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Temporal Variability of SPAD Chlorophyll Meter Readings and its Relationship to Total Nitrogen in Leaves within a Malaysian Paddy Field

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Abstract: Recently, site-specific crop management, well-established in some developed countries, is now being considered in other places such as Malaysia. So, describing within-field variability in a typical Malaysian paddy field was conducted to show the temporal variability of SPAD readings and leaves total N. The main objective of this study was to seek appropriate tool to expedite the adoption of PF for double cropping rice cultivation. For this reason, SPAD readings data was collected at 2 different rice growth stages (55DAT and 80DAT) using a Minolta SPAD 502. Leaf samples were collected at 20 random points in each plot to compare the results from SPAD readings values. Nitrogen content was extracted from samples in a laboratory. Finally, SPAD readings and total nitrogen maps were created on the interpretation of the data. Semivariograms, visual observation and statistical analysis indicated higher sampling error and stronger spatial dependence at 80DAT and also same trends of SPAD readings and leaves total N in most areas of the field. The increasing of SPAD readings values with growth stage was observed in this study. SPAD readings at 55DAT had a better relationship to leaves total N than 80DAT. The study concluded that SPAD chlorophyll meter is able to provide a rapid and reasonably accurate estimate of leaf N content and the potential for applying principles and technology of precision farming to understand and control spatial and temporal variation in Malaysian paddy fields.

Key words: Site-specific management, Temporal variability, Chlorophyll meter, Paddy field.

INTRODUCTION

Precision farming is a crop management strategy which seeks to address within-field variability and to optimize inputs on a point-by-point basis within fields. By reducing over-application and under-application of inputs such as nutrients and pesticides on a site-specific basis, this strategy has the potential to improve profitability for the producer and also to reduce the threat of ground or surface water contamination from agricultural chemicals. Precision farming is being adopted by innovative producers in many parts of the world. Sudduth *et al*. (2001) described that the philosophy behind precision farming is that inputs (seed, fertilizer, chemicals, etc.) should be applied only at the time and location that are needed in order to obtain the highest output.

Site-specific management requires a thorough quantitative knowledge of the factors and interactions that finally affect yield. Topography is frequently highly related to yield and topographical data are easy to obtain compared with labor and time-consuming measurements of plant and soil properties (Kravchenko, 2000). Plants need primary nutrients in high amounts, so a deficiency in any one of the essential nutrients will restrict plant growth. A nutrient management plan can be developed for each field on the farm (Dixon, 2002). This plan will prescribe the exact amount of fertilizer needed to have suitable nutrient content in plant, achieve crop yield goals and also helps to prevent the application of excess nutrients, which can have a negative impact on water quality and the environment.

The site-specific nutrient management approach was developed in Asian rice-producing countries through partnerships of the Irrigated Rice Research Consortium (Swain, 2010). Several studies have used site-specific

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nitrogen management to study the impact or sensitivity of nitrogen application on rice yield (Pampoloni, 2007; Dobermann, 1998). On farm research comparing site-specific nutrient management and the farmer's fertilizer practice showed increased yield with site-specific nutrient management with reduced fertilizer N rates (Balasubramanian, 2000; Dobermann, 2002; Peng, 1996). Site-specific N management such as real-time N management and fixed-time adjustable dose N management improved N use efficiency of irrigated rice (Huang, 2008).

Nitrogen is one of the key limiting nutrients in crop growth; therefore, finding efficient levels of nitrogen in rice is important for growth, development, protein, and yield. Knowing the rice nutrient content can be used as an aid in making decisions about nutrient applications such as N. It is also used in fruit and vegetable crops as a guide for nutrient application during the season. Estimating this critical element is a good way to confirm that your fertility management plan is working. Moreover, it can be used to evaluate new fertilizer placement and timing techniques.

The chlorophyll meter or SPAD meter is a simple and portable tool that measures the greenness or relative chlorophyll content of leaves (Inada, 1963; Inada, 1985; Kariya, 1982). Meter readings are given in Minolta Company-defined SPAD (Soil Plant Analysis Development) values that specify relative chlorophyll contents. Since SPAD readings are closely related to leaves' total N content, the SPAD meter can be used to monitor the N status of rice and thereby to adjust the rate of N fertilization in order to increase N use efficiency (Balasubramanian, 1999; Hussain, 2000; Peng, 1995; Peng, 1996; Varvel, 2007). In other words, there is a strong linear relationship between SPAD values and leaves total nitrogen concentration which varies with crop growth stage and/or variety (Takebe, 1989; Turner, 1994), mostly because of leaf thickness or specific leaf weight (Peng, 1993). SPAD readings indicate that plant nitrogen status and the amount of nitrogen to be applied are determined by the physiological nitrogen requirement of crops at different growth stages (Balasubramanian, 1999).

Rice cultivation in Malaysia follows the double cropping system which is used in little number of countries. When two rice crops per year are grown on the same land, a completely different situation develops. Under a double cropping system better control over the availability of plant and soil critical parameters is necessary than was obtained under the traditional system because during the off-season regeneration of the soil takes place, making it suitable again for the next main-season rice crop to produce enough nutrients for plant and maintain a good level of productivity. Lacking of rice farming technologies leads farmers to apply management practices such as fertilization uniformly across the field and at different seasons which is not efficient and could result in either insufficient or excess nutrient supply. They also apply the same rate as in the previous season.

Therefore, the ability to improve management such as high amount and high cost inputs can lead to a significant effect on the profitability of a crop production operation.

The main purpose of this study was to seek appropriate tool to expedite the adoption of PF for double cropping rice cultivation. The research also decided to describe the temporal variability present in a typical paddy field, to determine that chlorophyll meter readings of leaves at which stage of rice growth shows higher amount and to obtain the relationship between SPAD readings and leaves total N in order to use it in evaluating nitrogen amount in plant and then making nitrogen fertilizer top-dress recommendation.

MATERIALS AND METHODS

2.1. Study Area:

This study was conducted in March and April 2009 at the Tanjung Karang Rice Irrigation Scheme located on a flat coastal plain in the Integrated Agricultural Development Area (IADA). It is in the district of Kuala Selangor and Sabak Bernam on latitude 3˚ 35' N and longitude 101˚ 05' E. The scheme is composed of eight compartments which are divided into 24 blocks namely blocks A to X. Block C was selected for this. It contained 118 plots and each plot size was 1.2 ha with the total area of about 142 ha.

Tanjung Karang area is mainly composed of mineral and organic soils. The soils of the Tanjung Karang Irrigation Project area are classified into 15 soil series. These are Kranji, Banjar, Sedu, Jawa, Sempadan, Karang, Telok, Selangor, Bernam, Bakau, Serong, Brown Clay, Briah, Organic Clay and Unclassified series. Kranji, Banjar and Karang are developed on the marine alluvium along the coast and riverine alluvium along the Bernam River. Brown clay, Briah and Organic Clay are transition soils between the mineral soils and the peat soils in the swamp. They are composed of brown clays derived from brackish water deposites and organic clays and muck which originated from peat soil. Within Block C, there are only two major soil series namely Telok Series *(Typic Suifaquept)* and Jawa Series *(Fine, Mixed isohyperthermic Sulfic Tropaquept).*

In the study area, rice cultivation starts from weed eradication before and after ploughing and field preparation, drain and bunds after harvest. The next steps are ploughing, rotovation and a land leveling to maintain uniformity of water level throughout the field. Rotovation is done twice per season while, ploughing and land leveling are rarely done or once after several years. After the second rotovation, the field was irrigated for about 3 to 5 cm for pre-saturation. During pre-saturation, pre-germinated seeds (MR 219) for transplanting or direct seeding system will be prepared. 15 Days After Planting (DAP) seedlings were started to transplant in plots, the range of transplanting dated in whole block C was about 15 days. For variety MR 219, the maturity is about 115 days after planting.

Fertilizer management in the study area is usually based on the general recommendation rate suggested by the Department of Agriculture (DOA). The recommendation rate is 170:80:150 kg ha^{-1} for N: P_2O_5: K_2O at four different growth stages with the range of one week in whole block. These fertilizers are uniformly broadcast over the field for all seasons. Water is supplied from the main canal through the tertiary canal and directly to the plots. The current practice is water to be supplied after rotovation up to 5 cm standing height for pre-saturation. Water will be drained out after a day before seed broadcasting. Seven to ten days after broadcasting, standing water up to 3 to 5 cm is expected and again will be drained out 15 to 20 days before harvesting.

2.2. Crop Measurement:

Booting and heading stages are important in rice productivity (Yoshida, 1981), so leaf samples were collected at these two specific stages (55 Days After Transplanting (DAT) (Booting) and also 80 DAT (Heading)). The SPAD data was used to compare between 60 plots using 7 replicates for each plot. Triplicate readings were taken on one side of the midrib of the uppermost, fully expanded leaf (Yang, 2003), midway between the leaf base and tip; all these readings then were averaged. Furthermore, leaf samples were taken to laboratory to estimate their N content using the Kjeldahl digestion technique (Bremner, 1982) in order to determine the relationship between SPAD readings and total nitrogen content.

2.3. Conventional Statistical and Geostatistical Analysis:

The important information about variables is provided by descriptive statistics using the Statistical Package for Social Science (SPSS) version 15.0. Measures of tendency of variables were determined by mean, median and mode as well as computing the dispersion of a variable in variance, standard deviation, coefficient of variation (CV) and range (Park, 2008). It should be noted that smaller values of CV represent lower variability and higher values of CV represent higher variability (Romanuk, 2002). In which CV values of <15%, 16-35% and >36% indicate low, moderate and high variability of data distribution, respectively (Aimrun, 2006). Geostatistical analyses of SPAD readings were calculated for their semivariogram. A semivariogram indicates autocorrelation as a function of distance (semivariance versus distance separation) to plot spatial variability (Cohen, 1990). Its components which include fitted model type, nugget variance (C_0), structural variance sill (C_0+C), range (A), residual sum of square (RSS), coefficient of determination (r^2) and proportion (C/[C_0+C]) were calculated by GS^+ software version 7 (Robertson, 2008).

2.4. Spatial and Temporal Variability Maps:

Variability has been identified as spatial, temporal and predictive (Blackmore, 2003). Temporal variability of SPAD readings was obtained in this study to monitor difference in maps of SPAD readings at two different stages of plant growth (55 DAT and 80 DAT).

SPAD data was interpolated geostatistically by kriging technique using ArcGIS 9.2 through spatial analyst extension based on semivariogram results derived from GS^+ software. The purpose of this interpolation was to produce a surface of predicted value in order to identify the surface coverage or spatial distribution of aforementioned parameters.

3. Results:

3.1. Relationship Between SPAD Readings and Growth Stages:

Descriptive statistics for the collected data are presented in Table 1. The summary statistics for this large field (about 142ha) indicated that the SPAD readings information could be collected intensively. The coefficient of variation (CV) values was 8.12% and 5.75% for 55 DAT and 80 DAT, respectively. This means SPAD readings at 55 DAT varies more than SPAD readings at 80 DAT. Furthermore, it can be explained that low SPAD reading variation at 80 DAT indicated that it was almost homogeneous for the entire study area while higher variation as can be seen at 55 DAT indicated more heterogeneous. T-test showed that the average SPAD value at 80 DAT was significantly higher than the average of SPAD value at 55 DAT. Correlation of two stages SPAD readings was analyzed by Pearson two-tail test to check the relationship between them and also to indicate the trend of their changes during these two growth stages. The test showed that SPAD readings at 55 DAT had a positive significant correlation ($P \leq 0.01$) with 80 DAT.

Table 1: Descriptive statistics for SPAD readings in two growth stage

	SPAD (55DAT)	SPAD (80DAT)
Mean	33.86	37.74
Median	34.24	37.80
Mode	35.0(a)	36.3(a)
Standard Deviation	2.75	2.17
Variance	7.59	4.71
Coefficient of Variation	8.12	5.75
Range	11.9	10.5
Minimum	27.1	32.3
Maximum	39.0	42.8

a; Multiple modes exist. The smallest value is shown.

3.2. Relationship Between SPAD Readings and Nitrogen Content:

Regression analysis of the data showed that nitrogen concentration in the flag leaf was linearly correlated with the SPAD readings at both stages (R^2=0.93 and R^2=0.90 for 55 DAT and 80 DAT, respectively) that are displayed in Figure 1. The linear regression of leaves total N and SPAD values at both stages was highly significant at each growth stage ($p < 0.001$).

3.3. Geostatistics Description and Semivariogram Analysis:

Geostatistical analyses of rice leaf SPAD readings at 55 DAT and 80 DAT were presented according to their semivariograms. As mentioned in materials and methods section, semivariogram had different parameters and those are displayed in Table 2.

Table 2: Summary of Isotropic semivariogram parameters

	SPAD (55DAT)	SPAD (80DAT)
Model Type	Spherical	Exponential
Nugget Variance (C_o)	0.05	0.41
Structural Variance Sill (C_o+C)	7.62	4.77
Partial Sill	7.57	4.36
Range (A_o)	231	354
Residual Sum of Square (RSS)	0.81	1.75
Coefficient (R^2)	0.85	0.56
Proportion (C/[C_o+C])	0.99	0.91

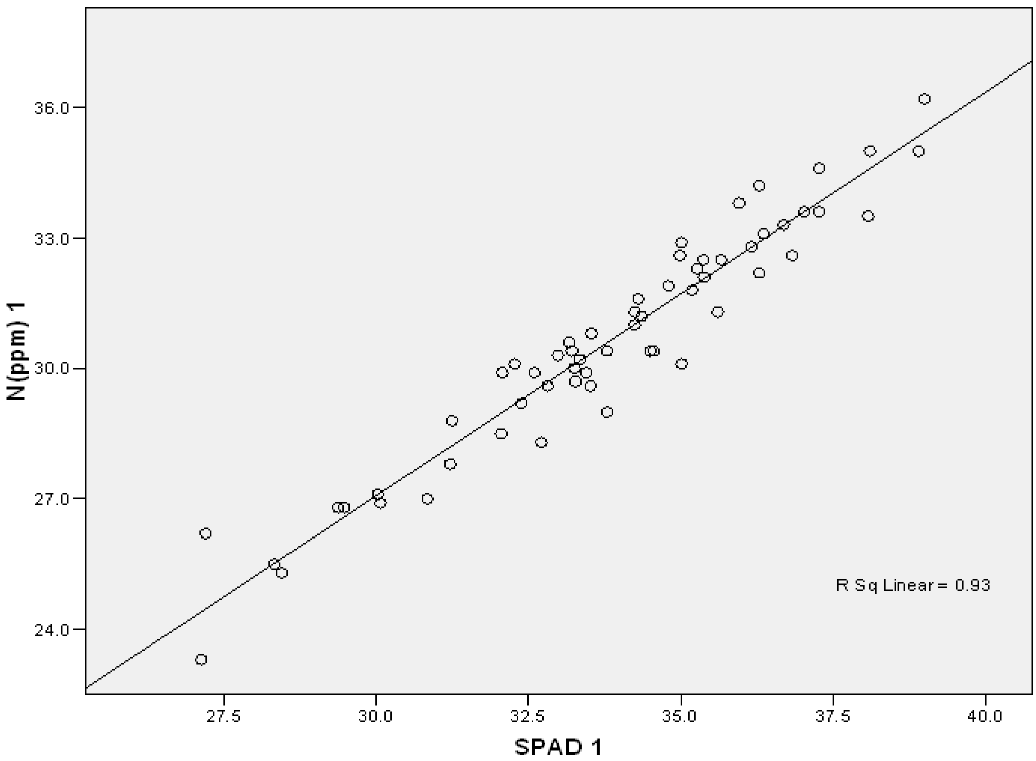
Lag distance was set as 900m with the lag interval of 120m.

Lag distance of each variogram were determined based on width of the field (Robertson, 2008). The variograms of SPAD readings at 55 DAT and 80 DAT are shown in Figure 2, respectively. As can be seen, variogram for SPAD readings at 55 DAT was best fitted to spherical function, while, for SPAD readings at 80 DAT was exponential model. 80 DAT had higher nugget (0.41). Sill and the proportion of partial sill values changed from higher amount at 55 DAT to the lower at 80 DAT. 55 DAT had higher R^2, lower RSS and also lower range (A_o) as compared to 80 DAT.

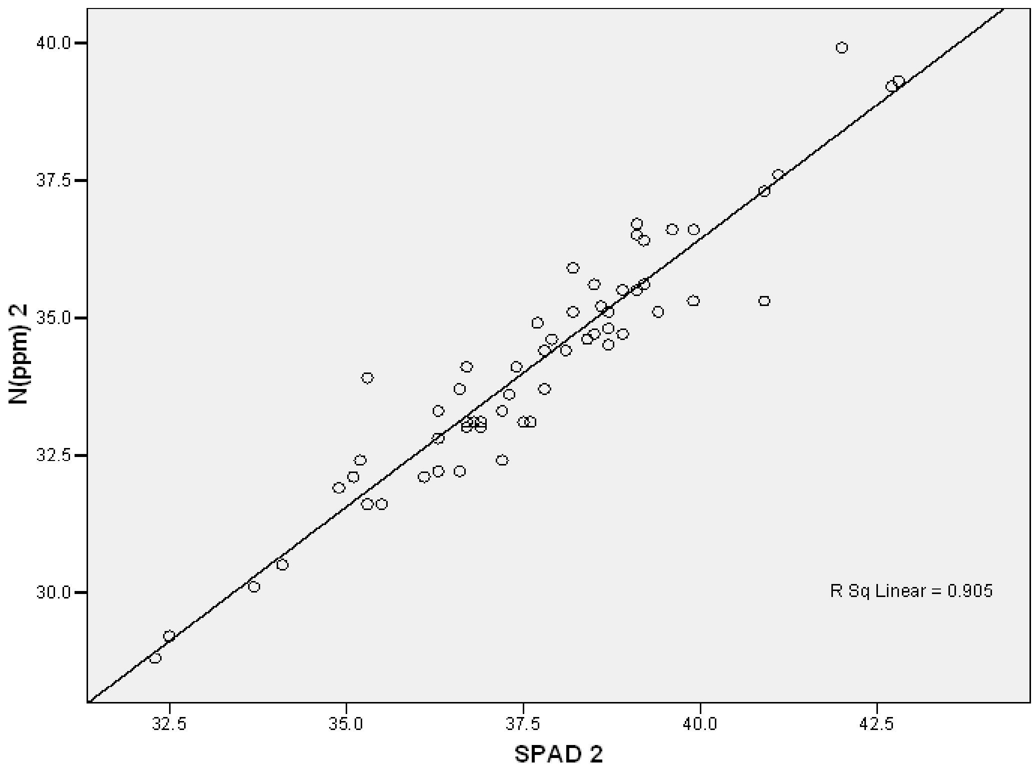
3.4. Spatial and Temporal Variability Maps:

Through the use of raster calculation and zonal statistics on spatial analyst extension, the spatial variability of SPAD readings and total N in leaves were created. Their kriged maps were classified into the standard classification recommended by DOA. Since the standard classification did not visualize much variability for the SPAD readings and total N in leaves, then most of the data points fell into a single class. Thus, the classification technique of smart quantiles, which was introduced by ESRI (2001), was selected to visualize variability. This was based on natural groupings of data values. It identifies break points by looking for groupings and patterns inherent in the data. This study decided to zone the area into 6 and 5 zones for SPAD readings and total N, respectively based on manageable zone.

According to SPAD readings map at 55 DAT (Figure 3a), the areas were mostly occupied by the moderate range of 33.13 to 35.07 and it seemed to be concentrated on some plots in the south. The low SPAD readings (27.30-31.18) were scattered mostly in the center of the area while, the highest readings (35.07-38.95) were observed in the northern plots.

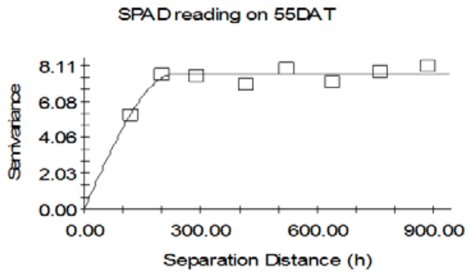


(A)

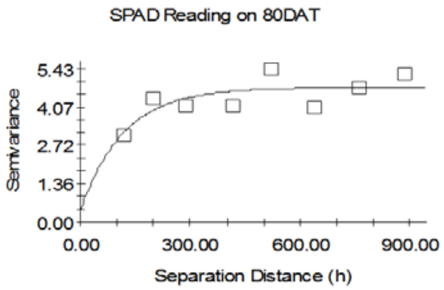


(B)

Fig. 1: Relationship between SPAD readings and N content in flag leaf at 55 DAT (a) and 80 DAT (b).



(A)



(B)

Fig. 2: Isotropic semivariogram of SPAD readings at 55 DAT (a) and 80 DAT (b).

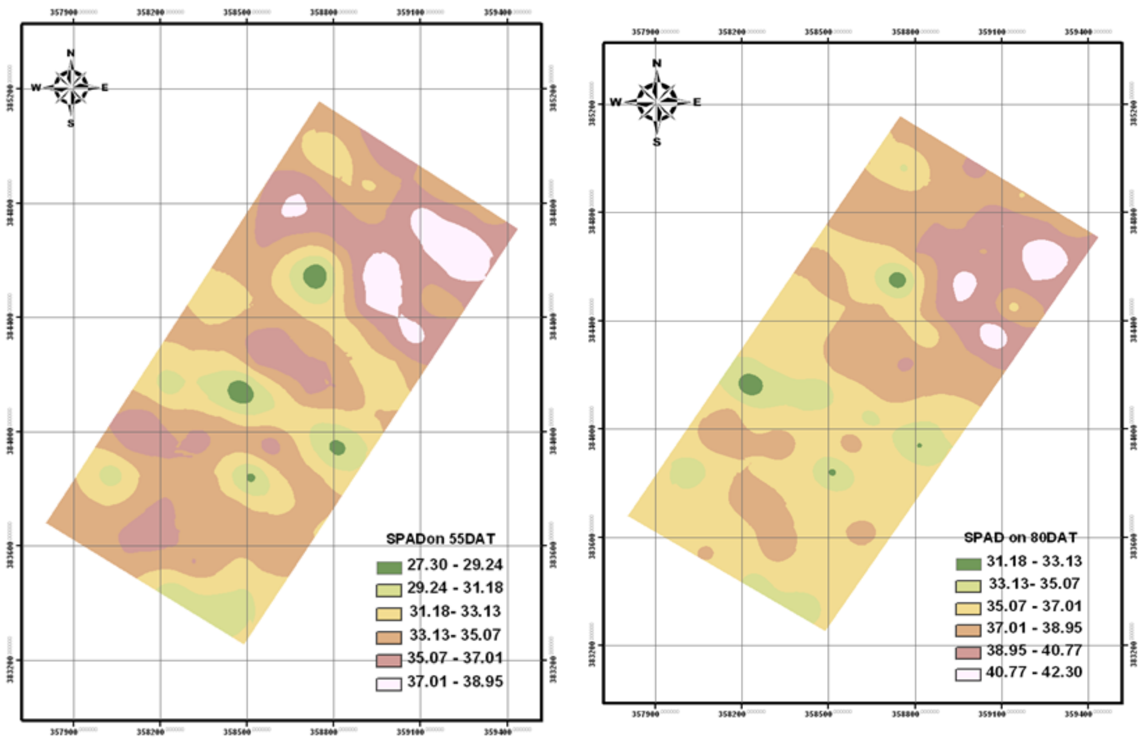
The same pattern could be seen in the other map for SPAD readings at 80 DAT (Figure 3b) but the values where significantly higher than 55 DAT readings. It means that classes 1 and 2 (low values) at 55 DAT map were not found at 80 DAT map while, classes 5 and 6 (high values) at 80 DAT map did not exist in the map of 55 DAT. Zonal statistics displayed that in 55 DAT map the area was covered by moderate values (31.18-35.07) for about 52% of the total area. While 80 DAT map showed that 81% of the total area was covered by the higher SPAD readings of 35.07-38.95.

The variability map of total N at 55 DAT (Figure 4a) illustrated that class 3 (28.59-31.10 ppt N) covered the largest area (more than 45% of the total area) but for 80 DAT (Figure 4b) 33.62-36.20 ppt N was found the most. Class 1 (the lowest amount of N) was the smallest covering area in maps and indicated that the least amount of N in both stages was found in small area.

4. Discussion:

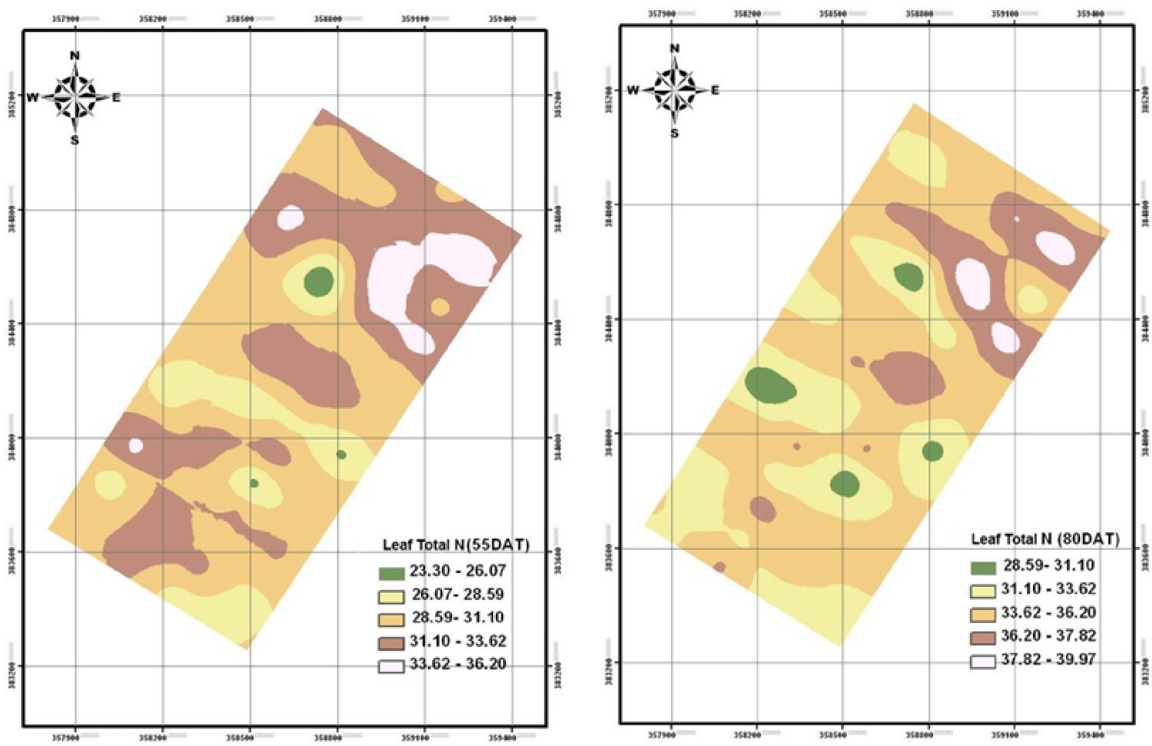
4.1 Relationship Between SPAD Readings and Growth Stages:

Higher mean of SPAD readings at 80 DAT to 50 DAT and also positive correlation of SPAD value at 55 DAT and 80 DAT maybe was due to effect of leaf thickness or specific leaf weight, accumulation of more chlorophyll and also N in uppermost, fully expanded leaf. Peng *et al*. (1993) reported a linear relationship between N and SPAD values at each growth stage, but regression lines differed significantly among growth stages. Mutters *et al*. (2003) reported that the amount of chlorophyll and leaves' total N for rice at 55 DAT is lower than these parameters at 80 DAT, moreover, they mentioned that nitrogen status in the flag leaf varies throughout the life cycle of rice and the rice plant transitions through the most nitrogen sensitive growth stages within a few days. Rostami *et al*. (2008) also reported the same results on corn. The increasing of SPAD readings with plant growth has already been documented by Schepers *et al*. (1992), Smeal and Zhang (1994), Turner and Jund (1994) and Costa *et al*. (2003) too. But Cen *et al*. (2006) found the different result where they observed that SPAD readings in oilseed rape were decreased by plant growth and development which is



(A) (B)

Fig. 3: Krigged map of SPAD readings at (a) 55 DAT and (b) 80 DAT classified by smart quantile method.



(A) (B)

Fig. 4: Krigged map of total N in leaves at (a) 55 DAT and (b) 80 DAT classified by smart quantile method.

caused by the decreased of the chlorophyll. This because of the nutrient element in the green leaves has been transferred to the fruit and the tracking leaves are gradually decrepit.

4.2. Relationship Between SPAD Readings and Nitrogen Content:

The results which were obtained in section 3.2 were similar to Mutters *et al*. (2003), Yang *et al*. (2003), Cen *et al*. (2006), Rostami *et al*. (2008) and Felix *et al*. (2002) for different crops including rice. They reported that the determination coefficient (R^2) between SPAD readings and N concentration were 0.96, 0.80, 0.86, 0.84 and 0.53, respectively. Peng *et al*. (1993) showed that the linear relationship between N concentration and SPAD readings varied depending on plant development stage, position of the measurement on the leaf and genotype. In general, this is because the chlorophyll content in a leaf is closely correlated with leaf N concentration (Evans, 1983; Blackmer, 1994) and there are also some studies that show there is a high correlation between chlorophyll content and SPAD readings (Felix, 2002). Therefore, using SPAD chlorophyll meter could provide an indirect assessment of leaf N status.

4.3. Geostatistics Description and Semivariogram Analysis:

Proper interpretation of the semivariogram and selection of appropriate models are very important to the analysis process (Vieira, 1999; Bakhsh, 2000). So, paying attention to results in part 3.3 shows that 80 DAT had higher nugget which indicated that there was higher sampling error. Sill and the proportion of partial sill values for both stages (55 DAT and 80 DAT) were very weak or considered as pure nugget. Higher proportion amount means the weakness of spatial dependence decreased accordingly to the SPAD readings. Accuracy of semivariance estimation (R^2 of the fitted variogram model) decreases with growth stage that can be relates to higher nugget (C_o). Lower range (A_o) for 55 DAT indicated that this variogram had spatial dependence at a very short distance.

4.4. Spatial and Temporal Variability Maps:

As mentioned before, maps of SPAD readings and leaf total N at each stage, showed the same pattern that could be because of high correlation between these parameters. Variation in amount and range of SPAD readings and total N, and also higher readings at 80 DAT may be due to leaf thickness and more chlorophyll at 80 DAT (Peng, 1993). Aimrun (2006) results about soil N spatial maps showed a relatively similar trend with this research variability maps trend, so SPAD readings and total N variation in different growth stages can also be related to soil fertility gradient differences in soil. This result is similar to Mutters *et al*. (2003), Yang *et al*. (2003), Cen *et al*. (2006), Rostami *et al*. (2008) and Felix *et al*. (2002).

5. Conclusion:

We have described a conceptual frame work for applying principles and technology of precision farming to understand and control the system of agriculture towards a low input, high efficiency and sustainable agriculture in a Malaysian paddy field.

Analyses of collected data at different growth stages were useful to determine when SPAD data can be used to predict leaves' total N amount and future crop N need. The increasing of SPAD readings values with growth stage could be observed in this study. SPAD readings taken at 55 DAT had a better relationship to leaves' total N than those taken at 80 DAT.

Semivariograms were showed both higher sampling error and stronger spatial dependence at 80 DAT. Descriptive statistics; semivariograms analysis and point kriging were employed to determine the temporal variability maps in the measured parameters. Visual observation and statistical analysis indicated the same trends could be observed in most areas of the field for several SPAD readings and leaves' total N.

The experiment concluded the adaptation of the SPAD meter to assess crop nitrogen status and to determine the plant's need for additional nitrogen fertilizer in Malaysian paddy field under double cultivation system. It also showed potential for applying principles and technology of precision farming to understand and control temporal variation in Malaysian paddy fields.

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REFERENCES

Aimrun, W., 2006. Paddy field zone delineation using apparent electrical conductivity and its relationship to the chemical and physical properties of soil. Dissertation, Universiti Putra Malaysia.

Bakhsh, A., D.B. Jaynes, T.S. Colvin and R.S. Kanwar, 2000. Spatio-temporal analysis of yield variability for a corn-soybean field in Iowa. Trans. ASAE, 43(1): 31-38.

Balasubramanian, V., A.C. Morales, R.T. Cruz and S. Abdulrachman, 1999. On-farm adaptation of knowledge-intensive nitrogen management technologies for rice systems. Nutrient Cycling in Agroecosystem, 53: 93-101.

Balasubramanian, V., A.C. Morales, R.T. Cruz, M. Thiyagarajan, R. Nagarajan, M. Babu and L.H. Hai, 2000. Adaptation of the chlorophyll meter (SPAD) technology for real-time N management in rice: A review. Int. Rice Res. Notes, 25: 4-8.

Blackmer, T.M. and J.S. Schepers, 1994. Techniques for monitoring crop nitrogen status in corn. Soil Science and Plant Analysis, 25: 1791-1800.

Blackmore, S., 2003. The role of yield maps in precision farming. Dissertation, Crandfield University at Silsoe. National Soil Resources Institute.

Bremner, J.M. and C.S. Mulvaney, 1982. Nitrogen-total, pp: 595-624. In A.L. Page *et al*. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Cen, H., Y. Shao, H. Song and H. He, 2006. Non-destructive estimation of rape nitrogen status using SPAD chlorophyll meter. ICSP 2006.

Cohen, W.B., T.A. Spies and G.A. Bradshaw, 1990. Semivariograms of digital imagery for analysis of conifer canopy structure. Remote Sensing of Environment, 34: 167-178.

Costa, C., D. Frigon, P. Dutilleul, L.M. Dwyer, V.D. Pillar, D.W. Stewart and D.L. Smith, 2003. Sample size determination for chlorophyll meter reading on maize hybrids with a broad range of canopy type. Journal of Plant Nutrition, 26: 1117-1130.

Dixon, J.B. and D.J. Schulze, 2002. Soil mineralogy with environmental applications, (Madison, Wis.: Soil Science Society Amer).

Dobermann, A. and P.F. White, 1998. Strategies for nutrient management in irrigated and rainfed lowland rice systems. Nutr. Cycl. Agroecosyst, 53: 1-18.

Dobermann, A., C. Witt, D. Dawe, S. Abdulrachman, R. Nagarajan, T.T. Son and S. Chatuporn, 2002. Site-specific nutrient management for intensive rice cropping systems in Asia. Field Crops Res., 74: 37-66.

Evans, J.R., 1983. Nitrogen and photosynthesis in the flag leaf of wheat. Plant Physiology, 72: 297-302.

ESRI., 2001. Using ArcGIS; Geostatistical Analyst. ESRI, CA.

Felix, C.W.L., J.C. Grabosky and N.L. Bassuk, 2002. Using the SPAD 502 chlorophyll meter to assess chlorophyll and nitrogen content of Benjamin Fig and Cottonwood leaves. Horttechnology, 12: 4.

Huang, J., F. He, K. Cui, J. Roland, B.X. Buresh, W. Gong and S. Peng, 2008. Determination of optimal nitrogen rate for rice varieties using a chlorophyll meter. Field Crops Res., 105: 70-80.

Hussain, F., K.F. Bronson, Y. Singh, B. Singh and S. Peng, 2000. Use of chlorophyll meter sufficiency indices for nitrogen management of irrigated rice in Asia. Agronomy Journal, 92: 875-879.

Inada, K., 1963. Studies on a method for determining deepness of green color and chlorophyll content of intact crop leaves and its practical applications. 1. Principle for estimating the deepness of green color and chlorophyll content of whole leaves. Proceeding of the Crop Science Society of Japan, 32: 157-162.

Inada, K., 1985. Spectral ratio of reflectance for estimating chlorophyll content of leaf. Japanese Journal of Crop Science, 54: 261-265.

Kariya, K., A. Matsuzaki and H. Machida, 1982. Distribution of chlorophyll content in leaf blade of rice plant. Japanese Journal of Crop Science, 51: 134-135.

Kravchenko, A.N. and D. Bullock, 2000. Correlation of Corn and Soybean Grain Yield with Topography and Soil Properties. Agronomy Journal, 92: 75-83.

Mutters, R.G., J.W. Eckert, J. Williams, G. Fenn and J. Cardosa, 2003. Development of a leaf color chart for California rice varieties, UC Cooperative Extension University of California.

Pampoloni, M.F., I.J. Manguiat, S. Ramanathan, H.C. Gines and P.S. Tan, 2007. Environmental impact and economic benefits of site-specific nutrient management (SSNM) in irrigated rice systems. Agric. Syst., 93: 1-24.

Park, H.M., 2008. Univariate analysis and normality test using SAS, Stata, and SPSS. Technical Working Paper. The University Information Technology Services (UITS) Center for Statistical and Mathematical Computing. Indiana University.

Peng, S., F.C. Garcia, R.C. Laza and K.G. Cassman, 1993. Adjustment for specific leaf weight improves chlorophyll meter's estimation of rice leaf nitrogen concentration. Agronomy Journal, 85: 987-990.

Peng, S., R.C. Laza, F.C. Garcia and K.G. Cassman, 1995. Chlorophyll meter estimates leaf area-based N concentration of rice. Commun. Soil Science and Plant Analysis, 26: 927-935.

Peng, S., F.V. Garcia, R.C. Laza, A.L. Sanico, R.M. Visperas and K.G. Cassman, 1996. Increased N-use efficiency using a chlorophyll meter on high-yielding irrigated rice. Field Crops Research, 47: 243-252.

Robertson, G.P., 2008. GS+: Geostatistics for the environmental sciences. Gamma Design Software, Plainwell, Michigan.

Romanuk, T.N. and J. Kolasa, 2002. Environmental Variability Alerts the Relationship between Richness and Variability of Community Abundance in Aquatic Rock Pool Microcosms. Journal of Ecoscience, 9(1): 55-62.

Rostami, M., A.R. Koocheki, M. Nasiri Mahallati and M. Kafi, 2008. Evaluation of chlorophyll meter (SPAD) data for prediction of nitrogen status in corn *(Zea mays L.).* American-Eurasian Journal of Agricultural and Environmental Science, 3(1): 79-85.

Schepers, J.S., D.D. Francis, M. Vigil and F.E. Blow, 1992. Comparison of maize leaf nitrogen concentration and chlorophyll meter readings. Soil Science and Plant Analysis, 23: 2173-2187.

Smeal, D. and H. Zhang, 1994. Chlorophyll meter evaluation for nitrogen management in maize. Soil Science and Plant Analysis, 25: 1495-1503.

Sudduth, K.A., S.O. Chung, J.H. Sung, S.T. Drummound and B.K. Hyun, 2001. Spatial variability of yield chlorophyll content and soil properties in a Korean rice paddy field. In P.C. Robert *et al*. (ed.) Proc. 5th International Conf. on precision agriculture. [CD-rom] ASA, CSSA, Madison, WI.

Swain, D.K. and S.J. Sandip, 2010. Development of SPAD values of medium- and long-duration rice variety for site-specific nitrogen management. J. Agron., 9: 38-44.

Takebe, M. and T. Yoneyama, 1989. Measurement of leaf color scores and its implication to nitrogen nutrition of rice plants. Japanese Agricultural Research Quarterly, 23: 86-93.

Turner, F.T. and M.F. Jund, 1994. Assessing the nitrogen requirements of rice crops with a chlorophyll meter method. Australian Journal of Experimental Agriculture, 34: 1001-1005.

Varvel, G.E., W.W. Wilhelm, J.F. Shanahan and J.S. Schepers, 2007. An algorithm for corn nitrogen recommendations using a chlorophyll meter based sufficiency index. Agronomy Journal, 99: 701-706.

Vieira, S.R., 1999. Geostatistical applications in mapping of crop yield and soil properties. Proc. 2nd European Conf. on Precision Agriculture, J. V. Stafford (ed.). Sheffield Academic Press, Sheffield, UK, pp: 365-375.

Yang, W.H., S. Peng, J. Huang, A.L. Sanico, R.J. Buresh and C. Witt., 2003. Using leaf color charts to estimate leaf nitrogen status of rice. Agronomy Journal, 95: 212-217.

Yoshida, S., 1981. Physiological analysis of rice yield . In : S.Yoshida (Ed). International Rice Research Institute, Los Banos, Laguna, Philippines. Fundamentals of Rice Crop Science, 231-247.