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Expert System For Detecting Soil Fertility Levels for Oil Palm Cultivation Using the Fuzzy Tsukamoto

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Abstract

Soil fertility is one of the critical factors that affect the productivity of oil palm plants. Inappropriate soil fertility levels can cause suboptimal plant growth and even crop failure. Low public knowledge about soil fertility is also a significant factor. This research aims to build an expert system that can detect the soil fertility level for oil palm plants using the fuzzy Tsukamoto method. This system uses three main parameters as a reference: soil acidity (pH), soil moisture, and soil texture. The fuzzy Tsukamoto method was chosen because it can handle uncertain data and provide more flexible results. The system was developed web-based using the PHP programming language and MySQL database, and tested on 49 soil data points from the Agricultural Extension Center of Matangkuli District, North Aceh Regency. The system successfully detected soil fertility levels accurately and consistently. Tests were conducted on 49 soil sample data from various villages in Matangkuli District, North Aceh Regency, where soil fertility in the Low category was found in 43 villages with a percentage of 84%, soil fertility in the Medium category was found in 6 villages with a rate of 16% and soil fertility in the High category was not found in any town of Matangkuli District with a percentage of 0% with valid fertility classification results and by expert judgment. With this system, farmers and agricultural extension workers can be helped to make the right decisions regarding the feasibility of land for planting oil palm plants.

Keywords: *Expert System, Soil Fertility, Oil Palm, Fuzzy Tsukamoto, PHP, MySQL.*

1. Introduction

In the agricultural sector, soil fertility is one factor that plays a vital role in determining the success of farming businesses. Each region has a different soil fertility level, depending on the type of soil and its geographical location. Inappropriate tillage with the characteristics of the kind of plant can cause plants to wither easily, and plant growth is not maximized. This factor is often the leading cause of crop failure that farmers do not know about [1]. Soil is one of the many components related to soil characteristics in the context of Oil Palm. It is used as a starting point to understand the cultivation technology that will be used to increase land productivity. The process of soil formation is influenced by five factors that work together physically and chemically in various ways to form soil. These soil-forming factors are climate, organisms, parent material, relief, and time. Therefore, generalizing soil fertility status on a land with a different physical environment is irrelevant [2].

Oil palm (Elaeis guineensis Jacq) is an industrial crop producing cooking oil, industrial oil, and fuel (biodiesel). Indonesia is the largest oil producer in the world. Oil palm plantations are one of the critical factors in the development of the Indonesian economy. A supporting factor is needed to get high-quality oil palm, such as soil fertility [3]. North Aceh is one of the oil palm-producing districts. Through data from BPS Aceh, the oil palm planting area in North Aceh District in 2015 was 17,251.00 Ha with a total production of 39,348.00 tons, then there was an increase in the planting area to 17,911.00 Ha with a total output of 39,643.00 tons. Oil palm production in North Aceh has indeed increased, but sadly, the price of oil palm FFB has declined. This can be caused by poor productivity and quality results, so land is also the main problem oil palm farmers face today. The development of computer technology can be utilized in various branches of science, one of which is artificial intelligence. One branch of artificial intelligence that often gets attention today is expert systems [4].

An expert system is a computer system capable of mimicking the decision-making abilities of human experts. An expert system is a system that applies human knowledge to computers, so that computers can solve problems as experts do. A sound expert system is designed to solve a particular issue by mimicking the work of experts. With expert systems, even ordinary people can solve complex problems that can only be solved with the help of experts. Expert systems will also help experts' activities as highly experienced assistants [5]. Several methods can be used in building an expert system, including the Tsukamoto fuzzy method. The Tsukamoto fuzzy method is based on the degree of membership of fuzzy set theory. In the Tsukamoto method, every consequent in an IF-Then rule must be represented by a fuzzy set with a monotonous membership function. As a result, the inference output of each rule is given crisply based on the α-predicate (fire strength). The final result is obtained using a weighted average [6]. Research on the soil fertility level in oil palms is essential because the expert system can help farmers decide the appropriate soil type before doing anything on the plantation / agricultural land. Specifically, this study is a type of oil palm plant because it is considered a versatile and efficient oil-producing plant with various kinds of oil, and is very dominant in the North Aceh Region. In this research, the expert system applied uses the Tsukamoto fuzzy logic method, which has a flexible data tolerance. The advantages of the Tsukamoto fuzzy method are that it is intuitive and can provide responses based on qualitative, inaccurate, and ambiguous information.

2. Literature Review

2.1. Palm Oil

Oil palm (Elaeis guineensis Jacq.) is one of Indonesia's primary plantation crop commodities. Palm oil can contribute the largest foreign exchange for Indonesia. Indonesia's current palm oil production also ranks first at 29,278,200 tons, followed by Malaysia at 19,667,016 tons in 2014 [7]. Oil palm is a plant that contains high vegetable oil per unit area, which exceeds other oil-producing plants, so palm oil is widely used as the primary raw material for processed vegetable oil. The part of the oil palm utilized as a raw material for various derivative products comes from CPO (crude palm oil), which is found in oil palm fruits. Oil palm is a promising plantation commodity to be developed, given that this commodity produces an increase in farmers' income if appropriately managed by proper cultivation techniques [8].

Currently, two types of cultivated oil palm are commonly planted: E. guineensis and E. oleifera. There are functions and advantages to these two types. The type owned by E. guineensis has a very high production, while E. Oleifera has a low plant height. Many cross these two species to get five species with high yield and easy to harvest. E. oleifera is now also being cultivated to increase the genetic resources available. Oil palm Elaeis guinensis Jacq is a tropical plant native to West Africa. It can be grown outside its native range, including Indonesia [9].

2.2. Soil

Soil is a layer of the earth's surface that is useful for the growth and development of roots that underlie the sturdy growth of a plant, providing water and air [10]. The definition of soil in agriculture is a medium where plants grow. Soil comes from the weathering of rocks mixed with organic matter and organisms (vegetation or animals) living on or in it. In addition to mixing mineral materials with organic materials, soil layers or horizons are formed in soil formation [11]. One of the soil properties that determines whether soil quality is good or bad is soil physical properties. Soil physical properties can affect root growth and its ability to absorb water and nutrients, thus affecting crop production [12]. One of the soil properties that determines whether soil quality is good or bad is soil physical properties. Soil physical properties can affect root growth and its ability to absorb water and nutrients, thus affecting crop production [13]

2.3. Expert System

Expert System is a system that seeks to adopt expert knowledge into a computer designed to model capabilities and solve problems. The expert system will solve a problem obtained from a dialog with the user. With the help of an expert system, someone who is not an expert can answer questions, solve problems, and make decisions usually made by an expert [14]. The characteristics of expert systems include being limited to a particular domain of expertise, being able to provide reasoning on incomplete or uncertain data, providing reasons in a way that is easy to understand, working according to rule rules, can easily make modifications, knowledge base and mechanism in separate inference, the resulting output is recommended, the system can activate the appropriate directional regulations and is guided by dialog with the user.

2.4. Fuzzy Tsukamoto Method

Fuzzy Tsukamoto is an extension of monotone reasoning. In the Tsukamoto Method, each consequent in an IF-Then rule must be represented by a fuzzy set with a monotonous membership function [15]. As a result, the inference output of each rule is given crisply based on the α-predicate (fire strength). The final result is obtained using a weighted average. In its inference, the Tsukamoto method uses the following steps [16].

1. Fuzzyfication, the first phase of fuzzy calculation, is a change in firm values to fuzzy values. Where each fuzzy variable is calculated, the value of its membership degree to each fuzzy set.

$$\mu \text{ low}[x] = \begin{cases} 1; & x \le a \\ \frac{x-a}{b-a}; & a \le x \le b \\ 0; & x \ge b \end{cases} \quad (1)$$

$$\mu \text{ medium}[x] = \begin{cases} 1; & x \le b \\ \frac{x-a}{b-a}; & b \le x \le c \\ 0; & x \ge c \end{cases} \quad (2)$$

$$\mu \text{ high}[x] = \begin{cases} 0; & x \le c \\ \frac{x-a}{b-a}; & c \le x \le d \\ 1; & x \ge d \end{cases} \quad (3)$$

Description:
x: Firm value
a: Range upper limit between 1 and 0
b: Range center limit between 1 and 0
c: Range lower limit between 0 and 1
μ: Degree of membership

2. Form a Fuzzy knowledge base (Rule in the form of IF...THEN).
3. Inference engine Using the MIN implication function to get the α-predicate value of each rule (α_1, α_2, α_3,..., α_n) Then each of these α-predicate values is used to calculate the output of the inference result strictly (crisp) each rule (z_1 〖,z〗_2 〖,z〗_3,...,z_n).
4. Defuzzification Using the average method.

$$Z = \frac{\Sigma aiZi}{\Sigma ai} \tag{4}$$

$$Z = \frac{\alpha_{pred1} * Z1 + \alpha_{pred2} * Z2 + \cdots + \alpha_{predn} * Zn}{\alpha_{pred1} + \alpha_{pred2} + \cdots \alpha_{predn}} \tag{5}$$

3. Research Methods

3.1. Place and Time

This research was conducted in the field of the Agricultural Extension Center (BPP) Matangkuli District, North Aceh Regency, to support and strengthen the results of the detection of soil fertility levels in this study, which required soil sample data with aspects of soil acidity (pH), soil moisture, temperature and soil texture. The time of this research starts from January 2023.

3.2. Method

1. Literature Study
   At the data collection stage, literature studies are taken from various sources such as journals, books, papers that have a relationship with this research, then an evaluation, study, and analysis process will be carried out, which can be used as a reference in this research.
2. Observation
   This stage contains observation and data collection activities, where the data used are soil samples of Oil Palm Plantations in North Aceh Regency.
3. Interview
   In conducting observations, the interview stage is accompanied by interviews with expert sources or experts who handle the types of fertile soil for oil palm planting in Matangkuli District, North Aceh Regency.

3.3. Designing The Program

The author designs the program in such a way that the system to be built can carry out the process of detecting the level of soil fertility using the fuzzy Tsukamoto method. The first step of this stage is to design the flow of system performance using UML (Unified Modeling Language) and flowcharts that will explain the processes in the system in detail. This research material is in the form of reference books on related materials, especially artificial intelligence and web-based system design, which will later become a data source for the built system. In addition, this research material includes functional and non-functional requirements, such as hardware and software requirements. In designing this system, some computer hardware that can be physically seen and felt consists of: 1. Acer E5-75-30UA @ 2.00 GHz laptop with specifications: 4 GB DDR 4 Memory, 100 GB HDD, and 128 GB SSD. Then, this system design also uses software for data processing, which consists of the Windows 10 Operating System, Microsoft Word 2010, App Server, Notepad++, Visual Studio Code, and Google Chrome as supporting devices in system creation and development.

4. Results and Discussion

4.1. System Analysis

The system to be built utilizes an expert system with the fuzzy Tsukamoto method to detect the soil fertility level for oil palm plants. The expert system to be built is like an expert in concluding existing problems with the expertise of a soil fertility expert. The expert system to be built is web-based and uses the PHP programming language and MySQL Database. Before this expert system is run, some data is used as a knowledge base: village data, soil acidity (pH) data, soil moisture data, and soil texture data. All of these knowledge bases are used to provide the results of detecting the soil fertility level, whether it is low, medium, or high.

4.2. Search with Fuzzy Tsukamoto Method

1. Fuzzification
   In this research, the author has input variables in the form of soil acidity (pH), soil moisture, and soil texture. Fuzzification converts crisp values of water quality data into fuzzy values that can be processed in a fuzzy inference system. Here are the membership functions for each parameter.

Table 1. Membership Variable

No	Membership Variable	set	Domain
1	Soil Acidity (pH)	low	0-4
		medium	5-7
		high	8-10
2	Soil texture	coarse	0-40
		Medium	50-70
		Fine	80-99
3	Soil moisture	Dry	0-65
		Normal	66-75
		Wet	76-99

4	output	Low	0-4
		Medium	5-7
		High	8-10

2. Membership variable Soil Acidity (pH)

$$\mu \text{ low} = \begin{cases} 1; & x \leq 4 \\ \frac{5-x}{1}; & 4 < x < 5 \\ 0; & x \geq 5 \end{cases}$$

$$\mu \text{ medium} = \begin{cases} \frac{x-4}{1}, 4 < x \leq 5 \\ 1,\ 5 \leq x \leq 7 \\ \frac{8-x}{1},\ 7 < x < 8 \\ 0, x\ \geq 8 \end{cases}$$

$$\mu \text{ high} = \begin{cases} \frac{x-7}{1}, 7 < x < 8 \\ 1, x\ \geq 8 \end{cases}$$

3. Membership Variable Soil Texture

$$\mu \text{ coarse} = \begin{cases} 1; & x \leq 40 \\ \frac{50-x}{10}; & 40 < x < 50 \\ 0; & x \geq 50 \end{cases}$$

$$\mu \text{ medium} = \begin{cases} \frac{x-40}{10}, 40 < x \leq 50 \\ 1,\ 50 \leq x \leq 70 \\ \frac{80-x}{10},\ 70 < x < 80 \\ 0, x\ \geq 80 \end{cases}$$

$$\mu \text{ fine} = \begin{cases} \frac{x-70}{10}, 70 < x < 80 \\ 1, x\ \geq 80 \end{cases}$$

4. Membership Variable Soil Moisture

$$\mu \text{ dry} = \begin{cases} 1; & x \leq 65 \\ \frac{75-x}{10}; & 65 < x < 75 \\ 0; & x \geq 75 \end{cases}$$

$$\mu \text{ Normal} = \begin{cases} \frac{x-65}{10}, 65 < x \leq 75 \\ 1,\ 66 \leq x \leq 75 \\ \frac{85-x}{10},\ 75 < x < 85 \\ 0, x\ \geq 85 \end{cases}$$

$$\mu \text{ wet} = \begin{cases} \frac{x-75}{10}, 75 < x < 85 \\ 1, x\ \geq 85 \end{cases}$$

5. Membership Variabel Output

$$\mu \text{ low} = \begin{cases} 1; & x \leq 4 \\ \frac{5-x}{1}; & 4 < x < 5 \\ 0; & x \geq 5 \end{cases}$$

$$\mu \text{ medium} = \begin{cases} \frac{x-4}{1}, 4 < x \leq 5 \\ 1,\ 5 \leq x \leq 7 \\ \frac{8-x}{1},\ 7 < x < 8 \\ 0, x\ \geq 8 \end{cases}$$

$$\mu \text{ high} = \begin{cases} \frac{x-7}{1}, 7 < x < 8 \\ 1, x\ \geq 8 \end{cases}$$

6. Determine The Rules
   Fuzzy inference rules are used to determine water quality conditions based on a combination of fuzzified parameters. Some of the regulations used include:

Table 2. Fuzzy Rules

Rules	Antiseden	Soil Acidity (pH)	Soil Moisture	Soil Texture	Output
1	IF	Low	Dry	Coarse	Low
2	IF	Medium	Dry	Coarse	Low
3	IF	High	Dry	Coarse	Low
4	IF	Low	Dry	Medium	Low
5	IF	Medium	Dry	Medium	Medium
6	IF	High	Dry	Medium	Medium
7	IF	Low	Dry	Fine	Low
8	IF	Medium	Dry	Fine	Medium
9	IF	High	Dry	Fine	Medium
10	IF	Low	Normal	Coarse	Low
11	IF	Medium	Normal	Coarse	Medium
12	IF	High	Normal	Coarse	Medium
13	IF	Low	Normal	Medium	Medium
14	IF	Medium	Normal	Medium	Medium
15	IF	High	Normal	Medium	High
16	IF	Low	Normal	Fine	Medium
17	IF	Medium	Normal	Fine	High
18	IF	High	Normal	Fine	High
19	IF	Low	Wet	Coarse	Medium
20	IF	Medium	Wet	Coarse	High
21	IF	High	Wet	Coarse	High
22	IF	Low	Wet	Medium	High
23	IF	Medium	Wet	Medium	High
24	IF	High	Wet	Medium	High
25	IF	Low	Wet	Fine	High
26	IF	Medium	Wet	Fine	High
27	IF	High	Wet	Fine	High

These rules are based on a logical combination of the three parameters and previous experience determining water quality. If these rules are analyzed, then:

1. The output value tends to be low or medium if the humidity is very dry.
2. If the humidity is normal, the output varies from low to high depending on the texture and pH.
3. If the humidity is high, the output tends to be high, indicating that wet conditions favor increased output.
4. Fine texture and high pH produce higher output values than coarse and low pH.

The following is an example of a test case using rules using data no. 1, namely Trieng Teupin Keube village, with K1 = 5, K2 = 50, and K3 = 35. Where K1 = Soil acidity, K2 = Soil texture and K3 = Soil moisture

a. Rule 1
   IF K2 coarse AND K3 dry AND K1 low, THEN Output low
   $\alpha_1 = \min(\mu_{coarse}, \mu_{dry}, \mu_{low})$
   $\alpha_1 = \min(1, 1, 0)$
   $\alpha_1 = 0$
b. Rule 2
   IF K2 Coarse AND K3 dry AND K3 medium, THEN Output low
   $\alpha_2 = \min(\mu_{coarse}, \mu_{dry}, \mu_{medium})$
   $\alpha_2 = \min(1, 1, 1)$
   $\alpha_2 = 1$
c. Rule 3

   IF K2 coarse AND K3 dry AND K1 high, THEN Output medium
   $\alpha_3 = \min(\mu_{coarse}, \mu_{dry}, \mu_{high})$
   $\alpha_3 = \min(1, 1, 0)$
   $\alpha_3 = 0$
d. Rule 4

   IF K2 medium AND K3 dry AND K1 low, THEN Output low
   $\alpha_4 = \min(\mu_{medium}, \mu_{dry}, \mu_{low})$
   $\alpha_4 = \min(0, 1, 0)$
   $\alpha_4 = 0$
e. Rule 5

   IF K2 medium AND K3 dry AND K1 medium, THEN Output medium
   $\alpha_5 = \min(\mu_{medium}, \mu_{dry}, \mu_{medium})$
   $\alpha_5 = \min(0, 1, 1)$

$\alpha_5 = 0$

f. Rule 6

IF K2 medium AND K3 dry AND K1 high, THEN Output high

$\alpha_6 = \min(\mu_{medium}, \mu_{dry}, \mu_{high})$

$\alpha_6 = \min(0,1,0)$

$\alpha_6 = 0$

g. Rule 7

IF K2 fine AND K3 dry AND K1 low, THEN Output low

$\alpha_7 = \min(\mu_{fine}, \mu_{dry}, \mu_{low})$

$\alpha_7 = \min(0,1,0)$

$\alpha_7 = 0$

h. Rule 8

IF K2 fine AND K3 dry AND K1 medium, THEN Output medium

$\alpha_8 = \min(\mu_{fine}, \mu_{dry}, \mu_{medium})$

$\alpha_8 = \min(0,1,1)$

$\alpha_8 = 0$

i. Rule 9

IF K2 fine AND K3 dry AND K1 high, THEN Output medium

$\alpha_9 = \min(\mu_{fine}, \mu_{dry}, \mu_{high})$

$\alpha_9 = \min(0,1,0)$

$\alpha_9 = 0$

j. Rule 10

IF K2 coarse AND K3 normal AND K1 low, THEN Output low

$\alpha_{10} = \min(\mu_{coarse}, \mu_{Normal}, \mu_{low})$

$\alpha_{10} = \min(0,1,0)$

$\alpha_{10} = 0$

For rules 11 to 27, all results will be zero because there is at least one membership value of 0. So that means only Rule 2 has a value of $\alpha \neq 0$, ie, α_2=1.

Defuzzification is converting fuzzy inference results into crisp values that can be used for further analysis. In this research, the Weighted Average method is used for defuzzification with the formula:

$$Z = \frac{\sum(u_i \text{x } z_i)}{u_i} \quad (6)$$

Where:
Z is the defuzzification value
u_i is the membership value of the i-th rule
z_i is the crisp value of the output of the i-th rule

If we refer to the calculation of fire strength that has been done previously for data at the Trieng Teupin Keube location, with the result that only Rule 2 has a value of $\alpha \neq 0$, namely: α2=1, then the defuzzification:

$$Z = \frac{(1\text{x } 2)}{1} = 2$$

Thus, for the Trieng Teupin Keube location (pH = 5, Humidity = 50, Soil Texture = 35), the prediction result using Fuzzy Tsukamoto is "Low" with a defuzzification value of 2.
From the results of calculations using the fuzzy method above, it can be seen that the results of defuzzication of soil fertility levels for oil palm plants are most (43 villages) are in the Low category, only six villages are in the medium category, and no High category was found in any village.

5. Conclusion

Based on this research, the following conclusions summarize the results of the detection and implementation of the Fuzzy Tsukamoto method to detect soil fertility levels for oil palm plants in Matangkuli District, North Aceh Regency:

1. Needs identification includes data collection from the parameters of Soil Acidity (pH), Soil Moisture, and Soil Texture as the primary input in the expert system. The data was collected from the Agricultural Extension Center (BPP) of Matangkuli District and used as a reference when designing the web-based system. Essential features such as soil data input, calculation results, and PDF reports are designed with a simple interface and are easy for farmers and agricultural extension officers.
2. Implementation includes the stages of data fuzzification, IF-THEN fuzzy rule implementation, α-predicate calculation, and defuzzification using the weighted average method. Each rule is organized based on expert knowledge to produce measurable and classified soil fertility values in three categories: low, medium, and high.
3. The system successfully detects the level of soil fertility precisely and consistently. Tests were conducted on 49 soil sample data from various villages in Matangkuli District, where Low soil fertility was found in 43 villages with a percentage of 84%, Medium soil fertility was found in 6 villages with a percentage of 16% and High soil fertility was not found in any town with a rate of 0%. with valid fertility classification results and following expert judgment.

4. The Fuzzy Tsukamoto method is proven effective in handling the uncertainty of vague and variable soil data. This system provides more accurate decisions than manual methods. It can be a valuable tool in deciding oil palm cultivation, with potential development in other agricultural and plantation fields.

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