Automatic Leaf Color Level Determination for Need Based Fertilizer using Fuzzy Logic on Mobile Application

A Model for Soybean Leaves

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***Abstract*— Detecting plant nutrient deficiencies and evaluating fertilizer program are done by leaf tissue analysis. Unfortunately, this quantitative method is quite expensive and time consuming for traditional farmers due to its laboratory procedure. In this research, an automatic and non-destructive method based on digital image for soybean leaf color level determination was developed. Color level status is used to determine the fertilizer dose based on crops current need. The color level was adopted from 4-panel Leaf Color Chart (LCC) and a fuzzy logic model was applied to capture the leaf color gradation. Therefore, the leaf color status is not restricted only in 4 categories, but gradually change from light yellow up to dark green. Using this mechanism the N fertilizer dose will also gradually adjust. Hence, the N fertilizer could be used efficiently and in the same time prevent the environment from negative effects of fertilizer overuse. The method was embedded in a mobile application to facilitate real time field application. Hence, detection of soybean nutrient deficiencies and fertilizer program evaluation will need less time and low cost. From the field test, it was known that the mobile application could determine the soybean color level correctly.**

Keywords—digital image; soybean; fuzzy logic; Leaf Color Chart (LCC); mobile application

I. INTRODUCTION

The maximization of plant nitrogen use efficiency (NUE) or fertilizer recovery in the crop production system has a direct impact on its productivity due to the increase of agronomic value of the fertilizer. Furthermore, optimization of fertilizer use will prevent the environment from damage because of nitrate leaching and nitrous oxide production [1-2]. Therefore, research on fertilizer recovery management is one of the important topics in agriculture. NUE maximization can be obtained by evaluating foliar nitrogen content of crops during growth. Hence, the fertilizer dosage could be determined precisely regarding the crop's condition.

The most common non-destructive methods to evaluate the foliar nitrogen content is using SPAD meter. This device is known quite accurately, unfortunately its price is quite expensive (around USD $2200) for traditional farmers. Moreover, it is known that SPAD meter not suitable for leaves of regenerated plants. Alternatively, farmers usually use the Leaf Color Chart (LCC) developed by the International Rice Research Institute (IRRI) to identify the color level and estimate the fertilizer dose [3-4]. Nevertheless, the subjectivity of the farmers in evaluating color and degeneration of the LCC color could decrease the accuracy in reading leaf color level. Thus, research on automatic facilities that could overcome such problem has been increasingly developed in information technology field. Regarding the fact that leaf color could represent the foliar nitrogen content, digital image analysis method was then proposed to evaluate the digital image of crops. Some research was done to demonstrate that color image analysis could provide fast and accurate estimation of foliar nitrogen content [5-8]. With the rapid growth of cell phones and tablets nowadays, those gadgets could be embedded with digital image analysis method and functioned as a calorimeter [9].

A mobile application called Baikhao was developed to automatically recommend amount of N fertilizer based on LCC recommendation system for rice [10]. So, Baikhao is a digital version of LCC recommendation system. Using Color Visibility (CV) index, Baikhao determine the color level of the rice leaf being estimate, which is level 1, 2, 3 and 4 and then relate it to the proper N fertilizer dose. But, in order to increase the maximization of NUE from manually LCC recommendation system, this method is still less efficient. Each color level will only relate to a certain dose of N fertilizer, that means only crop with foliar color exactly the same as one of the LCC's color level will get the most proper dose of N fertilizer. In fact, crops in the field will have foliar color in a huge variety ranging from color level 1 up to color level 4. Obviously, the four color levels used in Baikhao is too simple to represent those color gradation. Therefore, in this research a fuzzy logic model was proposed to create more accurate N fertilizer determination by altering the four color levels into a fuzzy membership function. Using such model each crop will get N fertilizer proportionally to its foliar color. Instead of rice leaf, object of this research is soybean leaf. Soybean color level determination model was developed in order to improve our previous mobile application called Mata Daun [11]. Product of this research was a higher version of Mata Daun.

II. LEAF COLOR CHART (LCC)

Leaf Color Chart is a simple tool used as an indicator for leaf color which is a proxy for its nitrogen content. First developed by Japanese researcher in 1987 and has been improved and modified until now. Numerous LCC units have been fabricated and distributed in Asia countries since 1990 [12]. The most widely used LCC was developed by IRRI in collaboration with the Philippine Rice Research Institute. Although LCC was first developed for rice evaluation, it is known that its color level was also suitable for other crops such as maize, wheat and sugarcane. Adjustment of the fertilizer dosage for each color level was then developed for each kind of crop. Some countries also perform such adjustment regarding their specific field condition. Fig. 1 is an example of IRRI 4-panel LCC which is distributed by the Nitrogen Parameters Company (www. nitrogenparameters. com) India. This kind of color chart was used in this research as a color level reference. The four color levels were implemented digitally in the mobile application.

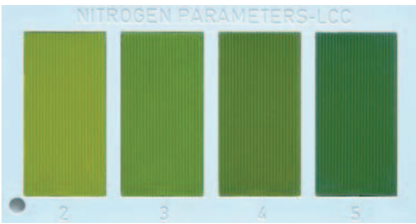

Figure 1. Example of a 4-panel LCC

III. METHODS

A. Hardware

This mobile application was installed on android smartphone Samsung Galaxy Ace 3 for field test. Samsung Galaxy Ace 3 specifications (related to this research) is as follow: (1) Camera resolution: 5 megapixels (2592 × 1944 pixels) with LED flash and autofocus support; (2) CPU speed: Dual-core, cortex-A9 1.0 GHz processor; (3) Operating system: android 4.2; (4) Memory: 4 GB internal and up to 64 GB MicroSD card; (5) Network: 3G HSDPA 900/2100; (6) GPS support.

B. Software

JAVA language was used to develop the mobile application. The application is compatible with Android mobile operating system up to version 4.3 (Jelly Bean). Input of the application is soybean leaf image which is taken in the field using white paper as the background. Fig. 2. depicts the image acquisition process.

Figure 2. Image acquisition process

Input image was then preprocessed in order to increase the measurement accuracy and decrease the processing time. After preprocessing, input image will be segmented to separate the soybean leaf from the (white paper) background. Pixels which is belonging to the soybean leaf, then processed by fuzzy logic inference algorithms to determine the color level. The fuzzy color level status was then used to adjust the N fertilizer dose recommendation. Hence, each crop being examined will get proportional N fertilizer ranging from the minimum until the maximum amount of the allowed N fertilizer dose. Fig. 3. depicts the application's flowchart.

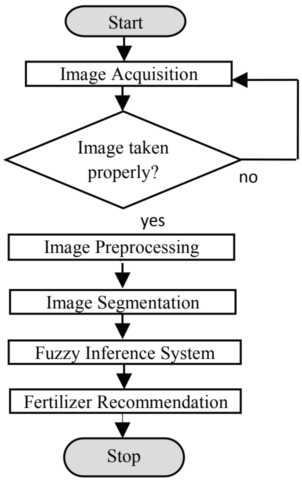

Figure 3. Application's flowchart

C. Image Preprocessing

Sunlight illumination fluctuation and object to camera distance was known to be the main problems due to field measurement. Therefore, comprehensive image normalization algorithm was embedded in the application to eliminate those problems. This algorithm was developed to remove image dependency on lighting geometry and illumination color [13]. It is consists of two major parts. First part normalizes the r,g,b pixels to remove the lighting geometry dependency and then continued to the second part which is normalize the r, g and b color channel to remove illuminant color dependency. Both parts are done iteratively until each normalization reaches a stable state. Only the first part of the algorithm was embedded in the mobile application due to assumption that in field measurement, lighting geometry dependency will be the only problem since sunlight is the only light source. Normalization of r,g,b pixels was done using (1).

$$\frac{r}{r+g+b}, \frac{g}{r+g+b}, \frac{b}{r+g+b} \tag{1}$$

In order to increase the processing speed, study on the image dimension was done. The aim is to acquire the minimum input image size with the best color level determination accuracy. As the result, input image size was determined to be 640 × 384 pixels. Using this size, the processing time was 4 times faster than the previous processing time using original input image size. Therefore, after preprocessing the illumination, the next step is resizing the input image into a smaller dimension..

D. Image Segmentation

The Otsu's method was embedded in the mobile application to obtain threshold value automatically [14]. Using that value, preprocessed input image will be segmented as object and background. Object pixels refer to soybean leaf and background pixels refer to white paper which is used as background during the image acquisition process (see Fig. 2). All object pixels then extracted and prepared to perform the fuzzy logic inference procedure.

E. Citrus Color Index (CCI)

All object pixels (in RGB format) should be transform to a certain value that could well represent the gradation color of the leaf. This step is important because not all colors in RGB space have significant contribution for leaf color level determination. It could be seen in Figure.1 that leaf color gradation has only ranged from light yellow to dark green. For this purpose CCI was chosen to summarize the object pixels. This index actually aimed to measure the degreening level of citrus [15]. Degreening is the process when green chlorophyll pigments in the peel are broken down and the yellow and orange xanthophyll and carotenoid pigments are formed. During this process fruits color will degrade from dark green to yellow. Instead of RGB, CCI uses Hunter L, a, b color space. Unlike the RGB and CMY color space which is ideally suited for hardware implementation [14], Hunter L, a, b color space designed to approximate human vision. Hence, this color space well suited for describing color (in term of human interpretation). The L component closely matches human perception of lightness, a component represents cyan color up to magenta/red color and the b component represents blue color up to yellow. The CCI value calculated using (2).

$$\mathrm{CCI} = \frac{1000.a}{L.b} \tag{2}$$

F. Fuzzy Logic Model

Two fuzzy variables were created in this research. One variable represent the CCI value was set to be an input and the other variable represent the fertilizer dose was set as an output. The CCI fuzzy variable was created by collecting CCI data from 120 samples of soybean leaf. This input variable was decomposed into 4 fuzzy sets, each fuzzy set represent the color level in LCC (see Fig. 1). For each fuzzy set, 30 soybean leaves were collected from the field. By performing statistical goodness of fit test, it was known that the distribution of CCI value extracted from those soybean leaves was close to a normal (or Gaussian) distribution. Figure 4 depicts the input variable membership functions. Panel 2, 3, 4 and 5 refer to each color level from 4-panel LCC in Fig. 1. The equations for each membership function are (3)-(6).

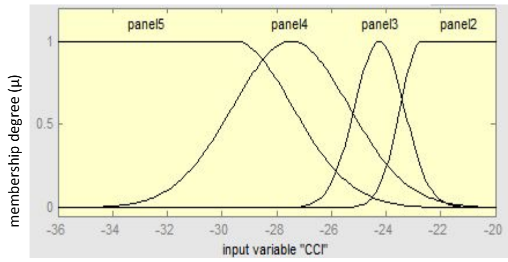

Figure 4. Membership function for input variable

$$\mu_{panel\,2}[x] = e^{\frac{-(x+22.706)^2}{2.0.764^2}} \tag{3}$$

$$\mu_{panel\,3}[x] = e^{\frac{-(x+24.242)^2}{2.0.903^2}} \tag{4}$$

$$\mu_{panel\,4}[x] = e^{\frac{-(x+27.474)^2}{2.2.131^2}} \tag{5}$$

$$\mu_{panel\,5}[x] = e^{\frac{-(x+29.540)^2}{2.2.125^2}} \tag{6}$$

Fuzzy singleton membership function was chosen as an output variable model. This model is considered suit to represent the fertilizer dose recommendation. As an example, suppose that fertilizer dose recommendation (in kg/ha) is determined in Table I. Then, the fuzzy membership functions for fertilizer are shown in Fig. 5- Fig. 8. This example was taken from fertilizer dose recommendation issued by Indonesia's Assessment Institute for Agricultural Technology for rice. The conversion of those values for soybean is being studied.

TABLE I. EXAMPLE OF FERTILIZER DOSAGE RECOMENDATION

Leaf Color Level	Expected Yield Increase			
	5 t/ha	*6 t/ha*	*7 t/ha*	*8 t/ha*
Between 2-3	75	100	125	150
Between 3-4	50	75	100	125
Between 4-5	0	0 or 50	50	50

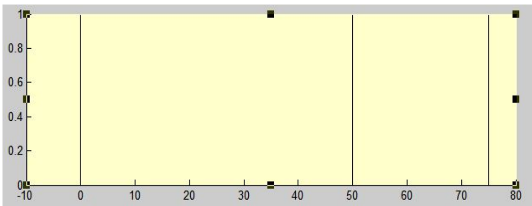

Figure 5. Membership function for output variable assume that expected yield increase is 5 t/ha

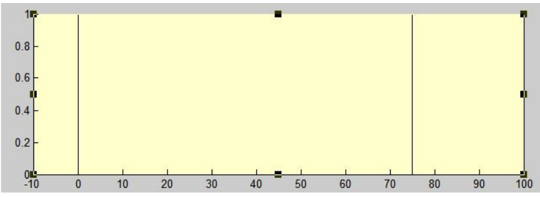

Figure 6. Membership function for output variable assume that expected yield increase is 6 t/ha

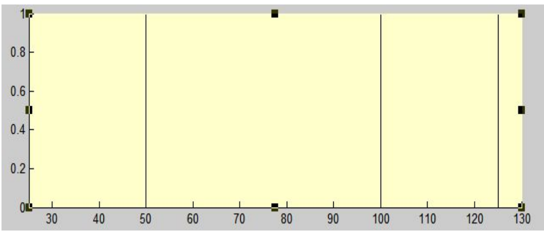

Figure 7. Membership function for output variable assume that expected yield increase is 7 t/ha

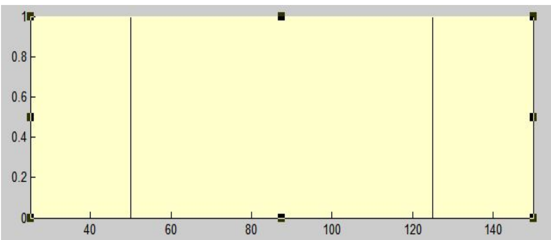

Figure 8. Membership function for output variable assume that expected yield increase is 8 t/ha

G. Fuzzy Logic Inference

Regarding the input and output variable that previously defined, Sugeno method was chosen as fuzzy inference algorithm. Here are examples of the rules:

IF CCI is Panel2 **THEN** Fertilizer_Dosage is 75
IF CCI is Panel3 **THEN** Fertilizer_Dosage is 75
IF CCI is Panel3 **THEN** Fertilizer_Dosage is 50
IF CCI is Panel4 **THEN** Fertilizer_Dosage is 50
IF CCI is Panel4 **THEN** Fertilizer_Dosage is 0
IF CCI is Panel5 **THEN** Fertilizer_Dosage is 0

Those rules are taken from the fuzzy inference process for fertilizer recommendation on 5 t/ha expected yield increase, the corresponding output variable membership function is depicted in Fig. 5. Suppose that a soybean leaf in Fig. 9 is being examined for fertilizer recommendation on 5 t/ha expected yield increase. Manual inspection of that leaf decides that its color level is between panel 2 and panel 3. From the mobile application the calculated CCI value is -23.4. Fig. 10 depicts the Sugeno fuzzy inference process for it.

Figure 9. Example of a soybean leaf

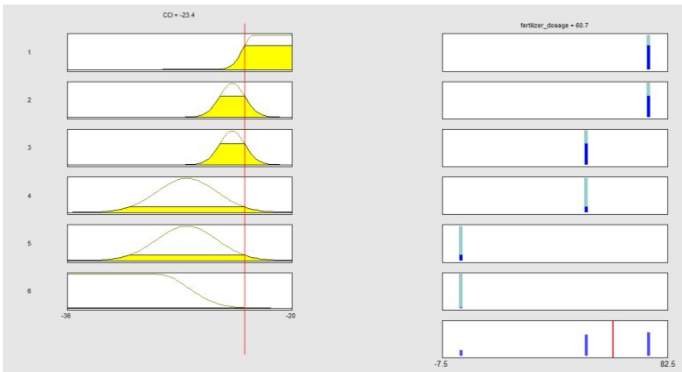

Figure 10. Illustration of Sugeno fuzzy inference process on soybean leaf in Fig. 9

It is seen in Fig. 10 that the CCI value strongly fall on panel 2 and panel 3 membership function. This result agrees with the previous manual inspection. With manual inspection the recommended fertilizer dose should be 75 kg/ha. By applying fuzzy inference methods the calculated fertilizer dose is 60.7 kg/ha. It is shown that using fuzzy inference method the fertilizer recommendation proportionally calculated regarding the CCI degree on panel 2 and panel 3 membership functions. So, the recommendation will not hardly restricted to just 3 values (in this example 0, 50, and 75 kg/ha) but varying between the minimum and maximum allowed fertilizer dose.

Therefore the fertilizer could be applied in a more accurate amount and finally lead to increase fertilizer use efficiency.

IV. RESULT AND DISCUSSION

A. *User Interface*

To fulfill ease of use requirement, the mobile application user interface was designed as depicted in Fig. 11. When the application is executed, user will see the splash screen (Fig. 11(a)) for about 3 second. Next, user will be directed to perform login or sign up process (Fig. 11(b)). After the login process success, user will see a main menu page (Fig. 11(c))..

Figure 11. Screenshot of the mobile application user interface (a) opening splash screen, (b) sign in and sign up page, (c) main menu page

The **see data** button is used to display the previous soybean leaf being examined, **profile** button is used to display user's personal data and **sign out** button is used to end current session. To begin the fertilizer recommendation session, user can tap the **start** button, the crops option will appear (Fig. 12(a)). There are 3 selectable crop categories, soybean (kedelai), rice (padi) and maize (jagung). Currently, the mobile application facilities for rice and maize is being developed. After the crops category is selected, the smartphone camera will automatically ready. Since the camera capture and save the target image, the result page will automatically appear (Fig. 12(b)). User could see fertilizer dose recommendation for all expected yield increase value and then by taping the **send** button, user could save the result in the database.

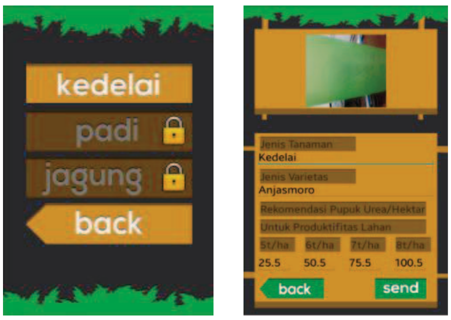

Figure 12. Another screenshot of the mobile application user interface (a) crop category option, (b) result page

B. *Field Test*

Ten soybean leaves with varying color was selected from the field to perform accuracy test on the mobile application. The accuracy test was conducted by comparing the result of manual inspection with the result of mobile application on the leaf color level determination. Table II. shows details of the test result. Manual inspection column contains the panelist's decision on leaf color level. "Between 4 and 5" for example, means that the panelist categorize the leaf color between LCC's panel 4 and panel 5. The CCI column contains the calculated CCI value for the leaf's digital image and the last column contains the list of corresponding fuzzy sets. For example, "4 and 5" means that the CCI value falls on two fuzzy sets which are panel4 set and panel5 set. It was shown that the mobile application determination on soybean leaf color level strongly agree with the manual inspection. A little inaccuracy occurs on sample number 7, 8 and 10. The corresponding fuzzy sets includes panel2 which is not mentioned by the panelist. Regardless, the membership degree of the three samples CCI value on panel2 set is extremely low, indicating that the mobile application still strongly agrees that the color level of those samples are between 3 and 4. Hence, it could be concluded that the mobile application accuracy of soybean leaf color level determination reach 100%.

TABLE II. FIELD TEST RESULT

Sample	*Manual Inspection*	*Mobile Application*	
		CCI	*Corresponding Fuzzy Set*
1	Between 4 and 5	-26.65	4 and 5
2	2	-21.54	2
3	2	-20.97	2
4	Between 4 and 5	-26.78	4 and 5
5	Between 4 and 5	-26.76	4 and 5
6	Between 3 and 4	-24.55	3 and 4
7	Between 3 and 4	-24.02	2,3 and 4
8	Between 3 and 4	-24.32	2,3 and 4
9	Between 3 and 4	-24.55	3 and 4
10	Between 3 and 4	-24.21	2,3 and 4
Accuracy : 100% correct			

Other than using the panelist to verify the color level determination, SPAD meter was also used to verify the consistency of CCI value. Using the CCI data shown in Table II., Fig. 13 depict the regression line between those CCI values obtained from the mobile application and chlorophyll content obtained from SPAD meter. From the regression, it was known that the coefficient of determination (R2) is 94.7% which means the correlation coefficient is 0.97. This coefficient confirms that the CCI value strongly correlated (negatively) with chlorophyll content. The lower the CCI value, the higher the chlorophyll content. The lowest CCI value refers to dark green color, whereas the highest chlorophyll content refers to dark green leaf.

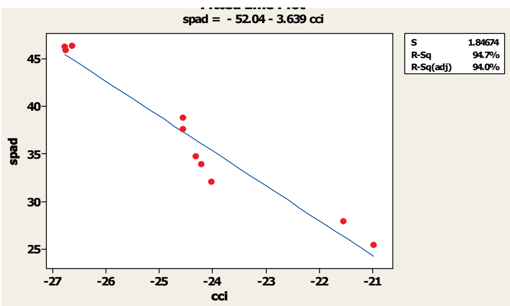

Figure 13. Regression line between CCI value and chlorophyll content

V. CONCLUSION

Using the improved version of Mata Daun mobile application, soybean leaf color level could be determined automatically such that the fertilizer dose could be objectively decide. This research also shows that by applying fuzzy logic inference, fertilizer dose recommendation could be given gradually, proportional to the color level gradation. Unlike previous methods that only able to give discrete fertilizer dose recommendations, by applying Sugeno method the fertilizer dose recommendation vary continuously from minimum up to the maximum allowed dose. From the field experiment, the algorithm used shows promising result with 100% accuracy on leaf color level determination.

VI. FUTURE WORK

Presently, there is no official conversion from rice to soybean fertilizer dose recommendation using LCC. Such conversion has been made for maize [16]. Regarding the conversion method used for maize, a research to obtain conversion for soybean was initially begun. The experimental procedure was being studied and field test was being prepared. Result of this experiment will be used to update the output variable membership function of the fuzzy inference system.

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