Plant Watering Management System Using Fuzzy Logic Approach in Oil Palm Nursery

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Abstract**—Plant watering is an important part of a nursery production. In oil palm plantation, the nursery is the basis to produce healthy seedlings. In nurseries, several plants of different stages of their growth are raised. Therefore, timely and right amount supply of water is essential. Thus, a proper arrangement should be made to meet the water requirement of a nursery. Nursery supervisor may face difficulties to acquire the exact amount of water requirement needed by plants due to factors like rainfall and watering time. The decision to determine the amount of required water is crucial to avoid excessive or inadequate water supply, which gives bad effects to the plant's growth. Therefore, Water Management System based on fuzzy approach is introduced to help nursery supervisor to manage the watering system in the nursery appropriately. External factors of rainfall and watering time are used to determine sufficient amount of water based on fuzzy logic approach. Nursery supervisor can view watering simulation, which shows the watering status of each plant bed in the nursery. This system emphasizes its benefit to assist nursery supervisor to manage and monitor a watering task for a better nursery management.**

Index Terms**—Fuzzification; Fuzzy System; Oil Palm Nursery; Watering Management.**

I. INTRODUCTION

Palm oil industry is one of the significant players in the agricultural sector that contributes to the development of Malaysia [1]. Oil palm has an economic productive lifespan of more than 20 years [2]. Accordingly, the selection of quality plant and its environment is vital to maximize the yields. The production of an oil palm plantation depends on several factors and one of them is the quality of planting materials raised at the nursery. Practically, the nursery is one of the important substances in the supply chain for palm oil production. The production of high-quality oil palm seedlings is very much dependent on good nursery management and practices. The nursery practices including watering, culling, pest and disease control, and weeding should be closely supervised to ensure that all operations are on time and correctly implemented. A nursery stage is required to have constant close attention during the first year of the plant's growth and development [3]. A nursery enables closer supervision and facilitates undesirable threat to the seedlings. Therefore, raising health seedlings with a good environment in the nursery is essential. The selection of planting material and nursery management is crucial to produce healthy plants.

A success factor in the nursery is the availability of sufficient water to ensure the optimum growth of the seedlings. The plant shall receive sufficient quantity of water until they are prepared for field planting. Inadequate watering caused pest infection and disease problems in the nursery due to the weak stage of seedlings. Inadequate watering in the nursery may be indicated by the incidences of *collante* and blast disease [4]. Poor or uneven coverage of the irrigation system may also lead to seedlings of poor uniformity. Meanwhile, excessive water may suffocate the plant roots and inadequate amount of water may affect the sustainability of the plants. Excessive water is harmful to crops and soils. Thus, palm oil requires a good nursery management to have quality and nutrition products.

Watering in the nursery is vital to ensure the growth of seedlings is healthy with the supplement of water from the resources. Usually, plant watering is done in the morning and evening [3]. However, the weather may influence the amount of water required by the plant. The farmer may face difficulties to decide when to water, due to some circumstances. For instance, if the weather changed suddenly, then a decision, whether to water the plant or vice versa must be made. If rainfall is heavy, it can affect the watering process and changes in the required amount of water must be made. In this case, the decision to the required amount of water needed by the plant is necessary. Inadequate or excessive amount of water to oil palm can lead to a poor watering management system if it is not handled sufficiently. Additionally, the decision of the right amount of water is usually imprecise as it depends on one's experience and skills. Linguistic terms such as 'little', 'sufficient' and 'much' result in the lack of precision when making decision. This issue can be addressed by using the right technique to improve the efficiency of the decision, i.e. fuzzy computation. Such situations may affect the efficiency of work process when determining the amount of water for plant watering in the nursery. Additionally, monitoring process for watering task is important to support part of the nursery management. Nursery supervisor requires a tool to monitor the watering status of various plant stages in the nursery. Poor watering task schedule management may lead to the inconsistent watering time, which may affect the right amount of water needed by plants.

Motivated by the above-mentioned circumstances, this study introduces a watering management system for oil palm nursery using a fuzzy logic approach. A fuzzy logic approach is utilized to support the decision to determine the amount of required water. A simulation tool is provided to determine the required amount of water for the oil palm nursery. The two input factors that used fuzzy decision making to determine the amount of water required for oil palm nursery in this study are time to water and rainfall condition. Fuzzy linguistics are determined for all input and output parameters. A watering management system is significant to help the farmer or the nursery supervisor to determine the amount of water requirement, handle the watering schedule, and monitor the watering process. Nursery supervisor can handle farm information in a database for proper data management. Using this system, a consistent watering schedule with sufficient amount of water is provided, hence supporting the farm's best practice.

This paper is organized into six sections. Section I introduces the background of the study. Section II sets out the review of the literature. Section III describes the methodology of the system, and Section IV explains the problem solution. Section V states the findings and conclusion are drawn in Section VI.

II. RELATED WORK

Oil palm is grown for the industrial production of vegetable oil [5]. The crop requires sufficient water supplies with a slight dry season, stable high temperatures, and good soil [4] to achieve optimal yields. Water resource for the oil palm usually comes from nature and rainfall. In the nursery, where oil palm seedlings are cultivated, it is important to ensure that the amount of water is sufficient to support the plant's growth. Currently, two types of irrigation water system to oil palm nursery are water sprinkler system and sumi-sansui system [6]. A pre-nursery seedling requires water every day, where 4 mm of water should be applied every two days if no rainfall [6]. The amount applied depends on the age of the plants. If rainfall is less than 10 mm per day, irrigation is required, and the system must be capable of uniformly applying 6.5 mm water per day [4,6]. Hand watering systems may be sufficient in small-sized nurseries. Monitoring during irrigation ensures the water is distributed evenly and soil is moistened appropriately [7]. Monitoring should be conducted to fully meet the water requirements of the plants throughout the nursery period. Practically, excessive watering has a bad influence on the plants compared with a slight lack of water.

In the field of agriculture, it is important to use proper method of irrigation and monitoring. Water management is the central issue in many cropping systems [8]. Automation of watering system has the potential to provide maximum water use efficiency. In conventional irrigation system, the farmer must monitor watering schedule. Different plant at different growing stage requires different supplies of water, which depends on several parameters. At present, automatic watering and irrigation system has been employed to optimize water usage based on plant's requirements. [9] proposes a new irrigation system using the fuzzy logic technique by mapping the knowledge and experience of a traditional farmer. [10] propose an intelligent controller using fuzzy logic approach for irrigation of agricultural field. Additionally, the artificial neural network is employed in water management system in crops to control water usage in flexible and knowledgeable approach [11]. Such intelligent approach, which is embedded into existing water system has shown its effectiveness to decrease manual effort, saves energy and resources, and maximize the productivity at an effective cost.

III. FUZZY DECISION MAKING FOR PLANT WATERING MANAGEMENT

The development of a Fuzzy Decision Making for Water Management System in Oil Palm Nursery involves the construction of a problem specific fuzzy knowledge base by acquiring knowledge from experts or documented sources. The process flow of water management system through fuzzy logic approach is illustrated in the following procedural steps:

1. Problem assessment: Determine the problem's parameter and justify important characteristic.
2. Knowledge Conceptualization and Formalization: Experts and analysts elucidate the fuzzy variables and membership function, relations, and information-flow characteristics needed to describe the problem-solving process. Subsequently, designing stage involves key concepts and relations mapping in a formal representation, and identifying system development requirements.
3. Fuzzy System Design: Fuzzification, fuzzy inference, and defuzzification process. Construction of fuzzy inference rules.
4. Implementation: the execution of plan, model, design, algorithm and program code.
5. Testing: Evaluation of the prototype program performance.

A. *Input and Output Requirement*

A solution of problems is outlined using one set of inputs and output fields. Input required to implement the fuzzy system are as follows:

i. Rainfall (millimeter)
ii. Time to water (24 hours)

The output specification is the process that happens in the interface of the system that is the watering management module. In this module, the output, which is the amount of water required for the oil palm nursery that will appear on the screen. The information that will be displayed in the system is as follows:

i. Value of membership linguistic for both inputs
ii. Value of membership linguistic for output
iii. Input and output membership function graphs
iv. Table of Fuzzy Associative Matrix (FAM)
v. The final output of the system, which is the water requirement

B. *Fuzzy System Design*

Fuzzy system design mainly consists of three important components, which are *fuzzification*, *fuzzy inference engine* and *defuzzification* [12-14]. The fuzzification is a process of converting the real crisp value into linguistic value. Fuzzy logic implements human experiences and preferences via membership functions and fuzzy rules. In fuzzy logic, each linguistic variable is associated with confidence values such that each term has its own confidence value. From the linguistic variable definition, a membership function graph can be drawn.

A membership function is a curve that defines how true a given statement is for a given input values. It defines how each point in the space is mapped to a membership value from

0 to 1. Fuzzy inference is then used to interpret the values in the input vector and referred to some sets of rules to assign values to the output vector. The inference engine consists of rules and knowledge base, which are important to generate the output. The defuzzification converts the linguistic variables into a crisp (numerical) value. The specific fuzzy system component is depicted in Figure 1.

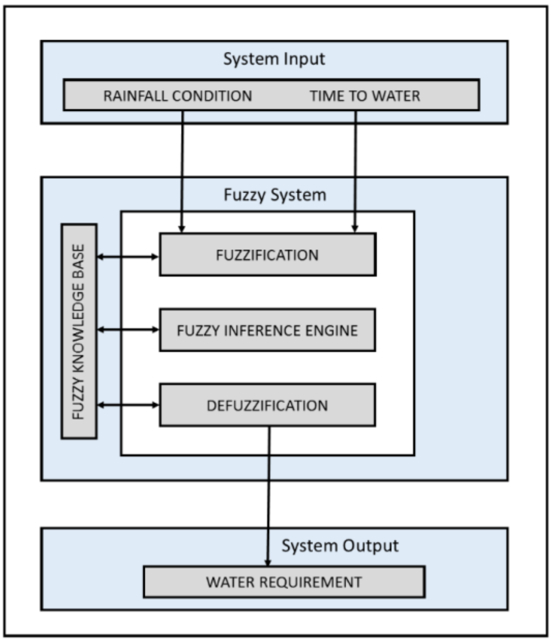

Figure 1: Fuzzy water management system architecture

(i) Fuzzification

Fuzzification is a process of changing a real scalar value into a fuzzy value. In this system, two fuzzy variables are identified as rainfall condition and time to water. Appropriate fuzzy linguistic values are assigned for each fuzzy variable. The determination of this information is assisted by the expert from the farm field.

- Input: *Rainfall condition* {light, medium, heavy}
- Input: *Time to water* {morning, afternoon, evening}
- Output: *Water requirement* {little, moderate, much}

(ii) Membership Function Graph

Membership function graphs are produced based on the input and output variables. The values of the range for the input and output variables are obtained and determined from the expert, nursery supervisor and agriculture officers.

Figure 2 illustrates the membership function graph for the input factor time to water. The linguistic variables involved are *morning*, *afternoon* and *evening*. If the value is less than 1000 (10.00 a.m), then the fuzzy set is labelled as *morning*. If the value is between 1200 and 1400, then the fuzzy set is labelled as *afternoon*. If the value is 1500 and above, the fuzzy set is labelled as *evening*.

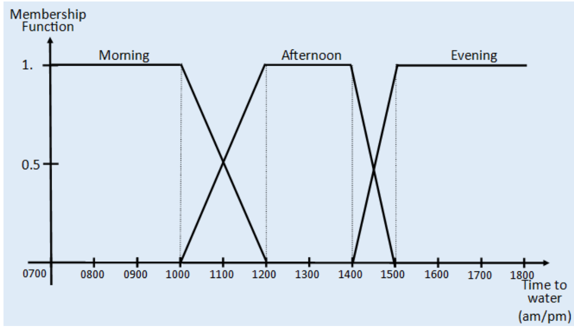

Figure 2: Membership Function Graph For Time To Water

Figure 3 illustrates the membership function graph for input factor rainfall condition. The linguistic variables involved are light, medium and heavy. If the value is less than 2mm, then the fuzzy set is labelled as *light*. If the value is between 5mm to 8mm, then the fuzzy set is labelled as *medium*. If the value is 10mm and above, the fuzzy set is labelled as *heavy*.

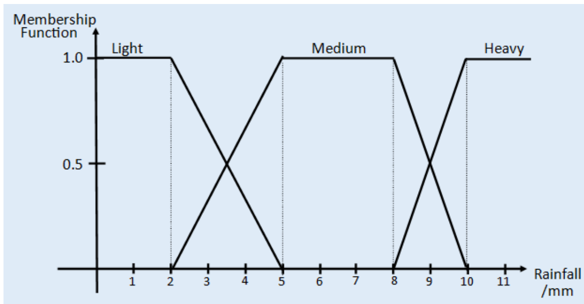

Figure 3: Membership Function Graph For Rainfall Condition

(iii) Fuzzy Inference

The knowledge base is a collection of knowledge and rules for certain problems. It is designed to imitate human thinking to solve problems and provide information [13]. In this system, the knowledge base is designed by using Fuzzy Associative Matrix (FAM) as presented in Table 1.0. FAM is identified by a matrix of fuzzy values. It allows the mapping of an input fuzzy set into an output fuzzy.

Based on expert explanation, there is no requirement to water in the afternoon. This is due to the stomata of oil palm is closed in the afternoon. The stomata open only in the morning and evening to undergo the processes of photosynthesis and respiration.

Table 1
Fuzzy Associative Matrix for Fuzzy Water Sprinkler System

Time to water/rainfall	Light	Medium	Heavy
Morning	Much = {light, morning}	Moderate = {medium, morning}	Little = {heavy, morning}
Afternoon	No need = {light, afternoon}	No need = {medium, afternoon}	No need = {heavy, afternoon}
Evening	Much = {light, evening}	Moderate = {medium, evening}	Little = {heavy, evening}

The fuzzy rules are constructed based on the FAM by using the if-then statement. The rules define the conditions expected and outcomes desired with `If/Then` statements. The fuzzy inference rule base is the controller part of the system, and it is based on truth table logic. The rule base is a collection of rules related to the fuzzy sets, the input variables, and the output variables.

Rule base which is derived from FAM are as follows:

1. If rainfall is *light* and in the *morning*, then the water requirement is *much*.
2. If rainfall is *light* and in the *evening*, then the water requirement is *much*.
3. If rainfall is *medium* and in the *morning*, then the water requirement is *moderate*.
4. If rainfall is *medium* and in the *evening*, then the water requirement is *moderate*.
5. If rainfall is *heavy* and in the *morning*, then the water requirement is *little*.
6. If rainfall is *heavy* and in the *evening*, then the water requirement is *little*.

The rule produced by the FAM contains AND operator which makes minimum method to be used for inferencing purpose. Let $A$and Bbe fuzzy sets that $, B \in \mathcal{U}$, and $u$is an element in the universe, $\mathcal{U}$. Intersection of the fuzzy set is as follows:

$$\mu_{A \cap B}(u) = min\{\mu_A(u), \mu_B(u)\} \quad (1)$$

(iv) Defuzzification

This phase is to find one single crisp value that summarises the fuzzy set. There are several mathematical techniques used such as Centre of Area (COA), weighted average, Mean of Maxima (MoM) and Centre of Sums (COS) [3]. Centre of Area (COA) is employed in this study as it is widely used for efficient computation [15]. It provides the center of the area under the curve of the membership function. COA is expressed as follows:

$$z^* = \frac{\int \mu_i(x) \cdot x dx}{\int \mu_i(x) dx} \quad (2)$$

where z* is defuzzified output, μ_i is a membership function and x is the output variable

Alpha and beta testing are held after the programming task and database development are completed. All the units developed in the implementation phase are integrated into a system after testing each unit. The watering simulations of plant bed are tested to the respective user in oil palm nursery.

IV. Fuzzy Watering Management System for Oil Palm Nursery

This section discusses the development of Fuzzy Watering Management System for Oil Palm Nursery. Generally, it explains the implementation and development of functional modules identified in the previous section. Functional testing is performed to ensure the developed system satisfies the system requirements.

Hypertext Preprocessor (PHP) language is used during the system development and MySQL as database management system. The interface development permits the user to interact with the system while system module's realization supports functionalities of the developed system. The watering management module allows the staff to calculate the amount of water by using the method of fuzzification where this method can decide the values by using the rules provided by the expert. Figure 4 shows the interface of the watering management module of the system.

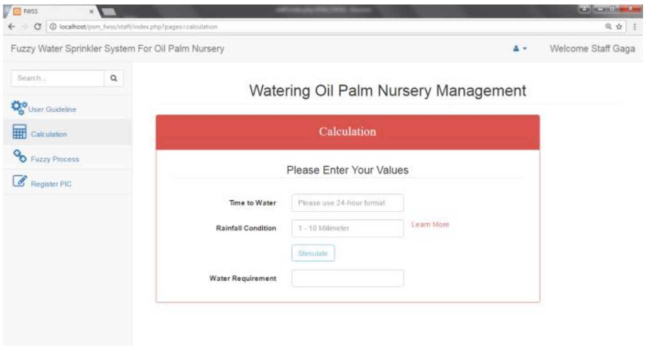

Figure 4: Interface of the watering management module

The Fuzzy System Management module is the module that manages the fuzzy system rules and its membership function of all the inputs and output which is time to water, rainfall condition and water requirement. Using the information displayed on this page, users can understand the fuzzy information process provided in this system. Figure 5 shows the interface of the Fuzzy System Management module of the system.

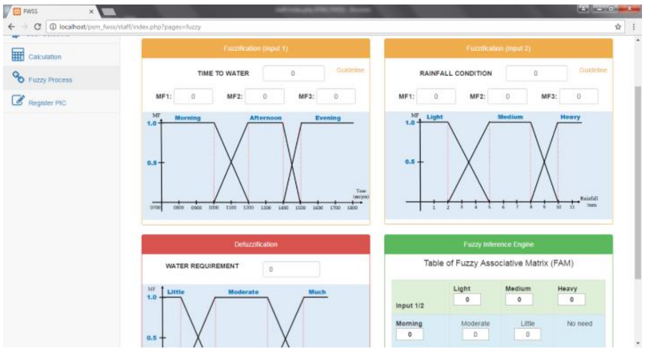

Figure 5: Interface of the Fuzzy System Management Module

Table 2 tabulates test case I for inputs. Values of test I are entered into the system through a user interface (i.e. Figure 4.0). Afterwards, the system generates the results based on fuzzy inference engine which has been built in the system. Table 2 shows the user input interface of test case I.

Table 2
User Input Test Case 1

Question	User Input
Variable 1: Time to water	1450
Variable 2: Rainfall Condition	2

The fuzzy simulation process is provided in the system to gives an explanation of fuzzy inferencing process. Figure 6 displays the fuzzy process.

Figure 6: Data displayed on the fuzzy system management

Further, Fuzzy Data Management is provided in this system. This module contains administrative functions such as calculation management, fuzzy set variables and ranges management, and fuzzy rule management as shown in Figure 7.0.

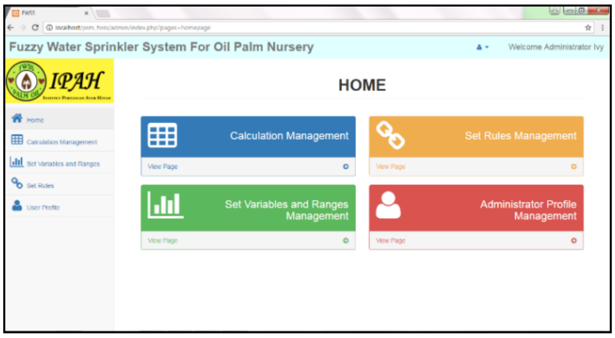

Figure 7: Administrative fuzzy data management

Figure 8.0 shows Watering management module used to view the data entered by staff. The information is recorded for monitoring purpose and reference.

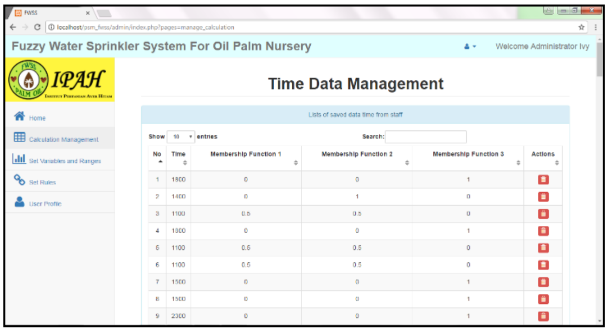

Figure 8: Calculation management page

Figure 9 shows the Fuzzy Variable Management. This function allows an administrator to insert new fuzzy variables (if necessary) and to manage linguistics variable.

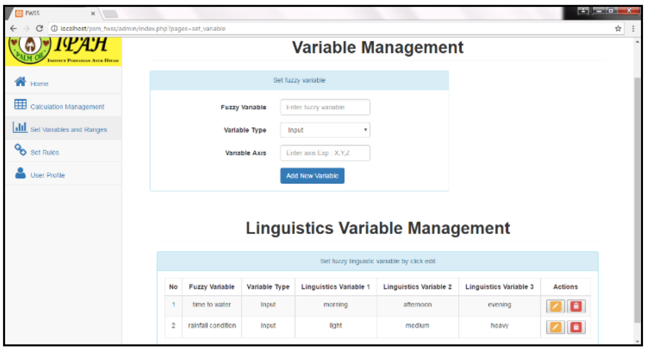

Figure 9: Variable management and linguistics variable management page

Simulation on fuzzy inferencing process for water management system is also conducted using the Matlab software. Figure 10 lists the fuzzy rules used in the system.

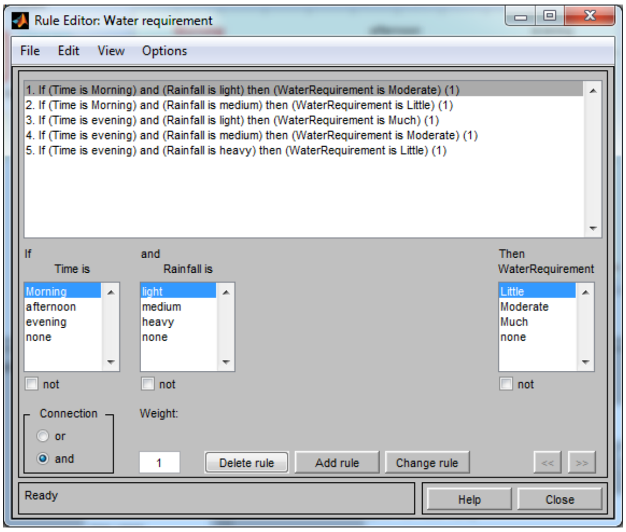

Figure 10: Fuzzy rules

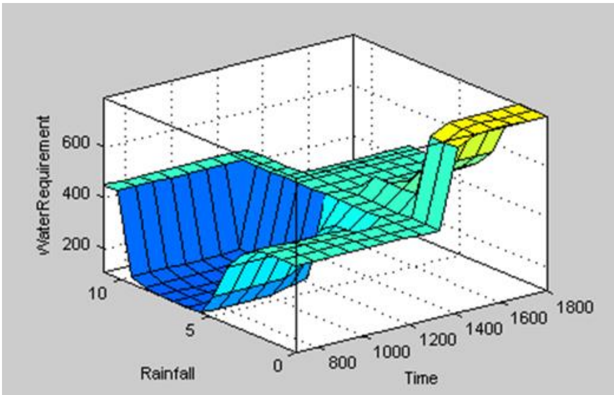

Figure 11: 3-Dimension graph for the system experiment

Figure 11 demonstrates the result of the system experiment. The 3-D graph illustrates optimality in making a decision towards water requirement based on the determined parameters, and support fuzzy based decision making for the decision maker in the nursery.

V. Conclusion

A watering management system for the oil palm nursery is developed based on fuzzy logic approach. Fuzzy decision making provided in the system is able to determine the optimal amount of water required by oil palm in the nursery based on the input given by the user. This system presents its functions which have been identified as follows:

i. Ability to calculate the amount of water requirement for oil palm in the nursery by using fuzzy logic approach.
ii. Easy handling for its user specifically to figure out the water requirement needed by oil palm nursery.
iii. Summary report for watering monitoring.
iv. Data management including information of fuzzy variables, linguistic variables, ranges and rules of the fuzzy logic.

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