UNMANNED AERIAL SYSTEM APPLICATIONS IN WASHINGTON STATE AGRICULTURE

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ABSTRACT

Three applications of unmanned aerial systems (UAS) based imaging were explored in row, field, and horticultural crops grown in Washington State. The applications were: to evaluate the necrosis rate in potato field crop rotation trials, to quantify the emergence rates of three winter wheat advanced yield trials, and detecting canker disease-infection and spread in pear orchards. The UAS equipped with green-NDVI imaging was used to acquire field aerial images. In the first application, one and two year crop rotation fields were imaged to evaluate the necrosis rates of 64 plots. The GNDVI data showed strong relationship with ground-truth necrosis measurements (R^2 = 0.911).

Winter wheat seeds planted in the 6 to 12 inch annual rainfall zones of Washington are normally sown deeper than usual (10 to 15 cm) for better availability of water to the germinating seed. Precipitation up to seven days after planting may result in formation of hard top-soil layers reducing seed emergence rates. Therefore, the second application evaluated applicability of aerial imaging to quantify the germination rates of the new winter wheat cultivars being developed by WSU wheat breeders. The aerial imagery data showed good

correlation to the ground scouting data with correlation of 0.78, 0.79 and 0.86 for soft white common, hard, and soft club wheat trials, respectively.

The pear orchards in the Pacific Northwest are usually very old and characterized by large and vigorous tree canopies. Such trees when irrigated by under the canopy system results in very humid microclimate that triggers the development of fungi. Many of these fungi are responsible for the formation of cankers in the bark growing inside the phloem and are difficult to control. If the trunk is infected, the tree health declines slowly with eventual death. Therefore, understanding the canker spread pattern is important to trigger appropriate management decisions. Therefore, UAS based imaging was successfully used in this study to identify the canker infection areas in Red Anjou pear variety. Overall, results suggest that the UAS based high resolution imagining is a versatile and complementary technique useful to both the researchers and growers in field trails quantification and scouting for crop diseases and management.

Keywords: Crop sensing, plant emergence, plant senescence, disease detection

INTRODUCTION

The unmanned aerial systems (UAS) are generating lot of interest in agricultural industry. The UAS are versatile, light-weight, and low-cost systems being explored for low-altitude high resolution remote sensing applications in precision agriculture (Swain et al., 2010; Ehsani and Maja, 2013) and forestry (Grenzdörffer et al., 2008). Some of the UAS agricultural applications include biotic and abiotic crop stress monitoring, crop loss assessment, and yield monitoring and estimation (Ehsani and Maja, 2013). Key component of UAS based crop sensing, independent of platform (fixed wing or rotary) type, is the sensing technique integrated with the platform. Researchers have used multispectral imaging (Nebikaer et al., 2008; Berni et al., 2009; Sankaran et al., 2013), hyperspectral reflectance and imaging (Saari et al., 2011; Mäkynen et al., 2012; Honkavaara et al., 2012), and thermal infrared imaging (Sullivan et al., 2007; Berni et al., 2009) with diverse unmanned aerial platforms. For example, Sullivan et al. (2007) studied cotton canopy water stress using thermal infrared images. The images with 0.5 m spatial resolution were acquired using UAS flights at 90 m altitude. Similarly, Berni et al. (2009) successfully tested UAS based thermal (resolution of 20 cm) and multispectral imaging (resolution of 40 cm) techniques for developing indices to estimate canopy temperature and water stress (corn), leaf area (corn and olives), and chlorophyll content [C_{ab}] (olive and peach). Recently, Sankaran et al. (2013) have used UAS based multispectral imaging to detect citrus greening disease.

In this study, UAS based imaging was explored in row (potato), field (wheat), and horticultural (pear) crops grown in Washington State to aid grower's decision making during production. Crop rotation length and sequence is critical in economical potato production while reducing infestation of pathogens, weeds, insects and nematodes and to improve soil quality (Hopkins et al., 2004; Larkin et al., 2010). In one of our on-going projects, the rotational crop sequence and duration is being evaluated to monitor above aspects. As with any biological science field study, the most pressing issue is to generate meaningful seasonal data to quantify the effect of the crop rotation.

Western Washington with 6 to 12 inch annual rainfall zones are well known for dry land winter and spring wheat production. Better economic returns are one of the key factors why growers prefer the winter wheat verities over the spring wheat. The winter wheat seeds are normally sown deeper than usual (10 to 15 cm) for better availability of water to the germinating seed. However, precipitation up to seven days after planting and lower night temperatures may result in formation of hard top-soil layers reducing seed emergence rates. Growers usually have to scout the large fields multiple times in a short time period to determine the emergence and decide upon the need of reseeding the winter wheat acreage. Thus, rapid crop sensing technique may reduce such scouting time and costs and may aid in better decision making as well.

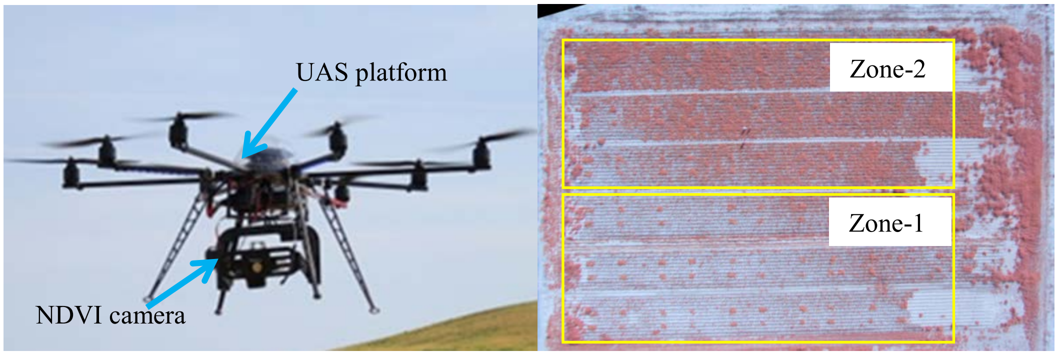
The pear orchards in the Pacific Northwest are usually very old and characterized by large and vigorous tree canopies. Such trees when irrigated by under the canopy system results in very humid microclimate that triggers the development of fungi. Many of these fungi are responsible for the formation of cankers in the bark growing inside the phloem and are difficult to control. If the trunk is infected, the tree health declines slowly with eventual death. Therefore, understanding the canker spread pattern is important to trigger appropriate management decisions.

In line with above discussion, the UAS based crop sensing was thought to be one of the alternatives for quick and easy monitoring and decision support tool. Therefore, Specific objectives of the study were to evaluate the necrosis rate in potato field crop rotation trials, to quantify the emergence rates of three winter wheat advanced yield trials, and to monitor canker disease-infection spread in pear orchards.

MATERIALS AND METHODS

Rotational Crop Necrosis

The UAS platform (model: OktoXL, HiSystems GmBH, Germany) equipped with NDVI imaging sensor (model: XNiteCanonNDVI, LDP LLC, NJ) was used for acquiring the field images (Fig. 1a). The imaging sensor is 12.1 megapixel Canon® camera modified to capture an NDVI image constituting near infrared (NIR), green (G) and blue (B) as three channels or bands.



a) b)

Figure 1. UAS integrated with (a) NDVI imaging sensor and (b) NDVI image of one (zone 1) and two year (zone 2) rotational field plots.

In this study, images were acquired from 130 m altitude and covered about two acres (90×90 m) of study plot. The imaged field was located at WSU's Othello research station, WA. Field had 64 plots, each sized 25'×25' (7.6×7.6 m) with buffer of about 30' (9.1 m). Prior to potato production in 2013 season, the plots were rotated with spring wheat, barley, and low and high levels of glucosinolate (GSL-1 and GSL-2) mustard crops. Plots were also treated with green manner for either one or two years. Thus, 32 plots were with one year rotation (2012 season alone) and 32 were of two year (2011 and 2012 season) rotation. During 2013 growing season, all the plots were seeded with potato tubers. These plots were imaged towards the end of August (20^{th} August, 2013) before the harvest.

The images were pre-processed and analysed in ImageJ® (ver. 1.47, National Institute of Health, USA). From the pre-processed imagery data, the green normalized vegetation indices (GNDVI) were estimated for each of the 64 field plots using Eq. 1

$$GNDVI = \frac{NIR-G}{NIR+G} \quad (1)$$

In each plot, region of interest (ROI) was 70×70 pixels. The GNDVI data was contrasted with the ground-truth necrosis (%) assessment of each plot by trained scout doing such evaluations for 10+ years. Field scout evaluates the 'greenness' and 'yellowing' of the potato leaves in a given field plot to rate the necrosis (%).

Winter Wheat Emergence

Winter wheat vigor is an important parameter that can define the photosynthetic and nitrogen use efficiency in crops (Pang et al., 2014). To evaluate the winter wheat vigor, wheat breeders are working to identify varieties that exhibit enhanced germination and winter hardiness. For achieving this objective, the current technique involves manual rating of the field plots on the scale of 0-100% to assess early germination and wheat vigor after winter. In this work, we used UAS-based sensing to evaluate the wheat germination of field plots with soft white club, hard red, and soft white wheat varieties. Each respective variety had

162, 108, and 108 field plots with each sized 1.5 × 3.6 m. The aerial images were acquired from altitude of 100 m. The false color imagery data was converted to GNDVI images as described in previous session. The image thresholding was applied to remove the background. Following the preprocessing, GNDVI (as average pixel values in selected region of interest) for each of the field plots was extracted and correlated with ground-truth emergence ratings data.

Pear Canker Spread Monitoring

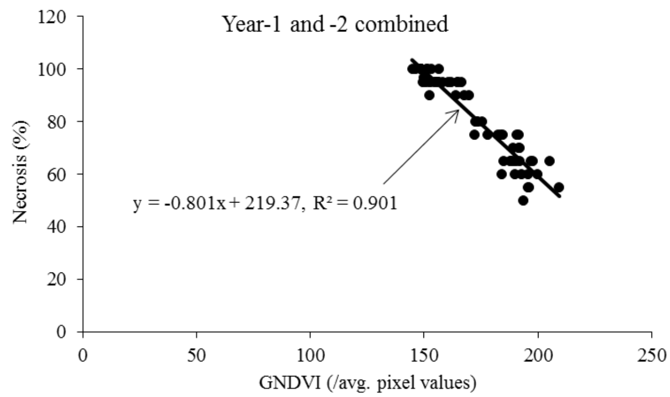
The pear canker disease is a devastating disease that results in canker trunk lesions and eventual death to the trees. The climatic conditions and weather pattern greatly influence the spread of this disease in Pacific Northwest. Different pear varieties are variably susceptible to this disease, with Red Anjou variety having higher susceptibility to this infection. One of the primary steps for disease management will be identifying the canker infection, and evaluating the disease spread pattern within an orchard. In this study, RGB images were acquired using a digital camera (SonyNEX 5R, 16.1 MP) mounted on an UAS platform, from an altitude of 100 m to evaluate the pear canker infection rates. The imagery data was post-processed and converted into 8-bit image and average pixel values for 20 healthy and 40 infected trees (20 each for sever and moderate levels of infection) were extracted for analysis. Also, using the RGB imagery, a simple index image (R-G/R+G) was generated to observe the pear canker spread in the study area.

RESULTS AND DISCUSSION

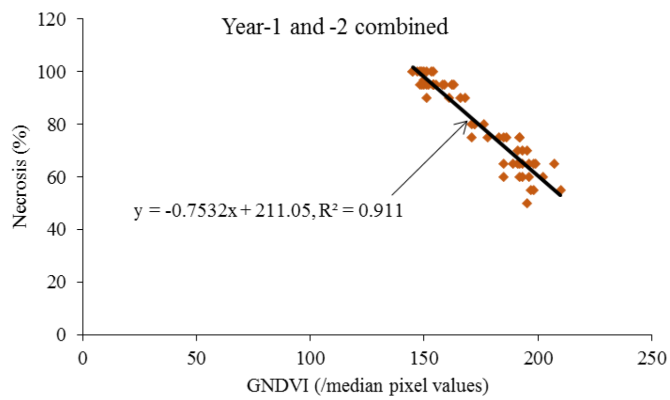
Rotational Crop Necrosis

Fig. 2a display the relationship of ground-truth crop necrosis (%) with that of the UAS based GNDVI estimates. The GNDVI data was strongly related with ground truth measurements with regression coefficient of (R^2=) 0.901. Similar relationship (R^2 = 0.911) was established between ground-truth necrosis and GNDVI expressed as median of pixel values from selected regions of interest of each of the 64 field plots. Overall, as the potato necrosis increased in the study plots, the GNDVI decreased.

Aerial images (Fig. 1b) and extracted GNDVI information clearly suggested that plots with two years of rotational crops delayed potato crop necrosis compared to one year rotation. The UAS platform integrated NDVI imaging system was successful in picking the potato crop necrosis and studies are ongoing to evaluate the suitability of the system to evaluate potato crop health (emergence, closure, canopy fill, and necrosis) and resulting yield differences. In summary, UAS based NDVI imaging can reduce the field scouting time and provide quantitative data, with reduced scout subjectivity, needed for accurate interpretation of rotational field research studies. Such system may also aid growers in deciding upon the crop harvesting schedule.



(a)



(b)

Figure 2. Relationship between field necrosis and UAS imagery based green normalized vegetation indices from the 64 field plots.

Winter Wheat Emergence

Fig. 3. shows the wheat field image after the processing and thresholding. The correlation between the visual emergence rating and average pixel values for each plot based on the wheat variety was determined. The correlation coefficient along with the emergence rating details is summarized in Table 1. The correlation coefficient varied between 0.82-0.93. The reason for lower correlation coefficient in soft white club could be due to a poor emergence compared to other two wheat varieties, which made the differentiation of each plot difficult.

However, the relationship between the visual rating and UAS-image based findings were found to be strong, indicating the potential of this technique for evaluating germination of wheat and other crops. This is critically important to winter wheat growers as well in determining the emergence of large fields. UAS based field scouting may aid growers in quick decision making in regards to re-seeding the field in poor emergence conditions potentially saving the cost of labor, and winter wheat produce.

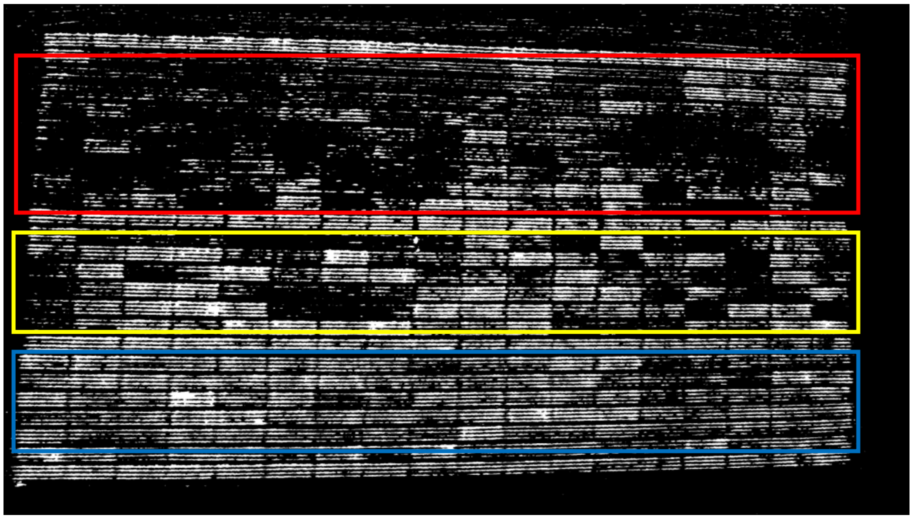


Figure 3. UAS-based image processed for wheat emergence assessment. The 1st, 11th, 18th, and 25th rows (from top) represent head rows and red, yellow and blue boxes represent soft white club, hard red and soft white wheat varieties, respectively.

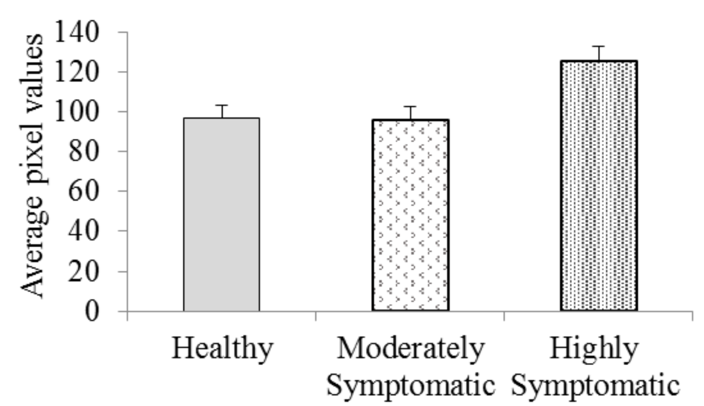
Table 1. Correlation between the emergence (%) evaluated by visual rating with that of average pixel values of individual plots of a single wheat variety.

Wheat variety	Emergence rating (%)	Ave. emergence rating (%)	Correlation (r)
Soft White Club	0-100	45.9	0.82
Hard Red	0-100	59.3	0.93
Soft White	10-100	64.2	0.87

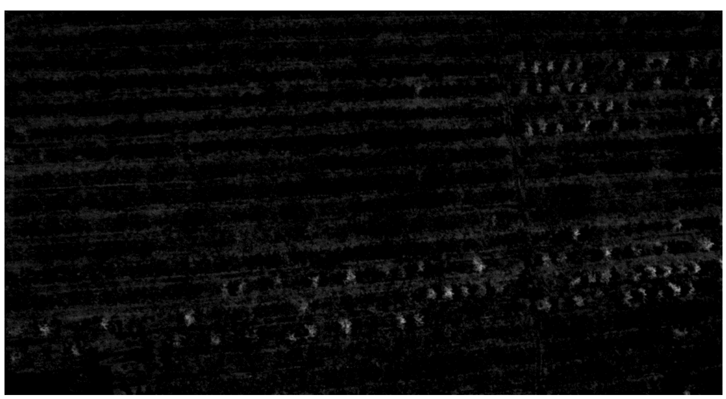
Pear Canker Spread Monitoring

Fig. 4a is the UAS-based aerial image showing pear canker infection. The image shows a distinct spread pattern of the canker disease within a row and few rows apart from the infected region. Trees that appear red are moderately symptomatic and highly symptomatic trees are on the verge of death appear as white. When the average pixel values of moderately and highly symptomatic trees of grey scale image were determined (Fig. 4b), the highly symptomatic trees had higher values in comparison to moderately symptomatic and healthy trees. However, moderately symptomatic trees had similar pixel values as the healthy, suggesting need of a robust pattern recognition algorithms to distinguish the canopy categories. The ratio-based image (R-G/R+G) showed a clear distinction of moderately stressed trees, from those of healthy and highly symptomatic trees (Fig. 4c). In our on-going studies, we plan to use spectral imaging to distinguish infected trees from healthy trees.

(a)



(b)



(c)

Figure. 4a) High-resolution aerial image of the orchard showing pear trees infected with canker disease, b) difference between the healthy and symptomatic tree representation in the image, and c) analyzed image showing spread pattern of the disease.

SUMMARY

The UAS systems were successfully evaluated as an aid for researchers in generating more meaningful data during plant breeding, and plant pathological associated in-field studies. Also, study demonstrated applicability of UAS integrated imaging systems for row, field, and tree crops production decision making and management.

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