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# Characterizing soybean vigor and productivity using multiple crop canopy sensor readings

Joshua J. Miller[a,*], James S. Schepers[b], Charles A. Shapiro[c], Nicholas J. Arneson[a], Kent M. Eskridge[d], Maxwel C. Oliveira[c], Loren J. Giesler[a]

[a] Dep. of Plant Pathology, Univ. of Nebraska, 406 Plant Sciences Hall, Lincoln, NE, 68583, United States
[b] USDA-ARS and Dept. of Agronomy and Horticulture, Univ. of Nebraska, Lincoln, NE, 68583, United States
[c] Dep. of Agronomy and Horticulture, Univ. of Nebraska, 57905 866 Rd., Concord, NE 68728, United States
[d] Dep. of Statistics, Univ. of Nebraska, Lincoln, NE, 68583, United States

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ABSTRACT

Canopy reflectance has been used in crops, such as corn and wheat, to assess crop status and direct in-season management practices, but less research has focused on using canopy reflectance in soybean research and production. In this study, soybean canopy reflectance measurements were measured at several growth stages throughout the 2015 and 2016 growing seasons using the RapidSCAN CS-45 Handheld Crop Scanner to determine if the normalized difference red edge (NDRE) index could be used to predict relative soybean productivity within a field prior to harvest. The NDRE values were used to calculate the cumulative reflectance of each experimental unit over the season. The cumulative reflectance readings through the R6 growth stage, termed the area under the reflectance progress curve (AURPC), and seed yield of every experimental unit were classified as top 25%, middle 50%, or bottom 25% within each location. Across all locations, bottom AURPC values correctly predicted bottom yield 52.5% of the time, and ranged from 46.7 to 86.2% by location. The probability of incorrectly predicting the bottom yield with a top AURPC value (9.7%) was also lower than incorrectly predicting the top yield with a bottom AURPC value (12.3%). Misclassifications by incorrectly identifying a bottom yield with a top AURPC ranged from 0.0% to 16.7% by location. Additionally, individual NDRE values at R2 were determined to be influenced by seed treatments at seven of the eight locations ($p = 0.10$) and, upon further investigation, found to be correlated to early-season soybean populations ($r^2 = 0.314$).

## 1. Introduction

Increasing soybean [*Glycine max* (L.) Merrill] yields is one of the primary goals of research involved in soybean production. However, determining the variables that consistently increase soybean yields, or stressors that reduce soybean yields, continues to challenge researchers, agronomists, and producers. The use of crop sensors has emerged as a new technology being used successfully in other cropping systems to monitor and manage agricultural inputs in a site-specific manner (Hatfield et al., 2008; Pinter et al., 2003).

Genetic improvements account for nearly two-thirds of on-farm yield gains (Rincker et al., 2014; Specht et al., 2014). The remaining gain is a result of changes in agronomic practices (Rowntree et al., 2013), including earlier planting dates (Heatherly and Elmore, 2004; Specht et al., 1999), narrower row spacing (Heatherly and Elmore, 2004; Specht et al., 1999; Voldeng et al., 1997), improved weed control (Luedders, 1977; Voldeng et al., 1997), and reduced harvest loss (Specht et al., 1999). Managing soybean diseases and insects is also an important agronomic practice to prevent soybean yield losses (Kandel et al., 2016). To increase soybean yields, growers have increased their use of seed treatments, foliar fungicide and insecticide applications at pod set, and the use of fertilizers (USDA-NASS, 2016). However, yield responses to these inputs are often inconsistent and vary by environment and cultivar (Gaspar et al., 2014; Swoboda and Pedersen, 2009).

Crop canopy sensors have emerged as a technology to evaluate plant characteristics using principles of leaf and canopy reflectance that can eliminate the bias inherent to typical evaluation practices. Reflectance properties in the near infrared (NIR) region (700–1300 nm) of the electromagnetic (EM) spectrum are influenced by leaf density and canopy structure (Kumar and Silva, 1973), while chlorophylls strongly absorb in the blue and red regions of the EM spectrum (Lichtenthaler and Buschmann, 2001). Additionally, absorption in the red edge (RE)

* Corresponding author.
*E-mail address:* joshua.miller@huskers.unl.edu (J.J. Miller).

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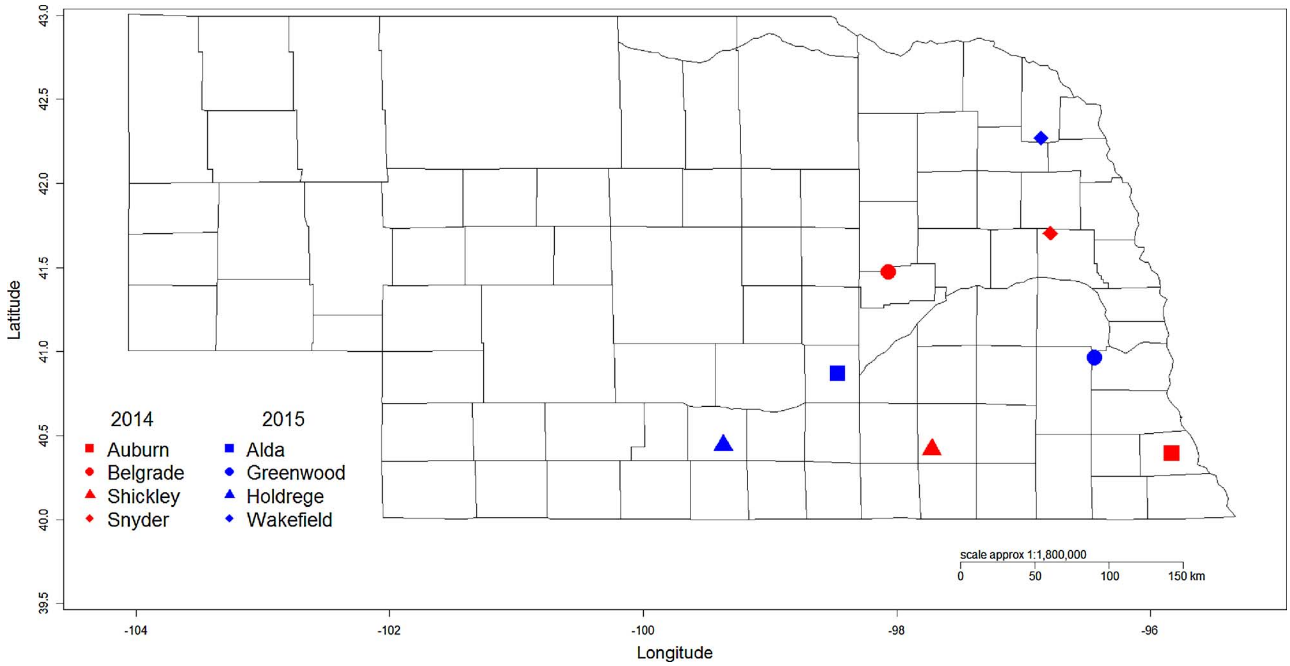


**Fig. 1.** Field trial locations across eastern Nebraska during 2014 and 2015.

region (680–750 nm) of the spectrum, defined as the inflection point between the red and near infrared regions of the spectrum, is sensitive to changes in chlorophyll content (Gitelson et al., 1996), which is closely related to gross primary productivity of terrestrial plants (Gitelson et al., 2006).

Numerous algorithms, or vegetation indices (VIs), have been developed using reflectance measurements in the visible and NIR reflectance bands to estimate biophysical characteristics of vegetation (Hatfield et al., 2004). The normalized difference red edge (NDRE) index, defined in detail in the Materials and Methods section, is a VI that has been used for crop canopy evaluations (Gitelson and Merzlyak, 1994). The RE band penetrates deep into the canopy and is sensitive to crop canopy chlorophyll at higher canopy biomass, overcoming the saturation inherent to the normalized difference vegetation index (NDVI), the most commonly used VI (Li et al., 2014). Eitel et al. (2010) found that using RE reflectance improved the ability to estimate variations in chlorophyll content ($r^2 > 0.73$, RMSE $< 1.69$) over devices that did not use RE ($r^2 = 0.57$, RMSE $= 2.11$).

Crop canopy sensors have been used for numerous agronomic applications, particularly as a tool in precision agriculture (Pinter et al., 2003). In wheat production (Raun et al., 2005) and corn production (Holland and Schepers, 2010; Solari et al., 2008) algorithms have been developed using vegetation indices to direct in-season nitrogen management based on changes in remotely-sensed chlorophyll content and biomass. Less work has focused on soybean production, most likely because nitrogen management is less important due to the plant's innate ability to fix its own nitrogen (Keyser and Li, 1992). However, research that has utilized crop sensors in soybean has primarily focused on individual components of soybean production, such as detecting weed infestations (Medlin et al., 2000), identifying insect infestations (Board et al., 2007), and detecting stress induced by soybean cyst nematode (SCN) at the field level (Nutter et al., 2002), while some have evaluated the ability to predict soybean yield (Ma et al., 2001; Mourtzinis et al., 2014; Zhang et al., 1999).

Management zones have been used in precision agriculture to efficiently manage agricultural crops. Often, management zones are created from historical yield records, field topography and soil properties, or soil electrical conductivity (Fleming et al., 2000; Schepers et al., 2004). Remote sensing has provided another tool to delineate management zones by providing characteristics of a growing crop during the season (Inman et al., 2008).

The RapidSCAN CS-45 Handheld Crop Sensor (Holland Scientific Inc., Lincoln, NE) is an example of a crop canopy sensor that is being used commercially in the field of agriculture. The RapidSCAN sensor is an active optical sensor that measures crop and soil reflectance at three wavelengths, red (670 nm), RE (730 nm), and NIR (780 nm). Active sensors utilize their own radiation source, thereby eliminating the need for sufficient ambient illumination to collect reflectance readings (Holland et al., 2012). The NDRE index is calculated from the RE and NIR bands to evaluate differences in crop canopy biomass and chlorophyll content (Gitelson et al., 1996). Because of the inherent limitations of the NDVI index, and the capability of this sensor to calculate NDRE, the latter index was examined to determine its utility in a soybean crop.

No studies to date have investigated the ability to use multiple NDRE index values to create management zones in soybeans. Vegetation indices have predominantly been recorded at a single point in the season to evaluate crop canopy characteristics. Therefore, the objectives of this study were to (i) determine if multiple crop canopy sensor readings using NDRE index values over the course of the soybean growing season could be used as an indicator of soybean yield and field productivity, and (ii) determine at what growth stages single readings by a commercially available crop canopy sensor could be used to evaluate physiological responses to soybean inputs in a small-scale research setting using NDRE.

## 2. Materials and methods

### 2.1. Experimental site and design

This study was conducted at four field locations each year between 2014 and 2015 across eastern Nebraska for a total of eight different locations (Fig. 1). Sites were selected to represent the major soybean-producing region of Nebraska with no prior knowledge of pest pressure.

The experimental design was an alpha lattice to account for variation inherent in large field experimentation (Barreto et al., 1996). All plots were planted in four complete blocks at 76-cm row spacing. In both years, thirty treatments were arranged in a 5 × 6 alpha-lattice