Jurnal Teknologi

Full Paper

VARIABILITY OF RICE YIELD WITH RESPECT TO CROP HEALTH

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Article history
Received
15 July 2015
Received in revised form
2 August 2015
Accepted
26 August 2015

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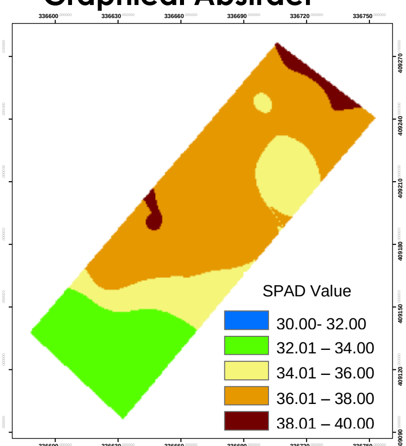
Graphical Abstract



Abstract

Chlorophyll content of leaf can be used as an indicator of the crop health. The SPAD chlorophyll meter has been acceptably used for rapid analysis of chlorophyll content and nitrogen status of crops while it has not been established how strongly the SPAD values are correlated with rice yield within a plot. This study was to explore the relationship between rice yields and the leaf SPAD value of the associated rice plots. Twenty sampling points of rice leaves plant were taken at three difference growing stages based on grid point sampling of 30m x 18m for two crop seasons. Two methods, namely instantaneous yield from on-board yield monitoring system mounted on a combine harvester and estimated crop yield from cutting test (CCT) yield were used to measure the variability of harvested rice yield within the rice plot. The SPAD values were found positively correlated with grain yield at different growth stages. The highest significant correlation was at crop age 70 days after planting with Pearson's correlations (r) ranging 0.7280 to 0.8336 (P<0.001). Consequently, information with regards to SPAD value variability could triggers farmers in taking immediate in situ action for improving the crop yield while information with regards to crop yield variability could assist farmers in planning the proper farming practice for the subsequent cropping seasons. Generally, this available technology would assist farmers in improving their crop yield and their economic status.

Keywords: Rice Cultivation, Crop Yield Variability, Crop Health, SPAD Value

1.0 INTRODUCTION

Crop production is known to have a high degree of variability in terrain topography, soil type and condition, leaf chlorophyll content and other major factors that influence crop yield. Nowadays, research on yield monitoring technology was able to show the relationship of crop yield with the crucial factors that influence the crop growth [1-3]. One of the major drawbacks of yield maps in rice cultivation is the effective interpretation of the maps for site-specific management of input, and identification and understanding of the causal factors influencing the variability of rice yields.

This study focuses on exploring rice yield variability with respect to leaf chlorophyll. The ability to validate and understand the nutrient factors influencing rice yield variability will enable farmers to manage their field more effectively. Using variability of leaf chlorophyll content, farmers could correct soil nutrient deficiencies to optimize the grain yield [4]. Optimum rate and timing application of fertilizer are crucial in achieving high yield [5]. Variability of yield is quantified by the yield map to explain the reason why certain area only produce low yield.

The chlorophyll content of leaves is associated with the condition of the plant, and thus can also be used to determine when additional fertilizer is needed. The

SPAD chlorophyll meter is a promising and non-destructive method to assess leaf N status of paddy crop [6, 7]. The SPAD 502 meter is used to directly measure chlorophyll content or "greenness" to reduce the risk of reduced crop yields and used as the basis over use of fertilizer. Several studies indicated the SPAD 502 chlorophyll meter readings are strongly correlated with actual chlorophyll content in several plant species [8-11].

Moreover, there is a direct relationship between leaf chlorophyll content and nitrogen [7]. Peterson [12] have shown closed correlation between leaf chlorophyll concentration and leaf nitrogen content of agricultural crops such as rice, corn, and wheat as the majority of leaf N is contained in the chlorophyll molecules. As a result, the chlorophyll meter is widely used to detect N deficiency and used as the basis for nitrogen management in the agricultural plots [4, 12].

Besides having a strong relationship with nitrogen, SPAD reading also has a relationship with yield. There are several studies that demonstrate the relationship of chlorophyll with crop yields [10, 13-15]. The SPAD value have highest correlation (r=0.99) with the grain yield at 70 days after sowing [13]. Moreover, Rostami [6] states that the relationship between SPAD readings and maize grain yield is not so high, but the correlation is positive and increases in the second half of the growth period (R^2 = 0.94). Varvel [16] also showed a high correlation between reading SPAD measurement and grain yield. In Malaysian paddy field, Gholizadeh [17,18] studied the relationship between SPAD for two stages of growth and grain yield. Result showed that SPAD readings at 55 days after transplanting (DAT) has a higher correlation compared with 80 DAT with R^2 values of 0.81 and 0.66, respectively.

The main objective of this investigation was to explore the relationship of instantaneous yield from the yield monitor and estimated yield by CCT method with leaf chlorophyll content of the associated rice plots.

2.0 EXPERIMENTAL

2.1 Description of Study Area

This study was conducted in the rice fields at Blok E5 Parit Timur 5 of Sungai Besar, Selangor at latitude 3° 41' 30.187" N and longitude 101° 01' 41.877" E location. The rice area is located on a flat coastal plain under the Integrated Agricultural Development Authority (IADA) Rice Granary within the district of Kuala Selangor and Sabak Bernam. The district of Sungai Besar is well known as one of the main rice growing area in Malaysia. Three rice plots with an individual size of 1.09 ha were randomly selected from the 40 available rice plots within the Parit 5 rice area of Sungei Besar. Field observations and data collection on the selected rice plots were done in two consecutive rice growing seasons. The measured data for first and second seasons of the three plots, namely lot 15467, lot 15466, and lot 15522. Lot 15467_1 means lot 15467 during the first season, while 15466_2 means lot 15466 during the second season, and so forth for the other lots.

2.2 Yield Data Collection and Analyses

The rice yield data was collected on June 2013 and January 2014 based on instantaneous yield using instrumentation system on combine harvester and Crop Cutting Test (CCT) method. The instantaneous yield by the instrumentation system on-board the combine was recorded in ton per hectare. The tonnage rate was calculated from flow rate sensor in kilograms per hour and the area of cut in m^2 which was calculated from the cutting width in meter multiplied by the travelled speed of the combine. The main components that make-up the developed instrumentation system for measuring and monitoring combine travel speed, combine cutting width, combine elevator rotational speed, combine geo-position, the flow and moisture content of the clean harvested grain by the combine. The Instrumentation system recorded yield data every second. The map of instantaneous yield was divided into 20 equal sub blocks. Zonal statistics by Arc GIS 10.1 are used to get the average yield value of each sub block.

For Estimated Crop Yield Using Crop Cut Test (CCT) Method, rice samples were collected for every plot the day before combine harvester. A total 60 samples (20 point x 3 plots) were collected from the lots 15467, 15466 and 15522 using the CCT method. Sampling grid widths were fixed at 30 m. The field length 180 m, was divided into 18 m long segments to creates 10 sampling point. Observation points for the CCT were aligned on a 30m x 18m, great data collection proceed easily without damage to the rice plants. The latitude and longitude position of each sampling point was recorded using a handheld DGPS receiver (Pro-XR). A traditional hand sickle and a square frame were used to harvest the rice yield samples. During the placement of the square frame, it was gently moved downward to minimize disturbance to the plant. A sickle was used to carefully cut the rice plants inside the square frame. The grains and spikelet were put into plastic bags with labels identifying the harvested location. The sample bundles were transported to the location for thresher. The grain was removed from the rice plant by manual threshing. Winnowing was also done to ensure the grain was free of trash, leaves or empty rice hulls.

This CCT procedure followed is from the Japan International Cooperation and Agency (JICA) recommendation. Steps for conducting the CCT are: (1) locate and mark of the experimental plot of a given size in the selected field, (2) harvesting of the CCT, (3) threshing of harvested crop from the CCT plots, (4) winnowing and weighing of the wet grain obtained from the CCT plot, and (5) weighing of the dry grain [19]. Sampling techniques for measuring and forecasting crop yields were made based on Huddleston [20]. Size and shape of plots used for field crops was rectangular with size 0.3 m^2. Statistical Analysis System (SAS) was used to analysis the statistic descriptive of the data and to establish correlation between instantaneous yield the combine harvester and estimated crop yield from the CCT.

2.3 SPAD Sample Collection

The chlorophyll content can be rapidly estimated in situ by Soil Plant Analysis Development (SPAD) readings. Chlorophyll content measurements were obtained using the SPAD-502 plus by Konica Minolta. This meter relies on chlorophyll fluorescence and screening of polyphone properties contained in plant leaf epidermis. Leaf samples were randomly collected from the planted crop at three crop growing stages, namely 45 days after planting (DAP), 70 DAP and 95 DAP. A total of 20 sampling points from a 30 m X 18 m sampling grid were examined each growing stage within the respective rice plots. Three plants, three leaves and three reading of each plant were taken for the chlorophyll content using SPAD-502 meter. The averages of the readings were used for the SPAD value at each point. For SPAD measurement at 45 DAP used the leaf blade as the leaves were young, while at 70 and 95 DAP, SPAD reading were collected from the flag leaves. SPAD measurements were collected between at 10 am to 2 pm. Sunshine at the time of measurement must be relatively bright to avoid signal interference (noise) in the data.

Measurements were taken at the uppermost portion of the leaf, as this is due to the fully accepted as a common practice [21]. Chlorophyll measurement technique during the field survey was carried out as follows: (1) measurements were taken at selected sample point, (2) capture position coordinates using handheld GPS, and (3) select plants randomly and take reading three times. The average values of the readings were used as the SPAD value of the plant. Sampling points on the leaves were on the tip, middle and base of the paddy leaf.

2.4 Rice Yield Prediction Models

The predictive models were created using multiple linear regression (MLR), to explain the relationship of response Y (Instantaneous yield), to variables, X (SPAD values at 45 DAP, 70 DAP and 95 DAP), and some unknown parameters, β. Y is a function of X and β. The rice yield prediction model took the following form:

$$Y = bo + b_1X_1 + b_2X_2 + b_3X_3$$

Where:

Y = Instantaneous yield (ton/ha)
bo = Intercept value
X_1 = SPAD value at 45 DAP
X_2 = SPAD value at 70 DAP
X_3 = SPAD value at 95 DAP
$b_{1,2,3}$ = Corresponding coefficients of X_1 through X_3

The SAS analysis was used to determine all of the model parameter such as R^2, sum of square, mean square, F value, errors, regression, Pprob>F and the value of b1, 2,3,4,5,6 [22]. The rice yield prediction model was evaluated based R^2 value for the predicted parameter. In fact, R^2 indicates the percentage of the variance in the Y variable that is accounted for by the X variables. R^2 values between 0.50 to 0.65 indicate that 50% to 65% of the variable Y is accounted for by variables X. An R^2 between 0.66 and 0.81 suggest approximate quantitative prediction, whereas, the values between 0.82 and 0.90 reveals good prediction. Prediction model having R^2 above 0.91 are considered to be excellent. Another interpretation based on the R^2 value come from Best and Kahn [23] from in which up to 0.20 is considered negligible, from 0.20 to 0.40 is low, 0.40 to 0.60 means moderate, 0.6 to 0.80 is substantial and from 0.80 to 1.0 is considered high to very high

3.0 RESULTS AND DISCUSSION

3.1 Statistical Analysis of SPAD Value at Different Growing Stage of the Associated Rice Plots

Result from the normality tests indicate SPAD data at different growing stages for the three associated paddy lots from the two growing season show some tendency for being normal distributed. The highest SPAD value occurred at 70 DAP and the lowest at 95 DAP. All associated paddy lots were planted with paddy variety of MR 220 CL2. This variety had a maturity of 100 DAP. The growing stages of this investigation could be classified into tillering stage, heading stage and maturing stage. Tillering stage (45 DAP) was characterized by thin green leaves with a mean SPAD reading of 34, while at the heading stage (70 DAP), the leaves were green and thickened with mean value of SPAD reading was of 35. The last growing stage which was "mature or 95 DAP" showed that leaves yellowed from the movement of N to the leaves. Mutters [7] mentioned that the nitrogen status in flag leaves varied throughout life cycle of rice and that rice plant transitions through the most nitrogen sensitive growth stages within few days. Silveira [24] claimed that leaf nitrogen changed day by day depending on the growing stages.

The SPAD peak value occurred at 70 DAP. SPAD values decreased as the rice paddy ripened, and the leaves turned yellow as the nitrogen in the leaves was utilized for grain growth. Lot 15522 was seen to have healthy plants with the highest SPAD value especially at 70 DAP. Lot 15522 had the highest yield compared to other lots. The highest SPAD values were explained by the greenness and the thickness of leaves, which in turn supported greater yield [25].

The ANOVA showed the mean effects of SPAD value at different crop growing stages (45 DAP, 70 DAP and 95 DAP), growing stage, sample point (20 point) and sampling point for associated plot. The observation was looking at the whole data, whether there were effects shown between sampling plots, measured time and sample point (Table 1). From Tables 1, it could be seen that the mean effect of lots, SPAD measured time and sample point were highly significant at 1% significance level on SPAD value. However, the replication of the treatment was not significant. The highly significant effect within the lot occurred due to fertilizer application. Every farmer managed their fields using deference approaches.

The amount and timing of fertilizer applications differed for each associated plot, which affected SPAD values. The highly significant difference between growth stages and SPAD values might be attributed to different growth stage of rice, especially as the leaves thickened. Turner [26] noted a strong linear relationship between SPAD values and leaf total nitrogen concentration which varied with crop growth stage and variety. This was supported by Peng [25] who stated that it was due to the thickness of leaves or specific leaves' weight. A thick rice leaf, which contained more photosynthetic potential per unit area, was an important morphological trait with greater yield potential. Nitrogen uptake in leaves decreased during the mature maturation process. The declining amount of nitrogen uptake will affect SPAD reading values. SPAD values are indicative of plant nitrogen status and may be useful for determining the amount of nitrogen to be applied to meet the physiological requirements of the crop at various growth stages [4]. Conclusively, SPAD meter can be utilized as an indicator of plant greenness and thickness of leaves.

Table 1 ANOVA for SPAD values for three growth stages of the associated rice plots

Source	DF	Sum of square	Mean square	F Value	P Value
Lot Sampling	2	1707.48	853.74	116.36	<.0001***
Growing stage	2	14683.77	7341.88	1000.63	<.0001***
Sampling Point	19	1056.45	55.60	7.58	<.0001***
Replication	2	18.31	9.15	1.25	0.2881ns

*Significance at 10% significant level or 0.1 probability level. **Significant at 5% significance level or 0.05 probability level. ***Highly significant at 1% significance level or 0.01 probability level

3.2 Kriged Map of SPAD Values at Different Growth Stage for the Associated Rice Plots

SPAD measurement were divided into five classes, namely very low (30 to 32), low (34 to 36), moderate (34 to 36), high (36 to 38) and very high (38 to 40) for the SPAD reading at 45 DAP and 70 DAP. Measurement at 95 DAP also grouped into five classes very low (15 to 18), low (18 to 21), moderate (21 to 24), high (24 to 27) and very high (27 to 30). The variation in SPAD values at 95 DAP was attributed rapid change to the plant leaf nitrogen content.

According to the SPAD value map of lot 15467 for two growing seasons at 45 DAP and 70 DAP, the most dominant distributions of the SPAD values were in high range (36 to 38) which covered up to 50% of the total area concentrated at the centre of the lot. Meanwhile for 95 DAP, the distribution of SPAD readings was almost equal to four classes with the highest percentage in the very high range of 27 to 30 over 33.68 % of the total area. Figures 1 and 2 showed the kriged map of SPAD value at 70 DAP and variability of instantaneous yield lot 15467_2.

In lot 15466, SPAD value varied the most compared to the other lots. The most dominant distribution of SPAD value at 45 DAP was within the low range of 32 to 34, which covered 50.54 % and 46.19 % of the total area in first and second season, respectively. At 70 DAP, the most dominant distribution of SPAD values was very low range (30 to 32) covering 40.71% of the total area for the first season, while in the second season was low range (32 to 34) covering 43.88% of the total area. At 95 DAP, the most dominant SPAD readings were in the low range (18 to 21) with 60.23% of the total area in the first season, while the second season SPAD reading fell in moderate range (21 to 24) with 58.12% of the total area. Compared to the other two lots, lot 15466 was said to have the gather variability.

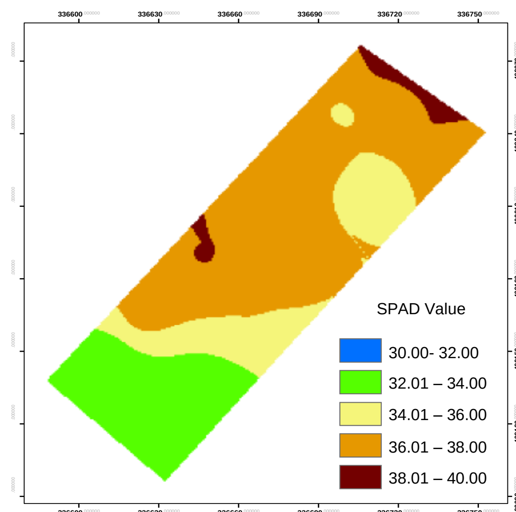


Figure 1 Kriged maps of SPAD value at 70 DAP lot 15467_2

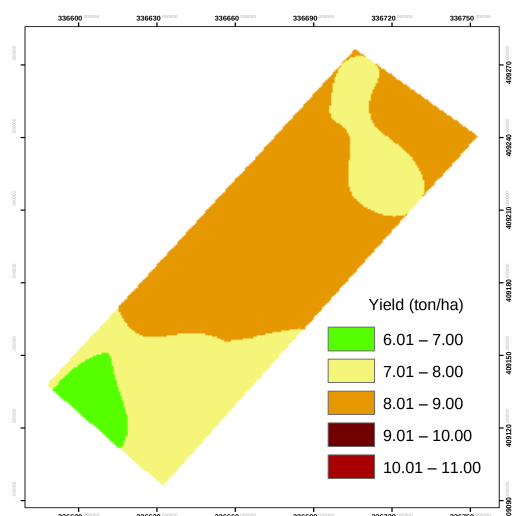


Figure 2 Kriged instantaneous yield maps at lot 15467_2

Lastly, for lot 15522 SPAD values the most dominant distribution at 45 DAP in the first season was low range (32 to 34) with 67.45% of the total area. Unlike the first season, the second season SPAD readings were evenly distributed between all five classes with a 40.01% of the total area. Similarly, SPAD reading at 45 DAP and at 70 DAP were distributed into class 3, 4 and 5 with the highest percentage in the moderate range (34 to 36) with 32.99% and 49.94% of the total area in the first sand second growing season, respectively. For SPAD reading at 95 DAP reading tell in (24 to 27) with 89.21% of the total area in first season. For The second season, the most dominant distribution was moderate (21 to 24) with 34.64% of the total area.

3.3 Correlation between SPAD value and Yield

The correlations between paddy yield and SPAD value at different crop growing stages (45 DAP, 70 DAP, and 95 DAP) were differed within paddy lots (Table 2). The main causes for yield variability at the individual locations might be due to the differences in soil structure, nutrient concentration and possible influences from other factors such as weather, genotype and management practices. SPAD correlations for the three growth stages and yield were analysed using Pearson's two tailed test.

Table 2 Pearson's correlation coefficient for average instantaneous yield, CCT estimated yield and SPAD values of associated rice plots

Location	Variable	Average Instantaneous Yield	Estimated yield By CCT
15467_1	45 DAP	0.65***	0.65***
	70 DAP	0.76***	0.69**
	95 DAP	0.55***	0.44*
15466_1	45 DAP	0.70***	0.67***
	70 DAP	0.83***	0.77***
	95 DAP	0.66***	0.63***
15222_1	45 DAP	0.64***	0.65***
	70 DAP	0.73***	0.73***
	95 DAP	0.56***	0.53**
15467_2	45 DAP	0.76***	0.56***
	70 DAP	0.88***	0.74***
	95 DAP	0.60***	0.79***
15466_2	45 DAP	0.78***	0.66***
	70 DAP	0.85***	0.86***
	95 DAP	0.63***	0.38*
15522_2	45 DAP	0.74***	0.76***
	70 DAP	0.81***	0.71***
	95 DAP	0.69***	0.63***

*Significant at 10% significant level or 0.1 probability level. **Significant at 5% significant level or 0.05 probability level. ***Highly significant at 1% significant level or 0.01 probability level

Positive correlations were found between SPAD readings and yield. The highest correlation of SPAD readings with rice yield were found at 70 DAP. This stage of rice growth represented the peak of its vegetative index and the highest chlorophyll content at any stage of crop growth. This was also a transition stage of vegetation and reproductive [27]. Similar results were presented by Swain [28]. In their study, results indicated a significant positive correlation between SPAD values and grain yield; for variety Lalat with R^2=0.92 and Swarna with R^2 = 0.98. Most researchers used SPAD reading to monitor rice N status, and it was widely applied to judge rice N demand at different growth stages to improve grain yield and N use efficiency [29,30].

During both growing seasons, SPAD values at 70 DAP had higher correlation with yield when compared to the readings at 45 DAP or 95 DAP. Dahal and Routray [31] noted that the interpretation of the correlation became easier when it was explained by the square of the coefficient correlation better known as coefficient of determination. The coefficient of determination measured the proportion of variation in one of the variables as explained by the variation in another variable. In the first season, the correlation between SPAD values at 70 DAP and average instantaneous yield was approximately 0.73 to 0.88 then r^2 = 0.53 to 0.78 as r = r^2. It showed that 53 to 69 percent of the total variations in instantaneous yield could be explained by the variation in SPAD value at 70 DAP. This means that 22 to 47 percent of the variations in yield could have been caused by the variables other than the SPAD value.

3.4 Rice Yield Prediction Model

Multiple regression models were evaluated to establish the relationship between three independent variables (X_1 to X_3) and the dependent variable Y (rice yield). The regression model of yield used the three explanatory variables against the rice yield. To examine the patterns of relationships among the variables, Pearson's correlation coefficient (r) was used. From the study it was concluded that there was a significant positive correlation between yield and SPAD values at all growth stages (45 DAP, 70 DAP, and 95 DAP) and also interaction within the variables of SPAD value. Due to there are significant correlation between interaction variable of X_1, X_2 and X_3, and the interaction variable included as independent variable (X_1X_2, X_2X_3 and X_1X_3).

The prediction model of instantaneous yield (Y) can be shown as:

$$\mathbf{Y = 12.01 + 2.78X_1 - 3.22X_2 + 0.055X_3 + 0.009X_1X_2 + 0.1027X_2X_3 - 0.103X_1X_3}$$

With R^2 = 0.53 or adjusted R^2 = 0.51 (P Value <.0001)

Rice prediction model had the R^2 value of 0.53. An R^2 value between 0.5 and 0.65 indicates that more than 50% of the variance yield was accounted for by variable X the leaf chlorophyll content. Low R^2 value may be caused by several factors. Dahal and Routray [31] mentioned that rice yield prediction not only based on leaf chlorophyll content and after harvest soil NPK status factors but also environmental, management and climate factors. Heege [32] claimed that crop properties were more variability when compared with soil properties, and that they may have been influenced by factors such as microclimate, variety, growth stage, farming practices, nutrient supply, and weed and pest competitions.

4.0 CONCLUSION

The instantaneous harvested crop yield had positive correlation with SPAD reading. The highest correlation of SPAD value with rice yield was found at 70 days after planting with Pearson's correlation ranged from 0.73 to 0.83 for the associated rice plot. The information obtained from variability could assist farmers in making management decisions capable of improving practice to regarding the succeeding crop. This technology would be able to maintain the yield of paddy hereby the economies status of farmers.

Acknowledgement

The authors are very grateful to the Department of Agriculture (DOA) and Integrated Agricultural Development Authority (IADA) Rice Granary within the district of Kuala Selangor and Sabak Bernam for providing us with the technical assistances throughout our field engagement at the paddy fields in Sungai Besar, Selangor.

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