Application of Simple Multispectral Image Sensor and Artificial Intelligence for Predicting of Drought Tolerant Variety of Soybean

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Abstract

Environmental stress such as drought is a limiting factor of the soybean production in Indonesia. The varieties of drought-tolerant soybean become necessary to be cultivated especially in a marginal farmland. The characteristics of these varieties can be identified from the morphology of plants and the content of chlorophylls. Conventional techniques for predicting the variety of drought tolerant are usually labor extensive, time consuming and costly. A simple and rapid method that based on an automatic system to provide predictions on the variety of drought tolerant soybean is proposed in this paper. The method uses a simple multispectral sensor from a web camera that captures physical and physiological characteristics such as leaf areas, plant heights and is also able to calculate the content of chlorophylls. This research also compared fuzzy logic and artificial neural network as artificial intelligence methods to process raw data in order to predict the variety of the drought resistance soybean. The drought tolerant variety can be best predicted by artificial neural network method with an accuracy of about 80 %.

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Keywords: Artificial intelligence; chlorophylls; drought tolerant; multispectral sensor; simple and rapid method.

Nomenclature

NDVI	normalized difference vegetation index
NIR	near infrared channel of image
RED	red channel of image
SPAD	soil plant analysis development
DAP	days after planting

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1. Introduction

Soybean or *Glycine max* (L.) Merrill is one of the biggest sources of *phyto* proteins among other plants. Diverse variety of processed soybean such as tempeh and tofu has become a regular diet consumed by many Indonesian people. Although widely consumed by the public, the soybean production in Indonesia tends to decline. To fulfill Indonesian soybean demand, government imported soybean from United States of America and Brazil. Some expert said that the Indonesian food security is threatened by high dependences on imported soybeans, which reached out to 70 %. The environmental stress such as drought is one of major limiting factors for the soybean production in Indonesia. Suhartini[1] revealed that during the dry season, soybeans pod filling period is getting shorter followed by faster maturity, as well as the leaves fall earlier that can affect the metabolism of plants. Therefore, drought can cut the production by 40 % or more. In the face of declining soybeans production in the dry season, it needs drought tolerant soybeans seeds, which can maintain soybeans production although suffered from environmental stress triggered by drought. The green color of chlorophyll leaves is one of the plant physiological parameters to identify drought tolerant crops[2]. In addition to chlorophyll content, plant morphology such as plant height and leaf areas also can be used to identify drought tolerant plants[2]. To obtain drought-tolerant soybeans seeds it needs studies involving the measurement of plant data, such as measurements of leaf areas and chlorophylls contents. Usually to obtain these data, one uses wet chemical laboratory methods such as spectrophotometric methods that labour extensive, time consume and costly. Thus, other methods are needed as an alternative to a chemical test that does not take a lot of time and easy to build.

Chlorophyll is one of the main parameters to identify drought tolerant properties of the plants and also give green color for plant leaves. According to Marcelinus[3], green color of the plant leaves image is closely related to its chlorophyll content. Soybeans responses to drought are reflected by the content of chlorophylls in the leaves as it is shown by the degradation level of the green color. In addition , the soybean morphology such as plant height and leaf area is also commonly used as main parameters to identify drought tolerant properties of the plants. Rapidly evolving computer technology can be an efficient solution in the search for drought tolerant soybean seeds[4]. Method of computer technology in the field of digital image can be used to process the color and morphology of soybean plants to be represented into form of numerical data. While, computer technology in the field of artificial intelligence is able to predict drought-tolerant trait in soybeans. Reasons for using the artificial intelligence to predict drought-tolerant soybean varieties reside in there is no fixed numerical representations for the drought tolerant index by using chloropyll content as an drought-tolerant characteristics.

One of the artificial intelligence methods is the fuzzy logic, which can be used to determining the seeds of drought-tolerant soybean plants. Fuzzy logic is one of artificial intelligence methods that can give a prediction. Another method is the artificial neural network. The neural network is an artificial intelligence system that is used to classify or predict from the given data sets. Neural network is working as neural networks in humans consisting of nodes. Each node has a certain value weights that are processed with certain mathematical formulas to produce a classification or prediction of a numerical data[5]. Neural networks does not require drought index as an input because neural network is able to predict without specific provisions. Requirement in neural networks train only the datasets that is processed by a particular statistical method that is able to distinguish drought-tolerant soybean varieties. Input for neural networks in this application were formed from three kinds of input as the degree of membership of the value of NDVI (Normalized Difference Vegetation Index), plant height, and leaf area and also a numerical value output that represented the degree of drought-tolerant soybean varieities.

2. Materials and methods

2.1. Multispectral image processing for chlorophyll and leaf area quantification

Multispectral imaging is one type of digital image processing that involve not only visible spectrum but also other spectrum such as ultraviolet and infrared spectrum. Multispectral imaging is not only can quantify leaf area of plants and chlorophyll content but also other parts of the plant, such as stems and pods. A custom low-cost desktop software and image acquisition facility that automatically analyze multispectral images of object plants also has been made in this research. Soybean plants image acquired inside the multispectral image acquisition box facility. A

Logitech C270 web camera was used at the top of the box for capturing visible image and near infrared filter (Hoya, Japan) was used for capturing near infrared image. Visible and infrared image processed using the formula NDVI (Normalized Difference Vegetation Index) to get the value of NDVI. NDVI is an index to represent the plant's photosynthesis ability and essential for monitoring plant growth[6]. The formula for calculating the index NDVI shown in Equation 1. Graphical User Interface (GUI) for Multispectral Image Acquisition is shown in Fig. 1.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

The NDVI image was then segmented using Otsu algorithm for separating the object with the background automatically. After that the process continues with erosion threshold operation. Erosion threshold was the image processing methods that used to shrink the area of the object so that it could remove noise (confounding objects) which interfere with the desired object. After erosion threshold process continues with dilation operation. Dilation was a method to grow or thicken object area. The last stage was cropping operation to eliminate confounding objects that cannot be removed by erosion and dilation operation. The process of cropping was done by cutting (changing the object color from white to black) in certain parts of the drawing area. The next stage was leaf area quantification. One pixel in the image represented 0.25 cm^2 (0.25×10^{-4} m^2) of the actual size. The object that was used as a comparison was a meter ribbon. Leaf area were calculated with automation systems that were tested for accuracy by comparing the results of predicted leaf area with the manual colored leaves.

Fig. 1. Graphical User Interface (GUI) for Multispectral Image Acquisition

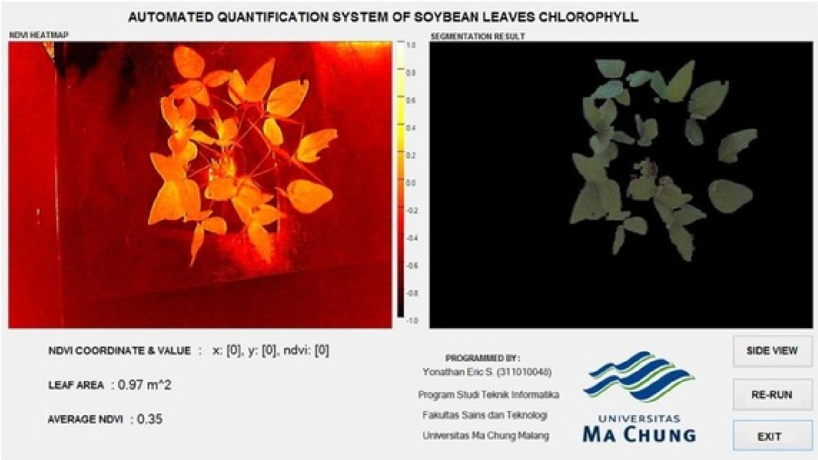

Fig. 1. (Continued) Graphical User Interface (GUI) for Multispectral Image Acquisition

2.2. Fuzzy logic

Fuzzy logic is one of artificial intelligence method that commonly used. Fuzzy logic works based on the degree of membership, so the answers are not always "black" and "white", a degree of membership became a new way of solving the problems[7]. Some components in fuzzy logic are fuzzy variable, fuzzy sets and membership function. Fuzzy variables are variables to be determined, whether the variables including black or white or in between. A fuzzy set is a set whose elements have degrees of membership. A element of a fuzzy set can be full member (100 % membership) or a partial member (between 0 % and 100 % membership). Membership function is the mathematical function which defines the degree of an element's membership in a fuzzy set. Fuzzy association class is a category of a fuzzy variable that is being observed. Fuzzy association can be divided into two kinds, which is the set of fuzzy linguistic and numerical. Fuzzy logic concept that used in this study was fuzzy database. Fuzzy database works by operating the resulting degree of membership of every fuzzy set that is the basis of Zadeh operators to produce fire strength. All fire strength resulting from the existing fuzzy rule will be compared and searched the greatest value. Input to fuzzy logic was the value of NDVI, plant height and leaf area. So, there were three kinds of fuzzy variables that is NDVI, plant height and leaf area.

2.3. Neural networks

Artificial neural network is one of the methods in artificial intelligence that works the same as the nerves in living things. Like nerves, the general structure of neural networks composed of nodes that are connected to the connecting elements[5]. Each connecting element has a weight which is mixed with certain mathematical functions to generate predictions. Neural network algorithm that was used in this research was the back propagation which was included in the supervised learning and had a target output. To produce the desirable output, targeted training was needed on artificial neural network structure. Training was based on the derivative function that is used to change the weight gradient (weight) and the activation function[8]. This training was useful to minimize the errors that was produced by the neural network structure in each iteration. The error in this system was how to deviate the output of neural network at desired output targets. The back propagation algorithm had several processes such as initialization, forward pass, and backward pass. Once the backward pass process was completed, a feed-forward process would follow with a calculation of the error rate. If the error rate has been less the same with the limits, that means artificial neural network architectures do not need to be retrained and is ready to be used with test data. To process the test data, artificial neural network architecture with one feed-forward process was used. Neural networks system that used in this research had the same input to the fuzzy logic. So there were three nodes for the input, which were NDVI index, plant height, and leaf areas. A number of hidden layers and nodes in each hidden layer had not been determined because it required experiments to find the hidden layer architecture were able to provide optimal results. the output layer had three nodes.

2.4. Drought tolerant

Drought-tolerant is one of the properties of plant seeds where plants can grow and develop properly in conditions of water shortage, not all plants have this trait. There are many characteristics that can be used to determine whether drought-tolerant plants have properties or not. One of the characteristics is the nitrogen and chlorophyll content in the leaf[2]. The green color of leaves comes from chlorophyll, and nitrogen is one of the chlorophyll constituent that hold an important role in plant metabolism[9]. If the nitrogen content in the plant is reduced then, the content of chlorophyll in the plant will also decreased and for long term, the color of plant leaves could be turn to yellowish color. Drought-tolerant plants are able to survive with water shortage conditions and the color of the leaves remain green. Drought tolerant can also be identified through the physical condition of the plant. Examples of the physical condition of the plant are the number of leaves and the plant height[2]. The number of leaves can then be expressed in a value of leaf area. Leaf area value is directly proportional to the number of leaves. The high number of leaf area in drought conditions indicates that these plants have drought tolerant properties. Equal to the number of leaves, plant height also shown similar trend to the plant under drought conditions, also indicates that these plants have drought tolerant properties.

2.5. Data collection

Three soybean varieties were used in order to develop the fuzzy logic and artificial neural network model. Anjasmoro, Grobogan, and Wilis were chosen to represent different drought tolerant characteristics. Wilis variety was representing soybean plants that have drought tolerant, Anjasmoro variety was representing soybean plants that have not drought tolerant characteristics[11] as well as Grobogan variety[12]. The soybean plant seeds were sown on 10 kg plastic bag (polybag) size, each with 10 kg soil substrate and positioned on rain-out shelter. Water was provided manually using measuring cup according to field capacity treatment (100 % of field capacity is equal to 2.4 L water for each plastic bag). There were total 90 samples of soybean plants, and 30 samples for each variety. Drought treatments were started on 41 days after planting during early generative stage which is done by discontinued the water supply. Data was taken twice: at 41 DAP (Days After Planting) and 51 DAP. The 41 DAP data used as initial analysis and 51 DAP data used for prediction analysis of drought tolerant variety after drought treatment. The collection of NDVI value, leaf area and plant height was done by multispectral image acquisition facility as shown in Fig. 2. Overall quantitative data from sample plant then used as training data to create a prediction model.

2.6. System design

The system was consists of two main part. The first one is the image acquisition hardware and the second one is the drought tolerant variety prediction software. The hardware will capture plant image, hereafter the software will automatically quantify the NDVI value, leaf area and plant height. Those quantitative value then used as input for fuzzy logic and artificial neural network model (which formerly developed using training data) to provide the prediction of drought tolerant variety. Hence, the final output is the prediction whether or not the plant being analysed having the drought tolerant characteristics.

3. Result and discussion

3.1. Chlorophyll and leaf area quantification by multispectral imaging method

The comparison between predicted and measured leaf area shows that the difference is moderately low (18.04 %). Comparison table between predicted and measured leaf area can be seen in Table 1. Using t-paired statistical test (Fig. 3) it is proven that the difference is not significant (p-value greater than 0.05). It means the software could provide accurate prediction of leaf area value. After leaf area measurement process continues to quantification of the average NDVI values, which compared its accuracy with Konica Minolta SPAD-502 chlorophyll meter. SPAD-502 chlorophyll meter value has strong relationship with total chlorophyll concentration on the plant leaves. The method was to mark one of the leaves with a paper sticker as reference point for SPAD and NDVI value measurement. The result of SPAD measurement was then compared with the results of the NDVI at the marked point. The result of the calculation is then displayed in the form of correlation and regression. The results showed a correlation p-value of 0, and the correlation value of 0.837. Regression showed a good value with r-square of 0.70. Regression results can be seen in Fig. 4. It can be concluded that the value of NDVI values in line with the SPAD value, not by the variation of the data. For leaves colored dark green that has a high SPAD values, can also be predicted to have a high NDVI value anyway. Vice versa, when the leaves turn yellow and SPAD value is low, predictable NDVI values are low as well.

a b c

Fig 2. (a) Inside area of image acquisition box; (b) outside area of image acquisition box; (c) soybean plant inside image acquisition box.

Table 1. Comparison between predicted and measured soybean leaf area

Image ID	Predicted leaf area (m^2)	Measured leaf area (m^2)	Difference (m^2)	Different percentage (%)
1	0.8	0.81	0.01	1.23
2	0.02	0	0.02	1.00
3	0.09	0.11	0.02	18.18
4	0.64	0.78	0.14	17.95
5	0.19	0.19	0	0.00
6	0.13	0.15	0.02	13.33
7	0.74	0.66	0.08	12.12
8	0.75	0.75	0	0.00
9	1.12	0.86	0.26	30.23
10	0.73	0.5	0.23	46.00
11	0.53	0.49	0.04	8.16
12	0.45	0.34	0.11	32.35
13	0.28	0.21	0.07	33.33
14	0.65	0.52	0.13	25.00
15	0.43	0.33	0.1	30.30
16	1.32	1.12	0.2	17.86
17	0.82	0.86	0.04	4.65
18	1.03	1.23	0.2	16.26
19	0.62	1.04	0.42	40.38
20	0.49	0.56	0.07	12.50
		Mean		18.04

```
Paired T-Test and CI: Predicted, Measured

Paired T for Predicted - Measured

N          Mean      StDev     SE Mean
Predicted   20  0.591500  0.346445  0.077467
Measured    20  0.575500  0.353932  0.079142
Difference  20  0.016000  0.154081  0.034454

95% CI for mean difference: (-0.056112, 0.088112)
T-Test of mean difference = 0 (vs not = 0): T-Value = 0.46    P-Value = 0.648
```

Fig. 3. Paired t-test result for predicted and measured leaf area value

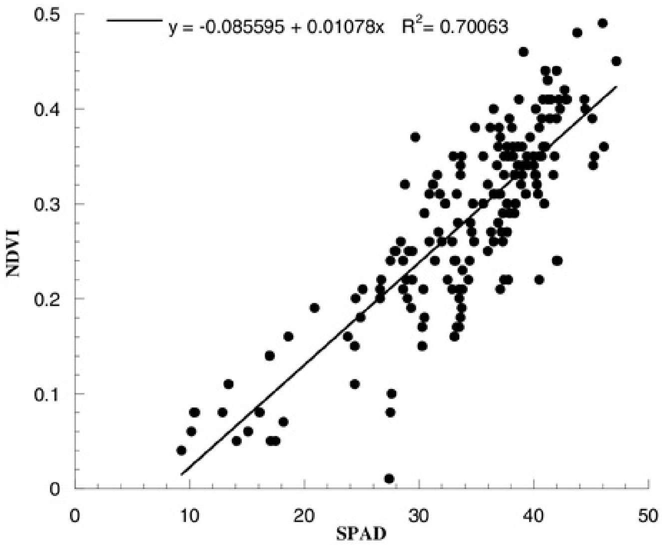

Fig. 4. Scatterplot diagram between NDVI and SPAD value

3.2. Fuzzy logic test results

The experiment using fuzzy logic algorithm was conducted twice using two different data test. First data set was retrieved from the multispectral soybean image at 41 days after planting (DAP) and the second was the multispectral soybean image at 51 DAP. In each test, the data set used was image of the soybean plants that treated by drought treatment 100 % that also used as control treatment. The result of experiment is shown in Table 2 for the result of experiments using data test at 41 DAP and Table 3 for the result of experiments using data test at 51 DAP. Comparison of the results derived from the three basic operators of Zadeh value for each rule, for TT (A) means that the basic results of Zadeh operators derived from the rule that represents the characteristics of soybean plants that are not drought tolerant, TT (G) means that the basic results of Zadeh operators derived from the rule that represents the characteristics of soybean plants that are not drought tolerant and for T (W) means the basic operators of Zadeh results derived from the rule that represents the characteristics of drought-tolerant soybean plants. Successful rate of Fuzzy Logic algorithm to predict drought-tolerant soybean variety was very low, only 40 % for 41 DAP dataset and 46 % for 51 DAP dataset.

Table 2. Fuzzy Logic Test Result for 41 DAP Dataset

Samples	Firestrength			Detected
	TT (A)	TT (G)	T (W)	
Anjasmoro 1	0	0	0	x
Anjasmoro 2	0	0	0	x
Anjasmoro 3	0.6	0.004	0.14	√
Anjasmoro 4	0	0	0	x
Anjasmoro 5	0	0	0	x
Grobogan 1	0.41	0	0	√
Grobogan 2	0.77	0	0.01	√
Grobogan 3	0.22	0	0	√
Grobogan 4	0	0	0	×
Grobogan 5	0	0.9	0	√
Wilis 1	0	0	0	×
Wilis 2	0.65	0	0.1	x
Wilis 3	0	0	0.35	√
Wilis 4	0	0	0	×
Wilis 5	0.05	0	0	x
Accuracy				40 %

Table 3. Fuzzy Logic Test Result for 51 DAP Dataset

Samples	Firestrength			Detected
	TT (A)	TT (G)	T (W)	
Anjasmoro 1	0	0	0.04	x
Anjasmoro 2	0.5	0	0	√
Anjasmoro 3	0.32	0	0	√
Anjasmoro 4	0	0	0	x
Anjasmoro 5	0	0	0	x
Grobogan 1	0.01	0.2	0	√
Grobogan 2	0.15	0	0	√
Grobogan 3	0.54	0.79	0	√
Grobogan 4	0	0	0	x
Grobogan 5	0	0	0	x
Wilis 1	0	0	0	x
Wilis 2	0.79	0	0.84	√
Wilis 3	0	0	0	x
Wilis 4	0	0	0.7	√
Wilis 5	0.38	0	0.06	x
Accuracy				46 %

3.3. Neural networks test results

The experiment using neural network algorithm was conducted twice using the same dataset as fuzzy logic algorithm data test. Experimental results are shown in Tables 4a to Table 4d. The result using 51 DAP data has seen a significant difference in accuracy for each neural network architecture as shown in Table 4c and Table 4d. The best neural networks architecture that able to provide the most optimal result to predict drought-tolerant soybean from 41 DAP dataset was neural network architecture that has double hidden layer. Otherwise the best neural networks architecture that able to provide the most optimal result to predict drought-tolerant soybean from 51 DAP dataset was neural network architecture that has single hidden layer with nodes, 0.1 learning rate value and the momentum that is 0.2. Successful rate of neural network algorithm to predict drought-tolerant soybean variety was good, 80 % for 41 DAP dataset and 53 % for 51 DAP dataset. Error threshold that is used in each experiment was 0.01 and the maximum allowable iterations is 2 000.

Table 4a. Single hidden layer neural network test result for 41 DAP dataset

Hidden node	3	3	3	2	3
Learning rate	0.1	0.5	0.35	0.2	0.1
Momentum	0.3	0.2	0.5	0.7	0.2
Accuracy percentage (%)	73	80	73	80	80

Table 4b. Double hidden layer neural network test result for 41 DAP dataset

Hidden node	2	5	3	3	4
Learning rate	0.2	0.1	0.1	0.2	0.35
Momentum	0.4	0.3	0.3	0.8	0.5
Accuracy percentage (%)	80	80	80	80	80

Table 4c. Single hidden layer neural network test result for 51 DAP dataset

Hidden node	3	3	3	2	3
Learning rate	0.1	0.5	0.35	0.2	0.1
Momentum	0.3	0.2	0.5	0.7	0.2
Accuracy percentage (%)	33	47	47	40	53

Table 4d. Double hidden layer neural network test result for 51 DAP dataset

Hidden node	3	3	4	2	5
Learning rate	0.1	0.2	0.35	0.2	0.1
Momentum	0.3	0.8	0.5	0.4	0.3
Accuracy percentage (%)	40	40	40	40	40

3.4. Comparative analysis of neural networks and fuzzy logic to predict drought-tolerant soybean varieties

Successful rate obtained from fuzzy logic algorithm to predict drought-tolerant soybean varieties of dataset 51 DAP by 46 % , 51 DAP dataset prediction result is higher than 41 DAP datatest that is 40 %. The best neural network algorithm architechture for 51 DAP dataset is architecture that has single hidden layer, 3 hidden nodes, 0.1 learning rate and 0.2 momentum, successful prediction rate by this architecture is 53 %. The best neural network algorithm architecture for 41 DAP dataset can not be defined, because successful prediction rate by this architecture is have similar result that ranges from 73 % to 80 % so it is still difficult to determine which architecture is able to provide the best predictions of drought-tolerant soybean varieties appropriately. Based on the comparison of the obtained results, neural network algorithm prediction results has better accuracy than Fuzzy Logic . This is because Fuzzy Logic work with fuzzy sets that have a range of values where the range of values obtained from the variation in the data. If the data is not reasonable or that do not represent the drought-tolerant characteristics, then the fuzzy set formed less represent traits of these drought-tolerant characteristics, resulting in less precise predictions. Instead, artificial neural network is able to tolerate unreasonable data or data that do not represent the drought-tolerant characteristic because this algorithm has higher learning capability. For the processing time using the Fuzzy Logic algorithm, has a duration of time for 1 s. As for neural networks have a longer duration of time that is 15 s while the process of feed back and feed forward. If only the process of feed-forward has a duration of time for 1 s.

4. Conclusion

Based on the discussion to the above, some conclusions can be drawn as follows: The prototype application for the prediction of drought tolerant successfully created using the C# programming language, from the results obtained quantification of leaf area difference by 18.04 %, quantification of the average NDVI values compared to SPAD value obtained r-square by 0.70, fuzzy logic and neural networks algorithm has been successfully applied for drought tolerant prediction. Obtained prediction result for 41 DAP and 51 DAP dataset shows that artificial neural network successful rate is better than the fuzzy logic which is 80 % versus 40 % for 41 DAP dataset an 53 % versus 46 % for 51 DAP dataset.

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