ILKOM Jurnal Ilmiah Vol. 14, No. 3, December 2022, pp. 255-263
Accredited 2nd by RISTEKBRIN No. 200/M/KPT/2020; E-ISSN 2548-7779 | P-ISSN 2087-1716

Research Article **Open Access (CC–BY-SA)**

Comparative analysis of Fuzzy Tsukamoto's membership functions for determining irrigated rice field feasibility status

Ummi Syafiqoh [a,1,*]; Anton Yudhana [b,2]; Sunardi [b,3]
[a] *STMIK PPKIA Tarakanita Rahmawati , Jl. Yos Sudarso 8, Tarakan and 77111, Indonesia*
[b] *Universitas Ahmad Dahlan, Jl. Prof. Dr. Soepomo SH, Warungboto, Yogyakarta and 55164, Indonesia*
[1] *ummi@ppkia.ac.id;* [2] *eyudhana@ee.uad.ac.id;* [3] *sunardi@ee.uad.ac.id*
** Corresponding author*

Article history: Received April 20, 2022; Revised June 04, 2022; Accepted November 29, 2022; Available online December 20, 2022

Abstract

The representation of the fuzzy set membership curve consisting of trapezoidal, triangular, and linear shapes, has an important role in the fuzzy logic system. The selection of the curve's shapes determines the useable membership function and affects the fuzzy output value. Previous studies generally used curves that had been employed in predecessors or other studies that did not explain the reason for choosing a fuzzy member curve. This condition became problem because there was not a guide in selecting the appropriate membership function model for the parameters used in the fuzzy process so that most researchers only use membership functions that are commonly used in previous studies or in the same case as their research. The purpose of this study was to determine the effect of selecting trapezoidal and triangular curves on the performance of Tsukamoto's fuzzy logic for determining the rice-fields suitability status. The research methodology comprised 3 main stages. The first stage was data collecting, to collect soil pH values, soil moisture, and air temperature in rice fields. The second stage was the implementation of the Tsukamoto fuzzy. At this stage, two membership function curves were used. The third stage was a comparative analysis of Tsukamoto's fuzzy's output of trapezoidal and triangular curves. The results obtained indicate that there is no significant performance difference between the two different membership functions. The results of the research with the trapezoidal membership function have a better accuracy rate of 93% while the triangular membership function has an accuracy rate of 90%..

Keywords: Membership Function; Fuzzy Logic; Fuzzy Tsukamoto; Fuzzy Inference System; Comparative Analysis

Introduction

Artificial intelligence is a form of technology that has been widely used in various fields of human life, including agriculture. Fuzzy logic is one approach in artificial intelligence that is used to solve ambiguous problems [1][2]. Fuzzy logic is developed based on the human reasoning system [2]. This characteristic makes fuzzy logic suitable to deal with problems that contain uncertainty using the true-false concept or 1 and 0 in the Boolean number system. [2][3]. Fuzzy logic is applied in the form of a fuzzy logic system that has an architecture as illustrated in the **Figure 1**[4].

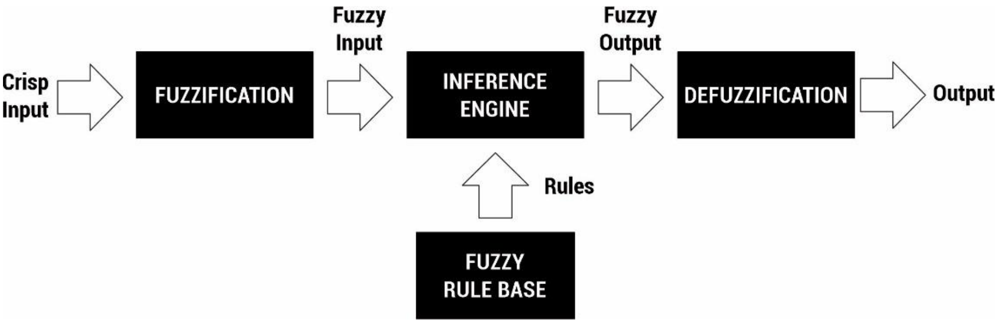


Figure 1. Fuzzy Logic System Architecture

http://dx.doi.org/10.33096/ilkom.v14i3.1156.255-263

The fuzzy logic system as illustrated in **Figure 1** comprises of 4 sub system, Fuzzification, Inference Engine, Fuzzy Rule Base dan Defuzzification [4]. Fuzzification is the process of changing the input value in the form of a firm value (Crisp) into a fuzzy value [5]. The fuzzy value from fuzzification then used as input data for the inference engine sub-system to produce fuzzy output. The inference engine sub-system works based on rules compiled into a fuzzy-based rule. The fuzzy output from the inference engine is processed in the defuzzification sub-system to produce system output [3][4][6].

In the inference engine subsystem, fuzzy input processing begins with assigning the membership function [3]. The membership function is a curve showing the mapping of data input points into their membership values which have an interval between 0 to 1[7]. Some membership functions that can be used are linear representations, triangular curves, trapezoidal curves, shoulder shape curves, S (Sigmoid) curves, π curves and so on [8]. Each of these membership functions has different characteristics which are formulated in the form of a mathematical equation. In fuzzy logic theory, the role of the membership function as a determinant of the existence of elements in a set is very important. If the system uses membership functions that are not well defined, consequently the system cannot function properly, therefore these functions must be defined carefully.

The problem that occurs at this time is that the unavailability guide of selecting the appropriate membership function model for the parameters used in the fuzzy process. Most researchers only use membership functions that are commonly used in previous studies or in the similar case of their research. Several literatures have developed specific fuzzy applications for certain cases [9][10], yet they do not explain the details of the running process, namely about setting of the most appropriate membership function. The literatures that discuss the influence of the membership function in the fuzzy inference process have been carried out in research [11][12][13][14]. These studies use the Mamdani fuzzy inference type and fuzzy logic in general, but have not discussed the influence of the membership function in the fuzzy logic inference process, so a deeper study is needed. The description of the previous research is the basis for this research aiming to determine the effect of the Tsukamoto fuzzy membership function. The Tsukamoto fuzzy membership function, the focus of this research, is applied to determine the feasibility status of irrigated rice fields

Method

Research methodology comprised of three main stages as shown in **Figure 1**. The first stage was data collecting. This research uses 4 data, soil pH, moisture, temperature dan the feasibility status of irrigated rice fields.

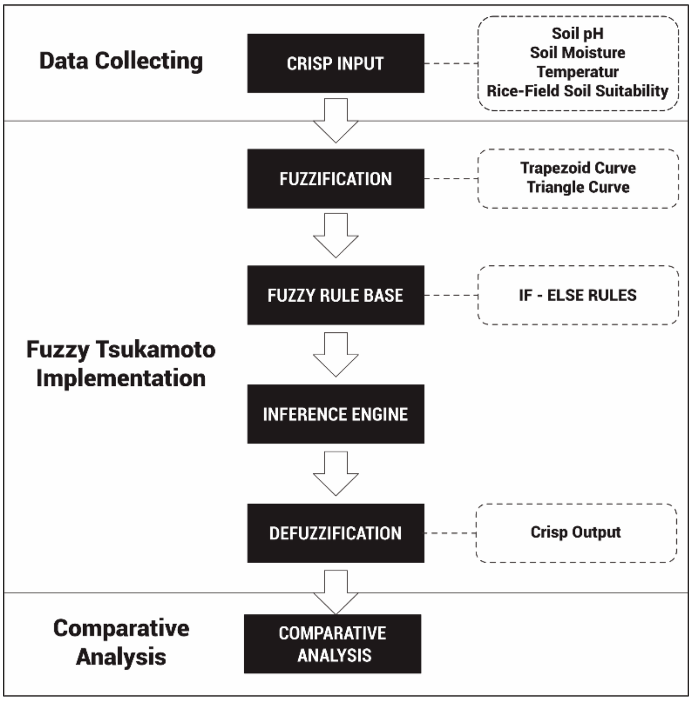


Figure 1. Research Methodology

The three values from soil pH, moisture, and temperature were used as crisp input. These values were collected from censors that build into device called AGRIMON [15]. Data was collected from rice field situated in Jogotirtio village, on Berbah District, Sleman-Yogyakarta[16]. The second stage was the implementation of fuzzy Tsukamoto. This stage began with fuzzification. The fuzzification process started with assigning membership function with 2 curves representation, trapezium, and triangular curve. Each curve representation, using 3 input variables and 1 output variable. **Table 1** shows the formulation of the input variable.

Table 1. Variabel Input

Variable Name	Association Member	Domain
pH	Strongly Acid	< 5,0
	Acid	4,0 – 6,0
	Neutral	5,0 – 7,5
	Slightly Alkaline	6,5 – 8,5
	Strongly Alkaline	>7,5
Moisture	Very Dry	< 31,5
	Dry	20 – 43
	Moist	32 – 95
	Wet	>85
Temperature	Very Cold	16 – 22
	Cold	20 – 25
	Warm	23 – 30
	Hot	28 – 34
	Very Hot	32 – 37

The input variables shown in **Table 1**, used to determine the feasibility status of irrigated rice fields that consist of three members set as shown in **Table 2**.

Table 2. Variable Output

Variable	Members Set
Feasibility Status	S3: Medium Appropriate
	S2: Quite Appropriate
	S1: Very Suitable

The fuzzification process was continued by generating the fuzzy rules according to the purpose of applying the Tsukamoto fuzzy, that was determining the feasibility status of irrigated rice fields. The output rules for feasibility status of irrigated rice fields was determined from the lowest class of each input class. The reference for determining feasibility status of irrigated rice fields obtained from the Regulation of the Minister of Agriculture No. 79 year 2013[17].

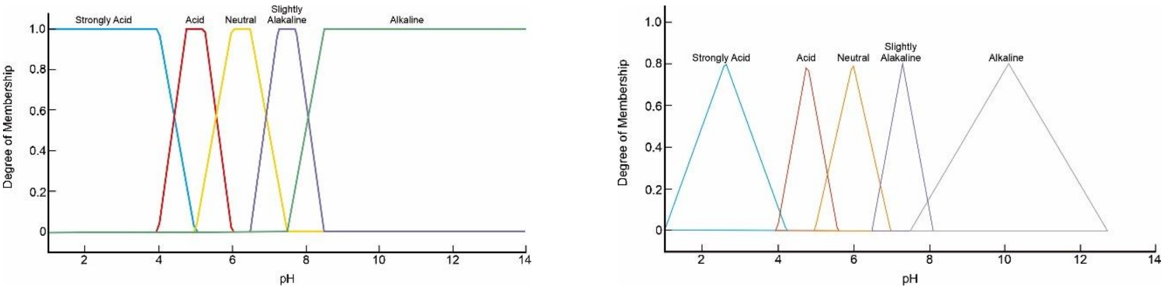
The rules formed were used for the inference engine process so that 2 groups of fuzzy output were obtained for the representation of trapezoidal and triangular curves. The function that used was MIN function, by choosing the minimum value from the rule output. Both groups of fuzzy output were processed in defuzzification to produce crisp output. The third stage was a comparative analysis of the 2 groups of crisp outputs to determine the best membership function. The best membership function was chosen based on the affirmation value calculated using the Weighted Average affirmation formula as in equation (1) [18].

$$z = \frac{\alpha pred_1 * z_1 + \alpha pred_2 * z_2 + \cdots \alpha pred_n * z_n}{\alpha pred_1 + \alpha pred_2 + \ldots \alpha pred_n} \quad (1)$$

Results and Discussion

A. Fuzzification

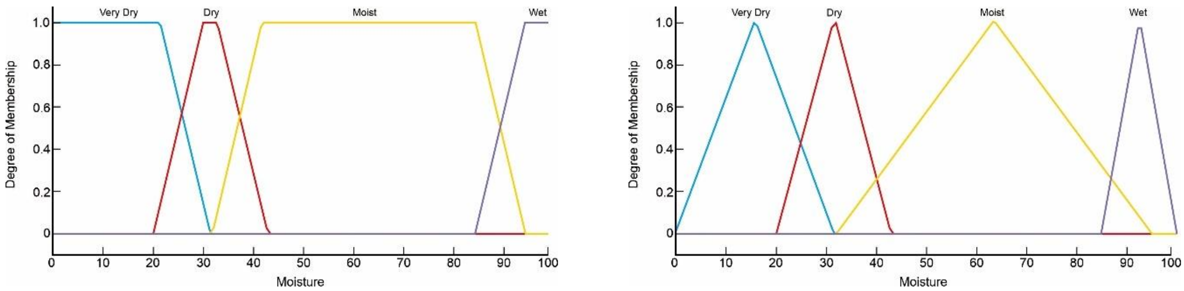
The fuzzification process from three input variables (soil pH, soil moisture, temperature) was started by assigning trapezoidal and triangular curves to each input variables. **Figure 2** shown the results of fuzzification from soil pH with both representation curves.



(a) (b)

Figure 2. Soil pH Fuzzification
(a) Trapezoidal Curve (b) Triangular Curve

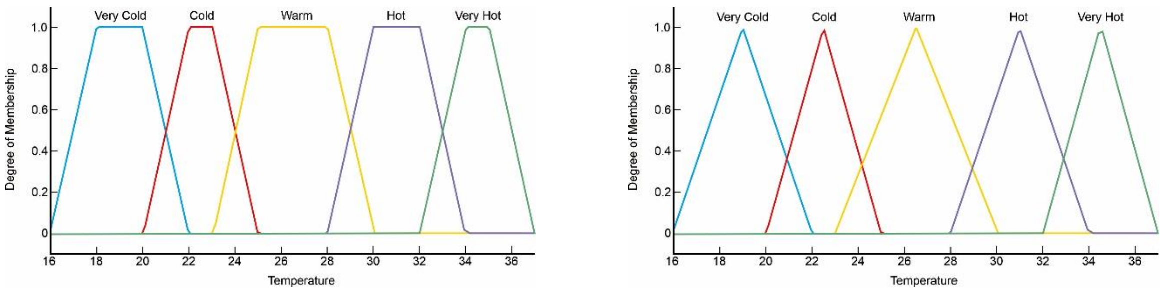
The fuzzification result for soil moisture input variable with four categories (very dry, dry, moist, wet) shown in **Figure 3**



(a) (b)

Figure 3. Soil Moisture Fuzzification
(a) Trapezoidal Curve (b) Triangular Curve

The fuzzification result for temperature input variable with five categories (very cold, cold, warm, hot, very hot) shown in **Figure 4**.



(a) (b)

Figure 4. Temperature Fuzzification
(a) Trapezoidal Curve (b) Triangular Curve

The fuzzification results from all three input variables with both trapezoidal and triangular curves were used as the basis to determine the membership function value ($\mu(x)$) based on curves that have been used before. The calculating example of membership function value for each curve shown in **Table 3** with soil pH value of 5.17, soil moisture of 78% and temperature of 25^{o}C.

Table 3. Linguistic Value Representation of Input Data

Input Data	Value	Trapezoidal Curve	Triangular Curve
Soil pH	5,17	$\mu_{Acid}(5{,}17) = 1$ $\mu_{Neutral}(5{,}17) = 0{,}17$	$\mu_{Acid}(5{,}17) = 0{,}83$ $\mu_{Neutral}(5{,}17) = 0{,}14$
Soil Moisture	78%	$\mu_{moist}(78) = 1$	$\mu_{moist}(78) = 0{,}54$
Temperature	25° C	$\mu_{warm}(25) = 1$	$\mu_{warm}(25) = 0{,}57$

B. Fuzzy Rule Base

The fuzzy rule generating was conducted based on the regulation of the Minister of Agriculture no. 79 of 2013. Table 4 shows the results fuzzy rules.

Table 4. The Feasibility Status of Irrigated Rice Fields Fuzzy Rules

No	Rules
[R1]	IF ph Very Acid AND Soil Moisture Very Dry AND Temperature is Very Cold THEN Medium Appropriate
[R2]	IF ph Very Acid AND Soil Moisture Very Dry AND Temperature is Cold THEN Medium Appropriate
[R3]	IF ph Very Acid AND Soil Moisture Very Dry AND Temperature is Warm THEN Medium Appropriate
[R4]	IF ph Very Acid AND Soil Moisture Very Dry AND Temperature is Hot THEN Medium Appropriate
[R5]	IF ph Very Acid AND Soil Moisture Very Dry AND Temperature is Very Hot THEN Medium Appropriate
[R6]	IF ph Very Acid AND Soil Moisture Dry AND Temperature is Very Cold THEN Medium Appropriate
[R7]	IF ph Very Acid AND Soil Moisture Dry AND Temperature is Cold THEN Medium Appropriate
[R8]	IF ph Very Acid AND Soil Moisture Dry AND Temperature is warm THEN Medium Appropriate
[R9]	IF ph Very Acid AND Soil Moisture Dry AND Temperature is Hot THEN Medium Appropriate
[R10]	IF ph Very Acid AND Soil Moisture Dry AND Temperature is Very Hot THEN Medium Appropriate
…	……………………………………………………………………………………………………
[R100]	IF ph Alkaline AND Soil Moisture Wet AND Temperature is Very Hot THEN Medium Appropriate

C. Inference Engine

The inference engine stage was conducted by calculating the Z value for each member of the output variable set consisting of the Feasibility Status of Irrigated Rice Fields. The following is an example of calculating the Z value for rule number 13 [R13] and rule number 33 [R33] with two curve representations.

1. Trapezoidal Curve

   - [R13] IF pH Very Acid and Soil Moisture Moist and Temperature was Warm meaning Quite Appropriate

     $$\begin{aligned} \alpha predikat_1 &= \mu_{Very\ Acid} \cap \mu_{Moist} \cap \mu_{warm} \\ &= \min(\mu_{Very\ Acid}(5.17) \cap \mu_{Moist}(78) \cap \mu_{Warm}(25)) \\ &= \min(1; 1; 1) \\ &= 1 \end{aligned}$$

     Calculating z_1 value for membership Quite Appropriate

     $$z_{11} = \frac{x-10}{4} = 1 \qquad z_{12} = \frac{20-x}{4} = 1$$

     $$= 14 \qquad\qquad = 16$$

     Because there were more than one z_1 values, then we used MAX function to get the maximum value of z_1

     $$z_1 = \max(z_{11}; z_{12}) = \max(14; 16)$$

$= 16$

- [R33] IF pH Neutral and Soil Moisture Moist and Temperature was Warm meaning Very Suitable

$$
\begin{aligned}
\alpha predikat_2 &= \mu_{Neutral} \cap \mu_{Moist} \cap \mu_{Warm} \\
&= \min(\mu_{Neutral}(5.17) \cap \mu_{Moist}(78) \cap \mu_{warm}(25)) \\
&= \min(0{,}17; 1; 1) \\
&= 0{,}17
\end{aligned}
$$

Calculating z_2 value for membership Very Suitable

$$z_{21} = \frac{x-20}{4} = 0{,}2 \qquad z_{22} = \frac{30-x}{4} = 0.2$$

$$= 20{,}8 \qquad = 29{,}32$$

Because there were more than one z_2 values, then we used MAX function to get the maximum value of z_2

$$
\begin{aligned}
z_2 &= \max(z_{21}; z_{22}) \\
&= \max(20{,}8; 29{,}32) \\
&= 29{,}32
\end{aligned}
$$

2. Triangular Curve

- [R13] IF pH Very Acid and Soil Moisture Moist and Temperature was Warm meaning Quite Appropriate

$$
\begin{aligned}
\alpha predikat_1 &= \mu_{Very\ Acid} \cap \mu_{Moist} \cap \mu_{Warm} \\
&= \min(\mu_{Very\ Acid}(5.17) \cap \mu_{Moist}(78) \cap \mu_{Warm}(25)) \\
&= \min(0{,}83; 0{,}54; 0{,}57) \\
&= 0{,}54
\end{aligned}
$$

Calculating z_1 value for membership Quite Appropriate

$$z_{11} = \frac{x-10}{5} = 0{,}54 \qquad z_{12} = \frac{20-x}{5} = 0{,}54$$

$$= 12{,}7 \qquad = 17{,}3$$

Because there were more than one z_1 values, then we used MAX function to get the maximum value of z_1

$$
\begin{aligned}
z_1 &= \max(z_{11}; z_{12}) \\
&= \max(12{,}7; 17{,}3) \\
&= 17{,}3
\end{aligned}
$$

- [R33] IF pH Neutral and Soil Moisture Moist and Temperature was Warm meaning Very Suitable

$$
\begin{aligned}
\alpha predikat_2 &= \mu_{Neutral} \cap \mu_{Moist} \cap \mu_{Warm} \\
&= \min(\mu_{Neutral}(5.17) \cap \mu_{Moist}(78) \cap \mu_{Warm}(25)) \\
&= \min(0{,}14; 0{,}54; 0{,}57) \\
&= 0{,}14
\end{aligned}
$$

Calculating z_2 value for membership Very Suitable

$$z_{21} = \frac{x-20}{5} = 0{,}14 \qquad z_{22} = \frac{30-x}{5} = 0{,}14$$
$$= 20{,}7 \qquad\qquad = 29{,}3$$

Because there were more than one z_2 values, then we used MAX function to get the maximum value of z_2

$$z_2 = \max(z_{21}; z_{22}) = \max(20{,}7; 29{,}3) = 29{,}3$$

D. Defuzzification

Defuzzification process was conducted by converting the fuzzy output from inference engine into crisp values according to membership set of the feasibility status of irrigated rice filed. The defuzzification process was conducted twice, each for trapezoidal and triangular curve. Example below shown the calculating of defuzzification values:

1. Trapezoidal curve

$$z = \frac{(1\times 16) + (0{,}17 \times 29{,}32)}{1+0{,}17} = 17{,}48$$

Because the z value is 17.48, then the feasibility status of irrigated rice field is belonged to S2 (very suitable)

2. Triangular Curve

$$z = \frac{(0{,}54\times 17{,}3) + (0{,}14 \times 29{,}3)}{0{,}54+0{,}14} = 19{,}77$$

Because the z value is 19.77, then the feasibility status of irrigated rice field is belonged to S2 (very suitable)

E. Comparative Analysis

The comparative analysis in this research was conducted by comparing the Tsukamoto fuzzy's output from trapezoidal and triangular curve with the feasibility status of irrigated rice field that came from manual calculating process (without Tsukamoto's fuzzy logic). The numbers of data that used were 30 rice field data. **Table 5** shown the comparation results.

Tabel 5. Comparation Results

No	Criteria Values			Class Output				
	pH	Moisture	Temperature	Without Fuzzy	Trapezoidal	Accuracy	Triangular	Accuracy
1	5,17	78 %	25	S2	S2	1	S2	1
2	3,37	87 %	26	S3	S3	1	S3	1
3	4,96	90 %	28	S2	S2	1	S3	0
4	2,33	88 %	28	S3	S3	1	S3	1
5	5,24	90 %	29	S2	S2	1	S2	1
6	2,6	89 %	28	S3	S3	1	S3	1
7	1,77	83 %	28	S3	S3	1	S3	1
8	2,05	85 %	28	S3	S3	1	S3	1

No	Criteria Values			Class Output				
	pH	Moisture	Temperature	Without Fuzzy	Trapezoidal	Accuracy	Triangular	Accuracy
…	…	…	…	…	…	…	…	…
30	1,01	88	26	S3	S3	1	S3	1

S1 = Very Suitable ; S2 = Quite Appropriate; S3 = Medium Appropriate

The accuracy values from **Table 3** had 2 values, one (1) and zero (0). The 1 value means that fuzzy output with trapezoidal and triangular curve have same value with manual calculating process. On the other hand, the 0 value means that fuzzy output with trapezoidal and triangular curve have different value with manual calculating process. The accuracy level in percentage for each trapezoidal and triangular curves was calculated as shown below.

$$Trapezoidal\ accuracy = \frac{(30-2)}{30} x\ 100\% = 93{,}33\%$$

$$Triangular\ accuray = \frac{(30-3)}{30} x\ 100\% = 90\%$$

From accuracy values above, we conclude that trapezoidal curve has better accuracy than triangular curve by 93.33% compared to 90%.

Conclusion

Based on the analysis, design and test results of the trapezoidal membership function and the triangular membership function in determining the suitability class of irrigated paddy fields, the following conclusions were obtained: (1) The use of the same parameters for the trapezoidal membership function and the triangular membership function did not produce a significant difference in the output of the suitability class for irrigated paddy fields. (2) The results of the comparison of the application of the membership function show that the trapezoidal membership function provided a better accuracy rate (93.33%), compared to the accuracy of the triangular membership function (90%).

References

[1] Z. Niswati, F. A. Mustika, and A. Paramita, “Fuzzy logic implementation for diagnosis of Diabetes Mellitus disease at Puskesmas in East Jakarta,” *J. Phys. Conf. Ser.*, vol. 1114, no. 1, 2018, doi: 10.1088/1742-6596/1114/1/012107.

[2] H. Thakkar, V. Shah, H. Yagnik, and M. Shah, “Comparative anatomization of data mining and fuzzy logic techniques used in diabetes prognosis,” *Clin. eHealth*, vol. 4, no. 2021, pp. 12–23, 2021, doi: 10.1016/j.ceh.2020.11.001.

[3] A. De and S. P. Singh, “Analysis of fuzzy applications in the agri-supply chain: A literature review,” *J. Clean. Prod.*, vol. 283, p. 124577, 2021, doi: 10.1016/j.jclepro.2020.124577.

[4] D. Ibrahim, “An Overview of Soft Computing,” *Procedia Comput. Sci.*, vol. 102, no. August, pp. 34–38, 2016, doi: 10.1016/j.procs.2016.09.366.

[5] D. M. Sihotang, “Metode Skoring dan Metode Fuzzy dalam Penentuan Zona Resiko Malaria di Pulau Flores,” *J. Nas. Tek. Elektro dan Teknol. Inf.*, vol. 5, no. 4, pp. 302–308, 2016.

[6] N. E. Zendrato, O. Darnius, and P. Sembiring, “Perencanaan Jumlah Produksi Mie Instan dengan Penegasan (Defuzzifikasi) Centroid Fuzzy Mamdani (Studi Kasus: Jumlah Produksi Indomie di PT. Indofood CBP Sukses Makmur, Tbk Tanjung Morawa),” *Saintia Mat.*, vol. 2, no. 2, pp. 115–126, 2014.

[7] O. A. M. Ali, A. Y. Ali, and B. S. Sumait, “Comparison between the effects of different types of membership functions on Fuzzy Logic Controller performance,” *Int. J. Emerg. Eng. Res. Technol.*, vol. 3, no. October, p. 76, 2015, [Online]. Available: https://www.researchgate.net/publication/282506091.

[8] A. A. Khoiruddin, “Algoritma Genetika untuk Menentukan Jenis Kurva dan Parameter Himpunan Fuzzy,” 2007.

[9] Amriana, A. A. Kasim, and Maghfirat, “Penentuan harga Tandan Buah Segar (TBS) kelapa sawit menggunakan Metode Fuzzy Logic,” *Ilk. J. Ilm.*, vol. 12, no. 3, pp. 236–244, 2020.

[10] U. Mustofa, Y. Yanitasari, and Dedih, “Perencanaan anggaran pinjaman dengan prediksi regresi linier sederhana dan optimasi menggunakan metode Fuzzy Tsukamoto,” *Ilk. J. Ilm.*, vol. 11, no. 28, pp. 206–213, 2019.

[11] L. K. Wardhani and E. Haerani, “Analisis pengaruh pemilihan fuzzy membership function terhadap output sebuah sistem Fuzzy Logic,” *SNTIKI III*, pp. 326–333, 2011.

[12] P. Harliana and R. Rahim, “Comparative analysis of membership function on Mamdani Fuzzy Inference System for Decision Making,” *J. Phys. Conf. Ser.*, vol. 930, no. 1, 2017, doi: 10.1088/1742-6596/930/1/012029.

[13] S. Susanto, “Perbandingan fungsi keanggotaan tipe segitiga dan tipe G-Bell terhadap analisis risiko,” *Ukarst*, vol. 3, no. 2, pp. 57–67, 2019.

[14] J. Gayathri Monicka, D. N.O.Guna Sekhar, and K. Ramash Kumar, “Performance evaluation of membership functions on Fuzzy Logic Controlled ac voltage controller for speed control of induction motor drive,” *Int. J. Comput. Appl.*, vol. 13, no. 5, pp. 8–12, 2011, doi: 10.5120/1778-2451.

[15] A. Yudhana, H. K. Dewi, D. D. Fairus, Z. Salsabila, and H. Yuliansyah, “Moisture monitoring of rice fields in Jogotirto Sleman using Internet of Thing,” in *International Conference of Science and Technology for the Internet of Things*, 2019, pp. 3–8, doi: 10.4108/eai.20-9-2019.2292093.

[16] U. Syafiqoh, “Dataset Soil Ph, Soil Moisture, Temperature,” 2022. https://www.kaggle.com/datasets/ummisyafiqoh/dataset-soil-ph-soil-moisture-and-temperature.

[17] P. M. P. N. 7. T. 2013 123, *Pedoman Kesesuaian Lahan Pada Komoditas Tanaman Pangan*. Jakarta, 2013.

[18] T. Sutojo, E. Mulyanto, and V. Suhartono, *Kecerdasan Buatan*. Andi Yogyakarta, 2011.