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Implementation of Decision Support System for Analyzing the Suitability of Plantation Crops

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***Abstract*— The productivity of plantation crops is a priori dependent on the suitability of the land and the quality of the land used. The objective of determining land suitability is to increase the amount of crop production, thereby preventing crop failure. The process of land evaluation entails the assessment of land performance with the objective of predicting the potential and limiting factors for crop production. This allows for the identification of alternative types of agriculture. The application of the Fuzzy Mamdani method to the land suitability assessment website, based on rainfall parameters, soil pH and planting depth, can provide a land class assessment while making recommendations for plantation crops as an alternative type of agriculture. The system accurately recommends with 100% success rate for very suitable classes (S1) and suitable (S2) categories.**

***Index Terms*— agriculture precision; decision support system; fuzzy mamdani; suitability of plantation crop**.

I. Introduction

Plantation commodities represent a significant component of the Indonesian economy, contributing to the country's foreign exchange earnings during the global pandemic. A review of the export value of plantation commodities in 2021 reveals that the total export value of plantations reached US$ 40.71 billion, equivalent to IDR 583.21 trillion (assuming 1 US$ = IDR 14,327) [1]. The productivity of plantation crops is a priori dependent on the suitability of the land and the quality of the land used. The objective of determining land suitability is to increase the amount of crop production, thereby preventing crop failure.

The term "land" encompasses the physical environment, including climate, topography/relief, soils, hydrology, and the state of natural vegetation. These elements collectively influence land use [2]. The process of land evaluation entails the assessment of land performance with the objective of predicting the potential and limiting factors for crop production. This allows for the identification of alternative types of agriculture [3]. The suitability of plants for cultivation is determined by their ability to thrive in specific types of land. The FAO has developed a classification system for land suitability that distinguishes between four categories: S1 (Very Suitable), S2 (Moderately Suitable), S3 (Marginal Suitable), and N (Unsuitable). [4].

Some of the plantation crops cultivated in Indonesia are palm oil, rubber, coconut, coffee, cocoa, cloves [5], pepper, tea, nutmeg, sugarcane, cinnamon, tobacco, etc. [1]. The Central Bureau of Statistics (BPS) of East Java Province reports that the most prevalent plantation crops cultivated in the region are coconut, rubber, coffee, cocoa, sugarcane, tea, and tobacco. The research on evaluation of land suitability for plantation crops that is referenced in this research study employs a variety of methods. These include an evaluation of land suitability for robusta coffee plants based on both physical environmental factors and economic factors, followed by an analysis of feasibility using the R/C ratio method. [6], A geographic information system (GIS) was employed to evaluate the suitability of the land for the cultivation of sugarcane [4], cocoa [7], and tobacco[2].

Decision support system method such as spatial decision tree algorithm for optimising oil palm land suitability with 23 rules [8]. In addition to the decision tree method, other techniques, such as fuzzy logic, are employed for the assessment of land suitability for the cultivation of sugarcane [9], rubber and oil palm plant suitability [10], the selection of horticultural crops [11], the determination of rubber plant quality [12] and the identification of superior cinnamon seedlings [13].

One of the most employed fuzzy methods is the Mamdani fuzzy method, which utilises the largest-smallest value to derive the output value. The stages of the Mamdani Fuzzy Inference System Logic Model, from the formation of the Fuzzy set to the affirmation process (deFuzzyfication), demonstrate a correlation between the input variables [14]. This correlation allows the model to determine the suitability of plantation crops.

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II. Theory

The research stages comprise a literature study, problem identification, data collection, application design and development, application testing and result analysis, as illustrated in Figure 1.

Fig. 1. Flow of research stages

A. Literature review and problem identification

A literature study is a preliminary stage of research, during which materials relevant to the topic under investigation are collected. These materials may take the form of previous theories or hypotheses related to the research in question. Additionally, the problem identification process may involve interviews and direct observations with farmers and experts who are knowledgeable about the subject matter.

B. Data collection

This research data came from the soil laboratory of Jember State Polytechnic with an expert, Ir. Abdul Madjid, MP as the head of the soil laboratory. The data on land suitability for plantation crops is presented in Table 1.

TABLE I. LAND SUITABILITY DATA

Factors	S1 (Very Suitable)	S2 (Moderately Suitable)	S3 (Marginal Suitable)	N (Unsuitable)
Drainage	Good	Rather Fast - Good	Rather Fast - Good	Somewhat inhibited - inhibited
Inundation	No inundation	At least 2 months inundation	Less than 4 months inundation	No permanent inundation
Salinity (mmhos/cm)	<1500	1500 - 2500	<4000	>4000
pH of soil	6 - 7	5.5 - 6 7 - 8	4.5 – 5.5 8 – 8.5	3.5 – 4.5 >8.5
Soil fertility	High	High - Medium	High - Low	Low
Number of stones	<5%	<25%	<50%	<75%
Texture	Clay	Loam, silty, silty clay	Clay, silty sand, clay	Clay, silty sand
Depth (cm)	>100	100 - 75	75 - 50	50 - 25

Source :Soil Laboratory Politeknik Negeri Jember

Table 1 presents a land suitability classification with four classes: S1 (Very Suitable), S2 (Suitable), S3 (Marginal Suitable) and N (Unsuitable). These classes are derived from 8 parameters, including drainage, inundation, salinity, soil pH, soil fertility, stone percentage, soil texture and planting depth. The land

TABLE II. LAND SUITABILITY BASED ON PLANTATION CROP CHARACTERISTICS

Plant type	Parameters	Land Suitability Classes			
		S1	S2	S3	N
Robusta coffee	Rainfall Rate	2000 - 3000	1750 - 2000 3000 - 3500	1500 - 1750 3500 - 4000	<1500 >4000
	pH of soil	5.3 – 6	6 – 6.5 5 – 5.3	>6.5 <5	-
	Depth (cm)	>100	75 - 100	50 - 75	<50
Palm oil	Rainfall Rate	1700 - 2500	1450 - 1700 2500 - 3500	1250 - 1450 3500 - 4000	<1250 >4000
	pH of soil	5 – 6.5	4.2 – 5 6.5 – 7	>7	-
	Depth (cm)	>100	75 - 100	35 - 55 50 - 75	>55 <50
Rubber	Rainfall Rate	2500 - 3000	2000 - 2500 3000 - 3500	1500 - 2000 3500 - 4000	<1500 >4000
	pH of soil	5 – 6	6 – 6.5 4.5 – 5	>6.5 <4.5	-
	Depth (cm)	>100	75 - 100	50 -75	<50
Cacao	Rainfall Rate	1500 – 2500	>2500 - 3000	>3000 - 4000 1250 - < 1500	>4000 <1250
	pH of soil	5.5 – 6.5	>6.5 – 7.5 5 - < 5.5	>7.5 – 8.5 4.5 - < 5	< 4
	Depth (cm)	>100	75 - 100	50 - <75	<50
Cloves	Rainfall Rate	1500 - 2500	2500 - 3000	1250 - 1500 3000 - 4000	<1250 >4000
	pH of soil	5 – 7	4 – 5 7 – 8	< 4 > 8	-
	Depth (cm)	>100	75 - 100	50 - 75	<50
Nutmeg	Rainfall Rate	2000 - 4500	1800 - 2000 4500 - 4800		<1800 >4800
	pH of soil	5 – 7	4 – 5 7 – 8	< 4 > 8	-
	Depth (cm)	>100	75 - 100	50 - 75	<50
Cinnamon	Rainfall Rate	2000 - 2500	1300 - 2000 2500 - 3000	1000 - 1300 3000 - 4000	<1000 >4000
	pH of soil	5 – 7	4 – 5 7 – 8	< 4 > 8	-
	Depth (cm)	>100	75 - 100	50 - 75	<50
Arabica coffee	Rainfall Rate	1200 - 1800	1000 - 1200 1800 - 2000	2000 - 3000 800 - 1000	<800 >600
	pH of soil	5.6 – 6.6	6.6 – 7.3	< 5.5 > 7.4	-
	Depth (cm)	>100	100 - 150	50 - 100	<50
Tea	Rainfall Rate	2500 - 4000	1800 - 2500 4000 - 5000	1300 - 1800 5000 - 6000	<1300 >6000
	pH of soil	4.5 - 5	4 – 4.4 5.1 – 5.5	3.5 - 3.9 5.6 – 6.5	<3.5 >6.6
	Depth (cm)	>150	100 - 149	40 - 99	<40

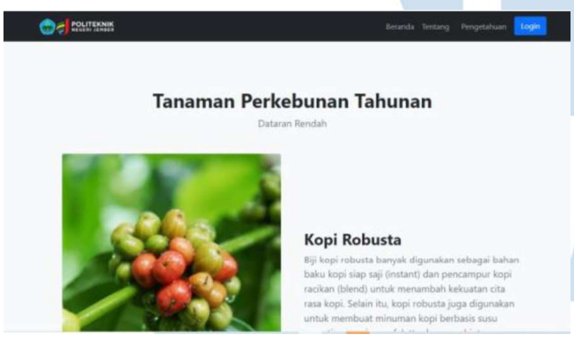
Source :Soil Laboratory Politeknik Negeri Jember suitability data for plantation crops based on three parameters such as rainfall, soil pH and depth of planting are presented in Table 2. The plantation crops we use are robusta coffee, arabica coffee, oil palm, rubber, cocoa, cloves, nutmeg, cinnamon and tea.

C. App design and build

The application design consists of several menus such as dashboard home, about the system, plant knowledge page, rule page and calculation page as shown in Figure 2. The development of the application commences with the construction of the fuzzy Mamdani method flowchart (Figure 3), which comprises the following sequence of operations:

a. The first step in this process is to input the requisite data pertaining to the crops, specifically the precipitation levels, the pH of the soil and the depth of the planting.

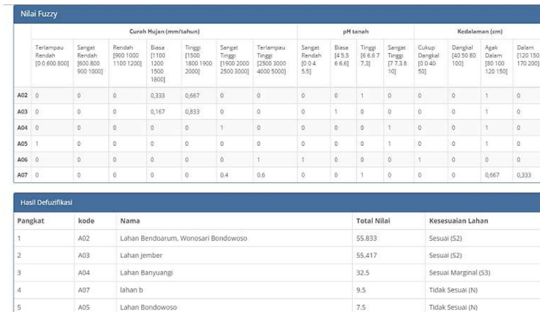
(a)



(b)

(c)

(d)



(e)

Fig. 2. illustrates an overview of the application design.

Figure 2 illustrates the application design, which comprises the following components: (a) home menu, (b) knowledge menu showing information about plantation crops used as data, (c) criteria menu containing parameters (rainfall, soil pH and soil depth) and land suitability classes, (d) rule menu used to create rules for land suitability classes and (e) calculation menu containing calculation tables from the fuzzy Mamdani method on selected rule options from the system.

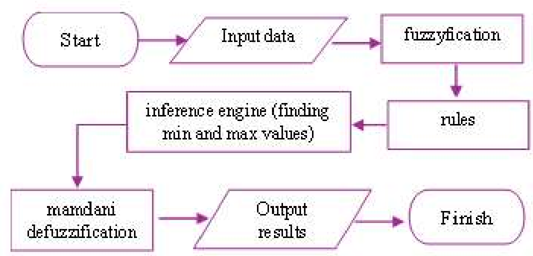


Fig. 3. Application design view

Figure 3 shows the stages of the mamdani fuzzy method which consists of input data, fuzzification, rule determination, inference engine, mamdani defuzzification and output results.

b. Fuzzification is the process of creating fuzzy sets from input variables and output variables.

a. Rainfall rate consists of 3 fuzzy sets with low, normal and high outputs.

$$\mu\ low\ (x) = \begin{cases} 0, & x \geq 1750 \\ \dfrac{1750 - x}{1750 - 1500}, & 1500 \leq x \leq 1750 \\ 1, & x \leq 10 \end{cases} \quad (1)$$

$$\mu\ normal\ (x) = \begin{cases} 0, & x \leq 1500\ atau\ x \geq 3000 \\ \dfrac{x - 1500}{1750 - 1500}, & 1500 \leq x \leq 1760 \\ 1, & 1750 \leq x \leq 2000 \\ \dfrac{3000 - x}{3000 - 2000}, & 2000 \leq x \leq 3000 \end{cases} \quad (2)$$

$$\mu\ high\ (x) = \begin{cases} 0, & x \leq 2000 \\ \dfrac{x - 2000}{3000 - 2000}, & 2000 \leq x \leq 3000 \\ 1, & x \geq 3000 \end{cases} \quad (3)$$

b. Soil pH consists of 3 fuzzy sets with low, normal and high outputs.

$$\mu\,low\,(x) = \begin{cases} 0, & x \geq 5.3 \\ \dfrac{6-x}{6-5.3}, & 5.3 \leq x \leq 6 \\ 1, & x \leq 5.3 \end{cases} \quad (4)$$

$$\mu\,normal\,(x) = \begin{cases} 0, & x \leq 5.3\ atau\ x \geq 7 \\ \dfrac{x-5.3}{6-5.3}, & 5.3 \leq x \leq 6 \\ 1, & 6 \leq x \leq 6.5 \\ \dfrac{7-x}{7-6.5}, & 6.5 \leq x \leq 7 \end{cases} \quad (5)$$

$$\mu\,high\,(x) = \begin{cases} 0, & x \leq 6.5 \\ \dfrac{x-6.5}{7-6.5}, & 6.5 \leq x \leq 7 \\ 1, & x \geq 7 \end{cases} \quad (6)$$

c. Planting depth consists of 3 fuzzy sets with outputs of shallow, slightly deep and deep.

$$\mu\,shallow\,(x) = \begin{cases} 0, & x \geq 50 \\ \dfrac{75-x}{75-50}, & 650 \leq x \leq 1000 \\ 1, & x \leq 50 \end{cases} \quad (7)$$

$$\mu\,slightly\,deep\,(x) = \begin{cases} 0, & x \leq 50\ atau\ x \geq 200 \\ \dfrac{x-50}{75-50}, & 50 \leq x \leq 75 \\ 1, & 75 \leq x \leq 100 \\ \dfrac{200-x}{200-100}, & 100 \leq x \leq 200 \end{cases} \quad (8)$$

$$\mu\,deep\,(x) = \begin{cases} 0, & x \geq 100 \\ \dfrac{x-100}{200-100}, & 650 \leq x \leq 1000 \\ 1, & x \leq 200 \end{cases} \quad (9)$$

The inference system generated 140 rules with three parameters (rainfall, soil pH and planting depth) and four output classes (S1, S2, S3 and N), as illustrated in Table 3.

TABLE III. EXAMPLE OF LAND AND SUITABILITY RULE

No.	Rules
1.	if Rainfall rate = low and Soil pH = very low and Planting depth = shallow enough then Land Suitability = Unsuitable (N)
4.	if Rainfall rate = low and Soil pH = very low and Planting depth = deep then Land Suitability = Marginal Suitable (S3)
5.	if Rainfall rate = low and Soil pH = low and Planting depth = shallow enough then Land Suitability = Unsuitable (N)
6.	if Rainfall rate = low and Soil pH = low and Planting depth = shallow then Land Suitability = Marginal Suitable (S3)
7.	if Rainfall rate = low and Soil pH = low and Planting depth = slightly deep then Land Suitability = Suitable (S2)
8.	if Rainfall rate = low and Soil pH = low and Planting depth = deep then Land Suitability = Very Suitable (S1)
9.	if Rainfall rate = low and Soil pH = Normal and Planting depth = shallow enough then Land Suitability = Unsuitable (N)
10.	if Rainfall rate = low and Soil pH = Normal and Planting depth = shallow then Land Suitability = Marginal Suitable (S3)
11.	if Rainfall rate = low and Soil pH = Normal and Planting depth = slightly deep then Land Suitability = Suitable (S2)
12.	if Rainfall rate = low and Soil pH = Normal and Planting depth = deep then Land Suitability = Very Suitable (S1)

c. Rule composition is a method of performing fuzzy system inference called the max method [15] with the equation:

$$\mu sf = \max\,(\mu sf[X_i], \mu kf[X_i]) \quad (10)$$

$\mu sf[X_i]$: The value of membership for a fuzzy solution up to rule i

$\mu kf[X_i]$: The value of membership in the fuzzy consequence of rule i.

d. The defuzzification process involves the input of a fuzzy set, which is obtained from the composition of fuzzy rules. The resulting output is a number within the domain of the fuzzy set. Defuzzification method on the composition of mamdani rules with centroid method (composite moment) with equation:

$$Z^* = \frac{\int z\mu(z)dz}{\int \mu(z)} \quad (11)$$

e. The calculation of land suitability and the analysis of the results related to the recommendations for plantation crops.

III. RESULT AND DISCUSSION

The calculation of land suitability can be based on a predetermined case study with three parameters (rainfall, soil pH and planting depth) as inputs, resulting in four outputs (Highly Suitable (S1), Suitable (S2), Marginal Suitable (S3) and Unsuitable (N)).

One example is a farmer who has land with :

1. Rainfall rate : 1700 mm/tahun
2. Soil pH : 6.5
3. Planting depth: 110 cm

a. A calculation of rainfall categories was conducted, utilising equations (1) and (2) to ascertain the rainfall value of 1700mm/year. The calculations are presented below.

$\mu\,low\,(x) = 0.2$; $\mu\,normal\,(x) = 0.8$

b. A calculation of the soil pH category was conducted, with the soil pH value determined to be 6.5, in accordance with the formulae (5) and (6). The calculation was as follows:

$\mu\,normal\,(x) = 0.6$; $\mu\,high\,(x) = 0.4$

c. The depth category for plant planting is 110 cm, calculated using Equations 8 and 9 :

$\mu\,slightly\,deep\,\,(x) = 0.9$; $\mu\,deep\,(x) = 0.1$

Subsequently, the most appropriate rule for determining the land suitability class should be identified by applying the maximum method with the formula equation (10) to the categories previously outlined :

a. Land value not suitable (N) = min (0) = 0

b. Land value in marginal suitability (S3) = min (0)

= 0

c. Land value suitable (S2) = min (0; 0.1; 0.2; 0.4; 0.6) = 0.6

d. Land value very suitable (S1) = min (0.1) = 0.1

Rule composition is an overall conclusion by taking the maximum membership level of each consequent of the implication function application and combining all the conclusions of each rule, so that the Fuzzy solution area is obtained as follows :

$$\mu sf = \max(\mu sf[X_i]) = \max(0.6)$$

The rule cut-off point is when $\mu\ agak\ dalam\ (x) = 0.6$ then the value of x can be determined as follows:

a.
$$\frac{200-x}{200-100} = 0.6$$
$$\frac{200-x}{100} = 0.6$$
$$x-200 = -(0.6*100)$$
$$x-200 = -60$$
$$x = 200-60$$
$$x = 140$$

b.
$$\frac{200-x}{200-100} = 0.1$$
$$\frac{200-x}{100} = 0.1$$
$$x-200 = -(0.1*100)$$
$$x-200 = -10$$
$$x = 200-10$$
$$x = 180$$

So we get the membership function of the solution area

$$\mu\ slightly\ deep\ (x) = \begin{cases} 0.1; x \leq 140 \\ \frac{200-x}{200-100}; 140 \leq x \leq 180 \\ 0.6; x \geq 180 \end{cases}$$

Defuzzification or affirmation is to convert Fuzzy sets into real numbers. The input of the affirmation process is a Fuzzy set, while the resulting output is a number in the Fuzzy set domain. The defuzzification method uses the centroid method using the formula equation (11):

$$Z = \frac{\int_{140}^{180}(0.6)x dx}{\int_{140}^{180} 0.6 dx} = \frac{0.3x^2]_{140}^{180}}{0.6x]_{140}^{180}} = \frac{3840}{24} = 160$$

Then the land suitability value is 160 with the appropriate class (S2) while for analysis recommending the yield of plantation crops obtained as in Table 4.

Plant type	Parameter		
	Rainfall rate (mm/year)	Soil pH	Planting depth (cm)
Palm oil	1450 - 1700	4.2 – 7	75 - 100
Cinnamon	1300 - 2000	4 – 8	75 - 100
Arabica coffee	1000 - 2000	6.6 – 7.3	100 - 150

If farmers have land with rainfall of 1700 mm/year, soil pH of 6.5 and planting depth of 110 then the recommended plantation crops are arabica coffee, cinnamon and oil palm with suitable land suitability category (S2).

The system was tested on 10 land sample datasets featuring rainfall, soil pH and planting depth parameters. The results were validated using the system output, which successfully recommended plants in the S1 (Very Suitable) and S2 (Suitable) classes, as detailed in Table 4.

Table 4 presents the results of the analysis, indicating that 10 land sample data sets correlate with the recommended plants in both S1 and S2 classes, with a 'valid' mark. This indicates that the system is effective in recommending plants according to the three parameters, with an accuracy rate of 100%.

TABLE IV. SYSTEM TESTING RESULTS

No.	Land and Parameters	Output Sistem		Validate results
		S1	S2	
1	Antirogo Rainfall : 1780 soil ph : 5.5 planting depth : 100	Cloves Oil palm Cocoa	Arabica coffee Cinnamon Nutmeg Robusta coffee	Valid
2	Rembangan Rainfall : 2100 soil ph : 5.7 planting depth : 105	Cloves Oil palm Cocoa Cinnamon Robusta coffee	Rubber	Valid
3	Dawuhan 1 Rainfall : 1300 soil ph : 5.7 planting depth : 100		Arabica coffee Cinnamon	Valid
4	Dawuhan 2 Rainfall : 1200 soil ph : 5.7 planting depth : 100		Arabica coffee	Valid
5	Senduro Rainfall : 1700 soil ph : 5 planting depth : 100	Cloves Oil palm	Arabica coffee Cocoa Cinnamon Robusta coffee	Valid
6	Tempurejo Rainfall : 1500 soil ph : 5.7 planting depth : 100	Cloves Cocoa	Arabica coffee Oil palm Cinnamon	Valid
7	Kebun Renteng PTPN XII Rainfall : 2700 soil ph : 5 planting depth : 100	Rubber Nutmeg	Cloves Oil palm Cocoa Cinnamon Tea Robusta Coffee	Valid
8	Gambir tea Rainfall : 4000 soil ph : 5.2 planting depth : 105	Nutmeg	Tea	Valid
9	Gambir tea Rainfall : 3500 soil ph : 4.6 planting depth : 105		Tea Nutmeg	Valid
10	Ijen Rainfall : 2200 soil ph : 5.3 planting depth : 100	Cloves Oil palm Cinnamon Nutmeg Robusta coffee	Rubber Cocoa Tea	Valid

Nevertheless, some plants remain red in colour, particularly within the S2 category. For example, the third data recommendation result indicates that the system has categorised cinnamon as land suitability class S2 (suitable). Cinnamon has a rainfall value of 2000–2500 mm/year, a soil pH of 5–7, and a planting depth of >100 cm. The system provides land suitability based on rainfall parameters, soil pH and planting depth in accordance with Rule 71. Where rainfall is normal, soil pH is normal and planting depth is rather deep, the system will recommend Class S2. Furthermore, as evidenced in Table 2, the data indicates that cinnamon exhibits rainfall with two value ranges: 1300–2000 or 2500–3000, and planting depth with a value range of 75–100. If these two parameters are fulfilled, the system will suggest a recommendation within the S2 category.

Another example is the results of crop recommendations on the 9th data set, which indicate that tea should be a very suitable crop recommendation (S1). Tea is planted at an annual rainfall of 3500 mm, a pH of 4.6 and a planting depth of 105 cm, as indicated in Table 2. However, the system instead recommends tea plants into a suitable class (S2) according to fuzzy Mamdani calculations for land in the Gambier tea garden.

IV. Conclusion

The study revealed that rainfall and soil pH are adequate for determining crop recommendations based on land suitability, because the average depth of plantation crops is more than 100 cm. The system accurately recommends with 100% success rate for very suitable classes (S1) and suitable (S2) categories. However, further enhancements are necessary, particularly in incorporating rules or comparing with alternative calculation methods to develop a decision system for plantation crop land suitability.

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