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Aerial multispectral imaging for crop hail damage assessment in potato

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Crop loss assessment after an event of hailstorm can be inaccurate, subjective, and time consuming with the conventional method. Low-altitude, high-resolution aerial imaging using an unmanned aerial vehicle can be utilized for rapid assessment of target crops in a large scale, which can potentially improve the evaluation procedure. The goal of this study was to evaluate the feasibility of rapid and accurate assessment of crop damage due to simulated hailstorms using aerial multispectral imaging. Field experiments were conducted during two seasons in two potato varieties (Russet Norkotah, Ranger Russet) with three levels of mechanical defoliation (33%, 66%, and 99%) at three growth stages (tuber initiation, early bulk, and late bulk). All defoliation treatments were compared to the non-treated control plots (0% defoliation). Aerial multispectral images were collected between 77 and 108 days after planting (0–60 days after damage). Vegetation indices such as green normalized difference vegetation index (GNDVI), normalized difference vegetation index, and soil-adjusted vegetation index were calculated from replicate plots of different treatments. Results from two seasons showed similar trends in GNDVI values, with maximum effect of hail damage observed in early bulk stages. The mean GNDVI value was significantly lower in crops with the severe damage (99% defoliation) than others upon hail damage at the early bulk stage, with imaging after 10 days after damage. The difference in GNDVI for crops with 33–66% damage could be detected within 10 days after damage, and crop regrowth after that time period removed the effects of defoliation. The 99% defoliation damage at the early bulk stage also affected the crop yield significantly. Correlation analysis between vegetation indices and yield data indicated a strong relationship ($r = 0.77$–0.90) for damage at the early bulk stage than other stages.

1. Introduction

Thunderstorm, especially a hailstorm is unpredictable and can cause serious damage to property and agricultural crops (Wang et al., 2012). In U.S., hail-induced crop damage accounts to 10% of the weather-induced crop losses resulting in an economic loss of US$ 914.6 million in 2014 (U.S. Department of Agriculture Risk Management Agency, USDA-RMA, 2015). As a risk management strategy, many farmers/growers purchase crop insurance to prevent severe economic losses related to such unintended natural events. The extent of crop loss due to hail damage is usually assessed by third party adjusters according to loss parameters, such as the amount of crop defoliation, harvesting difficulty, and direct amount of produce loss (Peters et al., 2000; Apan et al., 2005). The loss parameters are typically measured using a series of representative sites from the affected area. Often times, such assessment can be time consuming, labor-intensive, and subjective. Therefore, an alternative rapid, reliable (quantitative), efficient, and cost-effective crop loss evaluation technique is critically needed and desired by the agribusiness industry and growers.

Remote sensing technology has been used as a tool to detect crop loss due to biotic and abiotic stress, such as drought, disease, frost and fire in numbers of studies (Zhang and Kovacs, 2012; Mulla, 2013). Remote sensing commonly utilizes different optical sensors such as multispectral and hyperspectral imaging systems with various platforms such as satellites, aircrafts, and helicopters, to capture aerial images of target fields and derive various vegetation indices for crop loss assessment (Mulla, 2013). The potential of using remote sensing to improve the crop loss assessment for insurance purposes has been summarized in de Leeuw et al. (2014). The benefits and limitations of using remote sensing technology in crop insurance were evaluated, and the technology was recommended as a low-cost solution that could enhance the conventional crop loss assessment method. Capellades et al. (2009) analyzed the potential of using 'RapidEye' remote sensing system (Satellite Imaging Corporation, Tomball, TX) to estimate hail damage on insured corn and soybean crops. A soil-adjusted vegetation

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index (SAVI) was successfully used to classify crops into seven damage levels within each field. Zhao et al. (2012) studied the feasibility of assessing hail damage in corn using a mini-satellite with multispectral imaging system. Based on normalized difference vegetation index (NDVI) values, a model was developed to estimate the hail damage level and post-hailstorm damaged acreage. An overall accuracy of 86% in determining damage levels was reported in their study. Similarly, Peters et al. (2000) used an aircraft carrying a four band sensing system (red, green, blue, and near infrared) to evaluate the simulated hail damage on corn and soybean fields. The extracted NDVI values from the aerial images showed strong relationship with the ground reference spectroradiometer data ($R^2 = 0.88–0.93$). Utilization of satellite and aircraft for aerial imaging for crop assessment can be limited by low spatial and temporal resolution, and high cost of operation that may not be suitable, especially for small size farms.

In the past few years, unmanned aerial vehicles (UAVs) are attracting the interest of researchers and commercial sectors for high-throughput data collection in precision agriculture and phenomics (Sankaran et al., 2015; Khot et al., 2016). Compared to satellite-based remote sensing, UAV can collect images with high spatial resolution (up to cm) and temporal frequency based on the imaging needs at lower costs. Therefore, UAV may be used for acquisition of high-resolution data in insured fields to assess crop losses due to hail damage and other causes. The overall goal of this study was to evaluate the feasibility of UAV-based imaging to estimate potato crop loss caused by simulated hailstorms. The specific objectives were to determine the feasibility of using UAV-based temporal and spatial image data to estimate different levels of hail damage, compare the sensitivity of different vegetation indices in hail damage estimation, and assess the relationship between vegetation indices and crop yield.

2. Materials and methods

2.1. Field plots and hail damage simulation

The study was conducted during two field seasons in 2014 and 2015 at the Washington State University Research Station near Othello, WA. Two potato varieties of Russet Norkotah strain TX 278 (Norkotah), an early to medium maturing variety and Ranger Russet (Ranger), a late maturing variety were planted into a prepared potato field. The field was segmented into 18 crop rows (86 cm width) with both varieties planted at 25 cm apart and 20 cm deep (Rows 1–9 for Norkotah, Rows 10–18 for Ranger) as shown in Fig. 1. Each row was separated into 13 sections with 5 m in length, and three sections from adjacent rows were used as a plot for the hail damage treatments. The field was center-pivot irrigated and managed according to standard regional practices.

Effect of hail damage on the potato was tested in three different growth stages, i.e. *Tuber Initiation* (*TI*), *Early Bulk* (*EB*), *and Late Bulk* (*LB*) in both varieties. The details on the treatment time period are as shown in Table 1, with *TI* treatment at about 45 days after planting (DAP), *EB* treatment at about 75 DAP, and *LB* treatment at about 93 and 119 DAP in Norkotah and Ranger variety, respectively. Three levels of hail damage (33%, 66% and 99% defoliation) were simulated and compared with the control (0% defoliation, Fig. 2). Hail damage of 33% and 66% treatments was induced by sweeping a solid-tined garden rake with 16 curved tines, 2.5 cm apart, through the canopy along each row of the treated plot. Severe defoliation (99%) was induced using a Stihl® FS130 R string trimmer (Stihl® Corporation, Virginia Beach, VA, USA). The extent of defoliation was assessed by measuring ground cover with a ground cover grid for the *TI* stage treatments. The ground cover grid was 86 cm (one row wide) by 75 cm with 100 string-bordered squares formed by ten equally spaced strings stretched tightly from the sides of the grid. Following defoliation, the ground cover grid was held horizontally approximately 40 cm above the ground and centered over the row. A skilled person looked down to the grid from 40 cm above the grid and then counted the number of grid squares with more than 50% foliage coverage. The ground cover (%) was the percentage of the counted number (foliage area) to the overall number of squares (100), according to which the defoliation (%) was estimated. For example, a 67% ground cover will represent 33% defoliation. The defoliation of the *EB* and *LB* treatments was assessed by visual comparison of the canopy with the control plot (0%). The defoliated plant parts were moved to the outside of the plots to allow for accurate visual assessment of damage. The presence and absence of dead plants may affect the hail evaluation using imaging, although we anticipate that the effect will be minimal based on our previous work where we evaluated potato senescence rates using aerial imaging (Khot et al., 2016). Three different damage levels and control treatments were applied into twelve plots from each variety using a randomized complete block design (RCBD) method with three replicates.

Prior to tuber harvest, vines of Norkotah naturally senesced or were mechanically removed using a flail mower at 130 DAP and Ranger vines were mowed at 150 DAP. Tubers were harvested from each plot using a custom-built one row harvester. Final yield was measured using a custom-built electronic potato sizer.

2.2. Data collection

An unmanned aerial vehicle was used to collect high-resolution multispectral images from the target plots. The UAV (OktoXL 6S12, HiSystems GmbH, Moormerland, Germany) platform was remotely controlled by a radio transmitter (MX20 Hott, Graupner, Stuttgart, Germany) with control range of up to 4 km. The platform has a maximum payload of 4 kg and can fly about 20 min with a 6500 mA h Lithium-ion polymer battery pack. A modified

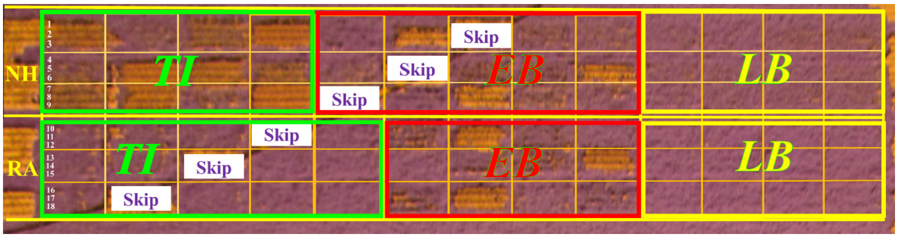

Fig. 1. False color image (R, G, NIR) taken at 95 days after planting (DAP) in 2015 shows the experimental plots. NH and RA refer to Norkotah and Ranger varieties, respectively. Potato crops were treated at three growth stages, *Tuber Initiation* (*TI*), *Early Bulk* (*EB*) and *Late Bulk* (*LB*) stages. Three replicate plots with four defoliation levels (0%, 33%, 66%, 99%) were applied to the crops in each growth stage using randomized complete block design. "Skip" indicates an unplanted gap left for the center-pivot tire track.