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Performance Evaluation of Active Canopy Sensor towards a Wireless Variable-Rate Fertilizer Application System in Paddy Production

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ABSTRACT

The performance of a crop canopy sensor measuring crop response to nitrogen variation of a local paddy variety, Siraj 297, was evaluated. Data for various crop parameters was taken before every fertilizer treatment application. The results show that the sensor was not able to distinguish the crop response to different fertilizer treatments in the early stages of crop growth. In the panicle initiation and booting stages (50 DAT and 70 DAT), the sensor showed better performance in the red edge and NIR spectral bands. A linear response was also observed for NDVI and NDRE indices. The results from this work will be used to develop a suitable mathematical model for a variable rate fertilizer application system.

Key words : Fertilizer Management; Paddy Production; Precision Farming; Active Spectral Sensor; Variable Rate Technology

1.INTRODUCTION

Paddy is one of the major agro-food commodities in Malaysia with a planted area of 730,016 hectares and a production of about 3.3 million tonnes nationwide in 2016 [1]. The self-sufficiency level in Malaysia for this crop hovered around 70% from the year 2008 - 2015 with an average yield of 4.5 tonnes per hectare in 2016. The National Agrofood Policy (NAP) 2011 - 2020 was introduced by the government to address three main issues; food supply and safe-ty, competitiveness and sustainability of the industry, and increasing the income level of its target groups [2].

Precision farming technology for paddy has the potential to ad-dress these issues [3]. It incorporates information and technology to achieve site-specific crop management [4] [5]. Variable rate tech-nology or VRT is one component of precision farming technology [6] [7]. It refers to a technology that is used to enable the variable rate application (VRA) of crop inputs such as fertilizer.

The VRA approach in fertilizer management determines the amount of applied fertilizer depending on the level of crop growth variability. This is to ensure the right amount of fertilizer is applied at the right time and at the right place as to obtain optimal yield and minimize its impact on the environment. A variable rate fertilizer application system requires the measurement of suitable soil and/or crop properties that are related to crop variability in order for the VRA system to adjust fertilizer input rate [8]. Existing systems either require tedious manual data collection or only tailored to other crops such as wheat and maize [9].

There are two basic methods of VRA: a map-based method and a sensor based method. Map-based VRA systems depend on an electronic prescription map to adjust the application rate of inputs. The map is generated by sampling soil or crop data across points in a field using a positioning system such as a GPS or a grid. One advantage of this system is that the user has a database that can assist in management-related decisions such as the acquired knowledge of the needed amount of chemicals or inputs prior to entering a field. Another advantage is that the user has more control of the applicant rate planning. On the other hand, some disad-vantages to this system are the cost and the fairly complicated pro-cessing needed to generate a map. There is also the time delay be-tween crop properties measurement and application of inputs. Ex-amples of research work on this type of system can be seen in [6], [10]–[14]. Companies such as Precision Hawk, URSULA Agricul-ture Ltd. and Agribotix provide commercial solutions using map-based VRA.

Sensor-based VRA systems on the other hand adjust the appli-cation rate of inputs by measuring soil or crop properties on the go using sensors mounted on the applicator. The continuous stream of information is sent to an on-board controller which governs the application rate based on an algorithm or model. The advantage of this system is that it does not necessarily require a geo-referenced location system or a map. Another advantage is that there are no time delay between measurement of soil or crop properties and application of inputs. The system is working on the go or real-time. The sensors produce a far denser dataset than traditional sampling methods. Moreover, the system is self-contained which reduces the risk of communication and interfacing error. Research work on this type of system can be seen in [15]–[17].

Regardless of which category of VRA is chosen, they both re-quire the process of soil or crop property measurement in order to generate a strategy to apply the input. With regards to fertilizer management, suitable soil or crop properties that relate to crop variability need to be measured in order for the VRA system to adjust fertilizer input rate. It was found that crop growth variability is directly related to the crops nitrogen (N) content [8], [18]. Different methods have been developed to measure the N content [19]–[21].

Specific to paddy, [22] developed a model to determine the N uptake based on the green area index (GAI) of the plant. The authors determined that the best parameters to describe the volume of green material of the crop were plant population, canopy and shoot size. The GAI model could be used to calculate the deviation of N content of the actual grown crop with respect to the N content of a reference crop. The information is then used to calculate a fertilizer treatment map which can be applied by a VRA system. However, the process is tedious, labour intensive and time consuming. It re-quires several stages of manual data processing before a treatment map can be produced.

Sensor-based systems such as the Hydro N-Sensor developed by Hydro Agri GmbH are commercially available and have been tested for wheat production in other countries [23]. Coupled with a variable rate applicator, this setup was turned into an on the go sen-sor-based VRA system. The advantage of this method is that it is quick, easy to operate and far less tedious. However, poor perfor-mance was observed when the sensor was tested on local paddy crop. This was due to the fact that the model relating the sensed parameter to the application rate was not suitable for paddy. The system did not have the means to allow a different model which was more suitable for paddy to be used. Another factor is that the sensor was developed for crops such as wheat where the soil is relatively dry. The sensor works by taking light spectrum images of the crop. The spectrum profile is then used to detect the green matter of the canopy. In paddy production where the plant is partly sub-merged under water, the sensor would fail as the reflectance from sunlight on the water surface is too great for it to compensate. Moreover, the fact that it is uses only one input parameter to deter-mine nitrogen uptake of the crop, means that it might miss out on critical information in characterizing crop variability.

A multispectral crop canopy sensor was developed to use sev-eral spectral bands to estimate the nitrogen content in crops [24]. An algorithm was subsequently developed to integrate the sensor in an on-the-go VRA system to apply fertilizer in a corn field. This meth-od has the potential to be used in paddy field. To the author's knowledge, this has not been tried. The above sensor was used to determine the nitrogen status of rice plants in China [25]. The authors concluded that the sensor has great potential in estimating paddy above ground biomass, nitrogen uptake and the nitrogen nutrient index. However, the authors stopped short of trying to integrate it in an on-the-go VRA system. To the author's knowledge, no on-the-go VRT system exists in the market which is suitable for rice production.

The objective of our work is to develop a wireless on-the-go VRA system for rice production by exploiting the advantages of the methods described in [24] and [25]. The scope of this paper is only limited to the evaluation of the crop canopy sensor's performance in measuring crop response to nitrogen variation of a local paddy variety, Siraj 297. However, the proposed system will be discussed in the following for the sake of completeness.

The proposed system is shown in Fig. 1. The system consists of an applicator attached to the back of a prime mover, sensors measuring paddy crop parameters such as plant canopy spectral reflectance and plant density per unit area, and a HMI to operate the system. The measured sensor signals are transmitted to a controller to be processed. The actuator output from the main controller is the fertilizer application rate at any given instant and is sent to a local applicator controller where the application rate value is set.

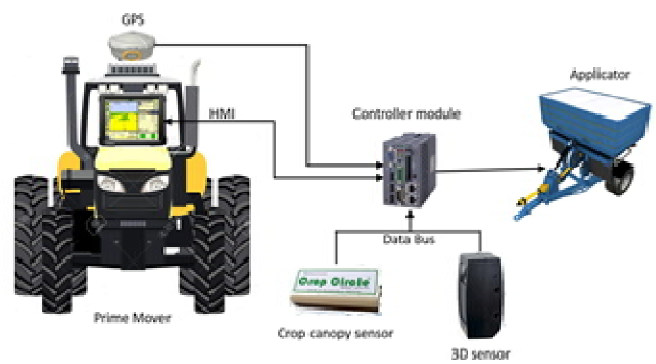

Figure 1: Variable rate applicator diagram

2. MATERIALS AND METHOD

2.1. Study Site

The study was conducted on an experimental plot belonging to the Muda irrigation scheme. It is located in the district of Yan, Kedah, Malaysia. This area belongs to the tropical wet climate with an average temperature fluctuating between 27 ◦C - 34 ◦C throughout the year. There a two planting seasons with the main season spanning from early September to late February. The second season spans from early March to late August. The average rainfall for this area is between 2032 mm to 2540 mm.

2.2. Experimental Design

A field experiment was conducted during the second season of 2018. A local rice variety Siraj 297 was planted for the study. The experiment was replicated eight times in a randomized complete block design. Each block had five nitrogen treatment rates of 0 kg/ha, 50 kg/ha, 100 kg/ha, 150 kg/ha and 200 Each plot in a block measured 5 m x 5 m. In all, a total of 40 plots were used to collect data.

All treatments were split four times to account for the tillering, stem elongation, panicle initiation and booting growth stages of rice crop. This corresponded to 5 Days After Transplanting (DAT), 25 DAT, 50 DAT, and 70 DAT. The fertilizer was applied at the ratio of 20:35:25:20. The ratio of N:P:K fertilizer given was 5:3:10 during the vegetative phase and 5:3:5 during the reproductive phase.

2.3. Active Canopy Spectral Reflectance Sensor

The active canopy sensor Crop Circle ACS-430 (Holland Scientific Inc., Lincoln, Nebraska, USA) was used in this experiment to measure the spectral reflectance from the crop. The sensor incorporates its own light source to illuminate the crop canopy. As such, its measurement is independent of sunlight. The sensor measures reflectance in three bands simultaneously: 670 nm, 730 nm and 775 nm bands. This corresponds to the red, red edge and near infrared (NIR) regions. Reflectance data measured by the sensor allows the user to calculate classic vegetation indexes from plant canopies such as the NDVI and SRI indices. The reflectance data produced by the Crop Circle data is height invariant and hence minimizes vertical position errors. The data produced by the sensor was stored locally on the device and extracted during analysis.

2.4. Field Data Acquisition

Data for various crop parameters using was taken before every fertilizer treatment application. First, the ACS-430 sensor was held approximately 1 m above the crop canopy at each quadrant of the plot to measure the crop canopy spectral reflectance readings. For each plot, the readings were sampled at four different points. Fig. 2 shows how the sensor was positioned above the crop canopy for data sampling. Next, crop parameter measurements were taken manually at these four points. The parameters were plant height, number of tillers, leaf length and leaf width. The acquired data was then analysed.

Figure 2: Field data acquisition using ACS-430 Crop Canopy sensor

3. RESULTS AND DISCUSSION

3.1 Spectral Response to Treatment Variability

The spectral reflectance measurements taken from the ACS430 sensor were plotted against nitrogen treatments at the different growth stages in order to determine its ability to measure the crop response of the Siraj 297 rice variety when treated with varying levels of nitrogen. The growth stages tillering, stem elongation, panicle initiation and booting correspond to 5 days after transplanting (DAT), 25 DAT, 50 DAT and 70 DAT respectively.

Fig. 3 shows the spectral response for the Red, Red Edge and NIR bands as well as two calculated vegetation indices, namely the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Red Edge Index (NDRE). In the tillering and stem elongation stages (5 DAT and 25 DAT), the ACS-430 sensor was not able distinguish the crop response to different fertilizer treatments. This was true for all three spectral bands and the two vegetation indices. In the panicle initiation and booting stages (50 DAT and 70 DAT), the ACS430 sensor showed a linear response in the red edge and NIR spectral bands. A linear response was also observed for NDVI and NDRE indices. The coefficients of determination were $R^2 = 0.56$ and $R^2 = 0.61$ at 50 DAT and 70 DAT respectively for the Red Edge band. For the NIR band, the results were $R^2 = 0.6$ and $R^2 = 0.61$ at 50 DAT and 70 DAT respectively. The correlation coefficients for NDRE were $R^2 = 0.58$ and $R^2 = 0.61$ whereas $R^2 = 0.35$ and $R^2 = 0.39$ for NDVI. These results show that the sensor has a good potential to be used for determining crop nitrogen status.

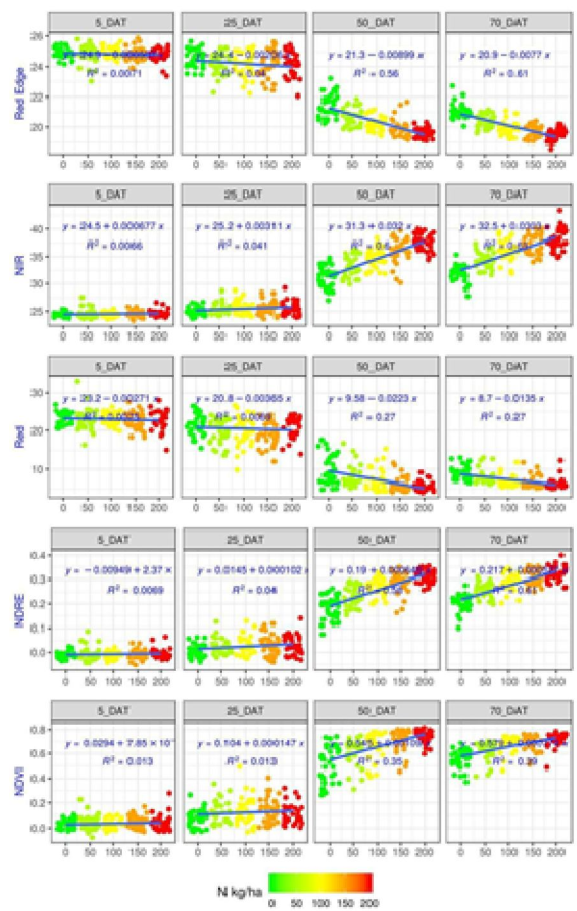

Figure 3: Spectral readings as a function of Nitrogen treatment

3.2. Correlation between Spectral Reflectance and Crop Parameters

The spectral reflectance data taken by the ACS-430 sensor were plotted against physical crop parameters plant height, leaf width, leaf length and plant tiller number at the different crop stages of tillering, stem elongation, panicle initiation and booting. This was done to determine whether any correlation exists between the sensor measurements and crop parameter.

Figure 4 to Fig. 8 show that no significant correlation exists between spectral reflectance and any crop parameter in all three bands and the two vegetation indices at 5 DAT and 25 DAT. The coefficients of determination ranged from R^2 = 0.0018 to R^2 = 0.2. For plant height, the red edge band showed the highest association with R^2 = 0.2 at 25 DAT.

The ACS-430 sensor showed a modest improvement in the latter growth stages of the crop at 50 DAT and 70 DAT for the Red edge and NIR bands. Plant height had the highest correlation with the red edge band and the NDRE index. This can be seen in Fig. 5 and Fig. 7. For the red edge band, the coefficients for 50 DAT and 70 DAT were R2 = 0.19 and R^2 = 0.18 respectively whereas for the NDRE index, they were calculated to be 0.2 and 0.16.

The values of all coefficients are presented in TABLE I for easy comparison. The results in this experiment showed that although there was a good correlation between the sensor measurements and nitrogen treatment variation, there were no significant correlation between the sensor measurements and any crop parameter. It can be deduced that the ACS-430 sensor is not suitable for precise phenol-typing of physical characteristics of rice plants. However, the results showed that the ACS-430 sensor can potentially be used to classify the nitrogen status of rice plants in broad categories such as “High”, “Sufficient”, and “Low”.

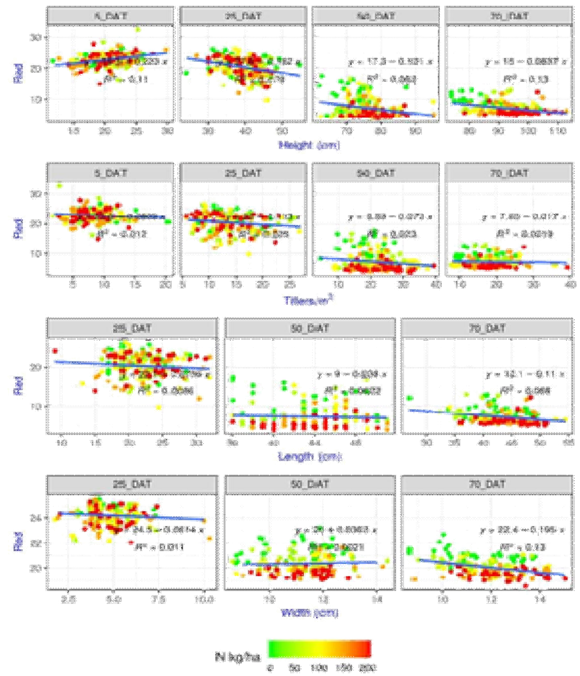

Figure 4: Red spectral band readings versus crop parameters

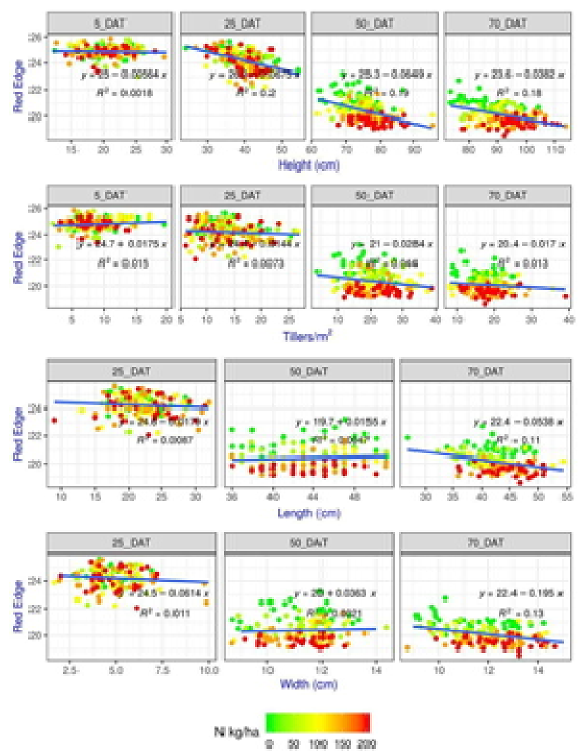

Figure 5: Red Edge spectral band readings versus crop parameters

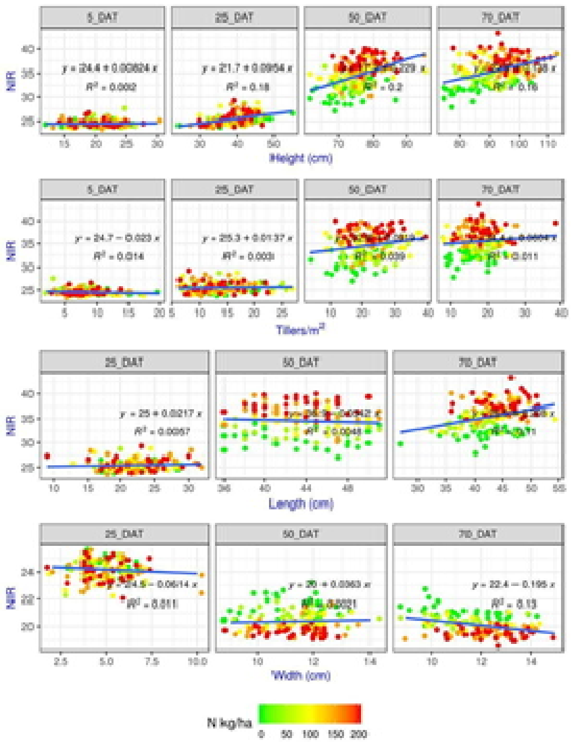

Figure 6: NIR spectral band readings versus crop parameters

The classification of nitrogen status in broad categories is more suitable for practical applications where calculations for variable rate fertilizing can be simplified. This simplification impacts system complexity and cost. Further work is needed in investigating the relationship between the sensor measurements and the nitrogen status in rice crops, especially for local varieties.

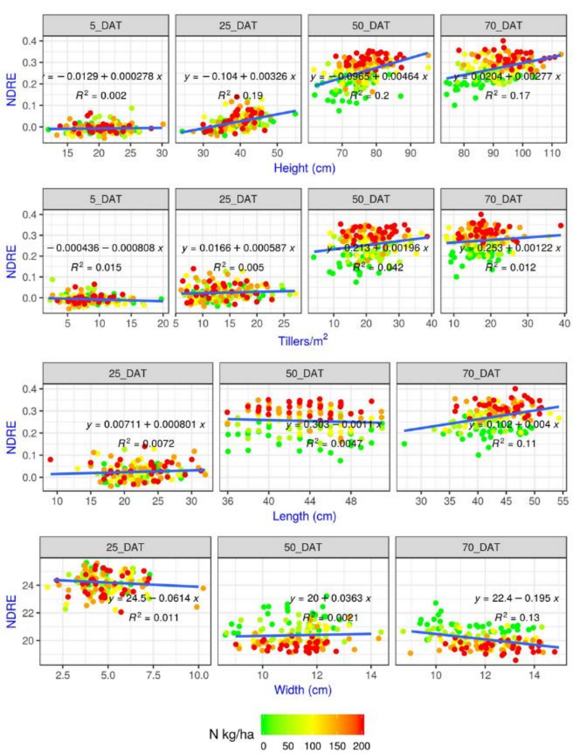

Figure 7: Plot of NDRE index versus crop parameters.

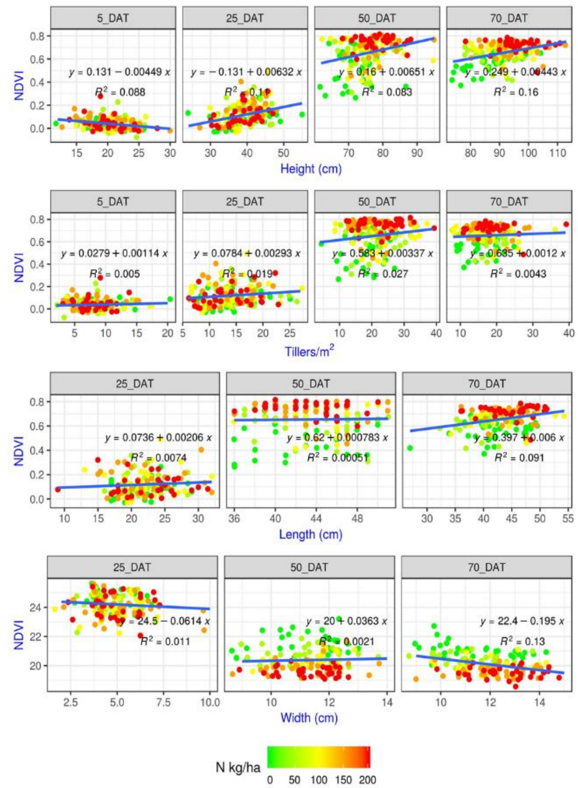

Figure 8: Plot of NDVI index versus crop parameters.

Table 1: Correlations of Spectral bands and crop parameters

Band	Height				Tiller				Length				Width			
	5DAT	25 DAT	50 DAT	70 DAT	5DAT	25 DAT	50 DAT	70 DAT	5DAT	25 DAT	50 DAT	70 DAT	5DAT	25 DAT	50 DAT	70 DAT
Red Edge	0.0018	0.2	0.19	0.18	0.015	0.0073	0.044	0.13	N/A	0.0087	0.0047	0.11	N/A	0.011	0.0021	0.13
NIR	0.002	0.18	0.2	0.16	0.014	0.003	0.039	0.011	N/A	0.0057	0.0048	0.11	N/A	0.011	0.021	0.13
Red	0.11	0.079	0.062	0.13	0.0012	0.003	0.039	0.011	N/A	0.0057	0.0048	0.11	N/A	0.011	0.0021	0.13
NDRE	0.002	0.19	0.2	0.17	0.015	0.005	0.042	0.012	N/A	0.0072	0.0047	0.11	N/A	0.011	0.021	0.13
NDVI	0.088	0.11	0.083	0.16	0.005	0.019	0.027	0.0043	N/A	0.0074	0.0051	0.091	N/A	0.011	0.0021	0.13

5. CONCLUSION

This work studied the correlation of the ACS-430 spectral reflectance sensor measurements with nitrogen treatment variation and physical crop parameters of the Siraj 297 rice variety. The results showed that the red edge and NIR spectral bands had good correlation with nitrogen treatment variation. On the other hand, none of the crop physical parameters have a significant correlation with the sensor measurements. The results from this study will be used to develop a fertilizer application model. The model will be integrated in the overall variable rate fertilizer application system as described in the introduction section of this work.

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