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# Performance of Automatic Watering System for Bean Sprout Based on Microcontroller ATmega 328p

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**ABSTRACT**

*Technological advancements in agriculture are crucial to meeting the increasing global food demand. Mung bean sprout (Vigna radiata) cultivation requires efficient irrigation to ensure optimal growth. This study designs and evaluates an automatic irrigation system based on the ATmega 328P microcontroller to address the challenge of watering every four hours. The system integrates water flow sensors, relays, and solenoid valves controlled by C-based software in the Arduino IDE. Nine different irrigation test combinations were conducted to determine the most effective strategy. Each treatment had three levels and was tested in triplicate. Data analysis was performed using ANOVA (α = 0.05), followed by the DMRT test to evaluate treatment interactions. Results indicate that the system operates consistently in regulating water flow, improving irrigation efficiency, and reducing human intervention. The best performance was achieved using 50 liters of water with a shower nozzle, yielding the highest production capacity. The system improves irrigation efficiency, prevents over- and under-watering, and enhances crop yield. Analysis shows that water quantity and spraying method influence the yield ratio value in a complex pattern. The W2N3 combination produced the highest value (3.6), while W1N1 had the lowest (2.4). Overall, their interaction significantly affects irrigation effectiveness.*

## 1. INTRODUCTION

Technological advancement in agriculture is a must to overcome the challenges of increasing food needs amidst global population growth. Agricultural automation is now a significant trend, offering opportunities to increase productivity and efficiency in crop management (Affrida *et al*., 2022; Hamdi, 2019; Wulandari *et al*., 2020). Mung bean (*Vigna radiata*) sprouts are important vegetable for human food diet. The sprouts are rich with protein, oligosaccharides, amino acids, and polyphenols and are widely consumed in Asian countries (Tang *et al*., 2014; Salvador Jr. *et al*., 2014). Producing mung bean sprouts requires a regular watering schedule to achieve optimal growth (Astawan, 2005). However, the majority of bean sprout farmers face obstacles in the manual watering process every four hours, which results in disruption to rest time and potential health risks (Maulana, 2010; Ulfa, 2014). The limited watering tools owned by farmers require technology-based solutions that can provide efficiency without sacrificing quality.

Previous studies have shown that a microcontroller-based automatic watering system can increase water use efficiency by up to 50% compared to manual methods (Kurniawan *et al*., 2015). Microcontrollers, such as the ATmega 328P, are a proven and programmable platform for controlling various agricultural activities, including automatic watering (Saputra *et al*., 2014; Widodo & Sigit, 2005). Several studies have also indicated that the use of microcontrollers in automatic watering systems can support plant productivity with precise settings for the duration and frequency of watering (Nurfaijah *et al*., 2015). In addition, supporting components such as solenoid valves and relays play an important role in controlling water flow automatically, thereby increasing accuracy and consistency in the watering process (Kurniawan *et al*., 2015; Pramana & Nababan, 2019).

The use of Arduino microcontroller for sprout watering system was recently reported able to produce good quality mung bean sprouts that are both odourless and fresh (Hakim *et al*., 2023). However, most of the existing automatic systems still use sensors that are relatively expensive and complex in their integration (Putra & Stefanus, 2019). Therefore, this study aims to design and performance testing an automatic bean sprout watering system based on the ATmega 328P microcontroller without using sensors, with the hope of reducing production costs and facilitating system integration on a wider scale. The successful implementation of this system is expected to provide a positive contribution in optimizing the growth of bean sprouts, increasing the efficiency of water use, and reducing the risks of over- or under-watering (Al-Hafiz *et al*., 2020; Sugandi & Armentaria, 2021).

Overall, this research not only focuses on increasing agricultural productivity through automation of watering system for mung bean sprout, but also embraces the values of sustainability and resource efficiency, which are expected to provide a positive contribution to the development of modern agriculture that is adaptive, efficient, and environmentally friendly (Hadi *et al*., 2017; Widiana *et al*., 2019).

## 2. MATERIALS AND METHODS

This research was conducted at the Center for Agricultural Mechanization and Workshop Research, Syiah Kuala Darussalam University, Banda Aceh and in Lam Alue Cut Village, Kuta Baro District, Aceh Besar Regency. The research was conducted from February 2024 until completion.

In this study, various tools and materials were used to support the research process. The main tools used include a 1000 liter water tank made of polyethylene, an ATmega 328P microcontroller that functions as the main controller, a solenoid valve that regulates water flow with DC12V specifications, and a relay module that controls current with a maximum capacity of AC 250V/10A and DC 30V/10A. In addition, a micro SD module is also used for data storage, a 12V adapter for voltage adjustment, a bucket as a container for cultivating bean sprouts, and a PVC piping system according to SNI standards. Dewalt workshop tools, electrical cables, and power outlets are also included in the research equipment.

The main material used is water from local sources with 100% purity. The piping material in the form of polyvinyl chloride (PVC) that meets SNI and ISO 9001:2015 standards is also used in this study. The Arduino ATmega 328P microcontroller-based system is designed to automatically control water flow using a flow meter sensor, solenoid valve, and relay module while recording data onto a MicroSD card. The flow meter measures the water flow rate by generating pulses counted by the Arduino to accurately determine the water discharge. Data from this sensor is then transmitted and stored on the MicroSD card via Serial Peripheral Interface (SPI) communication. Based on the obtained water discharge values, the Arduino controls the relay module to activate or deactivate the solenoid valve, enabling real-time water flow regulation. If certain conditions are met, such as exceeding or falling below the predefined flow threshold, the Arduino will activate the relay to open or close the solenoid valve as required by the system. This system operates in a continuous loop to ensure constant water discharge monitoring, accurate data recording, and optimal water flow control.

The research instrument consists of hardware and software that are integrated to monitor and control the irrigation system. The main hardware includes ATmega 328P, solenoid valve, and relay module, while the software used for programming the microcontroller is Arduino IDE. Automatic watering system design process is carried out by assembling the piping system and microcontroller mount, as well as integrating electronic components such as ATmega 328P, solenoid valve, and relay module. Finally, engineering analysis is carried out to test and evaluate the performance of the watering system based on the established design criteria.

Sampling was carried out using a purposive sampling method, where bean sprouts planted in Lam Alue Cut Village were selected as the object of research. Samples were taken randomly at certain time intervals to ensure representativeness. Sample measurements were carried out using a water discharge sensor connected to a piping system, with water discharge data flowing during the watering process recorded automatically by the micro SD module. The data were then analyzed using descriptive statistical methods to see the distribution and pattern of watering and correlation analysis to evaluate the relationship between watering frequency and bean sprout growth. The results of this analysis will be used to conclude the effectiveness of the designed automatic watering system.

The main tool circuit in the automatic watering system consists of a water tank, piping system, ATmega 328P microcontroller, solenoid valve, and relay module. The microcontroller acts as the main controller that regulates the time and duration of watering, while the solenoid valve regulates the water flow according to the command from the microcontroller. This system is designed to automatically water bean sprouts every 4 hours for 10 minutes. This circuit can be seen in Figure 1. The reading program on the solenoid is presented in Figure 2.

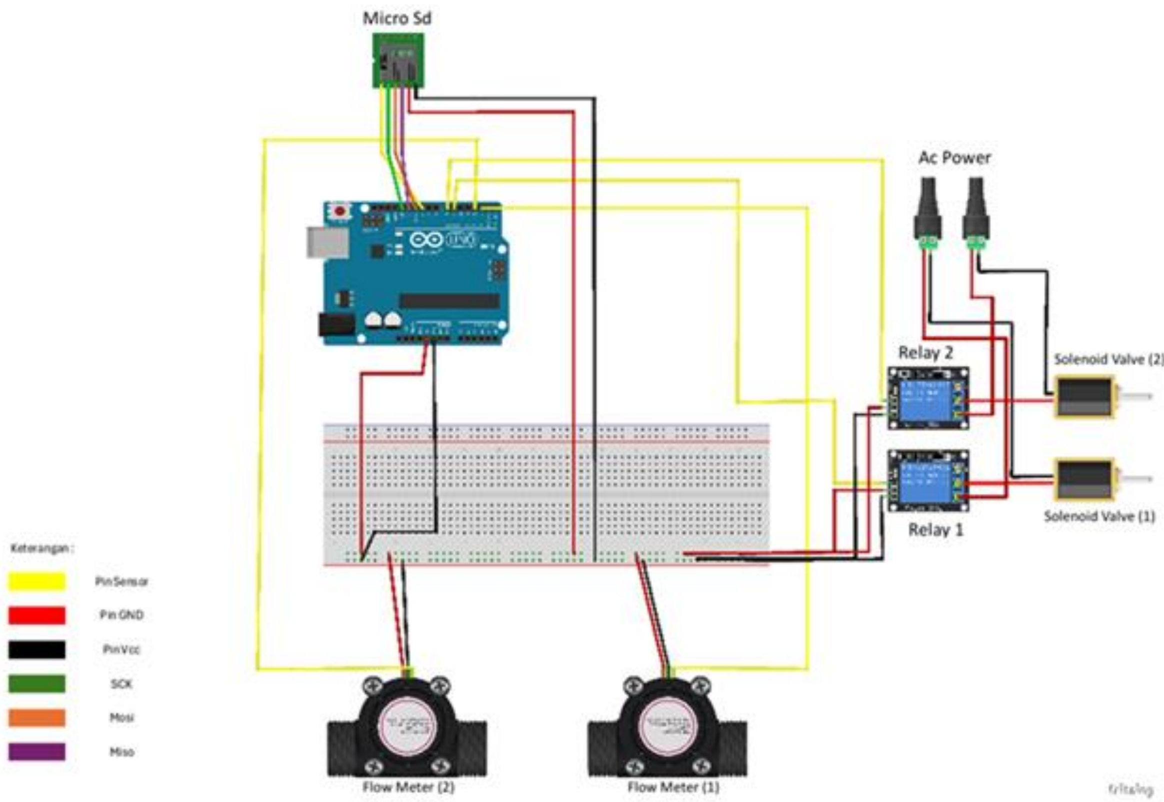


Figure 1. Irrigation System Circuit

Performance testing was conducted on three variations of water volume for irrigation, and three variations of nozzle types used (butterfly nozzle, sprinkler nozzle and shower nozzle), so that from 3 variations of volume and 3 types of nozzles produced 9 combinations of water irrigation treatments on the surface of the bean sprout container. The variation of the amount of water given was determined from the results of the initial flow rate test of 16.66 L/minute, the recommended water requirement for each bean sprout irrigation of 50 liters, from the results of the flow rate test, variations in the duration of irrigation time were given with 3 variations (1.5, 3.0 and 4.5 minutes), with the equivalen to the water volume variation of 25, 50 and 75 liters. The water distribution efficiency formula is expressed as follows (Rifai, & Wahyudi, 2024):

$$\eta = \left(\frac{Q_{out}}{Q_{in}}\right) \times 100\% \tag{1}$$

where η is water distribution efficiency (%), $Q_{out}$ is the discharge of water exiting the channel (m³/s), and $Q_{in}$ is the discharge of water entering the channel (m³/s).

Watering efficiency is determined by comparing the irrigation volume with the optimal water requirement for sprouts and its distribution on the container surface. Performance testing was conducted on three water volume variations (25, 50, and 75 liters) and three nozzle types (butterfly, sprinkler, and shower), resulting in nine treatment combinations. The water volume variations were calculated based on an initial flow rate of 16.66 L/min with a recommended irrigation requirement of 50 liters, leading to irrigation durations of 1.5, 3.0, and 4.5 minutes. Efficiency was analyzed through water distribution and its impact on sprout growth to determine the optimal combination.

```
void loop() {
  unsigned long currentMillis = millis();
  // Turns on the first relay
  if (currentMillis - previousMillis1 == onInterval1) {
    digitalWrite(relay1, LOW);
  }
  // Turns on the second relay
  if (currentMillis - previousMillis2 == onInterval2) {
    digitalWrite(relay2, LOW);
  }
  // Turns on the third relay
  if (currentMillis - previousMillis3 == onInterval3) {
    digitalWrite(relay3, LOW);
  }
  // Turns on the fourth relay
  if (currentMillis - previousMillis4 == onInterval4) {
    digitalWrite(relay4, LOW);
  }
  // Turns off the first relay
  if (currentMillis - previousMillis1 == offInterval1) {
    digitalWrite(relay1, HIGH);
    previousMillis1 = currentMillis;
  }

  // Turns off the second relay
  if (currentMillis - previousMillis2 == offInterval2) {
    digitalWrite(relay2, HIGH);
    previousMillis2 = currentMillis;
  }
  // Turns off the third relay
  if (currentMillis - previousMillis3 == offInterval3) {
    digitalWrite(relay3, HIGH);
    previousMillis3 = currentMillis;
    }
  // Turns off the fourth relay
  if (currentMillis - previousMillis4 == offInterval4) {
    digitalWrite(relay4, HIGH);
    previousMillis4 = currentMillis;
    }
  time();
  delay(1000);
}
  // digital clock display of current time
  Serial.print(days,DEC);
  printDigits(hours);
  printDigits(minutes);
  printDigits(seconds);
  Serial.println();
}
void printDigits(byte digits){
  // utility function for digital clock display: prints colon and leading 0
  Serial.print(":");
  if(digits < 10)
  Serial.print('0');
  Serial.print(digits,DEC);
```

Figure 2. Reading program on the solenoid

The butterfly nozzle (Figure 3) is an irrigation nozzle with a single outlet that generates a 360° rotating spray pattern, ensuring homogeneous and efficient water distribution in agricultural and landscape applications. The sprinkler nozzle is designed to produce a fine mist spray through small perforations, providing wide coverage with uniform water distribution while minimizing the risk of water pooling. The shower nozzle, featuring 421 circularly arranged holes, optimizes even water dispersion, enhancing irrigation efficiency and promoting effective water absorption by plants. The highest production capacity of the nine test combinations (Table 1) is the best performance of the automatic bean sprout watering system.

(a) (b) (c)

Figure 3. Three nozzles used for irrigation: (a) shower, (b) sprinkler, (c) butterfly

Table 1. Performance test combination

| No | Amount of water (L) | Nozzle Type |
|---|---|---|
| 1 | 25 | Butterfly |
| 2 | 25 | Sprinkler |
| 3 | 25 | Shower |
| 4 | 50 | Butterfly |
| 5 | 50 | Sprinkler |
| 6 | 50 | Shower |
| 7 | 75 | Butterfly |
| 8 | 75 | Sprinkler |
| 9 | 75 | Shower |

### 2.1. Data Analysis

This study employed an experimental method with a 3×3 factorial design, consisting of two treatment factors: water volume (W) and spraying method (N), each with three treatment levels and three replications. Data were analyzed using Analysis of Variance (ANOVA) at a significance level of 0.05 to assess the effects of the treatments on the yield ratio, which is sprout yield (kg) over the initial cultivated beans (kg). If significant differences were found, Duncan's Multiple Range Test (DMRT) was conducted to evaluate the interactions between treatments, indicated by superscript letters in the analysis results.

## 3. RESULTS AND DISCUSSION

This study develops an automatic bean sprout watering system based on the ATmega 328P microcontroller, which is able to measure and control water discharge accurately using a water flow sensor (flow meter) and solenoid valve. This system is designed to improve the efficiency of plant watering with automatic settings based on predetermined parameters. The system implementation process involves several important components such as relays, flow meters, and data storage devices, which are tested to ensure optimal performance.

The test results show that the hardware consisting of a microcontroller, solenoid valve, and water flow sensor has been successfully integrated into the system. In Flow 1, the solenoid valve functions optimally so that the water flow can flow smoothly, while in Flow 2 a problem was found in the solenoid valve which did not open completely, causing the water flow to be smaller than Flow 1.

In addition, the software developed using Arduino IDE with the C programming language functions to regulate the watering cycle and store water flow data from the sensor every second. This data is then analyzed to determine the water discharge produced during the watering process. In the water discharge test, Flow 1, which passed through Solenoid 1, recorded a water discharge of 34.21 L/min, while Flow 2, which passed through Solenoid 2, only recorded 24.18 L/min. This difference is caused by constraints on the solenoid valve in Flow 2.

To ensure the accuracy of the water flow sensor reading, calibration was carried out using a manual measurement method. The calibration results show a linear relationship between sensor data and manual measurements, as depicted in Figure 4 and Figure 5. This calibration process is important to ensure that the automatic watering system works accurately and provides the right volume of water according to the needs of the bean sprouts.

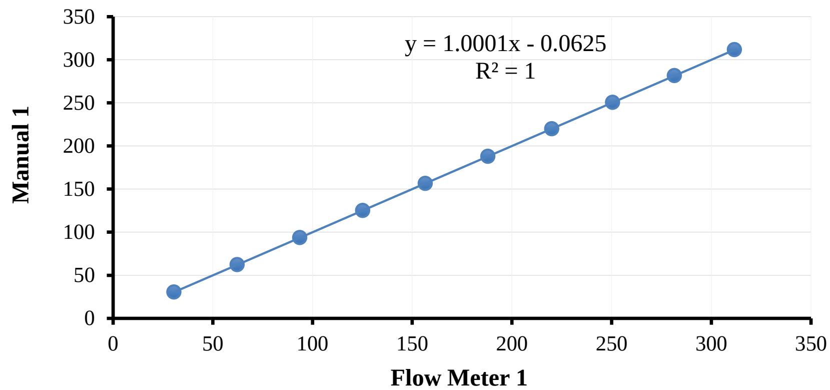


Figure 4. Linear function in flow 1

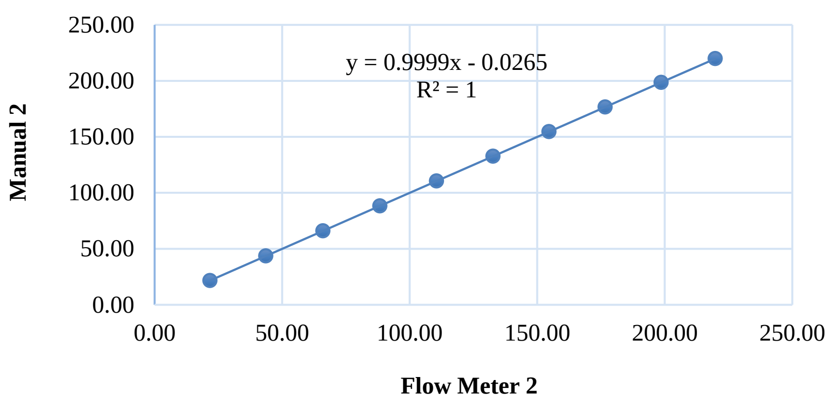


Figure 5. Linear function in flow 2

The study resulted in an efficiency of 50%, which is consistent with previous research, such as that conducted by Kurniawan *et al*. (2015), who found that a microcontroller-based automatic watering system can increase water use efficiency by up to 50%. Similarly, the findings of Nurfaijah et al. (2015) stated that the use of Arduino microcontrollers in irrigation systems can support optimal plant productivity. In this study, the developed system successfully controlled water discharge automatically, regulated based on signals from the microcontroller, and improved water use efficiency, as indicated by data obtained from the sensor.

The test results show that even though there is a difference in water discharge between Flow 1 and Flow 2, the developed automatic watering system is able to operate consistently. This can be seen in the graph of the water discharge test results which shows the stability of the water flow during the test, as depicted in Figure 6 and Figure 7. The difference between the two flows can be overcome by repairing the solenoid valve in Flow 2.

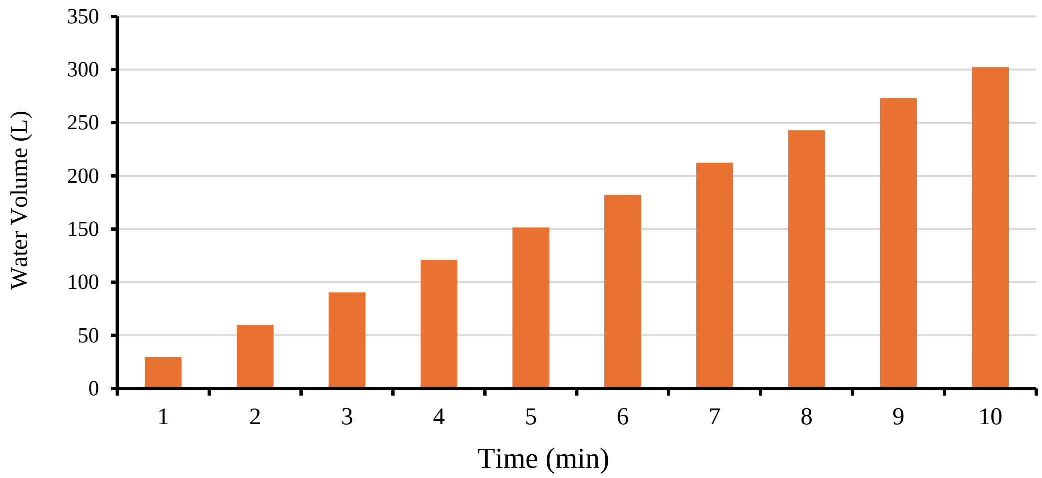


Figure 6. Testing the average amount of water on flow 1

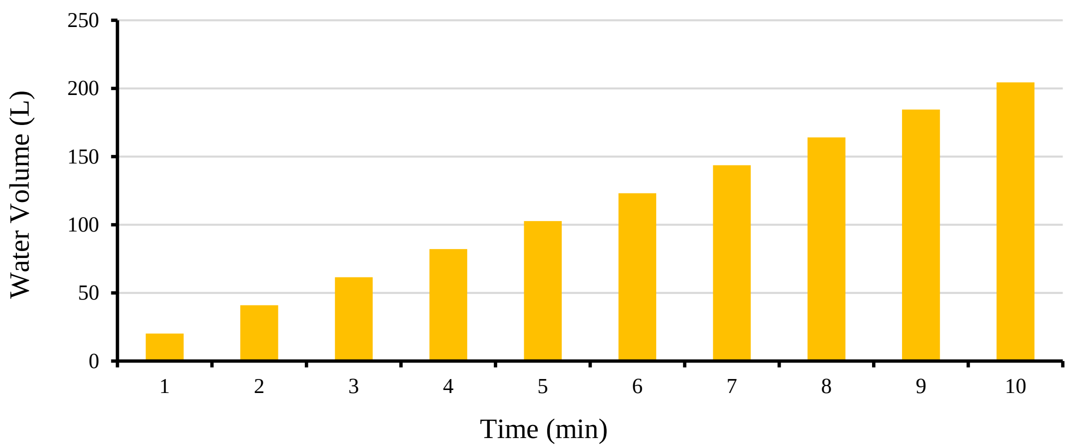


Figure 7. Testing the average amount of water on flow 2

Overall, this study proves that the automatic watering system developed using the ATmega 328P microcontroller can improve the efficiency of watering bean sprouts. The constraints found in the solenoid valve in Flow 2 are things that can be improved in the future to ensure that both flows function optimally. The results of this study provide a positive contribution to the development of a more efficient and environmentally friendly automatic irrigation system.

The irrigation performance test was given treatment to three nozzle variations with three variations in the amount of water given, resulting in 9 test treatments that can be used as a basis for analyzing the performance of the automatic irrigation system. Performance analysis was carried out on production capacity parameters and economic analysis. Production capacity is a parameter that indicates whether a tool is working well or not, the performance capacity of automatic bean sprout watering by providing 25 liters of water on three nozzle variations can be observed in Table 2.

Table 2. Bean sprout yield with 25 L of water for irrigation

| No | Nozzle | Initial Weight (kg) | Sprout Yield (kg) | Yield Ratio |
|---|---|---|---|---|
| 1 | Butterfly | 4.7 | 11.16 | 2.37 |
| 2 | Sprinkler | 4.7 | 13.99 | 2.98 |
| 3 | Shower | 4.7 | 16.51 | 3.51 |

The data in Table 2 shows that the production capacity by providing 25 liters of water for irrigation using a butterfly nozzle produces a yield ratio of 2.37, the type sprinkler of 2.98 and the type of shower of 3.51. The highest yield ratio is by using a shower of 3.51. The data in Table 3 shows the production capacity by providing 50 liters of water using a butterfly nozzle, resulting in a yield ratio of 3.17, type sprinkler of 3.27 and the shower type of 3.60. The highest yield ratio is also using a shower of 3.60.

The data in Table 4 has the same tendency as the previous provision of 25 liters and 50 liters of water, the best production capacity when providing 75 liters of water using the shower nozzle type, this can be seen from the results of the highest yield ratio when using the shower nozzle type of 3.55, lower when compared to using the butterfly nozzle type and sprinkler, namely 3.30 and 3.20 respectively.

Table 3. Bean sprout production capacity with 50 liters of irrigation water

| No | Nozzle | Initial Weight (kg) | Sprout Yield (kg) | Yield Ratio |
|---|---|---|---|---|
| 1 | Butterfly | 3 | 9.50 | 3.17 |
| 2 | Sprinkler | 3 | 9.80 | 3.27 |
| 3 | Shower | 3 | 10.80 | 3.60 |

Table 4. Bean sprout production capacity with 75 liters of irrigation water

| No | Nozzle | Initial Weight (kg) | Sprout Yield (kg) | Yield Ratio |
|---|---|---|---|---|
| 1 | Butterfly | 4.4 | 14.50 | 3.30 |
| 2 | Sprinkler | 4.4 | 14.10 | 3.20 |
| 3 | Shower | 4.4 | 15.60 | 3.55 |

(a) (b)

Figure 8. The raw materials and product, (a) mung bean and (b) harvested bean sprout

Figure 8 shows the raw materials for sprout production and the harvested bean sprout. Sprout production is started with soaking the mung beans in water. After soaking, the mung beans are allowed to sprout in a humid environment with regular watering every 4 hours for 4 days. Image 8b presents the final product in the form of sprouts, which has grown with a longer structure, white color, and a crunchy texture.

Then, statistical tests were carried out to examine the effect of two treatments, namely water amount (W) and spraying method (N), on the yield ratio value. Each treatment had three levels, and each combination was tested with three replications. Data analysis was conducted using ANOVA with a significance level of 0.05, followed by the DMRT post hoc test to evaluate the interaction between the two treatments. The results showed significant differences among some treatment combinations, indicated by superscript letters above each bar. Treatments with the same letters did not show significant differences, while different letters indicated a significant difference. In general, the combination of water amount and spraying method influenced the yield ratio value, with W2 and W3 treatments tending to produce higher values than W1.

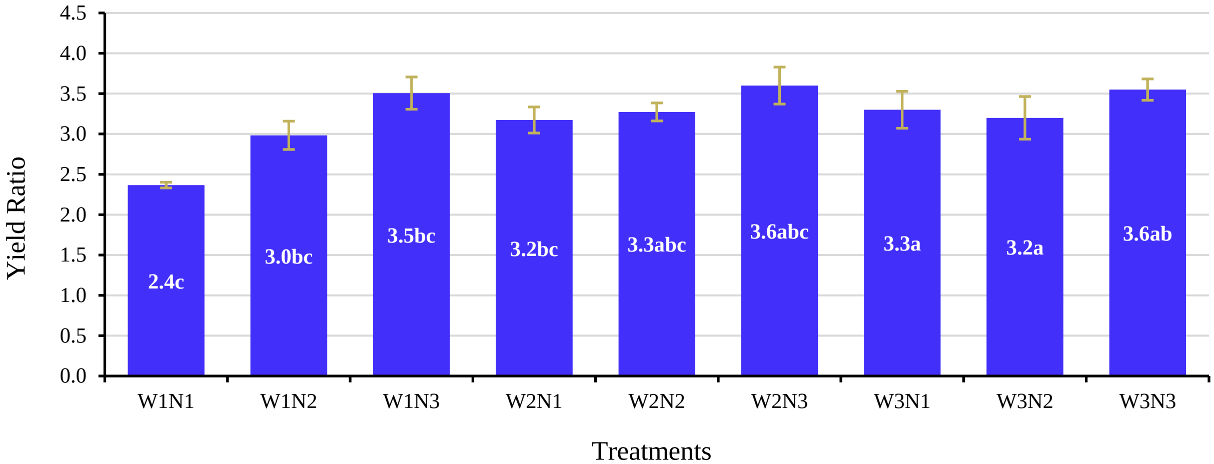


Figure 8. Effect of treatment on the yield ratio. [Different letter indicate significant difference in DMRT ($p \leq 0.05$)]

The analysis results showed that the W1N1 combination produced the lowest yield ratio value (2.4), indicating that a low water amount with the N1 spraying method did not yield optimal results. Conversely, the W2N3 combination resulted in the highest value (3.6), suggesting that a moderate water amount with the N3 spraying method significantly increased the yield ratio. The W3N3 combination also showed a high value (3.6ab), but it was not significantly different from several other treatments. This indicates that while increasing the water amount has an effect, the spraying method also plays a crucial role in treatment effectiveness. Overall, the interaction between water amount and spraying method exhibited a complex pattern, where certain combinations were more effective than others, although not all differences were statistically significant.

The amount of water given to the production capacity of bean sprouts shows that the highest yield ratio value is at 50 liters of water of 3.60, followed by 75 liters of water given at 3.55 and the lowest yield ratio value is at 25 liters of water of 3.51. In terms of the amount of water given and the use of the type of nozzle, the highest ratio obtained is at 50 liters of water given using the shower type of 3.60. This is in accordance with what was conveyed by bean sprout farmers in Lam Alue Cut village, that the amount of water given for each watering is 50 liters.

## 4. CONCLUSION

The development of an ATmega 328P microcontroller-based automatic watering system, incorporating a water flow sensor, relay, and solenoid valve, effectively regulated irrigation duration for bean sprouts. Performance testing demonstrated consistent and reliable results, enhancing watering efficiency and reducing water waste. The optimal performance, based on production capacity, was achieved with a 50-liter water supply using a 3.6-type shower nozzle. ANOVA and DMRT analyses confirmed that water volume and spraying method significantly influenced production capacity, with the highest efficiency observed in W2N3 and the lowest in W1N1. This system offers an effective solution for optimizing irrigation management.

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