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Design of Scheduled Fog Irrigation System with ESP 32 in Mustard Seedbed (*Brassica juncea* L.)

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ABSTRACT

Plants receive water from the fog irrigation system in the form of tiny, mist-like water particles. Currently, irrigation technology has advanced, nurseries can be automatically irrigated. In this research, the ESP32 microcontroller is used to create the electronic circuits for the automation of the fog irrigation control system in a mustard green nursery. This study's methodology combines direct field observation with an experimental or trial approach. Water flow (ml/minute), water use efficiency (%), plant height (cm), number of leaves, and scheduled fog irrigation system performance are among the measured parameters. In this investigation, four different treatments were used: manual irrigation using a watering can, two-time, three-time, and one-time irrigation. All is going according to plan with this mist watering system. With an average height of 4.58 cm and an average number of leaves of 3.24, the mist irrigation system had the highest water use efficiency of 77.35% during the test. It was also found that mist irrigation produced the highest amount of mustard leaves in the three-times-per-day treatment.

1. INTRODUCTION

The realization of agriculture's contribution to food security in the midst of climate change scenarios, economic and energy crises, has caused the concept of food sovereignty and agroecotechnology-based production systems to receive a lot of attention in developing countries in the last two decades (Amarullah *et al*., 2023). Many new approaches and technologies involve the application of a combination of modern agricultural science and indigenous knowledge systems and are pioneered by farmers. This combination is a system of local karifan values owned by the community in agricultural management that is carried out from generation to generation in the midst of agricultural modernization (Tamu, 2022). In addition, non-governmental organizations and several government and academic institutions have been shown to improve food security while preserving biodiversity, soil and water resource conservation in hundreds of rural communities in developing countries (Altieri *et al*., 2012). The development of science and technology has progressed to penetrate all areas of life, and almost all human activities, from industry to households and agriculture, use modern technology that can certainly speed up and streamline various kinds of daily work. On the other hand, some farmers still use traditional methods in agricultural techniques that result in not maximizing their agricultural or plantation yields (Mallareddy *et al*., 2023). To increase crop yields, one of them is the need to apply effective and efficient modern automation technology in this field (Fitriawan *et al*., 2020). One of the applications of modern automation technology is the use of control systems, which are an arrangement of system components that have long been developed and used by humans to maintain, govern, and regulate a system to keep it running properly (Subahi & Bouazza, 2020). The development of control systems in the modern era has evolved to optimize the interaction between devices and the environment, which is called the Internet of Things (IoT). The main goal of a control system is to get optimal quality of work on a system that has been designed, while the main goal of IoT is to improve efficiency and quality of life by optimizing the interaction between devices and the environment. IoT devices can automatically track and monitor conditions, make decisions and provide reports to users (Haris *et al*., 2023).

Along with the development of technology in agriculture, one of the food crops cultivated with the support of IoT devices is mustard greens (*Brassica Juncea* L.). Mustard greens (*Brassica juncea* L.) are a type of vegetable that is very well known and in great interest among farmers and consumers because in addition to being used as a vegetable food, it can also be used for the treatment of various diseases such as cancer (Alifah *et al*., 2019; Istarofah & Salamah, 2017), so that mustard greens are one of the parts of the vegetable group that has an important role in meeting the needs of food, nutrition, and medicine for the community. Mustard greens (*Brassica juncea* L.) adapt well to hot and cold climates so that if cultivated in highland and lowland areas, mustard greens will develop very well (Lehalima *et al*., 2021). Soil that is suitable and also good for planting mustard greens is soil that has a loose texture then contains a lot of humus and is fertile and has good water drainage. Mustard greens are one of the types of vegetables that are easy to cultivate, so they are often grown hydroponically (Nolan, 2019; Faruq *et al*., 2021). In addition, mustard greens can also be planted in polybags on narrow plots, for example in the yard of houses and also on plantations. In the process of cultivating mustard greens, the use of fertilizers to support plant growth and increase soil fertility is the main thing that needs to be considered (Rehman *et al*., 2022). Fertilization is an alternative that is carried out to obtain nutrients in the soil so that it can increase the production of soil fertility and agricultural products (Rohayu *et al*., 2024).

For the degree of acidity or pH of the soil, which is good for mustard greens, it is between 6 and 7 (Pratomo, 2022). Mustard greens are very happy to grow at low temperatures, especially in the rainy season (Shekhawat *et al*., 2012), so the thing that must be considered is that when entering the dry season, the need for water is very necessary because this mustard vegetable plant cannot survive the dry season. Therefore, water needs will greatly affect the growth of mustard greens (Koehuan, 2023; Hanum *et al*., 2021).

Not only that, the availability of water during the plant nursery period must be attentive, plant seedlings need water that suits their needs, no more and less. Excess water in plants can cause decay in plants and also if there is a lack of water, it can have a great effect on physiological and metabolic processes in seedlings or die (Fauzi, 2020; Felania, 2017). With the fulfillment of water needs in seedlings, plants can grow and reproduce properly. Unlike plants that are mature, and have many and strong roots so that they are able to find water on their own, even infrequent watering can usually survive. Currently, watering seedlings is still carried out by human labor, so it requires a long time and energy. In addition, the majority of irrigation systems in Indonesia are still traditional, so the effectiveness of water distribution into rice fields is still low. The low irrigation management system is one of the reasons for inefficient irrigation and low levels of irrigation services, causing wasteful use of irrigation water (Nasarudin *et al*., 2020).

Watering plant seedlings can be done automatically by taking advantage of very advanced technological developments and advancements, one of which is by utilizing a programmable microcontroller to water mustard seedlings according to the desired time. The use of microcontrollers with mist irrigation is a water delivery system that releases water into the air around plants automatically with smaller water droplets than sprinkler irrigation. Mist irrigation is not designed to drain water directly into the root zone, but mist irrigation systems can provide enough water to meet the water needs of plants (Maher *et al*., 2008). This mist irrigation is very suitable for giving mustard seedlings to maintain air humidity (Anjeliza, 2013) as well as the application of water-saving irrigation. Therefore, this study aims to design an aid for a scheduled fog irrigation system using ESP32 in the seedbed of mustard plants (*Brassica juncea* L.).

2. MATERIALS AND METHODS

2.1. Tools and Materials

The tools used are laptop, ESP32, Relay, jumper cable, 12 V water pump, Real Time Clock (RTC), Numpad 1x4, LCD 20X4, I2C backpack module, power supply, component box, hose, spray nozzle, seedling tray, water bucket.

2.2. Method

The method used in this study is an experimental method or experiment with direct observation in the field. The parameters to be measured in this study are as follows:

1. Water discharge (l/min)

Water discharge Q (L/min) was in the fog irrigation system calculated from volume of water V (L) coming out of the nozzles and length of time t (min) to fill the volume of containers according to the following equation:

$$Q = V/t \tag{1}$$

2. Water use efficiency (%)

The efficiency of water use E_i (%) in fog irrigation systems was calculated from the water distributed to plants W_a (L/min) and water discharge Q (L/min) according to the following equation:

$$E_i = \frac{W_a}{Q} \times 100 \tag{2}$$

3. Mustard plant height (cm)

Plant height was measured at the age of 2 HSS, 4 HSS, 6 HSS, 8 HSS, 10 HSS.

4. Distributable water (ml/min)

Calculating the water distribution that can be done in a scheduled fog irrigation system is carried out by conducting a test by accommodating the amount of water that can be distributed by the fog irrigation system to the ground level where seeding is carried out.

5. Number of leaves (strands)

Number of Leaves is calculated at the age of 2 HSS, 4 HSS, 6 HSS, 8 HSS, 10 HSS

6. Performance of scheduled fog irrigation system equipment

The performance test of the tool was carried out by observing the performance of the scheduled fog irrigation system applied to mustard seedbeds. The performance test of the tool was carried out by observing the performance of the scheduled fog irrigation system applied to mustard seedbeds. The success parameters of the tool are that the scheduled fog irrigation equipment runs well and according to the program language plan that has been made. On the 20x4 LCD the appropriate date and time can be displayed, with the time and date running well, it can be stated that the RTC and the 20x4 LCD can run according to the program.

1. Preparation

Preparation is the stage of identifying the completeness of tools or materials.

2. Review of research sites

The review of the research site is a stage to determine the research site that is in accordance with the needs of the research process carried out.

3. Calculation of water consumption

Plant water need is the amount of water used to meet plant evapotranspiration (ET_c) in order to grow normally. The magnitude of ET_c (mm/day) was obtained from the equation (Salman *et al*., 2016):

$$ET_c = K_c \times ET_o \tag{3}$$

where K_c is the plant coefficient, and ET_o is the potential evapotranspiration (mm/day)

The value of the plant coefficient (K_c) for mustard greens in the early growth period (0-10 days) was 0.3, the middle growth period (11-20) was 1.2, and the late growth period (21-30) was 0.6 (Simangunsong *et al*., 2013). The potential evapotranspiration (ET_o) value was obtained from the calculation of temperature data where the study was conducted using the Hargreaves method (Fausan *et al*., 2021; Hafeez *et al*., 2020).

4. Designing a scheduled fog irrigation system

The process of designing this tool consisted of two parts, namely hardware design and prototype program. For more details, it is presented in Figure 2.

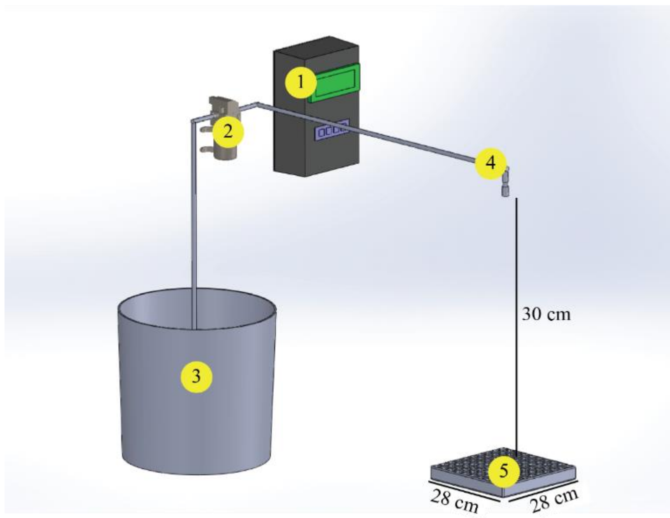

Figure 2. Scheduled fog irrigation system tool design. (Note: ❶ Controller, ❷ 12 V water pump, ❸ Water storage bucket, ❹ Mist nozzle and hose, ❺ seedling tray)

5. Calculate the water distribution that can be done

In fog irrigation systems, which distribute water to plants with finer and smaller water particles have a greater chance of losing water in the air when distribution is carried out. For this reason, a calculation of the amount of water distribution that can be carried out is carried out (Manik *et al*., 2020). The calculation was carried out by experimenting with fog irrigation and then storing water in the area to be watered. Calculating the distribution of water to plants W_a (L/min) in a fog irrigation system uses Equation (4) with V_i is the volume of water contained in fog irrigation areas (L), and t is time (min) to fill the volume of containers.

$$W_a = \frac{V_i}{t} \quad (4)$$

6. Testing of scheduled fog irrigation system

In this scheduled fog irrigation system, 3 trials will be carried out on different watering frequencies, including 1 watering, 2 watering, and 3 watering.

7. Seeding

Seeding mustard plants is carried out for 7 days by seeding using seedling trays. Mustard seeds are planted in each seedling tray hole with a total of 144 tray holes that will be filled with 1 mustard seed in each hole, in this seedbed it is noted that mustard seeds must be completely in the soil.

8. Observation

The observations made in this study include observations of the water discharge used and the growth of mustard seedlings. Observation of the growth of mustard seedlings was carried out for 7 days by measuring the height and number of leaves. Flow diagram of scheduled fog irrigation system was showed in Figure 3.

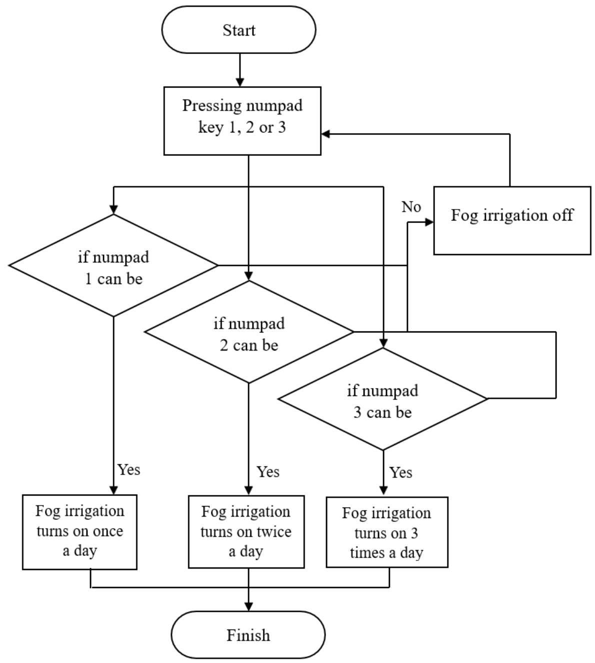

Figure 3. Scheduled fog irrigation system flow diagram.

Figure 3 shows the flow diagram of the scheduled fog irrigation system in the mustard seedbed, namely by making observations on the numpad and real time clock (RTC). When the Numpad 1 button is pressed, the mist irrigation system turns on 1 time a day, when the Numpad 2 button is pressed, the mist irrigation system turns on 2 times a day, and when the Numpad 3 button is pressed, the mist irrigation system turns on 3 times a day. The watering time at each watering frequency is adjusted to the water needs of the plants and the water discharge from the mist irrigation nozzle.

Table 1. DS3231 to ESP32 RTC component pin

Component	Pin	ESP32	Mark
RTC DS3231	VCC GND SDA SCL 32K SQW	3V G D21 D22 Unused Unused	The RTC DS3231 is a module that functions as a digital timer that uses I2C or two wires (SDA and SCL), of the six pins on the RTC DS3231, 4 pins are connected to the ESP32.
Keypad 1x4	1 2 3 4 5	D15 D2 D4 D5 3V	Keypad is a button arranged in a matrix that functions toinput data which has 5 pins, namely pin VCC, pin 1, pin 2, pin 3, and pin 4.
Relay	VCC GND IN	5V G D23	The relay functions as a switch that has 3 pins, namely the VCC(+) pin, the GND (-) pin, and the IN pin, which are then connected to the existing pins on the ESP32, namely the VCC pin to the 5v pin, the GND pin to the G pin, and the IN pin to the D23 pin.
LCD 20x4	VCC GND SDA SCL	5V G D21 D22	The 20x4 LCD is already equipped with an I2C module that makes the pins needed to connect to the ESP32 only 4 pins, namely VCC, GND, SDA, and SCL pins.

3. RESULTS AND DISCUSSION

Manufacture of Scheduled Fog Irrigation Control System

The hardware of the scheduled fog irrigation system consists of several components namely RTC DS3231, 1x4 Keypad, Relay, and 20x4 LCD. These components are connected to the microcontroller that will be used, namely the ESP32 using jumper cables. Table 1 summarizes hardware components along with pin types and ESP32.

Program Language Creation

The creation of the programming language uses the Arduino IDE as the software for making program sketches. The creation of the programming language in the Arduino IDE goes through several stages, namely sketching, header, variable declaration, and structure creation.

The program language of the scheduled fog irrigation system consists of several parts, namely headers, variables, void setup, void loops. The commands that will be done by the microcontroller are connected/related to the components that will be used in the tool, so that what is ordered in the program language runs well. The first step in creating a programming language on Arduino IDE is to open the Arduino IDE 1.8.19 software that has been installed on a laptop/computer and then enter the required library.

Designing Scheduled Fog Irrigation System Equipment

The design of the scheduled fog irrigation system begins by installing each circuit on the pump, which includes a 12V pump, hose, power supply and nozzle. Then it was continued with the installation of the scheduled fog irrigation control system and electrical parts, then the nozzle height adjustment was carried out, and the equipment was tested.

Testing of Scheduled Fog Irrigation System Equipment

Testing of scheduled fog irrigation system equipment is carried out to find out whether the equipment is running well and according to the program language plan that has been made. On the 20x4 LCD the date and time can be displayed well, with the time and date running well, it can be stated that the RTC and the 20x4 LCD can run according to the program.

Clock Calibration on RTC DS3231

Calibration is the process of checking and setting the accuracy of the tools used by comparing them with standard benchmarks. This calibration is necessary to ensure that the time indicated by the DS3231 RTC component is accurate and consistent with its comparator instrument.

Table 5. DS3231 RTC calibration results

Sample	RTC DS3231 (sec)	Smartphone (seconds)
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	7
7	7	8
8	8	9
9	9	10
10	10	11
11	11	13
12	12	14

After obtaining the second value on the RTC DS3231 and then comparing it with the second value of the clock on the Smartphone, the comparison value can be seen in Figure 4.

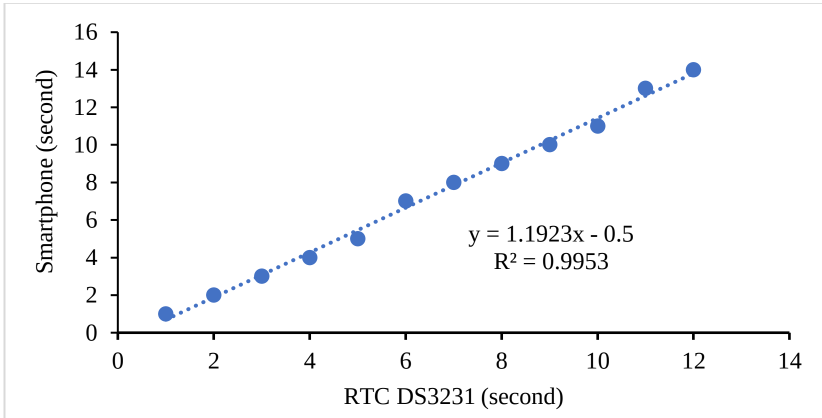

Figure 4. RTC DS3231 calibration chart

Through linear regression analysis, a mathematical model was obtained between the relationship between the RTC value of DS3231 and the value of the Smartphone. From this comparison, the equation y = 1.1923x + 12.5 was obtained, and a determination coefficient value of 0.9953 was obtained. This determination coefficient is generally used as match information in a model by being calculated to find out the extent of the match on the free variable in a model of multiple linear regression equations that are simultaneously able to explain the non-free variable (Marpaung & Winarto, 2018).

Plant Water Needs

Lack of water in plants can reduce the number of seedlings, change patterns in the roots, and delays in growth and development. Water is also one of the important factors in plant growth in cell expansion so that it can affect the height and number of leaves (Ruminta, *et al*., 2017). The provision of irrigation water in this study was carried out using two systems, namely a manual irrigation system and an automatic irrigation system. In the automatic irrigation system, it is divided into 3 ways of watering, namely one watering, two watering, and three watering.

Water needs are intended to determine the amount of water that will be given to plants every day. To determine the water needs of mustard plants, it is calculated based on the ET_c (plant evapotranspiration) that occurs in mustard plants. In the calculation for the ET_c value, the K_c value (plant coefficient) of mustard greens and ET_o (potential evapotranspiration (mm/day) are needed. In this study, mustard seed seeding was carried out for 10 days with a plant coefficient (K_c) value in the early growth period (0-10 days) of 0.3. The ET_o value is obtained from the calculation using the Hargreaves method with the results listed in Table 6.

Table 6. Water needs of mustard plants during seedbed

Date	Plant lifespan	Et_o	K_c	ET_c (mm/day)	Water requirements for 1 m^2 planting area (mL/day)*
10/04/23	1	18.22	0.3	0.55	315
11/04/23	2	18.43	0.3	0.55	318
12/04/23	3	18.63	0.3	0.56	322
13/04/23	4	18.84	0.3	0.57	326
14/04/23	5	19.04	0.3	0.57	329
15/04/23	6	19.25	0.3	0.58	333
16/04/23	7	19.46	0.3	0.58	336
17/04/23	8	19.67	0.3	0.59	340
18/04/23	9	19.87	0.3	0.60	344
19/04/23	10	20.08	0.3	0.60	347
Average Water Requirement					331

* To convert ET_c (mm/day) to ET_c (mL/planting area/day), use 1 mm = 1000 ml/m^2, and plant seeding area of 576 cm^2

Water Discharge

The water discharge in this study is the large volume of water that can come out of the nozzle in one minute. In this study, the water discharge was calculated to determine the length of watering. Water discharge measurements are carried out by collecting water coming out of the nozzle. Measurements were made by 3 experiments carried out by collecting water on the nozzle. In 3 water storage experiments at fog irrigation nozzles, the average water discharge was obtained as shown in Table 7.

Table 7. Water discharge in fog irrigation nozzle

Experiment to	Time (min)	Contained water (ml)
1	1	110
2	1	102
3	1	106
Average Water Discharge ± Std. Deviation		106 ± 4.0 ml/min

Possible Water Distribution

To calculate the water distribution, measurements are taken to find out the amount of water that can be distributed from the nozzle to the plant. Measurements are taken by collecting water on the surface and with a nozzle height of 30 cm on it. The fog irrigation system was turned on and 3 experiments were carried out to collect water, the average water storage results were obtained as shown in Table 8.

Table 8. Water distribution that can be done by fog irrigation system equipment

Experiment to	Time (min)	Contained water (ml)
1	1	80
2	1	84
3	1	82
Average Water Distribution ± Std. Deviation		82 ± 2.0 ml/min

When compared to the water discharge, the value of the test results in Table 8 is lower, this indicates that in the distribution of water carried out from the nozzle to the ground surface there is water loss during watering. Water loss that occurs when fog irrigation is carried out can be caused by several factors such as the distance of the nozzle to the plant and the ambient temperature so that evaporation occurs when water particles are still in the air.

Water Use Efficiency

In the application of mist irrigation, which distributes water to plants with finer and smaller water particles has a high probability of water loss occurring. For this reason, the calculation of water use efficiency in the application of fog irrigation in mustard seedbeds was carried out. The observation data carried out to calculate the efficiency of irrigation water use amounted to 3 discharge samples each for the average water discharge and the average distribution of water to the surface. The results of water use efficiency are presented in Table 9. Based on the calculation of water discharge and distribution that can be carried out by the scheduled fog irrigation system in mustard seedbeds, the water use efficiency is 77.35%. This shows that when watering using this scheduled mist irrigation system, there is 22.65% of water lost when watering is carried out. When compared to other irrigation systems such as drip irrigation systems, the efficiency of water use in this fog irrigation system is still low. In the drip irrigation system, the standard water use efficiency is >90% (Ekaputra, *et al*., 2016).

Table 9. Water use efficiency in fog irrigation systems

Average Water Discharge (ml)	Average water distribution (ml)	Water use efficiency (%)
106	82	77.35

Watering Duration

The duration of fog irrigation in this study is divided into 3 types each time watering according to the many waterings carried out in one day. The duration of watering carried out in this study is listed in Table 10. The duration of each watering that has been adjusted to water needs in 1 day is 4.03 minutes each watering in 1 flush in a day, 2.02 minutes each watering in 2 waterings, and 1.34 minutes each watering in 3 waterings.

Table 10. Watering duration in one day

Abundant Watering in a day (times)	Average Water Requirement (ml/day)	Average water distribution (ml/min)	Duration of watering every 1 flush (minutes)
1	331	82	4.03
2	331	82	2.02
3	331	82	1.34

Plant Growth

Plant growth is an event that increases the size of the plant, which can be measured based on the size and height of the organs in the plant along with the age of the plant. During the seedling period, the parameters that can be measured on the plant are the height of the plant and the number of leaves. In this study, the growth of mustard greens during seedling was calculated based on the height of the plant and the number of leaves on mustard plants.

Mustard Plant Height

Plant height is a growth indicator used to measure the treatment applied. Based on the results of research that has been carried out with a scheduled fog irrigation system using ESP32 in mustard seedbeds, high yields of mustard plants can be seen in Figure 5. It can be seen that the height of mustard plants during seedbeds, the largest height of mustard plants was obtained in the seedbed using a scheduled fog irrigation system with 3 waterings a day with an average height of 4.58 cm, after that the manual irrigation system used a 4.20 cm beam, then 2 treatments a day 4.01 cm, and the lowest value in 1 treatment a day was 3.93 cm.

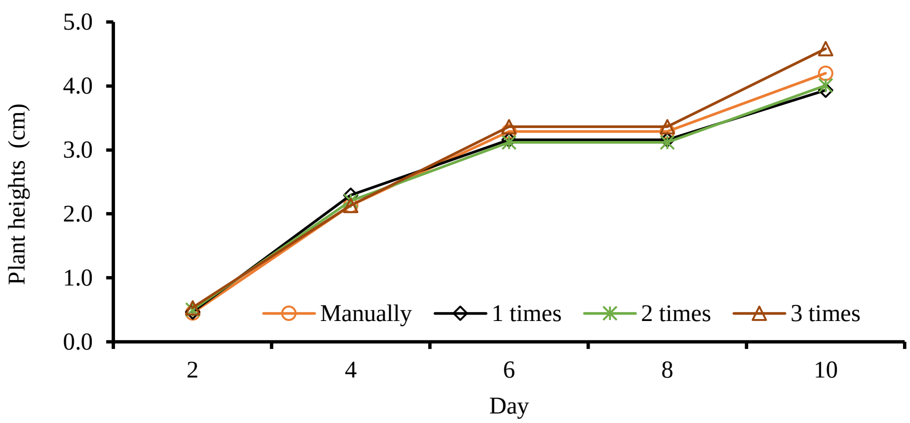

Figure 5. Height development of mustard plants during seeding

Number of Mustard Leaves

Based on the results of research that has been carried out with a scheduled fog irrigation system using ESP32 in mustard seedbeds, the results of the number of mustard leaves can be seen in Figure 6.

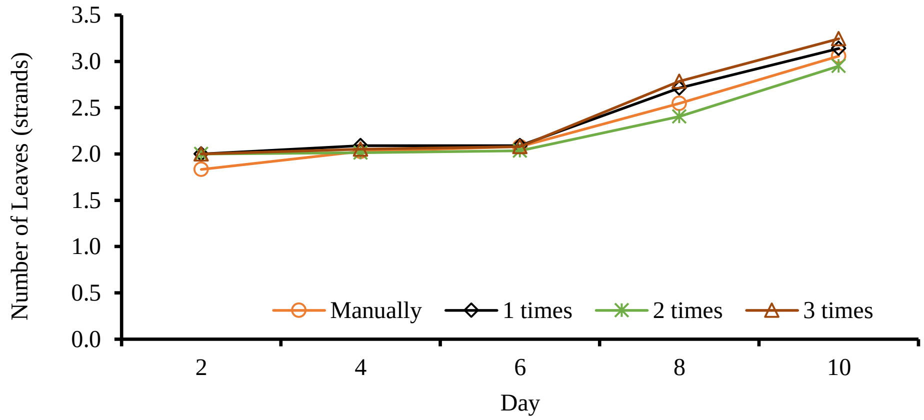

Figure 6. Growth of the number of mustard leaves during seeding

The growth and development of plants can be affected by external factors and internal factors. External factors in plant growth and development can be caused from outside the plant such as environmental factors. Internal factors or also factors caused from within the plant itself can be in the form of genetic and physiological factors of the plant (Buntoro *et al*., 2014). In this study, the difference in treatment in water administration can affect the growth and development of plants in the seedling period. In Figure 5, it can be seen that the number of leaves with 3 times of watering using the scheduled fog irrigation system has the highest value compared to the others, namely with an average number of leaves of 3.24 leaves, followed by 1 time of scheduled fog irrigation with 3.14 leaves, manual watering using a beam of 3.06 leaves, and the last with 2 times of treatment with scheduled fog irrigation of 2.95 leaves.

Performance of Scheduled Fog Irrigation System

The performance test of the scheduled fog irrigation system was carried out on mustard seedbeds with a seedling area of 28 cm x 28 cm using a nozzle as a trigger for the creation of fog in watering. Testing is carried out to find out if this fog irrigation system can work properly.

Watering is determined by pressing the button on the 1x4 keypad, namely button 1, to water 1 time a day at 07:00 WITA, button 2, to water 2 times a day at 07:00 and 17:00 WITA, and 3 times watering at 07:00, 12:00. And 17:00 WITA. The duration of fog irrigation watering is divided into 3 types each watering according to the many waterings carried out in one day. The duration of watering carried out in this study is listed in Table 10.

The performance of the scheduled fog irrigation system in this study was declared to be running well according to the plan that had been made, and in the application of this tool, the results of the growth of mustard plants during the seedling period, both high and number of leaves, were declared good.

4. CONCLUSION

Based on the results of the research and discussion, the following conclusions can be drawn:

1. This study produces a scheduled mist irrigation system using ESP32 in mustard seedbeds.
2. In the application of the scheduled fog irrigation system using ESP32, it has a water use efficiency of 77.35%.
3. The difference in the growth of mustard plants during seedling using treatment 3 times a day with a scheduled mist irrigation system showed the highest value among other treatments both in the height of mustard plants and the number of leaves.

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