Advances in Biological Sciences Research, volume 19

Proceedings of the 2nd International Conference on Smart and Innovative Agriculture (ICoSIA 2021)

Development of Irrigation Monitoring and Control Systems to Support the Implementation of the System of Rice Intensification (SRI)

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ABSTRACT

Indonesia is a tropical country with high average annual rainfall. The occurrence of unpredictable world climate changes makes it difficult to determine the planting schedule. Farmers often experience crop failure due to a lack of water during the dry season. To overcome these problems, it is necessary to apply the precision farming approach to maximize output with minimal input through technology. SRI (System of Rice Intensification) is one of the innovations in rice cultivation that approaches the concept of precision agriculture. SRI can increase rice production and also save water use. However, SRI irrigation still uses intermittent irrigation based on human intuition and is done manually. Therefore, it is necessary to develop an irrigation monitoring and control system for SRI based on environmental conditions of growth represented by reference Evapotranspiration (ETo) and soil moisture content. This study aims to develop a monitoring and control system for SRI irrigation based on ETo and soil moisture content. To accommodate ETo and soil moisture content, a model using fuzzy logic was developed. This system has a solar radiation sensor, temperature sensor, soil moisture sensor, proximity sensor, Arduino mega 2560, pump, chamber, and drum. The working stages of the system begin with the reading of environmental conditions by the sensor. Furthermore, the reading results will be processed by fuzzy logic as irrigation decision-making. The data obtained from the monitoring of Evapotranspiration, soil moisture content, water level are used to present the growing environmental conditions. Water use efficiency data is used to compare the performance of the SRI system using fuzzy and non-fuzzy logic. The results of irrigation efficiency show that the SRI system using fuzzy can save water up to 52.08% compared to SRI without fuzzy.

***Keywords**: System of Rice Intensification (SRI), precision agriculture, fuzzy logic.*

1. INTRODUCTION

The need for food will continue to increase along with the increase in population. Therefore agricultural production must be increased. However, recently climate change has made it difficult to predict the growing season. Especially in the dry season, there is often a shortage of water, and production results are not optimal, so applying the precision agricultural approach through technology is necessary. Precision agriculture is a management concept that uses minimal input resources to produce higher outputs [8]. Precision agriculture is based on monitoring, analyzing, and managing parameters related to agriculture. Parameter values such as soil moisture, soil temperature, air temperature, humidity, cloud cover, pressure are needed in real-time to manage the agriculture activity [13]. Precision agriculture is also being developed for precision irrigation systems that focus on environmental measurement and control, plant growth and motion estimation, farm work recording [12], integrating information, communication, and control technologies to obtain optimal water resources while minimizing environmental impact. [19]. The appropriate adaptation of precision agriculture is represented by improving the conventional farming method using the technological aspect by fostering their knowledge to adopt modern agriculture empowered with Information and Communication Technology (ICT) [11]. The environmental field monitoring is shifting from an offline data collection system to online data collection [10] [5].

The SRI (System of Rice Intensification) was first discovered in 1983 by fr. Henri de Laulanié, S.J., in

Madagascar. This system is believed to be able to increase rice production up to 12 ton/ha. According to [15], which is based on the water balance principle, the SRI method is 35% more efficient than the conventional method.

However, the challenge of the current SRI method is that water supply is still done manually by human intuition and feelings. Therefore, an approach based on environmental conditions represented by reference Evapotranspiration (*ETo*) and soil moisture content is also needed [9] [10]. In this study [4], an automatic irrigation system was developed that considers the condition of the plant and its relationship with the environment by combining soil moisture content and Actual Evapotranspiration (*AET*) in mustard plants. Both are used as fuzzy logic inputs to make decisions about watering duration.

This research aims to develop a monitoring and control system for irrigation SRI (System of Rice Intensification) based on *ETo* and soil moisture content.

1.1. The irrigation system of Rice Intensification (SRI)

The principle of SRI irrigation is the environmental management of rice plants using water-saving methods, namely with an intermittent irrigation system. Intermittent irrigation is a concept of saving water use by regulating water conditions in the land. According to land conditions and growth phase, the ground is alternately inundated and dry in intermittent irrigation [3]. The SRI method is considered successful if it can increase land productivity and streamline water use. The SRI irrigation method accompanied by good crop management can increase crop productivity by 30-100% compared to conventional irrigation methods (continuously flooded) [15]. Furthermore, reducing the criticality of water can be done with a good irrigation network [1].

1.2. Irrigation Control in the System of Rice Intensification (SRI)

The study [17] explained that intermittent irrigation in the SRI system was carried out mainly in the vegetative phase. It was done in a rather long dry period, about one week until the soil as a planting medium dries and cracks. With this SRI intermittent irrigation system, water consumption can be saved up to 50%. SRI recommends intermittent irrigation techniques to create oxidized root conditions, increase soil fertility and obtain long, dense plant roots. With SRI, unflooded conditions are only maintained during vegetative growth. Furthermore, after being disposed of, the rice fields are flooded with water as high as 1-3 cm (as is conventional practice). Rice fields are thoroughly irrigated 25 days before harvest [14]. The condition of the land must be considered regarding the water source used. Water is given one wet day and five dry days, except flowering and seed maturation [3]. Providing water intermittently can increase the efficiency of water use in the field of food production.

In the SRI system, to increase water use efficiency, it is necessary to transition from a mechanical system to an automated system. To make an automatic system, it is also required to design an irrigation control system. Research [6] carried out the control process (on-off) using fuzzy logic, where the control was programmed based on fuzzy rules. Thus the fuzzy system can assist farmers in controlling the pump motor work and water according to land needs and be more effective in water use. [2] in his research on the optimal irrigation volume for maize in summer, he designed a fuzzy decision control system based on the difference in leaf temperature and soil moisture. The results showed that the fuzzy model fits the experimental data. The fuzzy model can solve the uncertainty and non-linearity of the irrigation system, and the model has high precision and gets a more accurate predictive value.

2. MATERIALS AND METHODS

The design of the research instrument was carried out at Smart Agriculture Research, Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Gadjah Mada University. The trial was conducted at the Faculty of Agriculture, Gadjah Mada University.

2.1. Monitoring and Systems

The research framework for developing irrigation monitoring and control systems in the Rice Intensification System (SRI) consists of two processes. The first process is monitoring and collecting environmental data such as soil water content, temperature, humidity, Evapotranspiration, and water level. The data collection process was carried out at five-minute intervals. In the second process, the environmental data of Evapotranspiration and soil moisture content were used fuzzy logic in making irrigation decisions. At the same time, the water level data is used for irrigation decision-making without using fuzzy logic. As shown in Figure 1.

In this monitoring and actuation system using the Arduino Mega 2560 microcontroller board as the mainboard, several environmental sensors such as the HDC1080 sensor to measure temperature and humidity, MAX4409 to measure the light intensity of the growing light, WD-3 to measure the Soil moisture, and Ultrasonic HCRS04 to measure water level, water pump as the actuator, ESP 8266 as a wifi module to connect to an internet connection, and several additional supporting components (RTC, LCD, Datalogger).

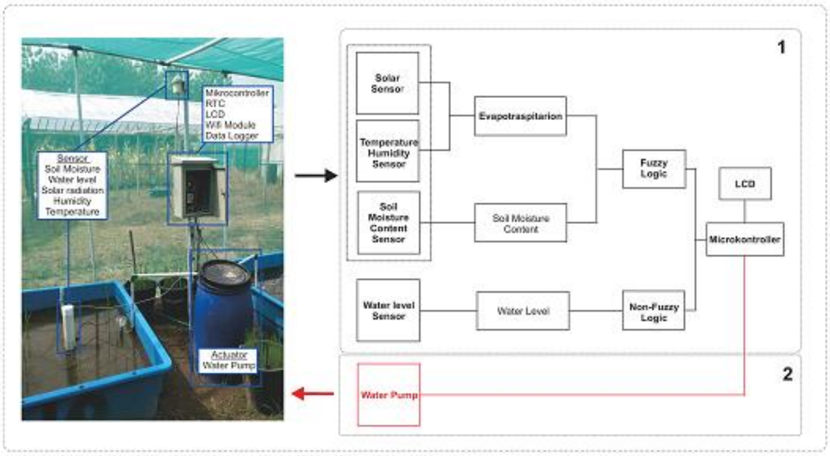

Figure 1. Illustration of the framework for the SRI monitoring and control system

2.2. Working steps

This study uses two chambers, as shown in Figure 2. each chamber has a different working step. The first chamber applies a fuzzy system, where irrigation decisions are based on evapotranspiration and soil moisture content value. The second chamber applies a non-fuzzy system, where irrigation decisions are made based on 2 to 3 cm water levels without using a fuzzy logic model, as shown in Figure 3.

Figure 2. Installation of the chamber in the field

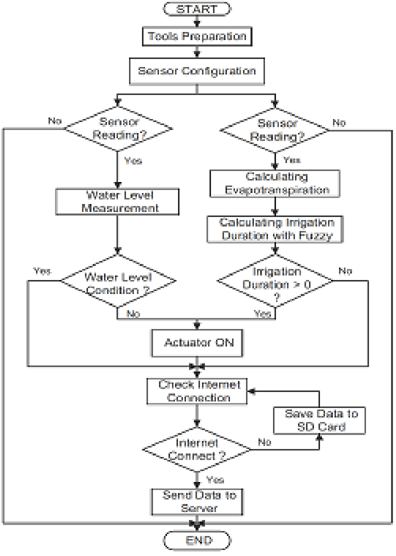

Figure 3. The main flow of the proposed system.

The percolation becomes 0 because both chambers are made of plastic. But both chambers have outputs to control runoff when it rains.

2.3. Mathematical modeling

The fuzzy rule base system is used to produce output according to the input given to the system. In this study, two input parameters are considered, and each parameter consists of 3 membership functions. The number of rules is calculated based on the membership function of each input parameter. Thus, the total number of rules is nine, as shown in Table1.

Tabel 1. The fuzzy rule table with various categories of input and output parameters.

Rules	Evapotranspiration	Soil moisture	Pump status
1	Low	Dry	Medium
2	Low	Medium	Fast
3	Low	Wet	Off
4	Medium	Dry	Medium
5	Medium	Medium	Fast
6	Medium	Wet	Off
7	High	Dry	Long
8	High	Medium	Medium
9	High	Wet	Fast

Figure 3 shows a Fuzzy Inference System where Evapotranspiration and soil moisture content are input values. After completing the Fuzzification, the Defuzzification methodology generates an output to create the pump status. input and output membership functions are formulated using trapezoidal functions. Figure 4 shows the membership function for Evapotranspiration, whose parameters were as low, medium, and high. Figure 5 illustrates the membership function for soil moisture, whose parameters were dry, medium, and wet. Figure 6 shows the membership function for Duration irrigation, whose parameters were as off, fast, medium, and slow.

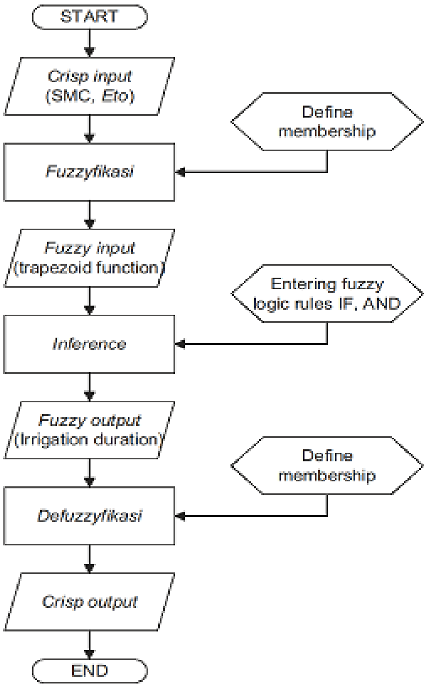

Figure 3. Fuzzy inference system.

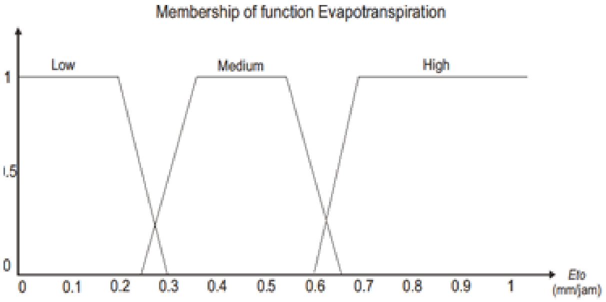

Figure 4. Evapotranspiration membership function

Membership functions for Evapotranspiration measurement:

$$\mu_{\mathrm{Low}} = \left\{ \begin{array}{cc} x \geq 0.3 & 0 \\ 0.25 < x < 0.3 & \dfrac{0.3 - x}{0.3 - 0.25} \\ x \leq 0.3 & 1 \end{array} \right\} \quad (1)$$

$$\mu_{\mathrm{Medium}} = \left\{ \begin{array}{cc} x \leq 0.25 & 0 \\ 0.25 < x < 0.3 & \dfrac{x - 0.25}{0.3 - 0.25} \\ 0.3 \leq x \leq 0.55 & 1 \\ 0.55 < x < 0.6 & \dfrac{0.65 - x}{0.65 - 0.55} \\ x \geq 0.6 & 0 \end{array} \right\} \quad (2)$$

$$\mu_{\mathrm{High}} = \left\{ \begin{array}{cc} x \leq 0.55 & 0 \\ 0.55 < x < 0.6 & \dfrac{x - 0.6}{0.6 - 0.55} \\ x \geq 0.55 & 1 \end{array} \right\} \quad (3)$$

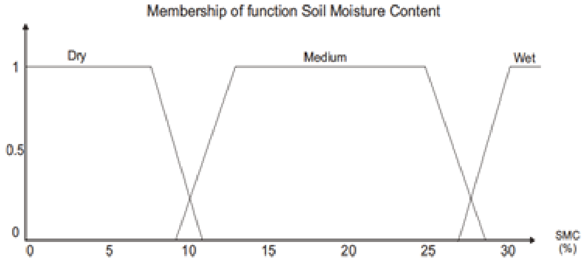

Figure 5. Soil moisture content membership function

Membership functions for Soil moisture content measurement:

$$\mu_{\mathrm{Dry}} = \left\{ \begin{array}{cc} x \geq 11 & 0 \\ 9 < x < 11 & \dfrac{11 - x}{11 - 9} \\ x \leq 11 & 1 \end{array} \right\} \quad (4)$$

$$\mu_{\mathrm{Medium}} = \left\{ \begin{array}{cc} x \leq 9 & 0 \\ 9 < x < 11 & \dfrac{x - 9}{11 - 9} \\ 11 \leq x \leq 27 & 1 \\ 27 < x < 29 & \dfrac{29 - x}{29 - 27} \\ x \geq 29 & 0 \end{array} \right\} \quad (5)$$

$$\mu_{\mathrm{Wet}} = \left\{ \begin{array}{cc} x \leq 27 & 0 \\ 27 < x < 29 & \dfrac{x - 29}{29 - 27} \\ x \geq 27 & 1 \end{array} \right\} \quad (6)$$

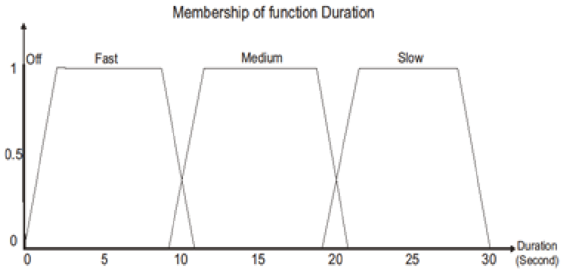

Figure 6. Duration membership function

Membership functions for Duration measurement:

$$\mu_{\text{Off}} = \left\{ \begin{array}{ll} x = 0 & 1 \\ x \geq 0 & 0 \end{array} \right\} \quad (7)$$

$$\mu_{\text{Fast}} = \left\{ \begin{array}{cc} x \leq 0 & 0 \\ 0 \geq x \leq 9 & 1 \\ 9 < x < 11 & \frac{11-x}{11-9} \\ x \geq 11 & 0 \end{array} \right\} \quad (8)$$

$$\mu_{\text{Medium}} = \left\{ \begin{array}{cc} x \leq 9 & 0 \\ 11 < x < 9 & \frac{x-9}{11-9} \\ 11 \leq x \leq 19 & 1 \\ 19 < x < 21 & \frac{21-x}{21-19} \\ x > 21 & 0 \end{array} \right\} \quad (9)$$

$$\mu_{\text{Slow}} = \left\{ \begin{array}{cc} x \leq 19 & 0 \\ 19 < x < 21 & \frac{19-x}{21-19} \\ 21 \geq x \leq 30 & 1 \\ x \geq 30 & 0 \end{array} \right\} \quad (10)$$

2.4. Calculation and data analysis

The study conducted observations of irrigation duration, irrigation time, and climatic conditions before and after irrigation were carried out in both treatments. Irrigation duration and irrigation time are used to calculate the volume of water. The equation calculates the irrigation volume using equation 11. The calculated volumes are then added together to determine the total irrigation volume using formula 12. Calculate the efficiency of irrigation supply by comparing the two treatments using equation 13. Statistical analysis using Independent Sample T-Test to determine whether there is a significant difference between treatment:

$$\mathbf{V} = Q \; x \; t \quad (11)$$

where $\mathbf{V}$ = volume of water (ml), Q = irrigation discharge (ml/second), t = duration (seconds)

$$\sum \mathbf{v} = \mathbf{v}_1 + \mathbf{v}_2 + \mathbf{v}_3 + \ldots + \mathbf{v}_n \quad (12)$$

Where $\sum \mathbf{v}$ = total irrigation, $\mathbf{v}_1$ = first irrigation, $\mathbf{v}_n$ = irrigation to n

$$\eta = \frac{\mathbf{v}_{non-fuzzy} - \mathbf{v}_{fuzzy}}{\mathbf{v}_{non-fuzzy}} x100\% \quad (13)$$

3. RESULT AND DISCUSSIONS

The reference Evapotranspiration steps per hour were estimated using the FAO 56 Penman-Monteith model implemented in real-time calculations [9]. In this study, the *ETo* measurement uses a Maxx 44009 sensor as a converted sunlight sensor and an HDC1080 sensor as a temperature and humidity sensor.

Observation of the value of (*ETo*) within seven days. On the 5th day, the highest ETo value was 0.85 mm/hour, as shown in Figure 8. However, if you look at the cumulative *ETo* value in one day, the highest was on the 4th day of 6.83 mm/day, as shown in Figure 7.

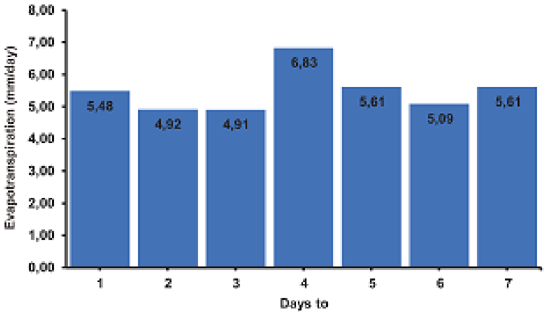

Figure 7. Cumulative daily *ETo*

In Figure 8, it can be seen that the Evapotranspiration conditions that occur are directly proportional to solar radiation, where at night, the *ETo* value is close to 0. However, during the day, *ETo* will increase with increasing solar radiation, with the *ETo* range reaching 0 - 8.5 mm/day. Soil moisture content conditions are also relatively stable, with soil moisture content values of 29-31%.

Provision of irrigation using a fuzzy model that pays attention to soil moisture content conditions and pays attention to environmental conditions through Evapotranspiration can maintain soil moisture content stability because Evapotranspiration can represent the relationship between plants and environmental conditions so that irrigation can adjust plant water need [4]. Soil moisture retained in the range of 29-31% in rice plants allows plants to grow optimally because their water needs are still being met. However, some anomalies are pretty apparent in the measurements but have no significant effect.

The calibration of the soil moisture content in this study used the gravimetric method carried out in the study [7]. in observing the value of soil moisture content for seven days. In observing the value of soil moisture content for seven days. In both irrigation treatments, with or without fuzzy, there was no difference. Soil moisture content is stable and maintained in the range of 29-31%. Irrigation with a fuzzy model based on ETo and the value of soil moisture content is proven to replace the lost water needs of plants due to absorption by plants and evapotranspiration. Irrigation without fuzzy also has the same value of soil mositure content even in flooded conditions. The results of laboratory tests, soil textured sandy loam, soil moisture content of 38.57% consider if pF = 1. Soil moisture content is in the range of 29-30% due to soil compaction. Waterlogging reduces the stability of soil aggregates through colloid swelling [18]. In line with research [16] in a 10-day experiment, waterlogging on silty clay soils decreased by 2.2%.

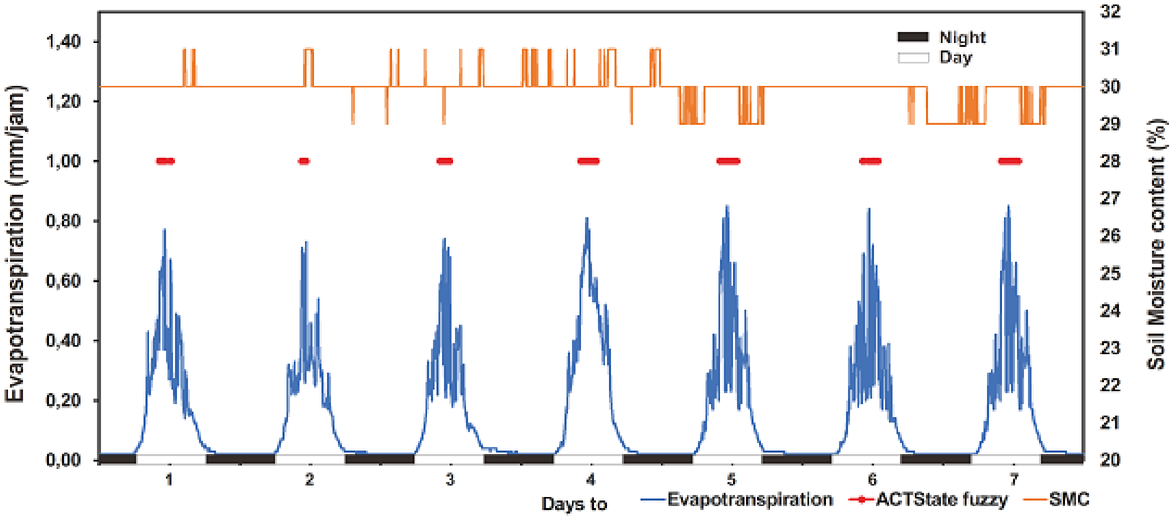

Figure 8. Hourly reference Evapotranspiration (*ETo*) and soil moisture content on irrigation response using a fuzzy model

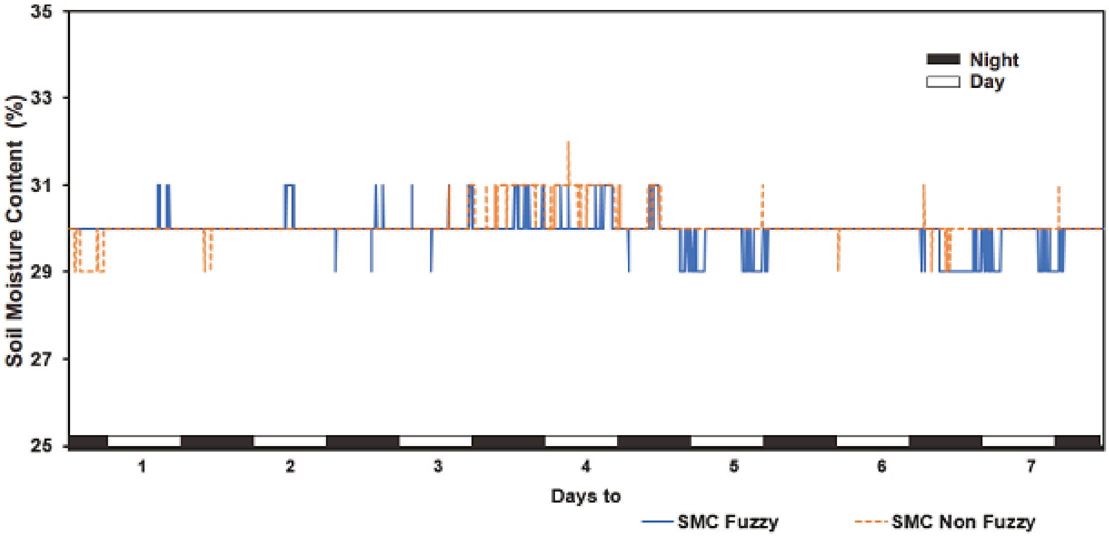

Figure 9. Comparison of soil moisture content of irrigation responses using fuzzy and non-fuzzy model

In this study, the measurement of water level (WL) uses an ultrasonic sensor HCRS04 as a distance sensor. Due to differences in irrigation, water level conditions in the two treatments were also different. In the treatment with non-fuzzy irrigation control, the water level was in the range of 1 - 3 cm above ground level. In the treatment with irrigation control using fuzzy, the water level is at -4 to 0 below ground level. As shown in Figure 10.

The calculation of irrigation volume in fuzzy treatment that occurs during the day when the maximum Evapotranspiration value and soil moisture conditions range from 29-31%, the analysis of the total irrigation time is 115 seconds. With a discharge of 0.52 L/s water so that the entire water flowed was 60 liters. While the non-fuzzy treatment was based on water level, the total duration of irrigation was 240 seconds. With a water discharge of 0.52 L/s so that the entire water flowed was 125 liters. And irrigation using fuzzy is more efficient by 52.08%.

The mean measurement results were statistically tested using Independent Sample T-Test with SPSS software. The test aims to determine the differences in 2 samples given different and unrelated treatments (Raharjo, 2015). The statistical analysis results of the Independent Sample T-Test with SPSS for irrigation efficiency are shown in table 2. The results of the statistical analysis of irrigation efficiency obtained a significance value of Sig. (2-tails) of 0.004 < 0.05, as shown in Table 2. It can be concluded that H0 is rejected and H1 is accepted, which means a significant difference in irrigation between the two treatments with a 95% confidence level, where fuzzy irrigation is more efficient than using non-fuzzy. SRI irrigation using fuzzy is 52.08% more efficient than SRI without fuzzy

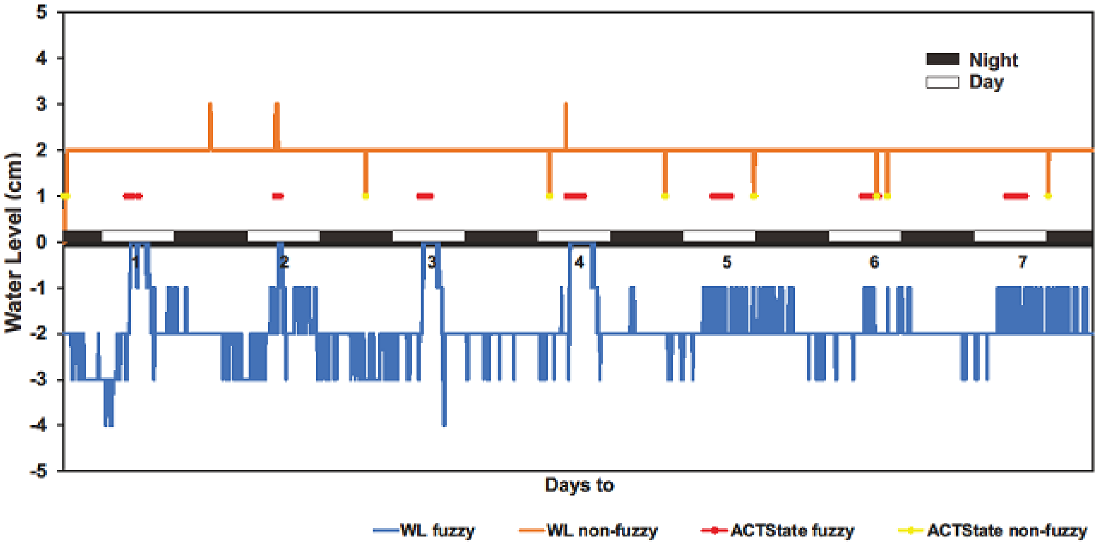

Figure 10. Comparison of water level to irrigation response using a fuzzy and non-fuzzy model

Table 2. Independent Sample T-Test statistical test on irrigation efficiency of both treatments

`Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Efisiensi irrigation	Equal variances assumed	7.744	.017	4.205	12	.001	13.00000	3.09157	6.26404	19.73596
	Equal variances not assumed			4.205	6.953	.004	13.00000	3.09157	5.67960	20.32040

4. CONCLUSION AND FUTURE WORKS

Implementing the irrigation monitoring and control system on SRI shows that the fuzzy logic system can control irrigation. *ETo* and soil moisture content can control irrigation for rice plant growth. The use of this system as an irrigation decision-maker can increase the efficiency of water use. The comparison of the SRI system that uses fuzzy 52.08% is more efficient than the non-fuzzy SRI system. Furthermore, implementing a monitoring and control system that occurs in real-time is essential for fast and accurate decision-making.

AUTHORS CONTRIBUTION

Rido Saputra prepares literature, creates program codes, collects research data, prepares and edits manuscripts. Andri Prima Nugroho provides program code suggestions, recommends system development and script review. Murtiningrum designed the research environment setting. Sigit Supadmo Arif developed the research system.

ACKNOWLEDGMENTS

This study was supported by the Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology at the Universitas Gadjah Mada. Also, the author would like to thank the Smart Agriculture Research group of Agricultural and Biosystems Engineering UGM for the support.

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