cross-validation, and 82% for independent validation. Near infrared (NIR) wavelengths were most sensitive to inoculation status, suggesting that canopy level detection is related to lower biomass influenced as a consequence of disease. Partial least square regression (PLSR) was used on a late-stage canopy level data to predict soybean seed yield, which is typically the metric most desired by growers and breeders, with calibration, cross-validation and independent validation coefficient of determination (R^2) values 0.71, 0.59 and 0.62 ($p<0.01$), respectively, and independent validation root mean square error (RMSE) of 0.31 t ha^{-1}. Therefore, it is concluded that: early reproductive stages are recommended for canopy spectral detection of soybean root Fv infection prior to canopy symptoms and that late reproductive stages are best for seed yield detection. SDS is detectable due to physiological effects on foliage, while detection of yield is based on indirect correlations with physiology. This study showed promising results for use of spectral sensing of canopy to identify Fv infection on soybean roots where no* *canopy symptoms are visually present. It is also concluded that the dual field of view, two spectrometers, tractor mounted system has shown spectral feasibility of operation for precision agriculture research and potential applications.*

Keywords. *Hyperspectral, precision agriculture, diseases detection, Piccolo, partial least squares, seed yield assessment, sudden death syndrome, soybeans.*

Introduction

Remote and proximal sensing are increasingly applied in agriculture for diverse applications, including estimation of yield, water content, crop nutrients, leaf area index (LAI), disease, pest and soil properties (Mulla, 2013). Here, we test the capacity of tractor-based proximal spectral measurements to detect *Fusarium virguliforme* (*Fv)*, which causes soybean sudden death syndrome and assess soybean seed yield. Sudden death syndrome (SDS) was among the top yield-suppressing diseases with average annual crop loss in the US assessed to be around $100 million US (Ji et al., 2006). The primary field detection method for SDS is canopy symptoms. Canopy symptoms are the result of fungal phytotoxins translocated from roots to leaves causing Rubisco and chlorophyll degradation, initiation of chlorosis and necrosis in leaves (Chang et al., 2016).

Proximal measurements using the sun as illumination can be a challenge. MacLellan and Malthus (2009) presented the concept of a two spectrometers system with dual field of view for each, alternately obtaining upwelling (radiance) and downwelling (irradiance) measurements, using a cosine response fore optic in lieu of the standard white reference. MacArthur et al. (2014) designed and presented an operational system (Piccolo) that is lightweight, self-contained, and wirelessly controlled, and similar in principle to dual field of view systems used at eddy covariance towers for canopy reflectance observations. Here, the two spectrometers Piccolo system is mounted on a moving platform at ground level for a precision agriculture application. As a test of its feasibility we assess the capacity to (1) detect disease status prior to visual canopy symptoms (Herrmann et al., 2018); and (2) predict yield in soybean from proximal visible-near infrared-shortwave infrared spectra (400–1630 nm).

Methodology

Field experiment was conducted during April to October 2016 at the University of Wisconsin Arlington Agriculture Research Station. The canopy level experiment was a split-split-plot arrangement with four replications arranged in completely randomized blocks, with three planting dates resulting in 144 plots, half of them were inoculated and the rest were control.

The canopy spectral data were obtained through the growing season by a tractor mounted Piccolo dual field-of-view two-spectrometer system equipped with two spectrometers: Flame and NIRQuest (Ocean Optics, Inc., Dunedin, FL, USA). The ability to obtain upwelling and downwelling data almost simultaneously derives from the use of two fiber optics, which together completely cover the inlet slit of each of the spectrometers. Relative reflectance values for each plot were obtained using a custom Python script (https://github.com/prabu-github/tracolo; Herrmann et al., 2018). Partial least squares regression (PLSR) was applied to assess the ability of canopy spectral data to predict soybean seed yield. PLS discriminant analysis (PLSDA) was implemented to classify *Fv* inoculation status of soybean plots on eight dates through the growing season.

Results

Best performance of classification models was during the early reproductive stages, spectrally discriminating *Fv* infection prior to visual canopy symptoms with total accuracy of classification of

88% for calibration, 79% for cross-validation, and 82% for independent validation. Near infrared (NIR) wavelengths were most sensitive to inoculation status, suggesting that canopy level detection is related to lower biomass influenced as a consequence of disease. Spectral prediction model was applied for a late-stage canopy level data to predict soybean seed yield, which is typically the metric most desired by growers and breeders, with calibration, cross-validation and independent validation coefficient of determination (R^2) values 0.71, 0.59 and 0.62 ($p<0.01$), respectively, and independent validation root mean square error (RMSE) of 0.31 t ha^{-1}.

Conclusions

Crop phenotyping is a bottleneck in plant research, and rapid methods to assess disease, yield and other traits for large numbers of samples are needed. Infection by the fungal pathogen SDS is detectable due to physiological effects on foliage, while, detection of seed yield is based on indirect correlations with physiology. We conclude:

- *Fv* inoculation that accrues in the roots can be spectrally detected in the soybean foliage at the canopy level prior to visual canopy symptoms.

- The dual field of view, two spectrometers, tractor mounted system has shown spectral feasibility of operation for precision agriculture research and potential applications.

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References

Chang, H. X., Domier, L. L., Radwan, O., Yendrek, C. R., Hudson, M. E., & Hartman, G. L. (2016). Identification of Multiple Phytotoxins Produced by Fusarium virguliforme Including a Phytotoxic Effector (FvNIS1) Associated With Sudden Death Syndrome Foliar Symptoms. Molecular Plant-Microbe Interactions, 29(2), 96-108. doi:10.1094/mpmi-09-15-0219-r.

Herrmann, I., Vosberg, S., Ravindran, P., Singh, A., Chang, H.-X., Chilvers, M., et al. (2018). Leaf and Canopy Level Detection of Fusarium Virguliforme (Sudden Death Syndrome) in Soybean. Remote Sensing, 10(3), 426.

Ji, J., Scott, M. P., & Bhattacharyya, M. K. (2006). Light is essential for degradation of ribulose-1.5-bisphosphate carboxylase-oxygenase large subunit during sudden death syndrome development in soybean. Plant Biology, 8(5), 597-605. doi:10.1055/s-2006-924175.

MacArthur, A., Robinson, I., Rossini, M., Davis, N., & Mac Donald, K. (2014, 22-24 April). A dual-field-of-view spectrometer system for reflectance and fluorescence measurements (Piccolo Doppio) and correction of etaloning. (Paper presented at the 5th International Workshop on Remote Sensing of Vegetation Fluorescence, 22-24 April, Paris, France)

MacLellan, C. J., & Malthus, T. J. (2009). High performance dual field of view spectrometer with novel input optics for, autonomous reflectance measurements over an extended spectral range. IEEE International Geoscience and

Remote Sensing Symposium, Vols 1-5, 2163-2166.

Mulla, D. J. (2013). Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. Biosystems Engineering, 114(4), 358-371. doi:10.1016/j.biosystemseng.2012.08.009.