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Performance Evaluation of Active Canopy Sensor for Variable Rate Fertilizer Model in Paddy Production

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This paper aims to evaluate the performance of an ACS-430 crop canopy sensor in distinguishing different N rate treatment applications on local paddy variety, Siraj 297 at different growth stages. Experimental plots were treated with 5 different nitrogen application rates of 0, 50, 100, 150 and 200 N kg/ha using randomized complete block design method. The sensor readings were collected during tillering, stem elongation, panicle initiation and booting growth stages of a rice crop. The performance evaluation involved the analysis of variance (ANOVA) test and regression analysis between treatment variation and sensor response. Chlorophyll meter readings were acquired for comparison, while the counted number of tillers and measured height of the crop were presented to explore the possibility of using these parameters as N indicators across growth stages for N detection by the crop canopy sensor. Our results showed the sensor output had no significant difference to the treatment variations at early growth stages, but a strong linear response can be observed at both panicle initiation and booting stages. It suggests the effect of treatment variations can be distinguished significantly by the sensor after panicle initiation. At these growth stages, the NIR, Red edge, and NDRE vegetation indices had a coefficient of determination ranging from 0.58 to 0.65. Meanwhile, number of tillers was found not suitable for crop N indicator due to saturation at critical growth stage while crop height seems insufficient due to low R^2 at both panicle initiation and booting growth stages. The results from this work will be used in modelling the algorithm for an on-the-go variable rate fertilizer application system for paddy production.

Keywords: variable rate technology; control mechanism; active spectral sensor; precision farming

I. 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. However, the self-sufficiency level in Malaysia for this crop only hovered around 70% from the year 2008 - 2015 with an average yield of 4.5 tonnes per hectare in 2016 (Ministry of Agriculture, 2016). The National Agrofood Policy (NAP) 2011 - 2020 was introduced by the government to address three main issues; food supply and safety, competitiveness and sustainability of the industry, and increasing the income level of its target groups (Ministry of Agriculture, 2011). Precision farming (PF) technology for paddy has the potential to address these issues (Chan, 2013). PF incorporates information and technology to achieve site-specific crop management (Bakhtiari and Hematian, 2013; Kutter *et al.*, 2009).

Variable rate technology (VRT) is one of the components in precision farming (Daud *et al.*, 2014; Sawyer, 1994). In fertilizer management, VRT is used to set the right amount of fertilizer application on crops at the right spatial and temporal as to obtain optimal yield with minimal environmental impact. A variable rate fertilizer application system requires the measurement of suitable soil and/or

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crop properties that are related to crop variability in order for the VRA system to adjust fertilizer input rate (Gastal and Lemaire, 2002). Existing systems either require tedious manual data collection or only tailored to other crops such as wheat and maize (Laweless *et al.*, 2005).

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. 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. On the other hand, some disadvantages to this system are the cost and the fairly complicated processing needed to generate the map. Examples of research work on this type of system can be seen in (Daud *et al.*, 2014; Han *et al.*, 1995; Weisz *et al.*, 1995; Fraisse *et al.*, 2001; Poh *et al.*, 2006; Teoh *et al.*, 2012). Companies such as PrecisionHawk, URSULA Agriculture Ltd. and Agribotix provide commercial solutions using map-based VRA.

Sensor-based VRA systems on the other hand adjust the application 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 is no time delay between measurement of soil or crop properties and application of inputs. 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 (Holland and Schepers, 2010; Schepers and Holland, 2011; Yao *et al.*, 2012).

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 (Gastal and Lemaire, 2002; Lemaire *et al.*, 2008). Different methods have been developed to measure the N content (Gitelson, 2003; Mistele and Schmidhalter, 2008; Sieling *et al.*, 2013).

Specific to paddy, Daud *et al.*, 2010 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 requires 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 AgriGmbH are commercially available and have been tested for wheat production in other countries (Feiffer *et al.*, 2003). Coupled with a variable rate applicator, this setup was turned into an on the go sensor-based VRA system. The advantage of this method is that it is quick, easy to operate and far less tedious. However, poor performance 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 submerged 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 determine 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 several spectral bands to estimate the nitrogen content in crops (Holland and Schepers, 2013). An algorithm was subsequently developed to integrate the sensor in an on-the-go VRA system to apply fertilizer in a corn field. This method 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 (Cao *et al.*, 2013). 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 (Holland and Schepers, 2013; Cao *et al.*, 2013). 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.

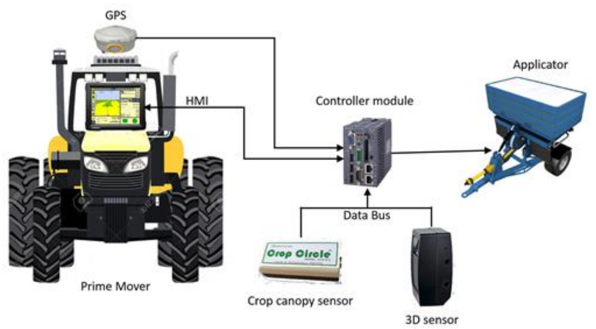

Figure 1. Variable rate applicator diagram

The proposed system is shown in Figure 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.

II. MATERIALS AND METHODS

A. Study Site

The study was conducted on an experimental plot belonging to 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.

B. 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, 50, 100, 150 and 200 N kg/ha. Each plot in a block measured 5 m x 5 m. In all, a total of 40 subplots 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, 25, 50 DAT, and 70 DAT respectively. 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.

C. 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 (red), 730 nm (red edge) and 775 nm (NIR) bands. Reflectance data measured by the sensor allows the user to calculate classic vegetation indexes from plant canopies such as the NDVI((NIR-red)/(NIR+red)) and NDRE ((NIR-red edge)/(NIR+red edge)) indices. The reflectance data produced by the Crop Circle sensor 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.

D. Field Data Acquisition and Data Analyses

Sample data was taken before every fertilizer treatment application. The sensor was mounted on a customized pole-holder as shown in figure 2 to maintain the uniform separation distance of 1m between sensor and the crop canopy. Although the sensor output is height independent, the constant separation distance is required to maintain the coverage of sensor readings as

$$W = 2h \tan\left(\frac{\theta}{2}\right) = 0.82h \quad (1)$$

where Θ is the angular field of view (FOV) in degrees (~45 degrees for the ACS-430), W is the projected beam width and h is the height of the sensor above the target.

Each subplot was divided into 4 quadrants and a sensor reading was acquired by positioning the sensor in the middle of each quadrant for at least 5s. By default, the sensor read 10 samples per second. The default sensor configuration was used throughout this study. The sensor readings in each quadrant were averaged, thus each subplot was presented by the 4 data points taken from the quadrants. In all, 160 data points were taken for 5 different treatments for each vegetation index. Next, chlorophyll meter readings, number of tillers and the crop height were taken at the sensed area of the crop sensor.

One-way ANOVA test was conducted to determine whether there was any statistically significant difference between the treatments while R^2 was computed to find a correlation between the sensor spectral reflectance responses to treatment variations across the critical growth stages. The graphs plotting and data analysis were performed using R.

Figure 2. Crop Circle ACS-430 sensor mounted on customized pole-holder during data acquisition on studied subplot

Table 1. Analysis of variance (ANOVA) and computed coefficient of determinations, R2, between ACS-430 canopy sensor spectral variables, SPAD meter and crop parameters to treatment variations across crop growth stages

	5-DAT			25-DAT			50-DAT			70-DAT		
	F-value	p-value	R^2	F-value	p-value	R^2	F-value	p-value	R^2	F-value	p-value	R^2
Red Edge	1.001	0.409	0.0099	2.159	0.0762	0.053	53.3	<2e-16	0.58	73.02	<2e-16	0.65
NIR	1.167	0.327	0.0084	2.032	0.0925	0.05	58.96	<2e-16	0.6	68	<2e-16	0.64
Red	0.621	0.648	0.0092	2.3	0.0612	0.052	15.19	1.68E-10	0.28	16.19	4.23E-11	0.29
NDRE	1.088	0.364	0.0092	2.096	0.0839	0.051	56.12	<2e-16	0.59	72.61	<2e-16	0.65
NDVI	1.073	0.372	0.014	2.276	0.0635	0.053	22.46	1.21E-14	3.70E-01	29.15	<2e-16	0.43
SPAD	NA	NA	NA	1.527	0.197	0.038	7.834	8.91e-06	0.16	9.807	4.25e-07	0.2
Tillers	0.47	0.758	0.0058	0.461	0.764	0.0071	2.756	0.0299	0.05	1.323	0.264	0.027
Height	0.614	0.653	0.012	0.764	0.55	0.011	6.278	0.000104	0.14	12.92	4.2e-09	0.25

III. RESULTS AND DISCUSSION

The response of Crop Circle ACS-430 canopy sensor to N treatment rate variations is depicted in figure 3. It can be observed that the sensor reflectance readings varied with different nitrogen treatments at later growth stages of 50 and 70 DAT. At early growth stages of 5 and 25DAT, the treatment variations did not show any meaningful changes to the reflectance readings for all spectral variables.

The statistical analysis of ANOVA and R^2 summarized in table 1 show very low F-values and R^2, and very large p-values at early growth stages (5 and 25 DAT) treatment variations which suggests the sensor cannot distinguish treatment variations at these stages.

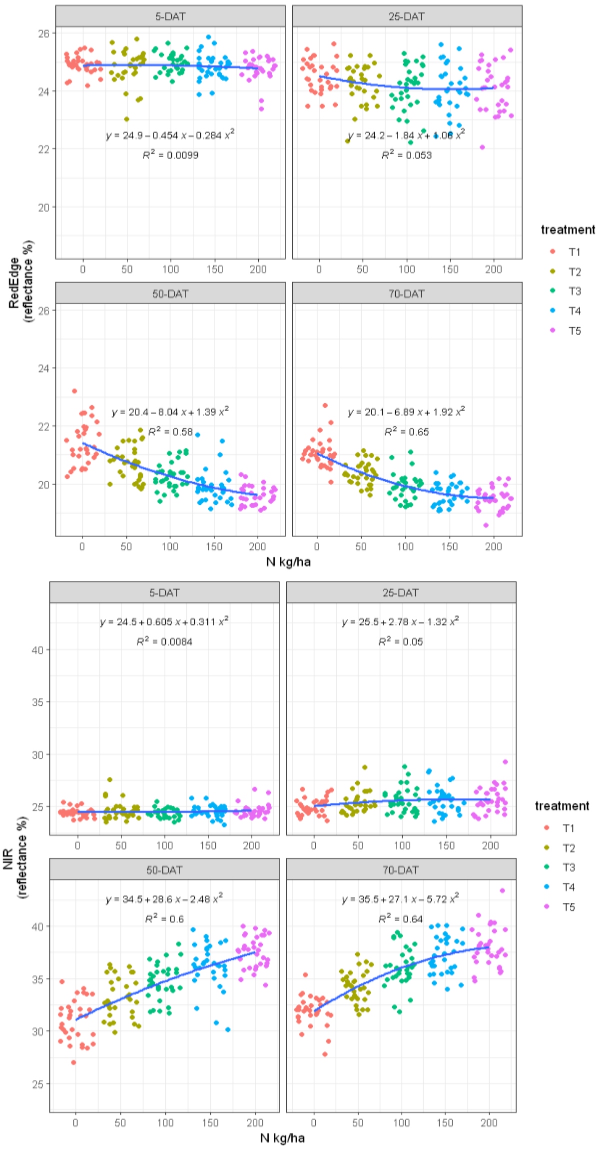

Figure 3. Measured spectral reflectance of sensor vegetation variables for different N rate treatments across paddy crop growth stages

This outcome was expected as both colour intensity and canopy density of the experimented crop were observed to have no difference regardless of the applied treatment rates. Our analysis shows that a strong linear response can be observed at both 50 and 70DAT. It suggests the effect of treatment variation is detectable significantly by the sensor after panicle initiation. At these growth stages, the NIR and Red edge bands performed the best with R^2 ranging from 0.58 to 0.65.

The relationship between observable crop parameters like number of tillers and crop height with treatment variations were studied to explore the possibility of using these parameters as N indicators for crop sensor N status identification. Figure 4 shows the boxplots of the corresponding parameters as a function of N treatment variations in different crop growth stages.

The result shows very poor correlation between the number of tillers and treatment variations with the best R^2 showing only 0.05 obtained at 50DAT. The R^2 showed improvement from 5 to 50 DAT and reduced slightly at 70 DAT, while the median was invariable in each growth stage. This suggests that the tiller count was only affected by crop maturity and saturated at the heading stage. This finding is consistent with the fact that the tillering process stopped once the panicle was initiated.

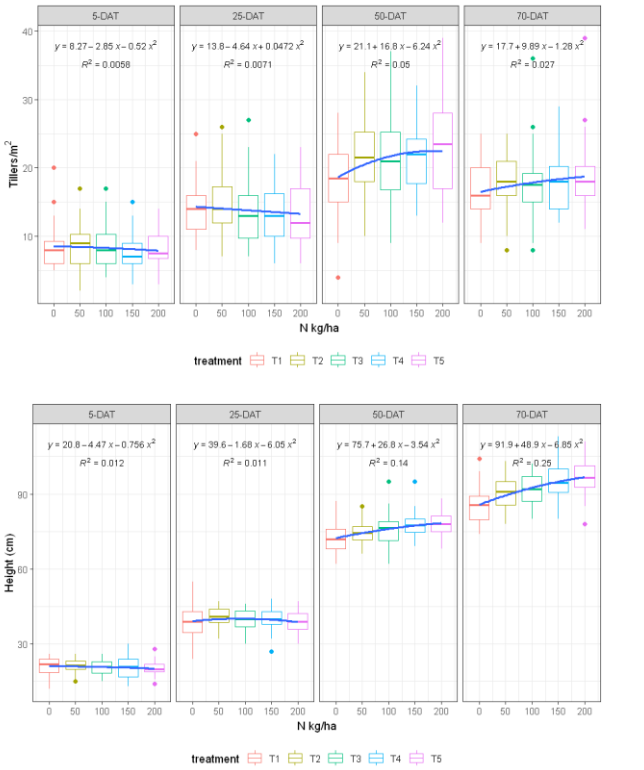

Figure 4. Crop parameters response to different N rate

As such, we conclude that the number of tillers is not suitable as an N indicator. Although crop height varied greatly across the growth stages, its response to treatment variations was very low. The best correlation was found at 70 DAT with R^2=0.25. The boxplot shows less variation in data while the median shows better distinction from one treatment rate to the other. Thus, even though crop height seems insufficient as an N indicator due to low R^2 at both 50 and 70 DAT, the parameter shows good potential for N content characterization in paddy crop.

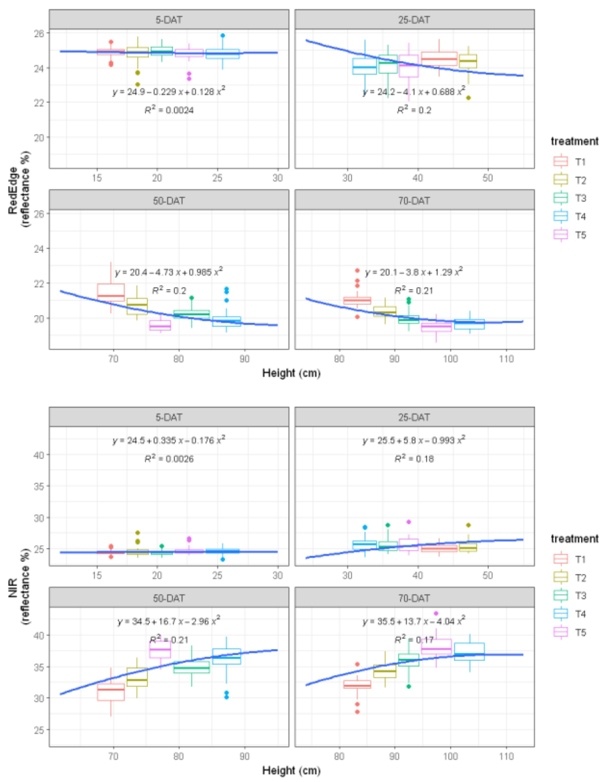

Figure 5. Crop sensor spectral reflectance as a function of crop height

Figure 5 shows the correlation between selected spectral variable of the crop sensor with crop height. The graphs show no significant correlation exist between spectral reflectance and the crop parameter. The Red edge band shows the highest $R^2 = 0.2$ at 25 DAT. The obvious separation between T1 and T5 at 50 and 70 DAT suggests that the ACS-430 sensor can potentially be used to classify the N status of paddy in broad categories such as "High", "Medium" and "Low". In fact, the broad categories classification 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 to utilize these data in translating the sensor output to the optimum N status of paddy crop. The data used in this paper is presented in Table 1 for easy comparison.

IV. CONCLUSION

This work studied the performance of ACS-430 spectral reflectance sensor measurements to detect the nitrogen treatment variation on 297 rice variety. The results show that the Red edge and NIR spectral bands and NDRE vegetation index have good correlation with nitrogen treatment variations. The data also shows better performance of the crop sensor as compared to SPAD meter due to the meter susceptibility to bias data sampling. Meanwhile, crop height shows potential N status indicators, but has no significant correlation with crop sensor output variables. However, the obvious separation between T1 and T5 at 50 and 70 DAT suggests that the ACS-430 sensor can potentially be used to classify the N status of paddy in broad categories such as "High", "Medium" and "Low", which is more practical in real application.

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.

V. ACKNOWLEDGEMENTS

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