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Evaluation of ground, proximal and aerial remote sensing technologies for crop stress monitoring

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Abstract: In this study, three different sensing technologies were evaluated for their performance in monitoring pinto beans crop stress at early stages. Treatments involved replicate pinto bean field plots with 50% and 100% irrigation throughout the season. Eight different pinto bean cultivars were seeded on the plots prepared with either strip or conventional tillage method. Evaluated technologies were a handheld linear ceptometer, and multi-spectral proximal and aerial remote sensing technologies. Spatial resolutions of the aerial remote sensing images acquired from 100 m above ground level (AGL) and the proximal sensing images acquired at 6.7 m AGL were 35.2 and 5.6 mm·pixel^{-1}, respectively. Crop indictors of leaf area index (LAI), green normalized difference vegetation index (GNDVI) and canopy cover (CC) were extracted from the data of ceptometer and multispectral sensors collected at the early stages of pinto beans on July of 2015. Results show that spatial coverage of aerial remote sensing was thus 700 times larger than that of proximal remote sensing utilized in this study. GNDVI and CC data from both aerial and proximal remote sensing was able to discriminate crops with different irrigation and tillage treatment significantly at 5% level. Similarly, leaf area index (LAI) from ground sensor (ceptometer) was also able to distinguish effects of different irrigations, but could not differentiate tillage treatments. Correlation trends showed that the aerial remote sensing and ground sensing based indicators were strongly related with crop yield compared to proximal remote sensing based indicators. Although data were collected for natural light variations, possibly latter sensing module had more predominant light variation effect on image quality at different imaging times on given imaging day.

Keywords: Remote sensing, ground sensor, sensing altitude, vegetation index, stress detection, row crops.

1. INTRODUCTION

Continuing growth in the global population requires an average increase in crop production of 44 million tons per year to meet perceived the food security target (Ray et al., 2013). However, current global environmental conditions, such as shortage of water and changing climate, adversely affect crop yield. It is reported that current crop yield increase rate is only 0.9-1.6% per year for major crops such as maize, rice, wheat and soybean (Ray et al., 2013). This rate is far from the targeted increase in agricultural production. Therefore, it is important to develop new crop varieties with stress tolerance and high yield potential, as well as to optimize field management for existing crops to maximize the outputs with limited inputs. One of the biggest challenges for developing new varieties and precision field management is lack of suitable sensing technologies towards site-specific information collection (Araus and Cairns, 2014; Fiorani and Schurr, 2013).

Current technologies for the acquisition of site-specific crop information include ground based (handheld) *en suite* sensing devices, satellite based aerial remote sensing technologies, ground based proximal remote sensing, and unmanned aerial system (UAS) based aerial remote sensing. Satellite based remote sensing technologies are widely used for large scale crop monitoring but offer limited spatial resolution (Rango et al., 2009). A higher spatial resolution is needed to obtain sufficient details of crops for accurately monitoring their stress. As supplement to satellite imagery, UAS-based remote sensing technologies are gaining interests of growers in crop stress monitoring. Compared to satellites, UASs are able to quickly acquire high-resolution data for specific fields and are flexible in terms of flying altitude and schedules based on needs. They are also less costly and might be safer than piloted aircraft. UAS-based remote sensing technologies have been used for crop stress monitoring, yield prediction and in high-throughput phenotyping under field conditions (Khot et al., 2016; Sankaran et al., 2015a).

Traditionally, some important crop traits, including leaf area index, leaf chlorophyll and yield were measured manually with ground based equipment or sensors (Gitelson, 2004; Sankaran et al., 2015a; Taugourdeau et al., 2014), which are time consuming and labor intensity (Bellvert et al., 2014). The field based devices usually take measurement in a small scale, such as several leaves, plant parts, and may result in substantial measurement error due to the variation within crops. Bellvert et al. (2014) compared the performance of the ground measurements of an infrared temperature sensor with those of

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UAS-based thermal imaging sensor in the detection of crop water stress of grapes. Authors suggested that aerial imagery flying at 200 m above ground level was effective in assessing the spatial variability of water stress of vine grapes when the data were collected at solar noon. However, the effect of flight altitude or the spatial resolution of imagery on the sensor performance was not discussed. One of the benefits of UAS-based sensing systems is that they are flexible to fly at different altitudes and able to collect data with various spatial resolutions (i.e. ground distance in a pixel). Several studies have been conducted to establish the relationships of crop traits with measurements taken with remote sensing data at a certain altitude. The question of how difference of the measurements taken from various altitudes for monitoring crop stress is not fully addressed based on our knowledge. Therefore, objectives of the study were to determine 1) the feasibility of using a ground-based proximal multispectral imaging and a UAS-based multispectral imaging for rapid crop stress monitoring in irrigated row crop (pinto beans), and (2) understanding the effect of spatial resolution on quantification of the crop stress in the early growth stages.

2. MATERIALS AND METHODS

2.1 Experimental plots

Experiment was conducted at Washington State University (WSU) research farm near Prosser, WA, USA in 2015. Eight cultivars of pinto bean (*Phaseolus vulgaris* L.) were planted in four irrigation plots of 80.1 m by 12.2 m in dimension with 4.6 m buffers. Full irrigation was scheduled for two of the irrigation plots (100% of evapotranspiration) and half irrigation (50% of evapotranspiration) for the other two plots. Each irrigation plot was spilt into four plots with even length in dimension of 18.3 m by 12.2 m with 2.3-m buffers and prepared with two tillage treatments, i.e. conventional and strip tillage. Within each tillage plot, eight subplots of 4.6 m by 6.1 m were split to grow eight cultivars of pinto bean based on random complete block design (RCBD). Overall, each pinto bean cultivar was repeated four times on 16 subplots with two irrigation levels and two tillage treatments, resulting in total of 128 subplots. Lorox herbicide was applied at 28 days after panting and irrigation treatments started at 30 days after emergence at around June 25, 2015. Two irrigation treatments of full and half level were applied to different plots until senescence. Plants were harvested on September 15, 2015 with a growth period of 117 days.

2.2 Data collection

Different sensing technologies were used to collect field data, including a ground-based handheld device (ground sensing), a ground-based proximal remote sensing (proximal remote sensing) and an UAV-based aerial remote sensing (aerial remote sensing), as shown in Fig. 1. Measurement of ground sensing technology was leaf area index (LAI) of crop canopies, which was measured under full-sun conditions at two locations within each plot using a linear ceptometer (AccuPAR PAR-80, Decagon Devices, Pullman, WA, USA). The ceptometer calculates LAI based on photosynthetically active radiation (PAR) intercepted by the plant canopy (Decagon devices, 2016). Two measurements of incident PAR were taken, with one taken at 1.0 m above crop canopy followed by the second measurement taken at the soil surface with the sensor placed perpendicular to and centered over two rows of each subplot. All measurements were taken between 11:00 h and 13:30 h (solar noon) to minimize the influence of solar zenith angle on PAR attenuation. Intercepted PAR was estimated as unity minus the fraction of the soil-surface to above-canopy measurements and then averaged for each plot. All readings were collected on July 21, 2015.

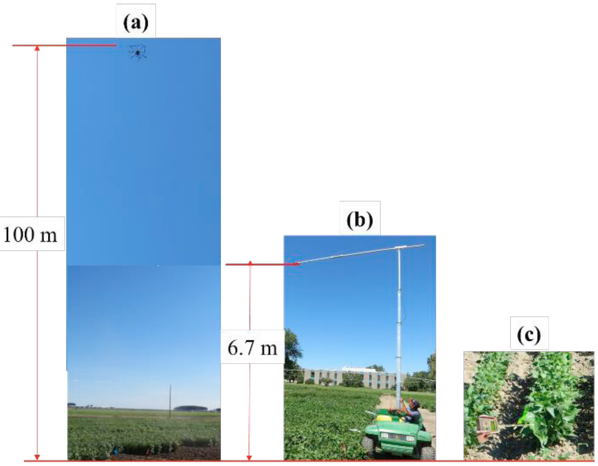

Fig. 1. Technologies used to collect field data. (a) An unmanned aerial system based aerial remote sensing with an altitude of 100 m above ground level (AGL), (b) a ground vehicle based proximal remote sensing with an altitude of 6.7 m AGL, and (c) a ground-based handheld sensing device to measure photosynthetically active radiation (PAR) intercepted around plant canopy.

Proximal remote sensing data were collected using a multispectral camera (RedEdge, MicaSense, Settle, WA, USA), including five spectral bands of blue (centre at 475 nm), green (560 nm), red (668 nm), red edge (717 nm) and near infrared (840 nm). Some selected specifications of the camera are listed in Tables 1 and 2. In the test, the camera was mounted on an aluminum structure which was perpendicularly attached to a vertical telescoping mast (LM20-S, Floatograph, Santa Barbara, CA, USA) (Fig. 1b). The mast is extensible and could raise the sensor to 6.7 m above ground level (AGL). An agricultural vehicle (4210, Deere & Company, Moline, IL, USA) was used to move the supporting system in the field. The sensor was powered with a USB battery pack and triggered and managed with a web-based interface on a remote laptop through Wi-Fi connection. The acquired images were saved into an on-board SD card of the camera. All images were collected around solar noon on July 16, 2015.

Table 1. Key specifications of imaging sensors used in this study.

Remote sensing	Focal length (mm)	Sensor size (mm)	Image resolution (pixel)
Proximal	5.5	4.8×3.6	1280×960
Aerial	4.0	6.2×4.6	4608×3456