ANALYSIS OF VEGETATION INDICES FOR ESTIMATING RICE LODGING UNDER AWD IRRIGATION

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ABSTRACT

Lodging incidence of paddy rice depends upon crop management and environmental conditions. The objective of this study was to investigate the effects of alternate wetting and drying (AWD) method with probiotics applied at tillering and panicle initiation stages on paddy lodging. To study the effects of AWD, spectral crop detection techniques were explored by using vegetation indices (VIs) derived from multispectral remote sensing images. The normalized difference vegetation indexes (NDVI), green normalized difference vegetation index (GNDVI) and simple ratio index (SRI) were calculated from unmanned aerial vehicle (UAV) imagery. T-test was used to study the potential effects of each of these indices. After applying probiotics and nitrogen fertilizer at the panicle initiation stage, three VIs (NDVI, GNDVI and SRI) were not significantly different between lodging and non-lodging areas. For a few days, three of the VIs for the lodging area was significantly different from those of the non-lodging areas. However, in the lodging area, three VIs were not significantly different between two measurement dates. On the other hand, GNDVI and SRI were significantly different in the non-lodging area. The study results indicate that the VIs of GNDVI and SRI were sensitive between lodging and non-lodging areas. Therefore, to monitor the state of rice plants to predict the incidence of rice lodging, GNDVI and SRI can be used in the rice cultivation method proposed in this study.

Keywords: Alternate wetting and drying (AWD), Vegetation indices (VIs), rice lodging

1. INTRODUCTION

Lodging, resulted from a long period of rain, has been recognized as one of the major destructive factors for crop quality and yield, particularly in rice (Oryza sativa L.). Recently, due to an unevenly temporal and spatial distribution in rainfall amount, precision irrigation and water management on-farm has become a real challenge in developed countries, like Taiwan. Under the subtropical climate in Taiwan, crops are asserted under non-optimal growing conditions between seasons. Therefore, vegetation water stress is a significant issue that currently affects plant growth and yield. Furthermore, to improve crop water usage, an accurate diagnosis approach of crops chlorophyll content can be is critical information for a timely irrigation decision support. Reducing water use in paddy rice systems is amongst the practices of irrigation management known as Alternate Wetting and Drying (AWD) [2]. Under AWD, fields are subjected to intermittent flooding (alternate cycles of saturated and unsaturated conditions) where irrigation is interrupted and water is allowed to subside until the soil reaches a certain moisture level, after which the field is re-flooded [3]. So, monitoring the chlorophyll content of AWD system can potentially improve the water use efficiency.
Several remote sensing algorithms were applied to map out the land surface spectral features using mostly satellite multispectral reflectance imagery data to determine

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spatial patterns of plant water stress [1-6]. Unmanned Aerial Vehicles (UAVs) have potentially given their low cost of operation in agriculture field with high resolution sensors, and their high flexibility in image acquisition. Satellite data have coarse resolution as compared to UAVs which can be payload with high resolution cameras to be flown at the users desired time schedule. There are some high-resolution satellite imageries, but their high cost often limits to access the information. In addition, it is difficult to get those data to a customized time and resolution of a local field context. For this reason, researchers are now looking at to an alternative image acquisition platform such as the use of Unmanned Aerial Vehicles (UAVs).

The advancements of UAVs and sensors technologies have made the unnamed aerial systems a deployable low-cost platform with high precision. With the advancement of UAV technology, there are several new multispectral cameras with high resolution for scanning crops field and derived precise information for crop management. UAV platform can be deployed as a decision support tool for farmers and growers to monitor crops water stress, plant health, and schedule irrigation and nutrients application, etc. Torres et al [7] measured early site-specific weed nitrogen status from UAV with different sensors that have visible and near infrared bands. Several studies have shown UAV application in agriculture for various purposes. Elarab et al. [8] estimated plant chlorophyll concentration through the use of a small, unmanned aerial system at 15-cm resolution. They reported that the reflectance bands of the multispectral (VIS–NIR) imagery were capable to estimate chlorophyll concentration in conjunction. Berni et al. [9] have used a multispectral camera onboard UAV to monitor vegetation chlorophyll. The results indicated that wavelengths with maximum sensitivity to chlorophyll content were found in the wide spectral range from 530 to 630 nm and near 700 nm [10]. Healthy plants capable of maximum growth are generally expected to have larger amounts of chlorophyll than unhealthy ones [11]. Other study reports found a correlation between wavelengths that can be the best estimates of the chlorophyll content. According to Lichtenthaler [12], chlorophyll absorption peaks of electromagnetic energy occur in the visible region, one in the blue (400 – 500 nm) and another in the red region (620 – 700 nm).

UAV system payload have high spatial resolution imagery (<1 m) and temporal frequency appropriate for timely responses in the production of actionable information about crop and field status. Today, however, practical applications for UAVs are expanding faster than ever in the agriculture industry. Nebiker et al. [13] reported one of the first successful applications of mini and micro-UAVs combined with low-weight and low-cost multispectral sensors for remote sensing applications in agronomical research. Turner et al [14] used UAVs to map soil moisture and enabled assessment of irrigation efficiency. Mathews et al. [15] estimated the canopy Leaf Area Index (LAI) of a vineyard with a digital camera mounted on a micro-UAV. Leila et al. [16] looked into the feasibility of low flying UAV and demonstrated the high-resolution remotely sensed data were useful to provide information about crop health; Matese et al. [17] mapped the wine vigor of a vineyard and extracted the vegetation index from a high-resolution multispectral camera mounted on an eight-rotor platform. UAVs images permit us a fast and easy way to obtain many precise measurements about crops, not only can define different crops characteristics but also manage crops situation.

The main objective of this study is to deploy UAV-based multispectral imager platform to develop the vegetation indices (VIs) to be the early warning index of lodging under AWD system in the South of Taiwan. In addition, irrigation management models based on rice paddy UAV imagery analysis can be applied for estimating crops chlorophyll in order to recommend irrigation management options for growers and extension irrigation associations in Taiwan. Therefore, this study explores the correlation between spectral vegetation indices and the situation of lodging and non-lodging. In turn, this methodology can be cost effective approach rapidly deployable to provide useful information for helping farmers in application fertilization, and the irrigation water management strategy.

2. METHODS

2.1 Field Experiment

Field experiment were conducted at Guanshan Township in Taitung County in the eastern Taiwan, as shown in Fig.1. The region is of warm temperature and tropical monsoon climate, where the mean annual temperature and rainfall are 23.7°C, 2,000 mm respectively. The soil type is silt loam with PH value of 6.8, soil series is Tekao Series (TK) .*Oryzasativa* L. japonica cv. KH147 were used in this study. Rice seeds were sown on February 25, 2018 with the spacing between rows was 25 cm.

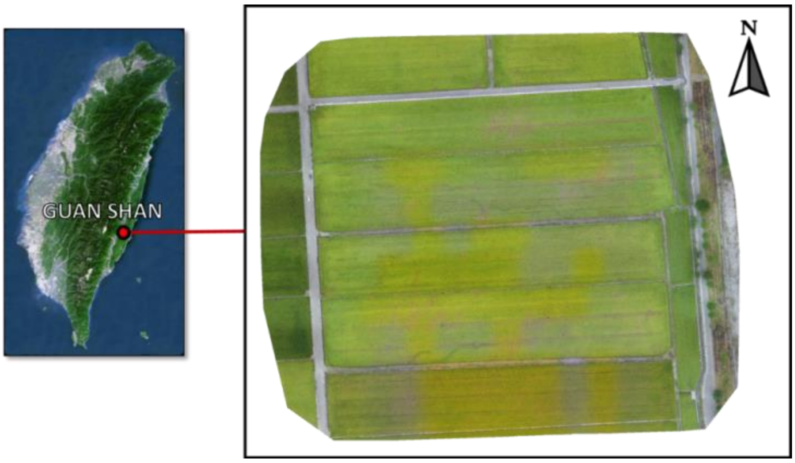

Figure 1. Geographic location of the experimental rice field

2.2 UAV-Camera System for Multispectral Imagery

In this work, a commercial aircraft Parrot Bluegrass (Parrot company, Paris, France) and a 5-band multispectral camera (Parrot Sequoia, Parrot company, Paris, France), as display in Figure 2, constitute a platform of low altitude UAV-camera system. The weight dimensions, image resolution of Sequoia camera is 72 g, 5.9 cm × 4.1 cm × 2.1 cm and 1290 × 960 pixels, respectively. Sequoia camera, equipped with GPS, can capture four spectral images simultaneously, where the spectral information is displayed in Table 1.

Table 1. Spectral information of Parrot Sequoia camera

Band No.	Name	Center Wavelength	Bandwidth	Panel reflectance
1	Green	550 nm	40	0.171
2	Red	660 nm	40	0.215
3	Red Edge	735 nm	10	0.266
4	Near Infrared	790 nm	40	0.370

Figure 2. UAV-camera system: Parrot Bluegrass UAV, Parrot Sequoia camera and reflectance panel.

Multispectral images were acquired on several key lodging date including before and after hearing fertilizer: 11/May/ 2018 and 30/May/2018, respectively. Flight altitude was set at 60 meters above ground, providing images with a ground spatial resolution of 5.65 cm/pixel. A iPad installed with Pix4d capture app to plan, monitor and control the UAV. The planned flight path and velocity, and camera triggering are designed that the consecutive images with overlap and sidelap up to 70% can be obtained for the purpose of accurate orthomosaic generation. An image of a reflectance calibration panel (Figure 2 for image and Table 1 for panel reflectance value) was always taken at about 1m height immediately before each flight to account for camera characteristics, reflectance characteristics and the effects of environmental variations. Each UAV aerial image contains necessary information for camera calibration and image stitching such as camera information (e.g. exposure time, ISO speed, focal length, black level), GPS and IMU (i.e. Latitude, Longitude, Altitude, Yaw, Pitch and Roll).

2.3 Image Prepossessing

Image pre-processing to generate calibrated and georeferenced spectral reflectance and VIs was performed by using commercial Pix4dMapper software of version 4.2.27 (Educational Licence of 1500 EUR, Pix4D SA, Switzerland) which include initial processing (e.g. key point computation for image matching), orthomosaic generation and index calculation (with reflectance calibration). Each layer output (e.g. spectral reflectance for each band and various SVIs) i a single high-resolution GeoTIFF image of the whole site. GeoTIFF images were further post-processed in ArcMap to extract raster data for spectral analysis can be performed.

2.4 Features: Spectral Bands and Vis

Features, describing data characteristics, are of vital importance for machine learning applications, directly affecting algorithm performance. To maximally represent data characteristics, raw band reflectance and SVIs for wheat plants are considered concurrently for feature extraction. VI is a simple but vital approach for extracting useful information from remotely sensed data, where most of them are calculated by using ratios or normalized difference of two or three bands (Hunt et al., 2013). VIshavealsobeen widely used to indirectly detect plant diseases in many preceding studies such as nitrogen monitoring (Ballesteretal.,2017), yellow rust detection (Ashourloo et al., 2014). It is noted that different from VIs for hyperspectral images, the Vis formultispectral image are limited to the existing wide bands of the Parrot Sequoia camera. Therefore, on the basis of adetailed and careful literature survey,the adopted VIspossibly related to paddy rice lodging monitoring are summarized in Table 2.

Table 2 Spectral bands and Vis adopted in this study

Name	Abbrev	Band	Formula	Ref
Normalized Difference Vegetation Index	NDVI	Red-NIR	(Rnir+Rre)/(Rnir+Rre)	Rouse et al. (1974)
Green Normalized Difference Vegetation Index	GNDVI	Green-NIR	(Rnir+Rg)/(Rnir+Rg)	Gitelson et al. (1996)
Simple Ration Index	SRI	Red-NIR	Rnir/ Rre	Birth et al. (1968)

3. RESULTS AND DISCUSSION

In the section, main results of this work are presented which directly address the research objectives. In the experimental field, lodging occurred after seven days of heavy rain, as shown in Figure 3. According to the lodging and non-lodging areas in 19/July/2018, the data on 11/May/2018 (before application fertilization) and 30/May/2018 (after application fertilization) were collected to investigate the relationship between spectral vegetation indices and the situation of lodging and non-lodging.

3.1 Spectral Analysis

The first processing performed to the multispectral images was to establish four individual bands. After four images transformation, the three vegetation indices were generated (Fig 4). Figure 4 illustrates the results obtained after image transformation. From previously described, spectral images were further post-processed in ArcMap. We choose 40 points of interest (POI) to extract spatial-temporal profiles comprising normalized difference vegetation index (NDVI) 、 green normalized difference vegetation index and simple ratio index.

Figure 3. The loading status in the experimental field

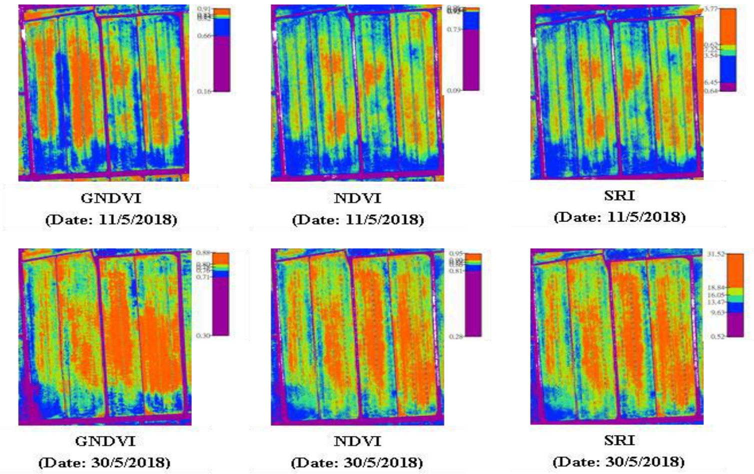

Figure 4 Different date for vegetation index maps for paddy rice (upper images date: 11/5/2018 and lower images date: 30/5/2018)

3.2 Statistical Analysis

In Table 3, the statistical analysis results indicated that, the VIs of SRI, GNDVI, and NDVI were not significant difference between non-lodging area (healthy area) and loading area before application fertilization. That is because the rice plants need nutrients for growth after a period of time. After application fertilization, however, the different between non-lodging area and loading area could be pointed out by the VIs of SRI, GNDVI, and NDVI. Due to the factor that there is excessive nutrient in the rice plant in loading area, especially nitrogen, the values of VIs in SRI, GNDVI, and NDVI were higher than in non-lodging area (healthy area). Accordingly, after a long period of rain, the inadequate standing power of the rice plant is not sufficient to support the grain weight. However, in a realistic environment, non-lodging area and loading area could not be easy to predict unless the lodging has taken place.

In Table 4, the emphasis is that the values of SRI and GNDVI were significant difference between the date of before and after application fertilization in the non-lodging area. NDVI was not significant difference. But in the lodging area, SRI, GNDVI, and NDVI were not significantly different between the date of before and after application fertilization. The results indicated that if there were not significantly decrease in the values of SRI and GNDVI before and after application fertilization, there are excessive nutrient in the rice plant, especially nitrogen. And this is one of the main factors resulted in lodging after a long period of rain.

Table 3. The comparison of SRI, GNDVI, and NDVI between non-lodging area and lodging area at the date of before and after application fertilization, respectively

	Before			After		
	SRI	GNDVI	NDVI	SRI	GNDVI	NDVI
Non-lodging area	22.86±1.84	0.89±0.03	0.81±0.02	12.94±0.58	0.85±0.01	0.76±0.01
Lodging area	24.49±1.24	0.92±0.01	0.82±0.01	23.30±0.57	0.92±0.01	0.82±0.01
P value †	0.4595	0.2628	0.2986	P < 0.0001	P < 0.0001	P < 0.0001

Table 4. The comparison of SRI, GNDVI, and NDVI between the date of before and after application fertilization at non-lodging area and lodging area, respectively

	Non-lodging area			Lodging area		
	SRI	**GNDVI**	**NDVI**	**SRI**	**GNDVI**	**NDVI**
Before	22.86±1.84	0.89±0.03	0.81±0.02	24.49±1.24	0.92±0.01	0.82±0.01
After	12.94±0.58	0.85±0.01	0.76±0.01	23.30±0.57	0.92±0.01	0.82±0.01
P value †	P=0.0003	P=0.0308	P=0.2191	P = 0.4599	P = 0.5617	P=0.9018

4. CONCLUSIONS

\This study aims at exploiting the potentials of low-cost four-band multispectral camera (Parrot Sequoia), low-altitude airborne platform and vegetation indices to detect the rice lodging. In this study, we first processing multispectral images by using a UAV, then generated a spectral index map to monitor and recognize lodged and non-lodged rice. The results show that the fertilizer will affect vegetation indices to identify the difference between lodged and non-lodged rice plant. More importantly, the results illustrate if there were not significantly decrease in the values of SRI and GNDVI before and after fertilization, there are excessive nutrient in the rice plant, especially nitrogen. And this is one of the main factors resulted in lodging after a long period of rain. The results of this study provide theoretical and practical guidance for accurate rice lodging monitoring.

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