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DEVELOPMENT OF SOIL NITROGEN MAPPING SYSTEM USING APPARENT SOIL ELECTRICAL CONDUCTIVITY SENSOR FOR PADDY FIELD

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ABSTRACT

The emerging technology in agricultural research has changed the scenario for crop management. The precision farming concept is emphasized in parallel with the essential technology used in agriculture. The tools such as variables rate technology (VRT) or variable rate application (VRA) seems like compulsory for decision making purpose. Thus, this study was carried out to develop a rapid mapping system as a new tool for N-fertilizer application based on soil electrical conductivity data. The result from this study has proven the merit of the developed system in terms of its performance and its reliability. The total nitrogen map produced via this system was shown to be reliable for use in the site specific application for best management practices. The variability map produced from this system is slightly similar as a kriging map produced via ArcGIS. The findings of this study show that applying nutrients at optimal rates and at the right place with the assistance of technology is feasible to achieve high yield and high efficiency of nutrient use by the crop. The use of this mapping system as a basis of measuring 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, Variability Map, Rice Yield*

INTRODUCTION

Soil nitrogen content is among the indicator of soil fertility that closely related to soil productivity. Nitrogen (N) nutrition is an important determinant of the growth and yield of every crop which is taken up by the crops throughout the growing season in nitrate form. From a study by previous researcher, during 18 years data collection and analyzed 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 [1]. 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 is increasing, the uptake of nitrate by plants is also increasing [2]. Some study shows that the yield of seed and oil canola was increasing significantly with N fertilizer and irrigation which assists in increasing soil moisture contents [3]. 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 expression [4]. In Malaysia, the optimum N nutrients requirement for paddy is around 0.2 to 0.3 % or 2 to 3 mg/kg. According to the previous study, the average amount of total N content in paddy field at Sawah Sempadan, Selangor approximately was 0.3 % and it was around the optimum requirement level [5]. Through the research done, it was shown that the nitrogen content is slightly essential to be known in order to apply the N fertilizer in the right amount and at the right place for best management practices. Thus, a reliable tool is necessary to provide accurate information to apply the fertilizer in the site specific.

The emerging of technology such apparent soil electrical conductivity (ECa) sensor was reported that it was reliable to describe field condition as well as N contents. The ECa sensor is developed for on-the-go measurement of soil properties and is a very practical tool in mapping different soil properties in the particular areas as the soil ECa can be measured quickly and knows the location exactly. The apparent Electrical Conductivity (ECa), is affected by several number of soil properties such as soil water content, clay content, salinity, temperature, organic compounds and also metals [6].The ECa sensor was also used to determine the relationship between rice yield and soil ECa where the analyses show that ECa value was associated with rice yield [7].

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 [8]. 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. Apparent soil electrical conductivity sensors could also help to define management zones with differing productivity and nutrient requirements because of its ability to measure the soil properties [9]. The yield potential can be estimated by determining topsoil thickness with the soil ECa measurements, and then can be used to employ a variable-rate N fertilizer. This approach for N management has been tested and found to be effective in many types of crop [10].

The traditional fertilizing recommendation that is used by the farmers in Malaysia for paddy cultivation will slightly causes many detrimental effects to the environment, soil properties, production efficiency and also to the crop itself. It is also increase the cost of production in terms of fertilizer use and represent 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 in paddy field to assist farmers and fertilizer provider to control and monitor the N requirement for best paddy management practices.

A study was conducted by previous researcher in Mississippi Delta where there were many variation of soil texture within a field with different rates of N restrain in during crop rotations. A soil EC map was used to define the area of different soil texture and eventually the N recommendation for the area was produced. Both low and high ECa soil received the planned N rates and the result shows that the cotton in both field grows in ideal height for its stage with profit to the growers and reducing in N application and damage to the crop. The other nutrient contents such phosphorus (P) and potassium (K) was not considered in this study [11].

MATERIALS AND METHODS

Site Description

The research 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 authority. It is in the district of Kuala Selangor and Sabak Bernam at latitude 3°35"N and longitude 101°05"E which covers 2300 ha. of paddy granary area. It is divided into 24 blocks namely Blocks A to X and Block C was chosen as the study area. The selected area comprised of 118 lots of paddy field with an average lot size of 1.2ha or less (Figure 1). The lots in Block C were used as experimental area in terms to analyze the significant of soil ECa to the total nitrogen (TN) content and to compare the actual TN to the predicted TN obtained from the developed system in the specific area.

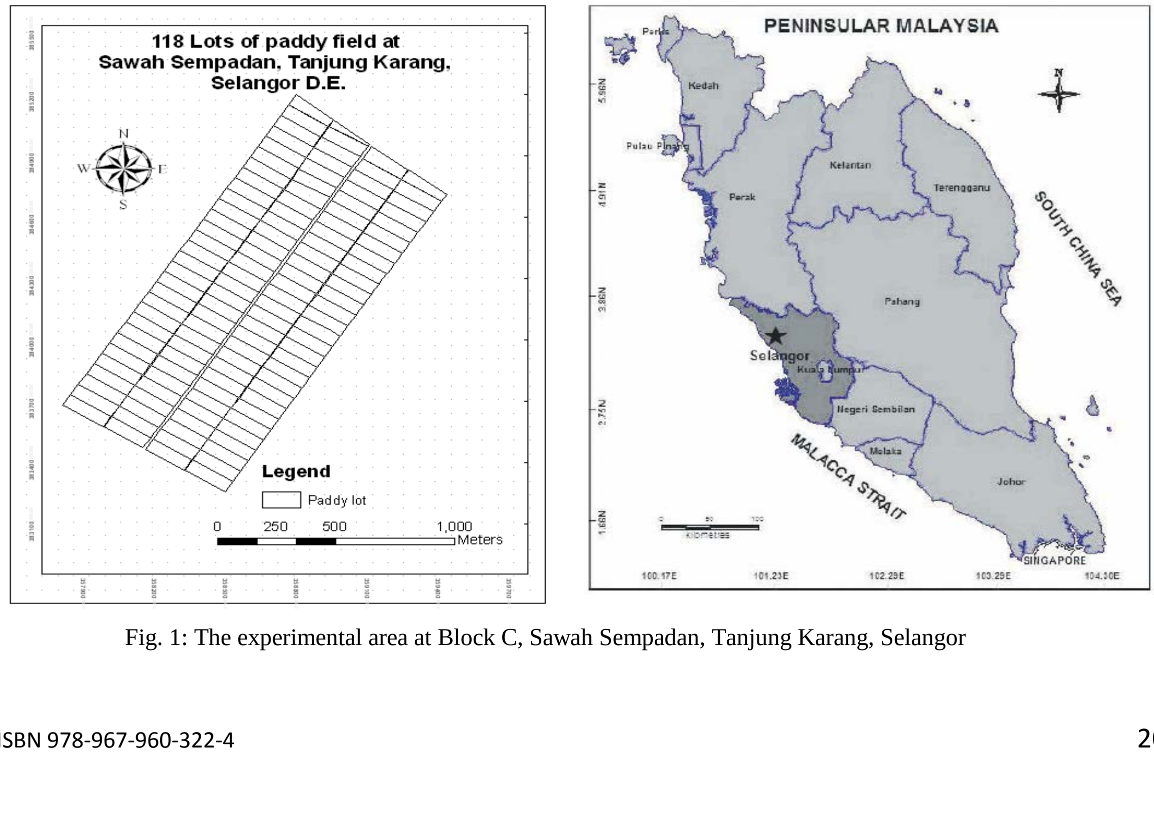


Fig. 1: The experimental area at Block C, Sawah Sempadan, Tanjung Karang, Selangor

Soil ECa Measurement

The ECa data was measured by using Veris 3100 soil electrical conductivity sensor (Figure 2). The sensor integrated with DGPS was pulled across each lot behind a tractor within an area of 60 m width and 200 m length. The sensor has three pair of coulter-electrodes to determine soil ECa. 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 center pair, situate closest to the emitting (reference) coulter-electrodes, integrate resistance between depth of 0 to 30 cm (ECas), while the outside pair integrate between 0 to 90 cm (ECad). Output from the data logger reflected the conversion of resistance to conductivity (1/resistance = conductivity). A Differential Global Positioning System (DGPS) Trimble AgGPS132 with sub-meter accuracy was used to geo-reference ECa measurements. This differential correction process was done automatically on real time basis by using the OmniSTAR DGPS System. The soil ECa data obtained from the sensor was used to generate the variability map using ArcGIS 9.2. The classification technique of manual, which was introduced by ArcGIS software, was selected to visual variability as groups. The manual classes is 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 [12]. 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 because since the technique has been recommended by many for its interpolation.

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

Soil Sampling

The soil sampling was carried out in the experimental lot at Block C by using Eijkelkamp soil auger. A sample in each lot was taken within a depth of 30 cm. The total of 118 samples then were brought to the laboratory to analyze total nitrogen (TN) content in the respective lot using the Kjeldahl digestion technique [13]. The TN was measured in order to compare the actual TN to the predicted TN derived from the developed system in a map based.

Reference Model

The system was developed based on the TN model that derived from the previous study [14]. The soil ECa was identified to be reliable to measure TN content at the study site for both dry and wet season. The statistical analysis shows that soil ECa was significantly related to nitrogen content at 0.05 level. The TN model based on soil ECa data was described as follow:

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

Program Development

The program of this system was developed by using MATLAB 7.4.0 software. The system was designed to produce TN content map during on-the-go measurement of soil ECa. The program was developed to be used as a window based system for plotting TN map in real time basis and display on the screen of a robust computer system mounted in the vehicle cab with TN data points plotted according to the coordinates retrieved from Differential Global Positioning System (DGPS). The program was facilitated with interpolation function to generate the variability map based on the plotting data that obtained from the ECa sensor. The interpolation function in this system has been separated into three methods. It is including the 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 with interactive tools for user to access as shown in Figure 3. It is a simple system with many selections of panels that is easy-to-use and understands the whole system. The management process for data loading and data acquiring is also really easy and straightforward where the user only has to ensure where the data are located and the devices to be used are properly connected.

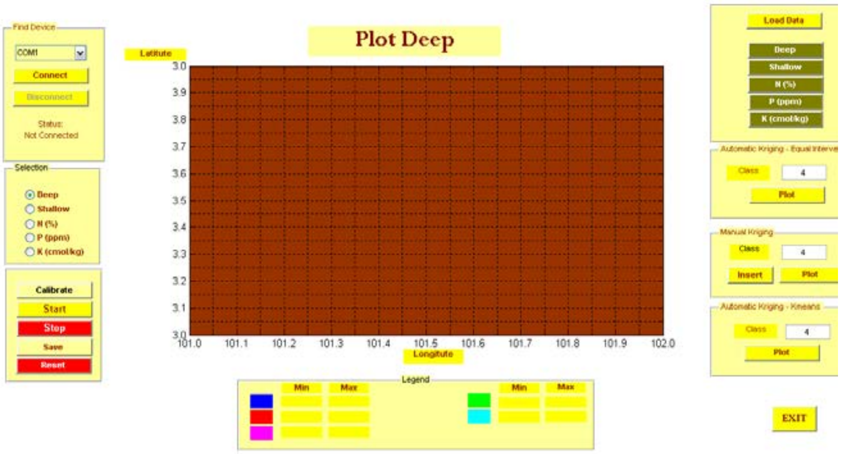


Fig. 3: Graphical User Interface (GUI) of the developed program

System Set-up

The developed system consist of various devices such DGPS, ECa sensor, a robust computer, a software and a tractor that integrated as a system to provide a necessary information as shown in Figure 4. The DGPS 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 DGPS and ECa sensor. The data obtained from DGPS and ECa sensor 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.

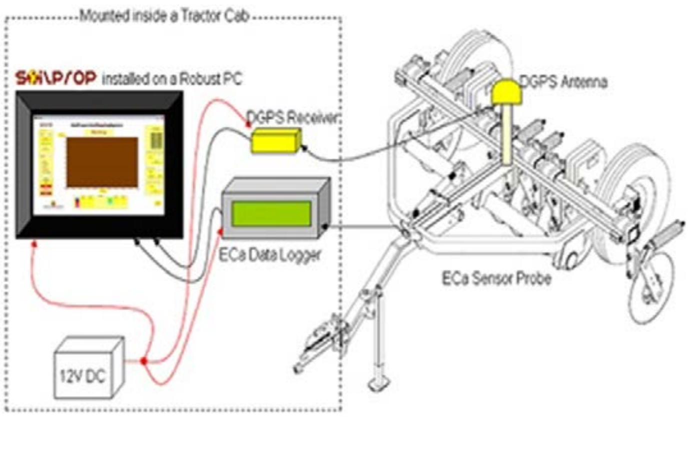


Fig. 4: The diagram of the developed system which comprising of various devices

RESULTS AND DISCUSSION

Soil Electrical Conductivity (ECa) Measurement

The ECa measurements were integrated over a soil depth of 0 to 30 cm for ECas and 0 to 90cm for ECad. The total number of ECa data was found to be 79,988 for all 118 lots of study area. The number of data depended on the speed of the tractor and the condition of the soil surface. With the logging interval of one second, a slow drive can collect more data points [15]. The descriptive statistic of soil ECa is shown in Table 2. The values of ECas were found to be 4.80, 223.00 and 30.16 mS/m for minimum, maximum and mean value, respectively. The value of ECad was slightly higher compare to ECas value. It was found to be 18.90, 248.40 and 77.35 mS/m for minimum, maximum and mean value, respectively. The coefficient of variation (CV) for ECas and ECad were 42.18 % and 37.76 %, respectively. This means ECas reading is more varies than ECad and this circumstance may be due to the intensive activities at the surface layer. The variability of ECad may caused by the difference of soil textures on the surface layer to the depth of 90 cm [5].

Table 2: Descriptive statistics for ECas and ECad in the experimental area

	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

Total Nitrogen (TN) Content

The descriptive statistics of predicted and actual TN content is shown in Table 3. The predicted TN was measured by the developed system and the number of data was obtained from the ECa sensor. The developed system was tested on field during soil sampling task was carried out. The values of the predicted TN were found to be 0.15, 0.72 and 0.2841 % 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 was predicted a heterogeneous nitrogen content in the study area. The actual TN content was also measured for comparison purpose. The number of data for actual TN content was found to be 118 as shown in Table 3. The number of data was smaller compared to the data from predicted TN because it was based on the sampling points that collected in each lot of the experimental area. The values of actual TN content were found to be 0.10, 0.66 and 0.393 % for minimum, maximum and mean value, respectively. The C.V. for actual TN content was 34.86 % in the entire experimental area. The higher value of C.V. show that the actual TN content is more varies than predicted TN content. It can be explained that a numbers of data set will influenced to the hypothesis.

Table 3: Descriptive statistics for predicted and actual nitrogen contents in the experimental area.

	Predicted TN	**Actual TN**
Number of Data	79988	118
Min	0.15	0.10
Max	0.72	0.66
Mean	0.2841	0.393
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

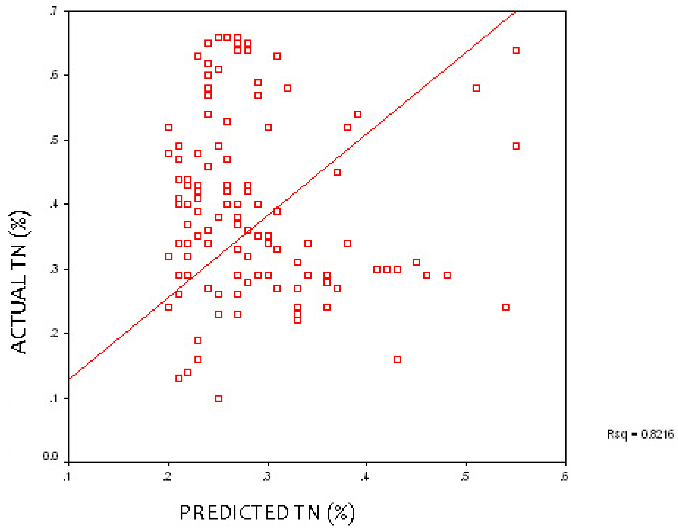
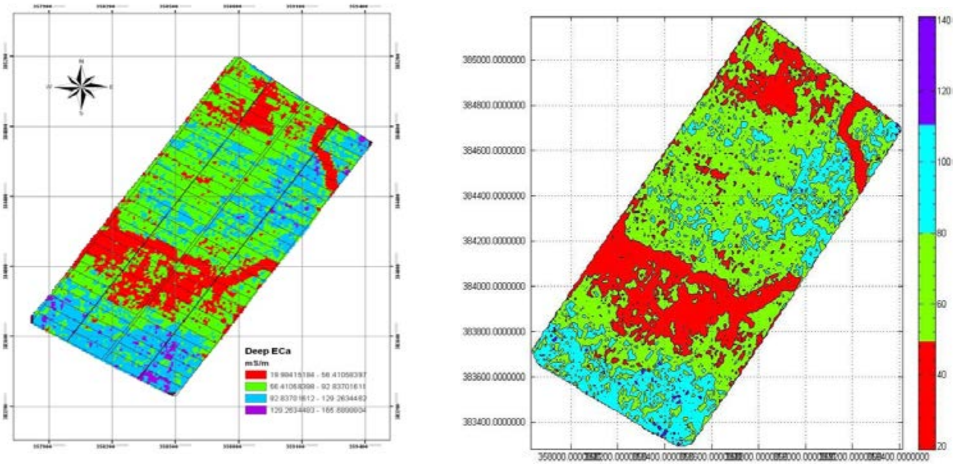


Fig. 5: Least square linear line of actual TN versus predicted TN in the study area

To be fair with the data, the predicted data again was analyzed by averaging all the samples for each paddy lots. The average predicted TN data in 118 paddy lots was used to get a linear line with actual TN data as shown in Figure 5. The coefficient of determination (R^2), indicates a significant relationship between actual TN and predicted TN with R^2=0.8216***.

Spatial Distribution Map

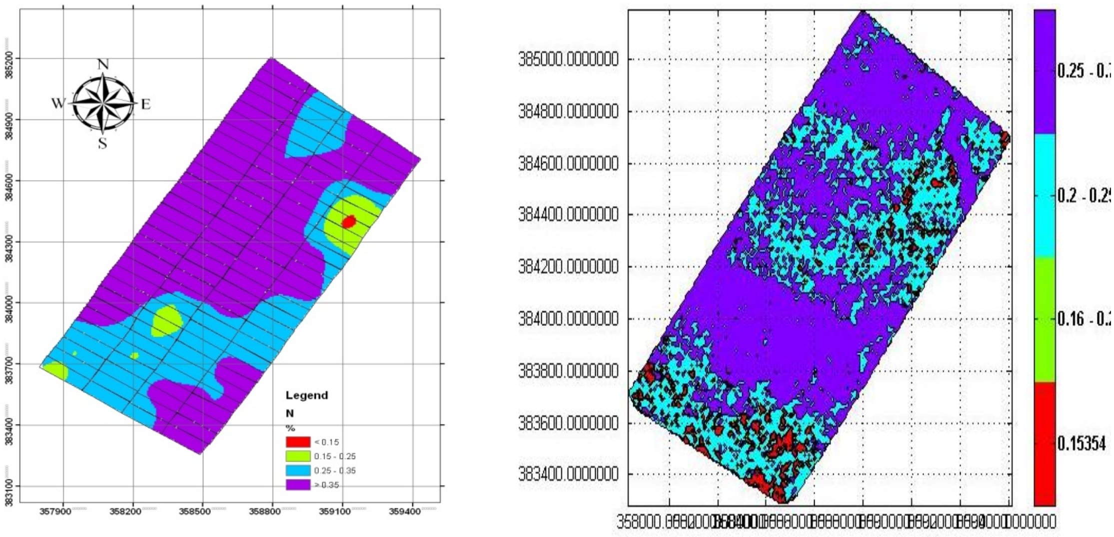
The classification approach using raster calculator, which was available in the spatial analyst for calculating the variables reading and calculated maps was produced. The maps produced via ArcGIS software were used to compare the spatial distribution to the map that produced from the developed system. This study decided to zone the area into 4 zones (respectively for ECa reading and nitrogen content) which could be manageable and also easy to compare. They were very low, low, moderate and high for first, second, third and forth zone, respectively. 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 6(a), the kriging map produced via ArcGIS software was similar to the map that produced by the developed system in Figure 6(b). The areas in the maps were mostly occupied by the low soil ECad. The moderate ECad seemed to be concentrated in the south and was scattered in the middle part of the experimental area. Furthermore, the highest ECad zone was almost not appeared in the variability maps. The similarity between both maps in Figure 6 shows that the developed system was promising to produce an accurate soil ECa map and reliable to define the ECa zones rapidly.



(a) *(b)*

Fig. 6: Kriging map of soil ECad produced from ArcGIS 9.2 (a) and from the developed system (b) for 118 lots of the study are

Yet, the developed system was not produced an accurate TN variability map as soil ECa map. The variation of the map is slightly different compare to the map that produced via ArcGIS as shown in Figure 7. The actual TN variability map produced by ArcGIS was performed based on 118 data which collected from soil sampling task. While the predicted map that produced by the developed system was based on the data that obtained from the soil ECa sensor which found to be 79988 numbers of data. Thus, the different of the variability map may caused by the number of variables that used for map generation. Nevertheless, the TN maps produced from both sources shown that the TN contents were higher in most part of study area. The predicted map in Figure 7(b) shows that the moderate TN was occupied on center and lower region of the study area. The actual TN map in Figure 7(a) obviously show that the TN was heterogeneous and some of the area was 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 developed system represent that the system was reliable to be used as a decision support system for N fertilizer management for site specific. The system was suggested for optimum N fertilizer application in the right place with the right amount through the variability map. The rapid information on soil fertility was valuable to practice precision farming.



(a) *(b)*

Fig. 7: Variability maps of actual TN contents (a) and predicted TN contents (b) for 118 lots at the study area

CONCLUSION

The result of this study showed that the variable rate technology for nitrogen fertilizer application is possible to be developed by using an on-the-go ECa data. This system can produce rapid and precise information on soil nitrogen content at the site specific area for paddy field. The variability map derived by using this system was reliable to be used for best paddy management practices and indirectly will promote the precision farming concept to be adopted in paddy industry.

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