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Development of a Support System Crop Yield Growth using Fuzzy Logic Machine Learning for Chili Plant

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Abstract

The increasing global population necessitates improved crop yields for food supply and preventing starvation. Agriculture, especially in developing countries like Malaysia, faces challenges like yield forecasting, soil health, and natural disasters. The research aims to create a Fuzzy Logic System to predict chili plant growth based on input parameters; soil moisture and temperature. The system uses Fuzzy Inference System (FIS) and MATLAB software to analyze soil and obtain precise crop growth values. The fuzzy modelling takes into account the triangular membership function. Data from MARDI is used to investigate crop growth under various conditions. The findings are validated by the MARDI organization. The performance of fuzzy logic for Crop Yield Prediction for Soil Analysis was evaluated. The model showed some accuracy but required constant optimization. The system offers farmers a flexible, adaptable approach to crop growth prediction, considering environmental factors like soil moisture and temperature, enhancing agricultural practices and production. This work contributes to precision agriculture and smart farming, providing innovative tools for better decision-making and resource management.

1. Introduction

The world's population is increasing, and food supply is crucial for preventing starvation and reducing global poverty. Crop yields play a crucial role in feeding an ever-increasing population and minimizing the environmental impact of agriculture. Factors such as light intensity, pH level, moisture, temperature, humidity, and soil macronutrients play a significant role in yielding a good crop. Imbalances in these factors can affect plant development and growth, and improper monitoring and management can pose risks to farms [1].

Agriculture is crucial in developing countries like Malaysia, where the population is expected to grow by 41.5 million by 2040, leading to a 60% increase in food demand [2]. However, farmers struggle with yield forecasting, soil health, and natural disasters. Low production rates, long planting durations, and the inability to optimize fertilizer can hinder crop yields. Soil health is crucial for crop growth, but farmers may suffer from loss of profits or reduced output due to challenges in nutrient, moisture, and temperature levels [3].

Researchers worldwide are developing methods to efficiently predict crop output in advance, using blockchain, IoT, machine learning, deep learning, cloud computing, and edge computing. [4]. Application of computer vision, machine learning, and the Internet of Things (IoT) have helped farmers increase production, quality, and profitability [5].

This research focuses on developing a Fuzzy Logic System to predict chili plant growth whether slow, average, or ideal based on soil moisture and temperature. The dynamic interaction between moisture and temperature, which is a key factor in plant growth, requires a modelling approach that is both flexible and interpretable. Fuzzy logic is a computing approach based on "degrees of truth" rather than Boolean logic, allowing for adaptable and interpretable modelling. The goal is to contribute to precision agriculture by providing farmers with a tool to simulate and predict chili crop growth under varied environmental circumstances. Fuzzy logic's adaptation to changing agricultural settings ensures a robust and user-friendly decision support system, improving the efficiency and sustainability of chili cultivation operations.

Maintaining the optimum level for any plantation is crucial. As for chili plant ideal plant growth, the preferable range of moisture level is 50% to 70%. A suitable temperature for efficient chili plant growth is between 25ºC and 28ºC.

2. Methodology

2.1 Fuzzy Logic Architecture

Fig. 1 shows the block diagram of fuzzy logic architecture system development. The first stage is the fuzzification step. Crisp input will be converted into fuzzy values that are represented by membership functions that are defined by the degree of membership of an input value to a fuzzy input set. The next stage is the fuzzy interface. It will take the fuzzy value produced by the fuzzifier and apply the fuzzy rules created to produce a fuzzy set. In this stage, it determines the degree of match between fuzzy input and rules and combines them to develop control actions. The last stage is the defuzzification process which is used to convert fuzzy sets into crisp output values which is the final output of the fuzzy logic system.

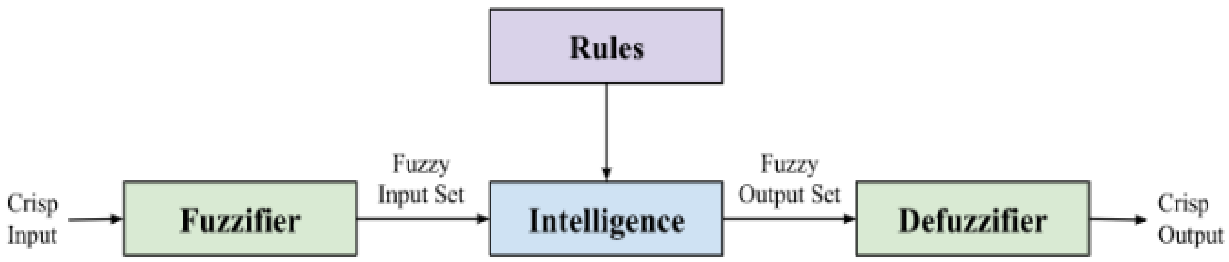

Fig. 1 *Fuzzy Logic Architecture System Development*

2.2 Details of Set Applied

The fuzzy set theory uses membership functions to map real-world measurement results to fuzzy values for operations. These functions represent the degree of membership in a range of 0 to 1, with the symbol (x) representing a variable's membership—triangular membership functions calculated using the Mamdani approach, also known as the Max-min method.

Moisture and temperature values are assigned linguistic values that indicate their degree of influence on crop growth prediction. Water shortages can negatively impact plant growth and quality, particularly in chili plants due to their shallow root system [6]. High soil temperatures can also impact plant growth and root development, affecting moisture and nutrient intake. Conversely, decreasing soil temperature can delay photosynthesis and reduce water viscosity, affecting plant growth [7]. Therefore, maintaining optimal temperature and moisture is crucial for the chili plant growth. Fig. 2 shows the structure of the fuzzy logic system for crop yield prediction that was developed in MATLAB Fuzzy Inference System (FIS) Toolbox. The logical interference flows from input variables to output variables. Moisture and Temperature are the input variable whereas the Crop Growth Prediction is the output variable.

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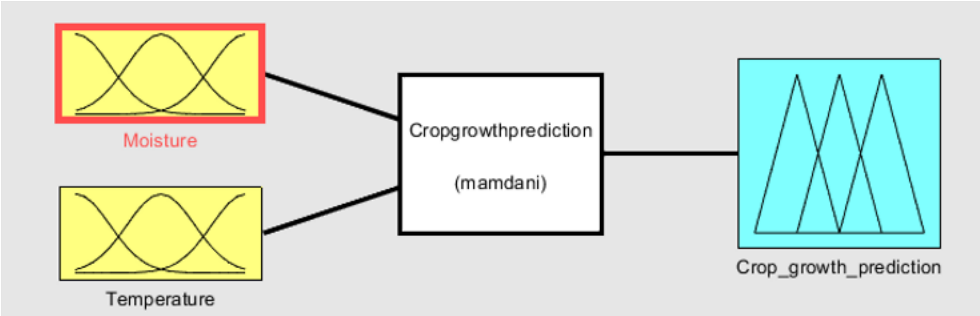

Fig. 2 *Structure of the fuzzy logic system for crop yield prediction*

2.2.1 Moisture Membership Function

Moisture input variable has three membership functions which are Low, Medium, and High. Degrees of membership (μx) are assigned to each linguistic value and are shown in equations (1), (2), and (3). Fig. 3 shows the membership functions for the moisture of soil.

$$\mu Low\ Moisture[x] = \begin{cases} 0 & ; \quad 0;\ x \le 0 \\ \dfrac{x}{27.5} & ;\ 0 < x \le 27.5 \\ \dfrac{55 - x}{27.5} & ;\ 27.5 < x \le 55 \\ 0 & ;\ x \ge 55 \end{cases} \tag{1}$$

$$\mu Optimum\ Moisture[x] = \begin{cases} 0 & ; \quad 0;\ x \le 50 \\ \dfrac{x - 50}{12.5} & ;\ 50 < x \le 62.5 \\ \dfrac{75 - x}{12.5} & ;\ 62.5 < x \le 75 \\ 0 & ;\ x \ge 75 \end{cases} \tag{2}$$

$$\mu High\ Moisture[x] = \begin{cases} 0 & ; \quad 0;\ x \le 70 \\ \dfrac{x - 70}{15} & ;\ 70 < x \le 85 \\ \dfrac{100 - x}{15} & ;\ 85 < x \le 100 \\ 0 & ;\ x \ge 100 \end{cases} \tag{3}$$

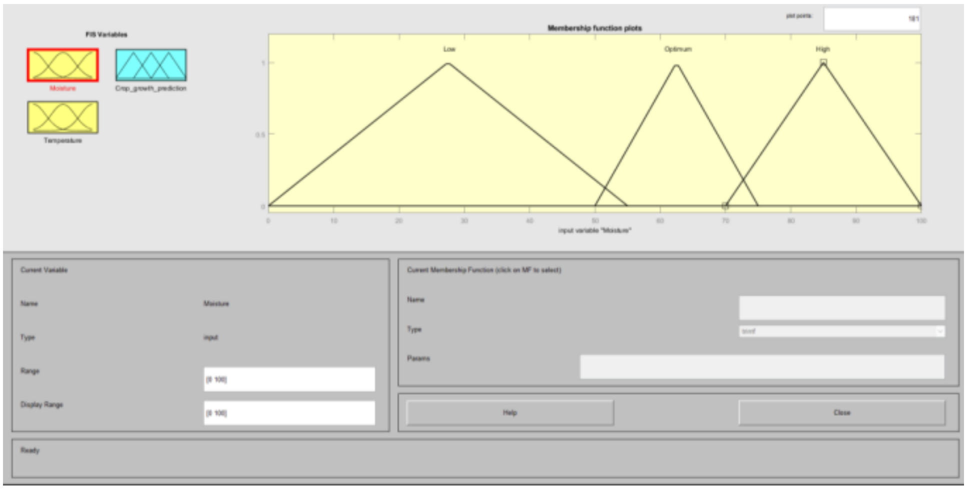

Fig. 3 *Membership function for moisture of the soil*

2.2.2 Temperature Membership Function

Temperature is measured in terms of Celsius (ºC) such as Low, Optimum, and High. Degrees of membership (µx) are assigned to each linguistic value and are shown in equations (4), (5) and (6). Fig. 4 shows the membership functions for the temperature of the soil.

$$\mu Low\ Temperature[x] = \begin{cases} 0 \quad ; \quad 0;\ x \leq 10 \\ \dfrac{x-10}{7.5} \ ;\ 10 < x \leq 17.5 \\ \dfrac{25-x}{7.5} \ ;\ 17.5 < x \leq 25 \\ 0 \quad ;\ x \geq 25 \end{cases} \tag{4}$$

$$\mu Optimum\ Temperature[x] = \begin{cases} 0 \quad ; \quad 0;\ x \leq 24 \\ \dfrac{x-24}{2} \ ;\ 24 < x \leq 26 \\ \dfrac{28-x}{2} \ ;\ 26 < x \leq 28 \\ 0 \quad ;\ x \geq 28 \end{cases} \tag{5}$$

$$\mu High\ Temperature[x] = \begin{cases} 0 \quad ; \quad 0;\ x \leq 27 \\ \dfrac{x-27}{11.5} \ ;\ 27 < x \leq 38.5 \\ \dfrac{50-x}{11.5} \ ;\ 38.5 < x \leq 50 \\ 0 \quad ;\ x \geq 50 \end{cases} \tag{6}$$

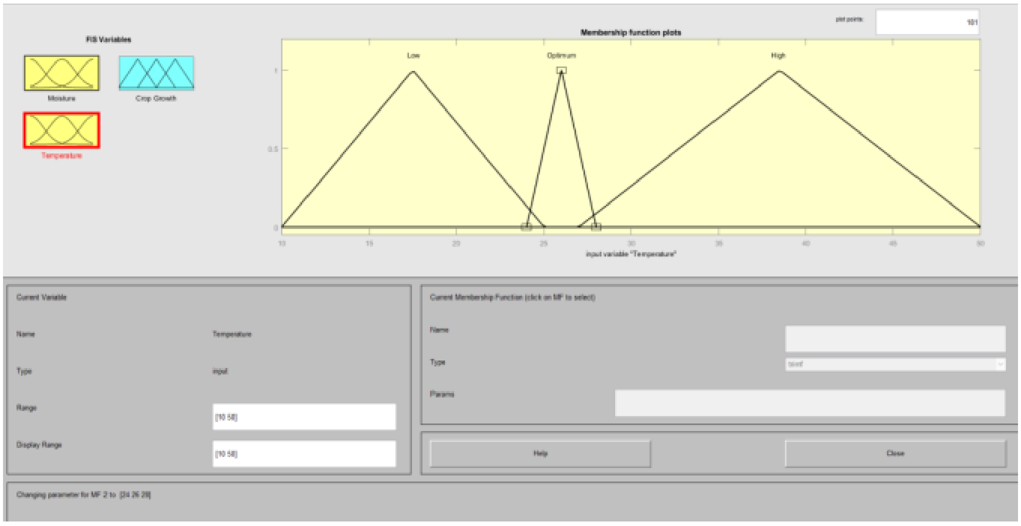

Fig. 4 *Membership function for the temperature of the soil*

2.2.3 Crop Growth Membership Function

The value of the output variable crop growth has three membership functions which are Slow, Average, and Ideal. Degrees of membership (µx) are assigned to each linguistic value and are shown in equations (7), (8), and (9). Fig. 5 shows the membership functions for crop growth prediction.

$$\mu Slow\ Growth[x] = \begin{cases} 0 \quad ; \quad 0;\ x \leq 0 \\ \dfrac{x}{22.5} \quad ;\ 0 < x \leq 22.5 \\ \dfrac{45 - x}{22.5} \quad ;\ 22.5 < x \leq 45 \\ 0 \quad ;\ x \geq 45 \end{cases} \tag{7}$$

$$\mu Average\ Growth[x] = \begin{cases} 0 \quad ; \quad 0;\ x \leq 40 \\ \dfrac{x - 40}{17.5} \quad ;\ 40 < x \leq 57.5 \\ \dfrac{75 - x}{17.5} \quad ;\ 57.5 < x \leq 75 \\ 0 \quad ;\ x \geq 75 \end{cases} \tag{8}$$

$$\mu Ideal\ Growth[x] = \begin{cases} 0 \quad ; \quad 0;\ x \leq 70 \\ \dfrac{x - 70}{15} \quad ;\ 70 < x \leq 85 \\ \dfrac{100 - x}{15} \quad ;\ 85 < x \leq 100 \\ 0 \quad ;\ x \geq 100 \end{cases} \tag{9}$$

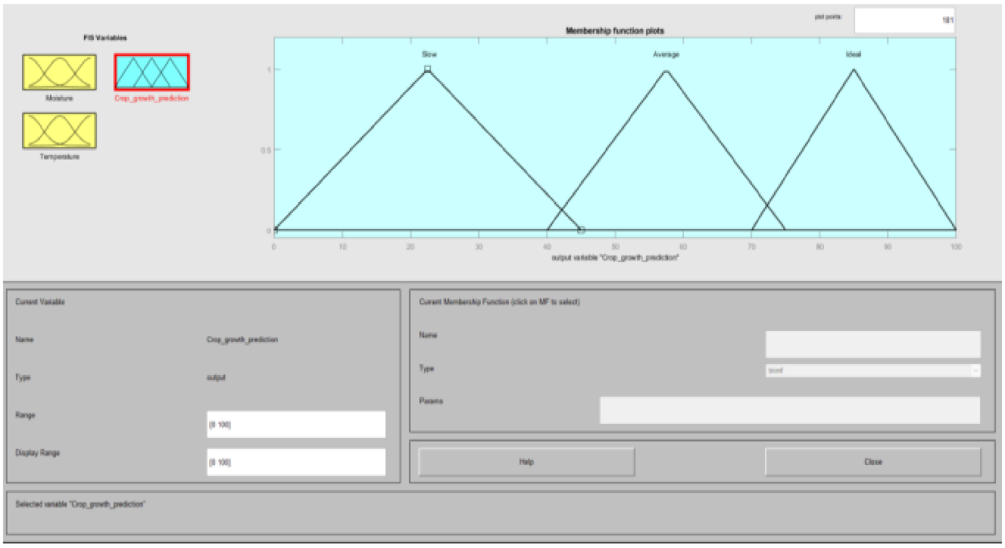

Fig. 5 *Membership function for crop growth prediction*

3. Results and Discussion

The results are achieved by varying the scale values of input variables, that is the moisture and temperature of soil. Fig. 6 depicts a rule editor that allows the generation of rules based on various combinations of input and output parameters. Nine rules link both input and output parameters using fuzzy intersection or conjunction (AND).

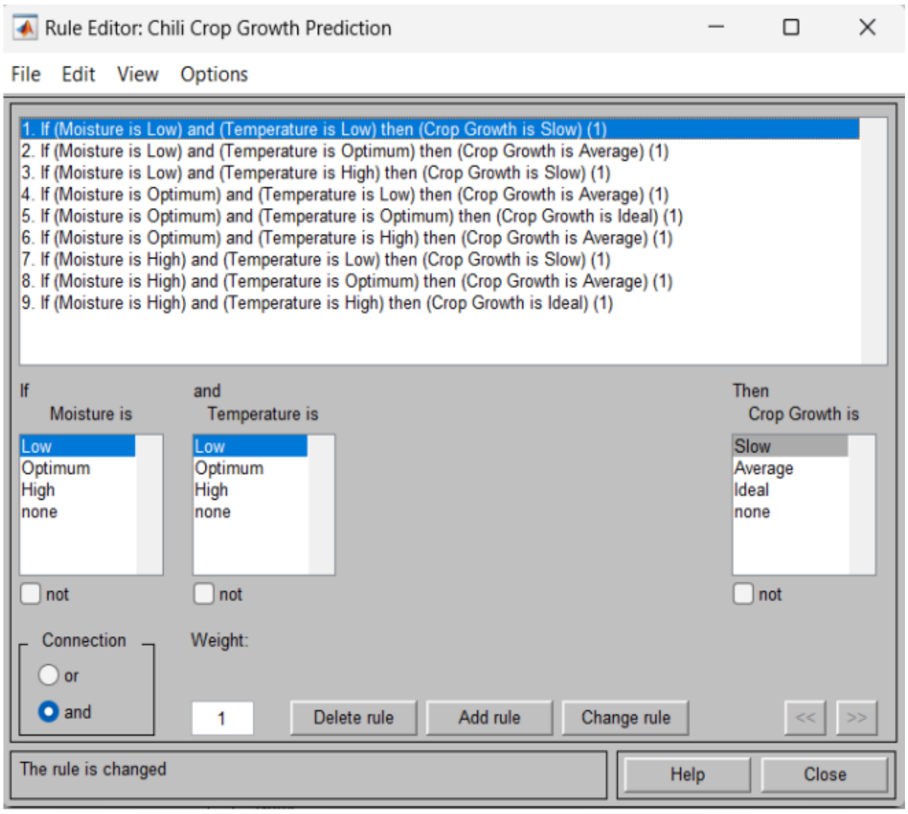

Fig. 6 *Fuzzy rule editor*

Fig. 7 depicts the rule viewer of the fuzzy toolbox. A fuzzy inference system's rule viewer allows for the visual analysis and interpretation of fuzzy rules by giving a graphical representation of the rule base. The membership function ranges were varied for every input variable to know the output projection. The MATLAB software's fuzzy toolbox is used to calculate the output value.

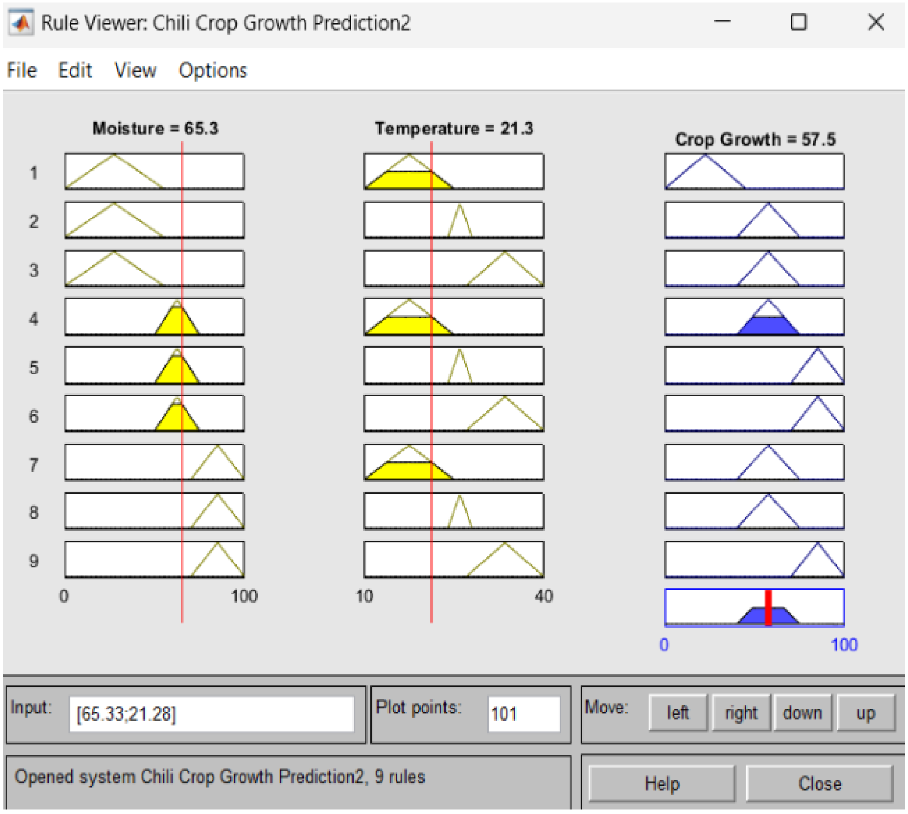

Fig.7 *Rule Viewer*

Fig. 8 shows the surface viewer of Temperature and Moisture vs Crop growth. A surface viewer is a graphical tool that visualizes the relationship between input variables and their related outputs in three dimensions.

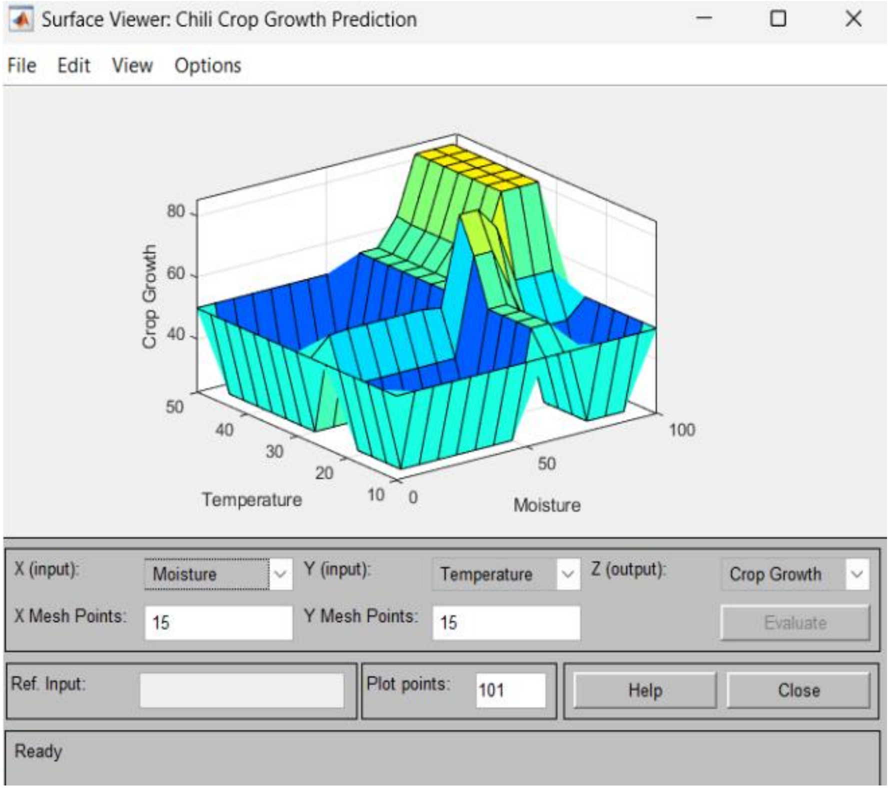

Fig. 8 *Surface View*

The prediction of chili plant crop development for several combinations of inputs is investigated using a fuzzy logic system. For the ideal chili plant growth, the preferable range of moisture level is 50% to 70% whereas the temperature is between 25ºC and 28ºC. A MARDI expert verified the output results. It is important to regularly monitor plants for early detection of pests, as high temperature and moisture can create favourable conditions for their growth.

4. Conclusion

This work explored machine learning techniques for soil analysis, focusing on fuzzy logic to eliminate ambiguity and uncertainty in agriculture. The goal was to develop a support system for predicting the crop growth of chili plants using a fuzzy logic approach. The system was developed using the Fuzzy Inference System (FIS) and MATLAB software, with input variables being soil moisture and temperature. Nine rules determine the output parameter, with a triangle fuzzifier evaluating the membership function. Historical facts and expert knowledge were used for the rule base design. Fuzzy modeling was performed using Mamdani's inference engine technique, and the centroid of area approach was used for defuzzification. The performance of the fuzzy logic system was evaluated through simulations and real-world data analysis provided by the MARDI organization. The results showed that the system could accurately predict crop development under changing conditions, making it a reliable tool for agricultural applications. However, it requires constant optimization and periodic updates based on environmental factors.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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