DEVELOPMENT OF ON-THE-GO SOIL NITROGEN MAPPING SYSTEM FOR SITE SPECIFIC MANAGEMENT

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ABSTRACT

Site specific management can potentially improve both economic and ecological outcomes in agriculture. Effective site specific management requires strong and temporally consistent relationship among identified management zones; underlying soil physical, chemical and biological parameters; and crop yield. Those requirements are possible to be obtained through the use of specific equipment and state-of-the art technology. This study was carried out to develop an on-the-go system to provide accurate soil nitrogen map by using an electrical conductivity sensor. The result from this study has proven the merit of the developed system in terms of its performance and its reliability. The soil nitrogen map produced via this system was almost similar to a kriging map produced via ArcGIS software and it was shown to be reliable for use in the site specific application for best management practices. This finding shows that the soil nutrient variability map was possible to be produced in real-time basis without engaging any tedious work in the field. The use of this mapping system as a basis of identifying the soil nutrient variability proved to be a good technique for the farmers to better manage their paddy fields.

Keywords: *Apparent Soil Electrical Conductivity (ECa), Nitrogen (N) Fertilizer, Paddy Field, Rice Yield, Variability Map*

1.0 INTRODUCTION

Nitrogen is a primary nutrient for plant growth since its involved in main biochemical processes[1]. Beside its crucial effects on plant growth and yield formation, feature and quality of final products are mostly affected. From previous studies of 18 years data collection and analyses shows that there has been significant decline in rice yield with low N rates (0 and 40 kg ha^{-1}) but at levels of 80 and 120 kg ha^{-1} rice yield was maintained [2]. Generally, nitrogen fertilizer is broadcasted uniformly throughout a field, although it is known that soil fertility varies considerably within a field and when the amount of nitrate concentrations in soil increased, the uptake of nitrate by plants is also increasing [3]. Because of the relatively low production cost of urea, and its low transportation cost per unit of N, there has been a widespread used of urea as the major form of N [4]. However, there is concern about the efficiency of using urea-N for agricultural crops, especially for flooded rice, since farmers' practices in Asia commonly result in recoveries of < 40% of the N applied [5]. The high rates of N application may support an excessive vegetative growth but unfortunately it also may even depress the yield and prevent the full yield potential [6]. In Malaysia, the optimum N nutrient requirement for paddy is around 0.2 to 0.3% or 2 to 3 mg/kg. The granary area at Sawah Sempadan, Selangor needs approximately 0.3% of total N content and it was around the optimum requirement level [7]. From previous research done, it was shown that the nitrogen content is essential to be known in order to apply the N fertilizer in the right amount, at the right place and for critical growth stages for best management practices [8]. Thus, a reliable tool is necessary to provide accurate information to apply the fertilizer for crop cultivation.

The emerging of technology such apparent soil electrical conductivity (ECa) sensor was reported to be reliable to describe field condition as well as N contents [9]. The ECa sensor is developed for on-the-go measurement of soil properties and is a very practical tool in mapping different soil properties as the soil ECa can be measured quickly with known locations. The ECa is affected by several soil properties such as soil water content, clay content, salinity, temperature, organic compounds and also metals [10]. Although many soil factors affecting ECa are relatively fixed over time (e.g. clay content), others may exhibit strong seasonal dynamics. The ECa sensor was also used to determine the relationship between rice yield and soil ECa where the analyses show that ECa value is closely associated with rice yield [11].

Soil conductivity appeared to be a reliable indicator of soluble N gains and losses in soil and may serve as a measure of N sufficiency for corn early in the growing season [12]. Soil conductivity may also be used as an indicator of N surplus after harvest when N is prone to loss from leaching and/or denitrification. The ECa sensor could also help to define management zones with differing productivity and nutrient requirements because of its ability to measure the soil properties [13]. The potential yield can be estimated by determining topsoil thickness with the soil ECa measurements, and then can be used to employ a variable-rate N fertilizer [14]. This approach for N management has been tested and application found to be effective in many types of crops [15].

The traditional fertilizing recommendation that is used by the farmers in Malaysia for paddy cultivation will slightly cause many detrimental effects to the environment, soil properties, production efficiency and also to the crop itself. It also increased the cost of production in terms of fertilizer use and represents a substantial financial burden to the Government to allocate the fertilizer subsidies to the farmers. Therefore, this study was conducted to develop a rapid system to determine N fertilizer for site specific area to assist farmers and fertilizer provider to control and monitor the N requirement for best management practices. The other nutrient contents such phosphorus (P) and potassium (K) were not considered in this study.

2.0 MATERIALS AND METHODS

A. Site Description

The study was conducted at the paddy fields of Sawah Sempadan, Tanjung Karang, Selangor, managed by the Integrated Agricultural Development Area (IADA) under the Ministry of Agriculture Malaysia & Agro-Based Industry Malaysia (MOA). It is in the district of Kuala Selangor and Sabak Bernam at latitude 3°35''N and longitude 101°05''E. The selected study area comprised of 118 lots of paddy field with an average lot size of 1.2ha or less (Figure 1). This granary area was chosen in order to compare the actual nitrogen content in the paddy soil obtained from soil analyses and the predicted nitrogen content derived by the developed system.

B. Soil ECa Measurement

Veris® 3100 Soil EC Sensor was used to measure soil ECa. The sensor consists of six coulters, two of which introduce an electrical potential into the soil. The remaining four coulters are spaced to measure EC over two approximate depths, 0-30 cm (ECas) and 0-90 cm (ECad). The coulters penetrate the soil surface into a depth of 6 cm. The depth of measurement is based upon the spacing of the coulter-electrodes. The sensor integrated with global navigation satellite system (GNSS) was pulled behind a tractor across each lot within an area of 60 m width and 200 m length. The output data from the logger reflected the conversion of resistance to conductivity (1/resistance = conductivity). A Differential Global Navigation Satellite System (DGNSS) with sub-meter accuracy was used to geo-reference ECa measurements. The soil ECa data obtained from the sensor was used to generate the variability map using ArcGIS version 9.2. The manual classification technique, which was introduced by ArcGIS software, was selected for visual variability as groups. The manual classes were used to compare features to specific and meaning values, emphasize a particular range of values and also can be used for isolating and highlighting ranges of data [16]. The spatial interpolation or kriging method was used to produce a surface of variable values in order to identify the surface coverage or spatial distribution. Kriging technique was used instead of Inverse Distance Weight because the technique has been recommended by many for its interpolation capability.

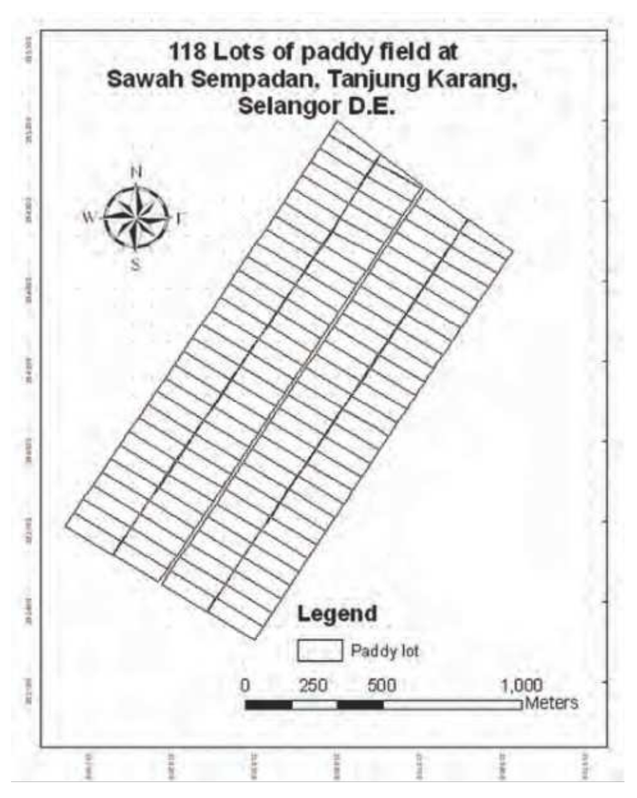


Figure 1: The experimental area at Sawah Sempadan, Tanjung Karang, Selangor

Figure 2: Soil ECa sensor integrated with Trimble Ag132 DGPS pulled by a tractor

C. Total Nitrogen Analyses and Reference Model

The soil sample from each lot was taken within a depth of 30cm. The sampling task was carried out by using Eijkelkamp soil auger. All the 118 samples were brought to the laboratory for analysis of total nitrogen (TN) content in the respective lot using the Kjeldahl digestion technique [17]. The method can be done with limited resources and is useful for analysis of TN from a single sample distillation. The value of actual TN is then compared to predicted TN. The purpose was to measure the reliability level of the developed system to produce accurate information.

The predicted TN model was derived from the previous study [18]. The soil ECa was identified to be reliable to measure TN content at the study site for both dry and wet seasons. The statistical analysis shows that soil ECa was significantly related to nitrogen content at 0.01 level. The TN model based on soil

ECa data can be described as follow:

$$TN = 0.1070 + (11.5606 / ECad) \qquad (1)$$

D. Program Development

The MATLAB software version 7.4.0 was used to develop the application program. It was designed to produce the nitrogen variability map during on-the-go measurement of soil ECa. The program was developed to plot the TN content in real time basis and the plotting map to be displayed on the robust computer screen mounted in a tractor cab. The coordinates of plotted data point were retrieved from DGNSS which was connected to the robust computer. The developed program was facilitated with interpolation function to generate the variability map based on the plotting data obtained from the ECa sensor. This function provide three selection methods; automatic interpolation, equal interval and K-means, and also a manual interpolation which allows user to insert the desired minimum and maximum range. The program was mounted as a very user-friendly tool with interactive Graphical User Interface (GUI) for user to access as shown in Figure 3. It is a simple system with many selections of panels and easy to use.

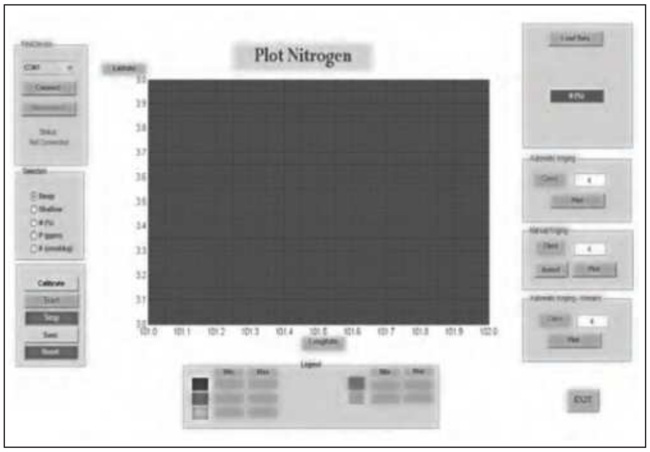


Figure 3: Graphical User Interface (GUI) of the developed program

E. System Setup

The developed system consist of various devices such DGNSS, ECa sensor, a robust computer, a software and a tractor integrated as a system to provide the necessary information as shown in Figure 4. The DGNSS and ECa sensor were connected to the robust computer which mounted in the tractor cabin. The developed program was installed in the robust computer as a tool or software to synchronize the DGNSS and ECa sensor. The data obtained from the system will appear automatically as a map based in the software when the synchronization was success. The tractor was role as a prime mover to pull the ECa sensor for data acquisition task within the paddy field. All the electronics devices were supplied by the 12 volts power source from the tractor's battery.

3.0 RESULTS AND DISCUSSIONS

A. Validity Test

The ECa data obtained from the sensor were integrated over a soil depth of 30cm and 90cm for shallow ECa (ECas) and deep ECa (ECad), respectively. The total number of ECa data points was 79,988 for 118 lots. The number of data is dependent on the speed of the tractor and the condition of the soil surface. The logging interval of one second, a slow drive can collect more data points [19]. Table 1 shows the descriptive statistics of soil ECa. The values of ECas (mS/m) were found to be 4.80, 223.00 and 30.16 for minimum, maximum and mean value, respectively. The value of ECad (mS/m) was slightly higher compared to ECas values; it was 18.90, 248.40 and 77.35 for minimum, maximum and mean value, respectively. The coefficient of variation (CV) for ECas and ECad were 42.18% and 37.76%. This means ECas reading varies more than ECad and this is expected due to the intensive activities at the surface layer. The variability of ECad may be caused by the difference of soil textures in the soil profile to a depth of 90cm [5].

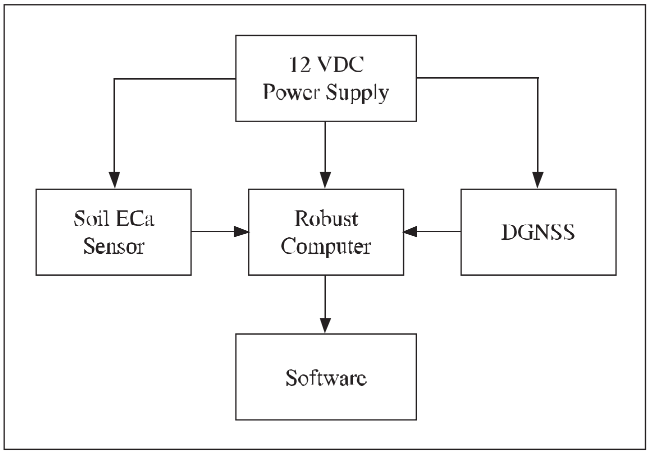


Figure 4: A diagram of the developed system comprising of various devices

Table 1: Descriptive statistics for ECas and ECad in the experimental area

Description	ECas	ECad
Number of Data	79988	79988
Min	4.80	18.90
Max	223.00	248.40
Mean	30.16	77.35
Range	218.20	229.50
Std. Deviation	12.72	29.21
Variance	161.83	853.19
Coefficient of Variation (C.V.)	42.18	37.76

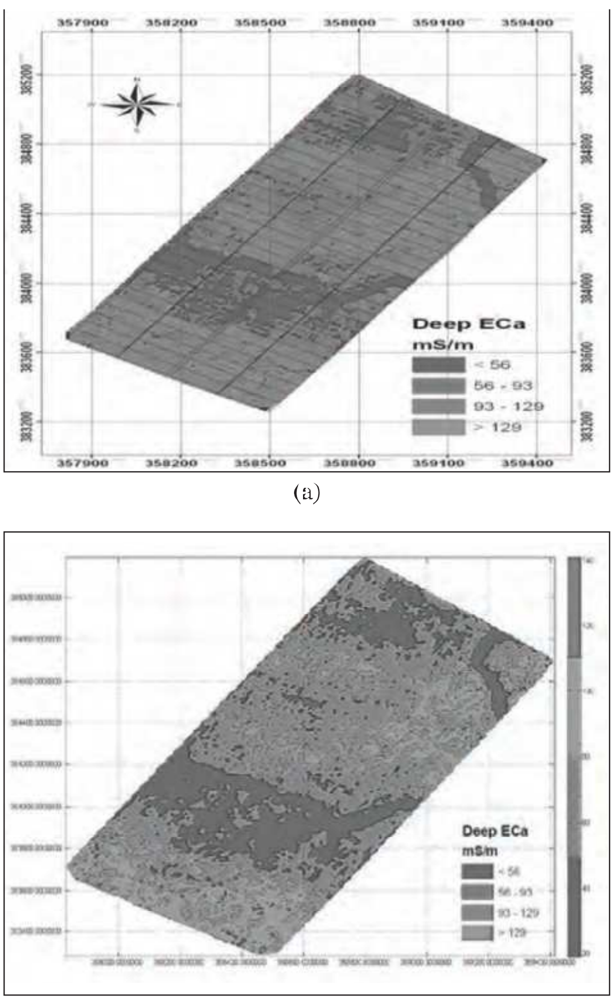
The descriptive statistics of predicted and actual TN content in the experimental area is shown in Table 2. The predicted TN was derived by the developed system and the number of data was obtained from the ECa sensor. The developed system was gone through the field tested during the soil sampling task. The values of the predicted TN were found to be 0.15, 0.72 and 0.28% for minimum, maximum and mean value, respectively. The C.V. for predicted TN was 29.57% in the entire experimental area. It can be explained that the system has predicted heterogeneous nitrogen content in the study area. The actual TN content was also measured for comparison purpose. The number of data for measured TN content was 118 as shown in Table 2. The number of data was smaller compared to the data from predicted TN because it was based on the sampling points collected in each lot of the experimental area. The values of measured TN content were found to be 0.10, 0.66 and 0.39% for minimum, maximum and mean value, respectively. The C.V. for actual TN content was 34.86% for the entire experimental area. The higher value of C.V. shows that the actual TN content is more varied than the predicted TN content. It can be explained that the number of data points will influence the hypothesis.

Table 2: Descriptive statistics for predicted and actual nitrogen contents in the experimental area

Description	Predicted TN	Measured TN
Number of Data	79988	118
Min	0.15	0.10
Max	0.72	0.66
Mean	0.28	0.39
Range	0.57	0.56
Std. Deviation	0.084	0.137
Variance	0.007	0.019
Coefficient of Variation (C.V.)	29.57	34.86

In relation to that, classification approach using raster calculator, by doing spatial analysis for calculating the variables and to produce map was carried out. The map produced was used to compare the ECa spatial distribution to the map produced from the developed system. The study area was divided into 4 zones (respectively for ECa reading and nitrogen content) which means more manageable and easy to compare. The ECa zones were 1) very low, 2) low, 3) moderate and 4) high. The shallow soil ECa (ECas) was not considered in this comparison purpose since the reference model that has been used in this study was only significant to the ECad. According to the maps in Figure 5(a), the kriging map produced via ArcGIS software was almost similar to the map produced by the developed system in Figure 5(b). The areas in the maps were mostly occupied by low soil ECad. The moderate ECad seemed to be concentrated in the south and was scattered in the middle part of the study area. Furthermore, the highest ECad zone was not able to distinguish in the variability maps. The similarity between both maps in Figure 6 shows that the developed system was able to produce an accurate soil ECa map and reliable to define the ECa zones rapidly.

The developed system could not produce an accurate TN variability map as soil ECa map. The variation of the map is slightly different compared to the map produced via ArcGIS as shown in Figure 6. The actual TN variability map was based on 118 lots collected from soil sampling work in the field. On the other hand, the predicted map produced by the developed system was based on the soil ECa sensor with 79988 data points. Thus, the difference of the variability map is caused by the number of sampling points used for map generation. Nevertheless, the TN maps produced from both sources show that the TN contents were higher in most parts of the study area. The predicted map in Figure 6(b) shows that the moderate TN occupied the center and lower region of the study area. The actual TN map in Figure 6(a) obviously show that the TN was heterogeneous and some areas spotted with lower TN contents. The area can be considered as fertile area since the TN contents was slightly higher in most of the study area. The TN variability map produced by the developed system indicates that the system was reliable to be used as a decision support system for N fertilizer management for site specific application. The system can recommend the optimum N fertilizer application in the right place with the right amount through the variability map. The rapid information on soil fertility is valuable to practice precision farming.



(a)

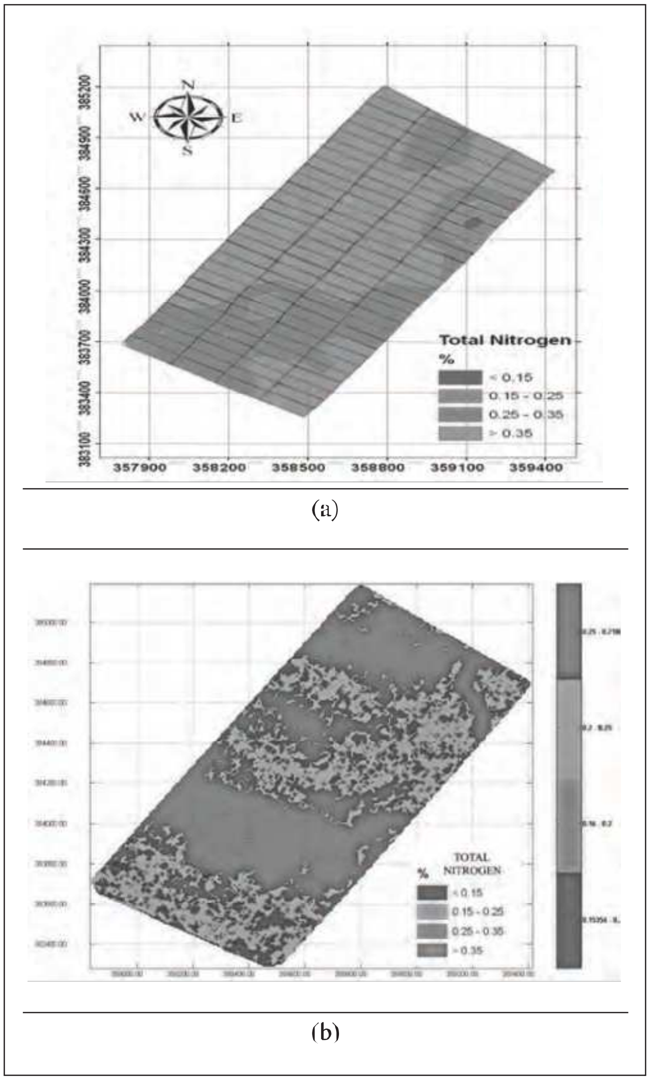
(b)

Figure 5: Kriging map of soil ECad produced from ArcGIS 9.2 (a) and from the developed system (b) for 118 lots of the study area

From the maps in Figure 6, most of the study area contains higher total nitrogen which is more than 0.35% and some of the areas especially in the southern part was found to be more than 0.25% soil nitrogen content. From the results, the paddy field was saturated with nitrogen which may contribute to the soil degradation. This developed system can assist the farmers to optimize the nitrogen fertilizer in their paddy field.

B. Reliability Test

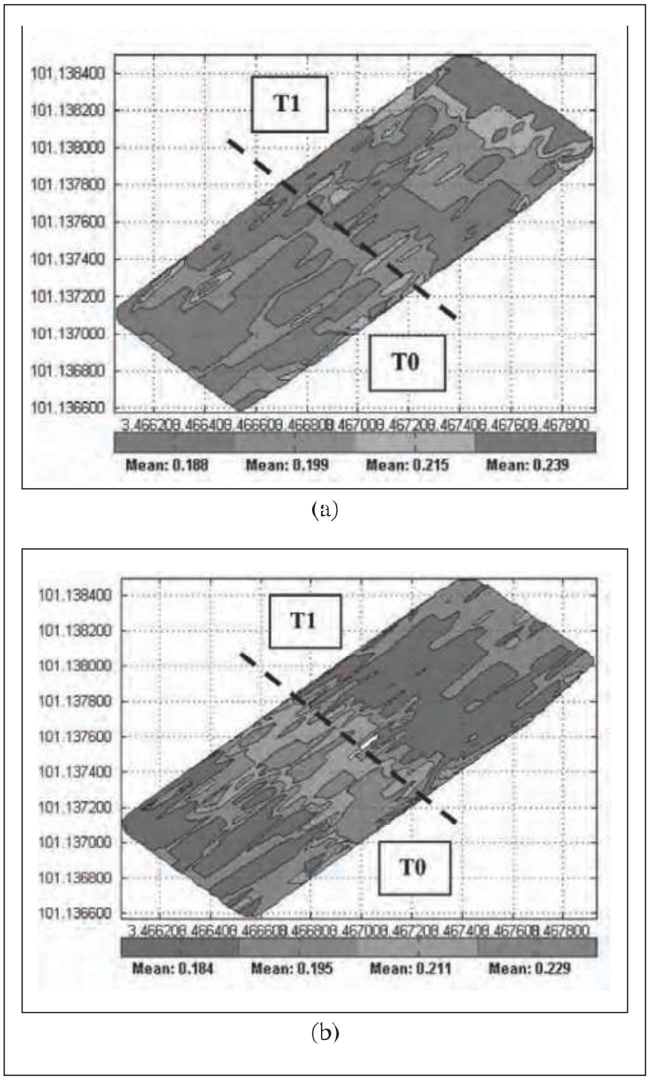
The test was conducted in a small trial area which covered 10,800m^2 for each lot. The yield data were recorded for 3 seasons, namely, from 1/2009 (February to June), 2/2009 (August to December) and 1/2010 (February to June). The first



(a)

(b)

Figure 6: Variability maps of actual TN contents (a) and predicted TN contents (b) for 118 lots at the study area



(a)

(b)

Figure 7: Variability maps of TN contents for season (a) 2/2009 and (b) 1/2010 generated by the developed system

season was considered as a monitoring season, where rice crop was planted as normally practiced. The actual reliability test was only begun during the second season (2/2009) where the TN variability map was generated from the developed system for both treatment (T1) and conventional practice (T0) lots, as shown in Figure 7(a). The treatment lot (T1) was an area where the fertilizer input was applied based on the map generated by the system and the conventional practice lot (T0) was an area where the fertilizer was applied based on farmers traditional practices and recommendation by Department of Agriculture (DOA). According to DOA, the nitrogen fertilizer was normally applied at the rate of 170kg/ha.

Based on the map in Figure 7(a), the nitrogen content indicated higher in the upper part of T1 but the amount was reduced at the centre and lower parts of the plot. The nitrogen content in lot T0 indicated lower in the entire area for season 2/2009 as shown in Figure 8(a). Next, the N fertilizer was applied in lot T1 based on the recommendation of the variability map and the amount of applied fertilizer as shown in Table 3. A total of 156kg of urea was used in that season; whereby the largest amount was used during the tillering stage at 35-40 DAP.

Table 3: Fertilizer rate application in the treatment lot based on the variability map (DAP is days after planting)

Season	DAP	Type of Fertilizer	Amount of Fertilizer (kg)	Total Fertilizer
2/2009	15-20	N Urea	40.5	156kg Urea
	35-40		57.7	
	55-60		42.3	
	65-70		15.5	
1/2010	15-20	N Urea	50.6	194.5kg Urea
	35-40		72	
	55-60		52.5	
	65-70		19.4	

The same procedure was also carried out in the third season. The nitrogen variability map was produced from the developed system as shown in Figure 7(b). The map represents the variation of TN, where higher amount was predicted at the centre region of the trial area or the upper part of the conventional practice lot.

TN increased in this lot compared to the previous season; while TN in the treatment lot was slightly reduced as compared to the last season. Then N fertilizer or urea was applied according to the predicted map. The amount of urea used in this season was increased up to 194.5kg, as shown in Table 3. This scenario was due to the crop requirement, where the developed system predicted a lower TN amount in the treatment lot during that season. The largest amount of urea was used during the tillering stage at the 35-40 DAP, similar to the previous season.

Next, the yield data were recorded so as to analyze the performance in 3 different seasons. As a result, rice yield increased from one season to another, as shown in Figure 8. In more specific, the yield for T1 in the initial season (1/2009) was slightly lower as compared to the T0, with a difference of 584 $kg.ha^{-1}$. Meanwhile, the yield for T1 increased dramatically (i.e. up to 5,630 $kg.ha^{-1}$) in the following season (2/2009), which an increase of more than 30% from the yield recorded in the previous season. This result showed that rice yield was responsive to the optimum fertilizer application recommended by the developed system. Moreover, the study results also manifested that the yield for T0 increased as compared to the previous season but the yield gap between T1 and T0 was slightly narrow (92 $kg.ha^{-1}$). Meanwhile, the second trial in the third season (1/2010) showed the reliability of the developed system, whereby the yield for T1 was higher than the yield for T0, with the total amount of 5,981 $kg.ha^{-1}$ and 5,759 $kg.ha^{-1}$, respectively.

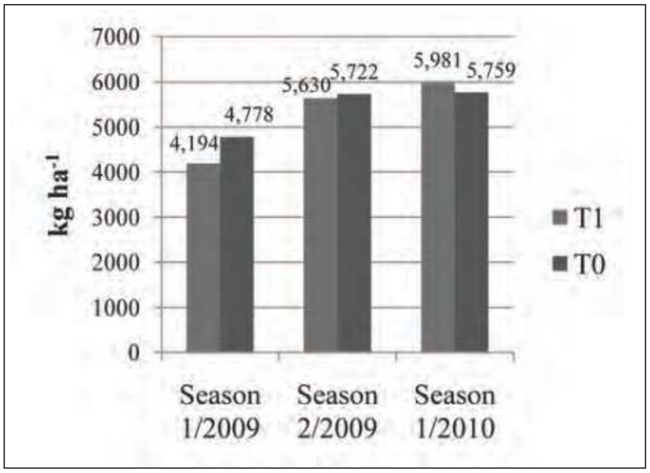


Figure 8: Comparison of gross rice yield harvested from treatment lot (T1) and conventional practice lot (T0) for 3 seasons

4.0 CONCLUSION

This study was carried out in order to optimize the nitrogen fertilizer application in the site specific area for best management practices. Results of this study showed that the developed system is capable to produce a nutrient variability map in real-time. The map is reliable to assist the farmers to manage their farm better and indirectly will optimize the cost of production and reduce the environmental degradation by applying optimum quantity of fertilizer. Nevertheless, the other essential nutrients such phosphorus (P) and potassium (K) is necessary to be considered in crop growth study. Thus, further investigation is strongly recommended to identify the relationship between soil ECa towards P and K in rice granary areas.

5.0 ACKNOWLEDGEMENT

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PROFILES

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