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Automation of a Combustion Engine-Driven Sprinkler Irrigation Pump in Shallot (*Allium ascalonicum*) Cultivation

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ABSTRACT

Sprinkler irrigation control is necessary not only for efficiency but also for reducing bulb rot in shallot cultivation caused by excessive watering. This study developed an Arduino-based automatic control system for a combustion-engine-powered sprinkler irrigation setup to prevent overwatering in shallot farming in Enrekang Regency, Indonesia. The system used a servo motor to adjust the throttle lever of the combustion engine, allowing it to stop pumping the water when the soil moisture level detected by the YL-69 sensor exceeded the optimal threshold. This ensured that the irrigation was applied according to the ideal soil moisture level. The testing included infiltration rate measurement, sprinkler uniformity analysis, sensor calibration, system performance evaluation, and shallot yield assessment. The results showed an average irrigation uniformity coefficient (CU) of 84.34%, with the system operating for 10–28 minutes to maintain soil moisture at no more than 70%. The plot using the control system yielded 140 kg of shallots, whereas the plot without the system produced only 96.2 kg. Additionally, the percentage of rotten shallots in the control plot was 5%, which was significantly lower than that observed in the uncontrolled plot (18%). This system effectively reduced bulb rot, demonstrating its feasibility for optimizing water use and improving crop productivity in areas without access to electricity.

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1. INTRODUCTION

The agricultural sector in Enrekang Regency extensively applies sprinkler irrigation as a tool for watering agricultural land, particularly for horticultural crops. Sprinkler irrigation is used because it conserves water usage and is well-suited for dry lands and sloping topography. It achieves water savings and irrigation uniformity of over 80% and can be implemented on both flat and undulating terrains (Tusi & Lanya, 2016). However, farmers in Enrekang often face challenges when applying this method, such as root and bulb rot due to overwatering. The duration of watering is typically determined manually by inserting a finger into the soil to check its condition, with an average irrigation operation time of 30 minutes.

Horticultural crops commonly cultivated in Enrekang Regency include shallots (*Allium ascalonicum L.*), which are tuber plants that are highly sensitive to both excess and deficiency of water. This is evident from the significant portion of shallots experiencing bulb rot due to overwatering. For optimal growth, shallots require additional water provided through efficient irrigation methods as they are prone to moisture loss from the topsoil layer because of their shallow root systems (Patel, 2013, as cited in Fauziah et al., 2016).

Irrigation scheduling (when, how, and how much) depends on the soil moisture (Chaube et al., 2023). In addition to the plant's water requirements, the duration of irrigation is a crucial factor, and the timing of irrigation must be adjusted according to the plant's needs. Therefore, a control system is required to regulate the irrigation schedule such that the soil moisture remains aligned with the plant's requirements. This control process involves sensors such as soil moisture sensors, which measure the surrounding moisture level using two electrodes.

The use of sensors and microcontrollers has become widespread in agriculture, both in cultivation processes (Ramsari & Hidayat, 2022; Yudhaprakosa et al., 2019) and post-harvest handling (Ayusari et al., 2024; Laba et al., 2024). The application of such technologies has proven to be more effective and efficient, resulting in better productivity compared with conventional methods that do not utilize automatic control systems.

Another challenge in the irrigation process of shallot fields in Enrekang is their remote location, which lacks access to electricity. Consequently, water pumps are powered by gasoline-fueled combustion engines that are widely used by farmers (Pien et al., 2024). Unlike electric motors, which can be easily automated using microcontrollers, combustion engines can only adjust their RPM or be turned off, while starting them requires a more complex mechanism.

To prevent over-irrigation, which can lead to bulb rot and reduced shallot yields, this study automated the sprinkler irrigation system using an Arduino-based control method. The system issues an "off" command to a servo motor actuator that manipulates the throttle lever of the combustion engine, thereby reducing the RPM or shutting down the pump. Soil moisture sensor readings were used as the basis for determining the irrigation duration according to the crop's water needs.

2. MATERIALS AND METHODS

2.1 Materials

The study utilized various tools, including software such as Arduino IDE, a water pump (Honda GX160H), an Arduino Uno microcontroller, soil moisture sensor YL-69I, a pressure gauge, catch-can, a double ring infiltrometer, a 10 kg, 180° DC servo motor and 4 sprinklers with 2 m spraying radius. The materials used consisted of buckets and shallot plants.

2.2 Research procedure

This study employed methods of system design and installation of the control mechanism in the field, followed by direct observation in the following stages:

2.2.1 Irrigation network evaluation

The evaluation of the sprinkler irrigation network involved calculating the soil infiltration and sprinkler watering rates. The soil infiltration rate was measured to determine the soil water absorption capacity, while the sprinkler watering rate was analyzed to assess irrigation uniformity, sprinkler reach, applied pressure, and required duration.

A. Measuring infiltration rate.

The procedure for measuring the infiltration rate using a double ring involved creating a measurement plot, measuring the height of the double ring, placing the double ring at a depth of 5 cm on the land, pouring water into the outer ring, followed by the inner ring using a water barrier, removing the barrier, and measuring the water level drop in the inner ring using a stopwatch and measuring tape. The water level drop was recorded every 3 minutes until it stabilized, and the data were processed using Horton's equation.

B. Sprinkler watering rate

The procedure for determining the sprinkler watering rate involved creating a measurement plot, placing 81 catch cans at intervals of 1 m, operating the water pump connected to the sprinkler irrigation system, and running the sprinkler system at intervals of 10, 20, and 30 minutes. Measuring the discharge, pressure, maximum reach, volume of water collected in the catch cans, diameter at each interval, and processing of the data.

Sprinkler discharge calculations using the following formula:

$$Q = V/T \qquad (1)$$

where Q is the discharge rate (L/s), V is the volume (liters), and T is time (seconds).

The sprinkler uniformity was calculated using the following formula:

$$CU=100.\left(1 - \frac{\sum_{i=1}^{n}|v_i - \bar{v}|}{\sum_{i=1}^{n} v_i}\right) \qquad (2)$$

Where CU is the uniformity coefficient (%), Vi represents the individual observed discharge values (liters/hour), $\bar{v}$ denotes the average discharge value (liters/hour), and n is the total number of observations.

Plant evapotranspiration was determined using the Penman-Monteith method, which is the standard method for calculating reference crop evapotranspiration (Allen et al., 1998; Yustiana & Sitohang, 2019). And Effective rainfall (CH) was calculated using an 80% probability of occurrence (Wicaksono et al., 2023).

2.2.2 Controller design

The design of the control system involved the development of an off-control mechanism for the combustion motor used in sprinkler irrigation systems. The system consisted of (1) a soil moisture sensor (YL-69I), which operated using a resistive principle, (2) an Arduino microcontroller chosen for its simplicity, large memory capacity, and ability to manage on/off programs, (3) a servo motor to control the throttle lever of the combustion motor, and (4) the throttle lever itself, which regulated the fuel intake of the combustion motor. The control software for the automatic sprinkler system was developed using an Arduino IDE, serving as the central control unit. Initially, the system read the soil moisture levels through the sensor and processed the data using an Arduino microcontroller. These data determine whether the actuator will be activated or not, supported by the servo motor, based on the preset threshold values.

2.2.3 The off mechanism

The off mechanism uses a DC motor to drive the throttle lever of the combustion engine. The throttle lever was connected to a servo motor with specifications of 10 kg, 180 degrees, operating voltage of 4.8–7.2V, and producing torque in the range of 9.4–11 kgf.cm. This torque was sufficient to move the throttle lever of the combustion engine, which required a torque of 8.899 kg.cm (2.646 Nm). The maximum power output of the servo motor was 15 Watts. A motor bracket was mounted on the side of the combustion engine, and the power supply served as the electrical energy source for the system.

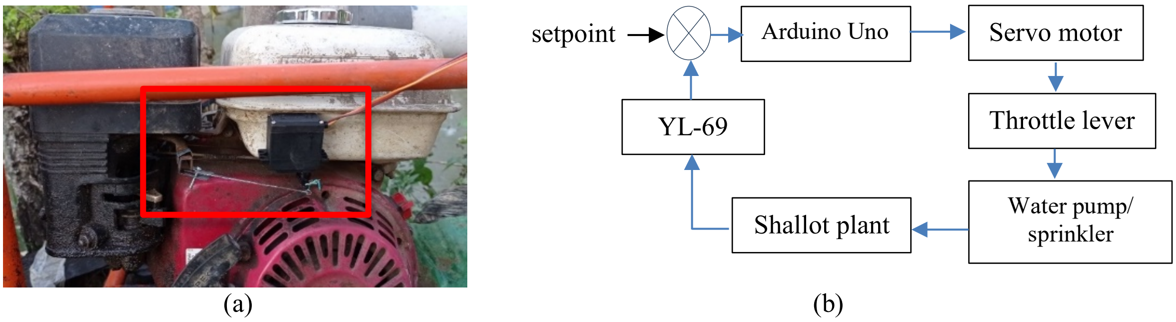


Figure 1. (a) Off mechanism position and (b) system block diagram

2.2.4 Functional testing.

Functional testing was performed to determine whether the assembled control system was operating effectively. The functional tests included calibration and validation of the soil moisture sensor. Sensor calibration aimed to adjust the soil moisture sensor to the physical properties of the soil, and to establish the relationship between the voltage measured by the sensor device and the soil moisture level obtained through gravimetric analysis. The soil moisture sensor calibration procedure included preparing soil samples, sieving the soil samples, weighing the container and soil sample, drying the soil in an oven at 105°C for 24 hours, reweighing the dry soil sample, and calculating the initial dry basis moisture content using gravimetric analysis with the following equation:

$$KA_{bk}=\frac{x-y}{y}\times 100\% \qquad (3)$$

where KAbk is the dry basis moisture content (%), x is the soil weight before drying (g), and y is the soil weight after drying (g). The procedure also included adding 10–100 ml of water to the soil, allowing the soil to absorb the water, measuring the voltage by inserting the sensor into the soil sample, recording voltage changes displayed on the LCD along with the moisture values, and plotting a graph of the relationship between soil moisture levels and voltage (v = soil moisture).

2.2.5 Performance testing

Performance testing assessed the functionality of the designed control system for a sprinkler irrigation network. The soil moisture sensor detected the soil moisture levels and triggered a servo motor based on the preset setpoint. The success indicator for this test was the watering time aligned with predefined soil moisture levels. The performance test procedure involved preparing the sprinkler irrigation network system, setting up the sprinkler irrigation control system, inserting a soil moisture sensor (placed based on the average uniformity of water distribution from the sprinkler irrigation system), activating the sprinkler irrigation system and control system, and observing changes in soil moisture levels detected by the sensor on the LCD.

2.2.6 Data used

1. Primary Data: Undisturbed soil samples were collected from soil sample rings at three sampling points.
2. Secondary Data: (1) Climatic data from BMKG Enrekang City, (2) plant data (kc values, effective root depth, and p-factor) obtained from the literature, (3) technical specifications and prices of control components sourced from distributors, online shops, or the market, and (4) physical soil property analysis (including soil texture determination) conducted in the Soil Physics Laboratory, Soil Science Study Program, Faculty of Agriculture, Hasanuddin University.

3 RESULTS AND DISCUSSION

3.1 Sprinkler irrigation network

The sprinkler irrigation network at the research location consisted of five main components, including a pump, manifold pipe, lateral pipe, main pipe, and sprinkler. All the irrigation components were in good condition. The water source was a river that supplied water to a storage tank. Water was delivered from the storage tank to the irrigation system using a Honda GX160H pump. This pump has specifications of 5.5 HP, 3600 rpm, 163cc, 4-stroke, and a maximum suction height of 8 m. The pump operates using gasoline as fuel. The sprinkler irrigation pump is shown in the Figure 2.

Water distribution was carried out using 3-inch PVC pipes to supply irrigation across all the planting beds. From the main 3-inch pipes, water was directed into 1½-inch manifold pipes. The manifold pipes, spaced 4 m apart, were connected to lateral pipes. Sprinklers were installed on the lateral pipes using 5/8-inch hoses connected to butterfly sprinklers with ½-inch connectors. These sprinklers (Figure 3) had a spraying radius of 4 m, were operated at a pressure of 1–3 bar, and were mounted on sprinkler poles at a height of 150 cm.

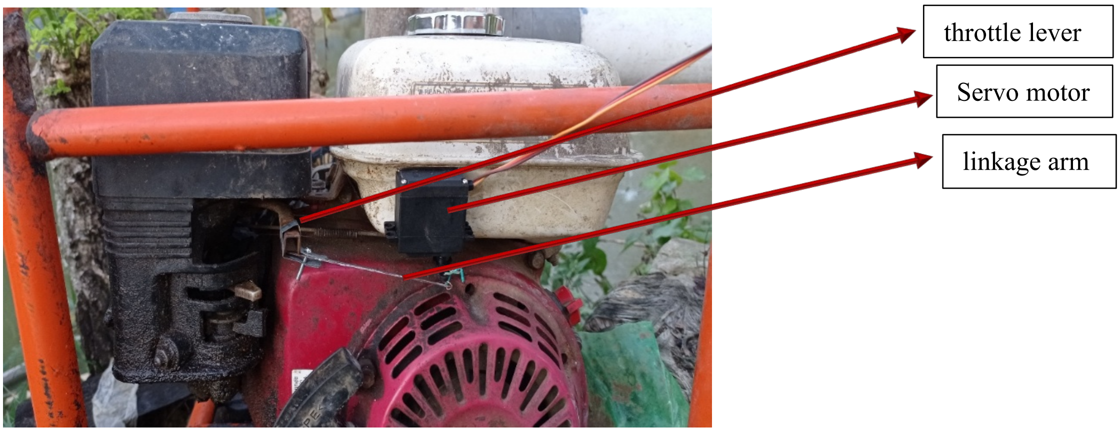


Figure 2. Water pump motor and shut-off mechanism

(a) (b)

Figure 3. Sprinkler used: (a) butterfly sprinkler and (b) sprinkler placement.

3.2 General conditions of the location

3.3.1 Soil physical properties

Soil texture can be identified through an analysis of physical soil properties. Soil texture influences moisture content at the permanent wilting point and field capacity (Darmayati & Sutikto, 2019). This information was used to determine the amount of water required by plants. The analysis was conducted in a laboratory using a soil texture triangle. The laboratory test results indicated that the soil texture at the research site was silty clay, comprising 25% of sand, 40% of silt, and 35% of clay.

3.3.2 Plant evapotranspiration

Reference evapotranspiration (ETo) values were calculated using Cropwat software (Shalsabillah et al., 2019). It showed that from January to December, the lowest ETo value was 2.75 mm/day and the highest was 3.98 mm/day, with an average of 3.36 mm/day. This study was conducted from October to November, with maximum and minimum ETo values of 3.98 mm/day and 3.92 mm/day, respectively. Figure 4 illustrates that plant evapotranspiration corresponded to the growth stages of shallots in the vegetative and generative phases. The vegetative phase occurs between days 11 and 35, whereas the generative phase consists of the bulb formation phase (days 36–50) and bulb maturation phase (days 51–56). The highest evapotranspiration rate was observed in November during the bulb formation phase, with a rate of 3.438 mm/day or 103.14 mm/month.

3.3.3 Effective rainfall

Figure 4 shows that during the initial and vegetative phases (October), the effective rainfall utilized by plants was 1.37 mm/day or 42.34 mm/month. During the bulb formation and maturation phases (November), rainfall utilization was relatively lower, at 1.34 mm/day or 40.21 mm/month. Because evapotranspiration exceeds effective rainfall, additional irrigation was required from the initial phase to the maturation phase to prevent drought stress, as shallots are sensitive to such conditions because of their shallow root system (Wahyuni et al., 2023).

3.3.4 Plant water requirements

Supplemental irrigation was required throughout all growth phases to meet the shallot water requirements (Figure 4). The maximum water demand occurred during the bulb formation phase at a rate of 2.10 mm/day or 62.93 mm/month. This was in line with Rafikul (2024), who stated that, during the vegetative phase up to bulb formation, shallot plants required a large amount of water, which then decreased during the maturation phase.

3.3.5 Infiltration rate

The infiltration rate must be determined to avoid runoff (Susanawati et al., 2018). Field data indicated an infiltration rate of 3.24 mm/hour, as shown in Figure 5. This infiltration rate served as a key indicator in assessing the feasibility of the system, such as the irrigation rate, the watering rate must be less than or equal to the infiltration rate to prevent surface runoff (Gultom et al., 2012).

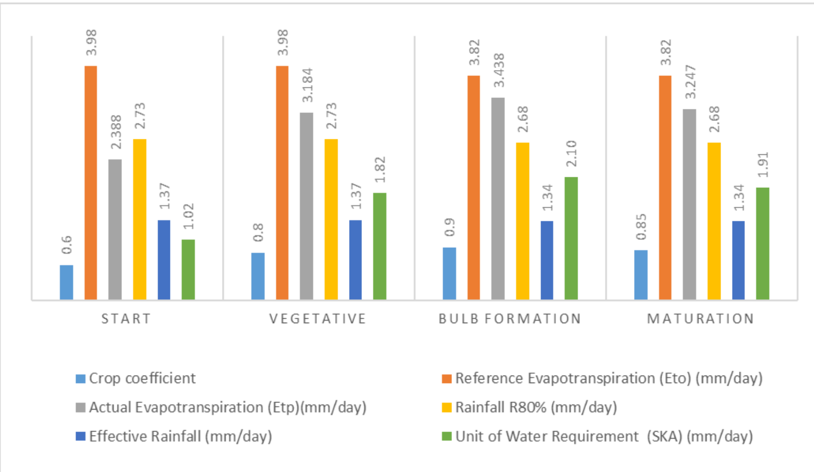


Figure 4. Calculation of plant evapotranspiration, rainfall 80%, effective rainfall, and unit water requirement (KSA) for each growth phase of shallot plants.

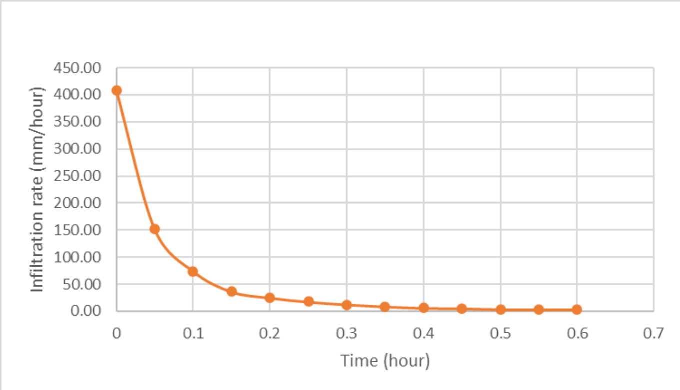


Figure 5. Infiltration rate at the research rite.

3.3 Irrigation Network Evaluation

Irrigation network evaluation aimed to assess the uniformity level and average application depth to determine the optimal placement of sensors.

3.3.1 Sprinkler discharge

The study showed a flow rate of 2.3 L/minute and 3.2 L/minute at 0.95 and 1.5 bar pressure. These results indicate that the discharge rate increased with increasing operating pressure.

3.3.2 Irrigation uniformity (Coefficient of Uniformity)

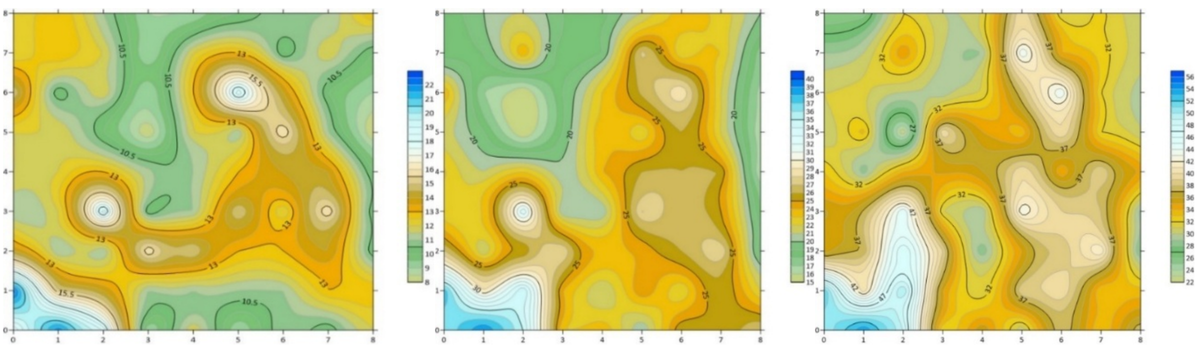
The calculated sprinkler uniformity (CU) results were presented in Table 1.

Table 1. Coefficient of uniformity of sprinkler irrigation

No	Pressure (bar)	Wind speed (m/s)	CU (%)
1	0.65	0.195	83.15
2	0.95	0.269	84.12
3	1.50	0.065	85.76

The average sprinkler application depth for the 81 catch cans was 35.1 ml over 30 minutes. The irrigation uniformity values varied owing to differences in pressure and wind speed. Higher operating pressures generally resulted in a more uniform water distribution as long as the pressure remained within the recommended range. However, when the pressure exceeded the specified limit, the water droplets became finer and more susceptible to wind drift.

The uniformity coefficient was calculated using Equation 2, with the highest value recorded at 1.5 bar (85.76%), and the lowest at 0.65 bar (83.15%). This finding aligned with the finding of Abd El-Wahed et al. (2016), who stated that the highest uniformity coefficient in sprinkler irrigation was achieved under the highest operating pressure. Furthermore, based on Table 1, another contributing factor to the high CU value was the wind speed observed during this study. This was consistent with the findings of Ravikumar (2023), who emphasized that sprinkler performance in the field was influenced by wind direction and intensity, which can cause deviations in water distribution and subsequently affect application uniformity. The uniformity levels are represented in a 2D contour form, as shown in the Figure 6.



(a) (b) (c)

Figure 6. Sprinkler irrigation uniformity (a) 0.65 bar, (b) 0.95 bar, and (c) 1.5 bar.

3.4 Control system for combustion motor off mechanism

3.4.1 Hardware design results

The control system for the off-mechanism combustion motor comprised several hardware components, including a soil moisture sensor, Arduino microcontroller, LCD display, MG996R servo motor (10 kg, 180^0), RTC (Real-Time Clock), SD-Card, memory, power supply, and breadboard, as illustrated in Figure 7.

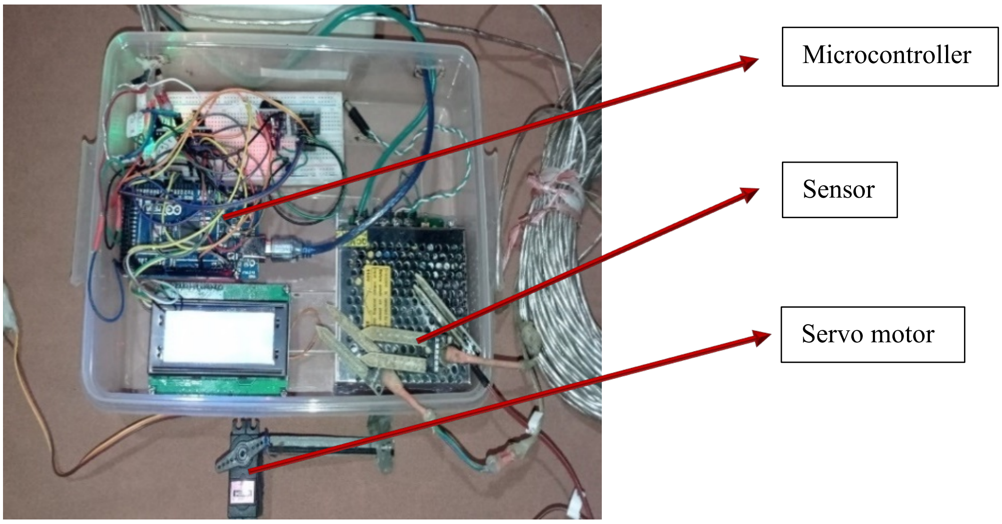


Figure 7. Control system for off-mechanism combustion motor.

This research utilized a YL-69 soil moisture sensor in an off-control system, where the microcontroller serves as the controller to instruct the actuator (servo motor) to shut down the combustion engine. The sensor acted as a reference to detect soil moisture levels, ensuring precise water distribution to the plants. Owing to its high sensitivity, the sensor provided immediate reading when the water was applied to the soil.

The control system design included tools such as an SD-Card to store processed sensor data, which was managed by the microcontroller. Data were further processed using a data logger and stored on a micro-SD card. In addition, a Real-Time Clock (RTC) was integrated to provide continuous time tracking for all data within the microcontroller.

3.4.2 Calibration and validation of soil moisture sensor

The sensor output must be in the form of a voltage (Volt), which served as the input data for the controller. Calibration was performed by measuring the soil moisture at various levels using a soil moisture sensor. The resulting data were then compared between the voltage output of the sensor and the corresponding soil moisture levels to establish a linear relationship. This linear equation was subsequently implemented in a programming language to enable the real-time conversion of voltage readings into soil moisture values.

The calibration results of the YL-69 soil moisture sensor obtained were presented in the graph shown in Figure 8. This graph illustrated the relationship between the volume of water added (in mL) and the voltage detected by the sensor. The calibration process yielded linear regression results, with correlation coefficients of 0.908, 0.921, and 0.948 for sensors 1,2, and 3 respectively. These linear equations were integrated into the system's program to accurately interpret the sensor voltage outputs as soil moisture levels increase.

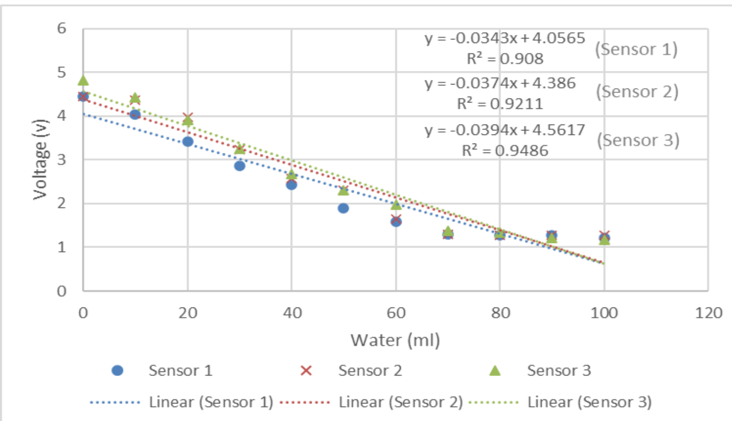


Figure 8. Calibration results of the soil moisture sensor.

During the sensor validation process, Equation 3 was applied using variations in predetermined soil moisture levels. This process involved comparing the output values of the sensor with the soil moisture levels determined by the gravimetric method. Soil samples were collected immediately after the sensor readings and oven-dried at 105°C for 24 hours to determine their actual moisture content. The measured soil moisture values were subsequently compared to the corresponding sensor readings to evaluate sensor accuracy.

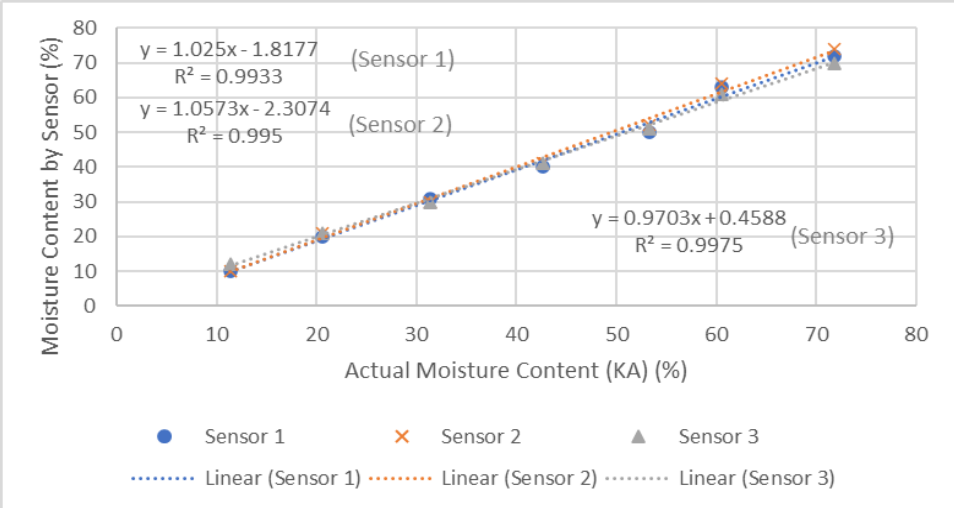


Figure 9. Validation of soil moisture sensor

The validation of soil moisture sensors 1, 2, and 3 yielded regression coefficients of 0.9933, 0.995, and 0.9975, respectively, for varying soil moisture levels. These results indicated a strong linear relationship with a margin of error ranging from 1 to 3%. This demonstrated the high accuracy and reliability of the sensors for measuring soil moisture. These findings were consistent with those of Faridah et al. (2025), who reported that the YL-69 sensor can achieve a measurement accuracy of up to 93% and a precision exceeding 90%.

3.4.3 Testing the control mechanism for combustion motor off system

Testing of the control mechanism for the throttle reduction system in the combustion engine aimed to ensure that the sensor system operated accurately at predefined threshold values. In this study, a servo motor was employed as an actuator to manipulate the throttle lever of the combustion engine, allowing the system to automatically reduce the engine throttle based on the specified setpoints.

The determination of soil moisture setpoints was not specifically tailored to the type of crop being cultivated but rather based on the physical characteristics of the soil used for shallot farming. According to Musthafa et al. (2018), clay-textured soil suitable for shallots ideally required a soil moisture level of 50 - 70%, along with adequate sunlight and air temperatures ranging from 25 to 32 °C. Given that local farmers often face issues, such as bulb rot due to overwatering, the setpoint was established at the upper limit of the ideal range, namely 70%.

Based on the response of the soil moisture sensor, as shown in Figure 10, the sprinkler system ceased operation when the soil moisture level reached 70%. The irrigation system operated for a duration ranging from 10 to 28 minutes to achieve the desired soil moisture level.

The control system responded to soil moisture levels by regulating the servo motor. The servo motor moved the throttle lever to the "off" position when the soil moisture reaches ≥ 70% and returned it to its original position when the moisture level dropped below 70%. In certain instances, as depicted in Figure 10, even after the gasoline engine stopped pumping water, the soil moisture continued to rise owing to external factors such as rainfall and the physical properties of the soil i.e. silty clay texture. This type of soil has a slow infiltration rate, causing delayed water penetration to the depth where the sensor was placed. As a result, the sensor readings were delayed, which in turn delayed throttle reduction. However, after the throttle was reduced, the accumulation of surface water became detectable only by the sensor.

Therefore, the sensor placement depth must be carefully considered for soils with slow infiltration rates. Additionally, it is recommended to use an irrigation system that delivers water directly to plant roots, such as a drip irrigation system. This method is more efficient and capable of delivering water at doses that match plant needs (Ali et al., 2024).

The watering interval was adjusted to match the irrigation practices of the farmers at the research site. Watering was performed once daily, typically in the morning and occasionally in the evening, and avoided during periods of heavy rainfall. This practice aligned with the statement of Manurung et al. (2022), which indicated that the optimal watering frequency for shallot cultivation was once per day.

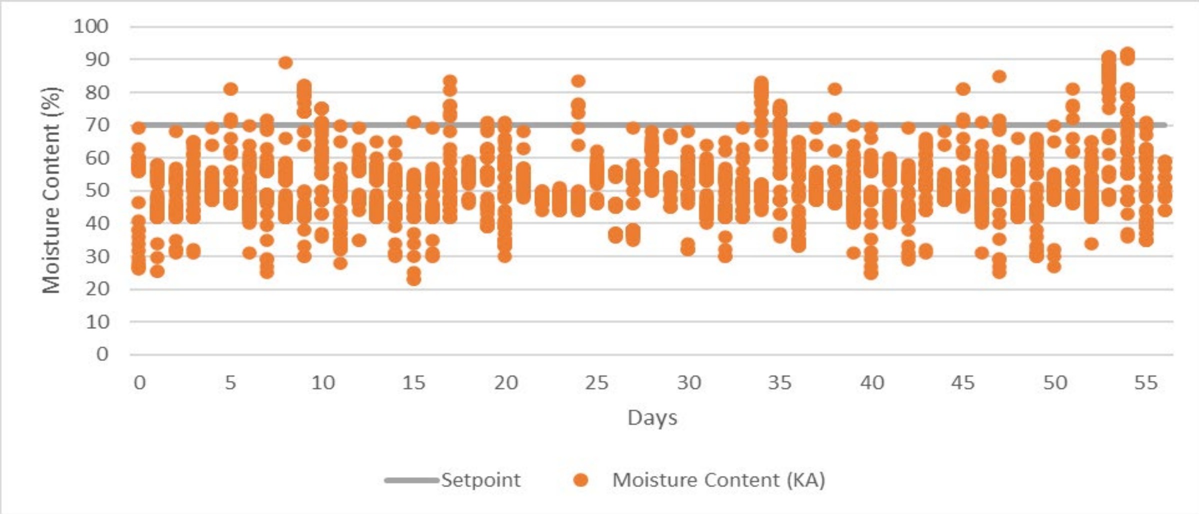


Figure 10. Control system response to setpoint

3.4.4 Shallot productivity

The shallot harvest was conducted to directly compare the productivity between two plots of 15 × 20 m: irrigated plot using a pump equipped with a control system and other plot without such a system. Harvesting occurred 56 days after planting (DAP). Total yield of the plot with control system reached 140 kg, with 6.5 kg (5%) being affected by decay. In contrast, the plot without the control system produced only 96.2 kg, with 17 kg (18%) decaying.

Based on these direct observations, it was evident that field with controlled irrigation resulted in higher yields and a lower proportion of decayed bulbs than field with conventional irrigation (Figure 10). This outcome may be attributed to the fact that excessive water can hinder bulb development, leading to imperfect growth and decay (Bagaskara et al., 2023) The problems caused by overirrigation ranged from inhibited root development to the emergence of pathogenic organisms. Therefore, the use of an off-mechanism control system for irrigation management can effectively reduce bulb decay, thereby ensuring better productivity and crop quality.

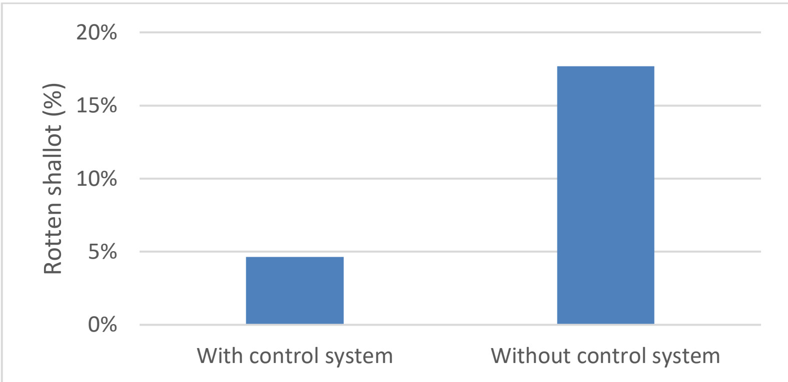


Figure 11. Percentage of rotten shallots between irrigation with a control system and without a control system.

4 CONCLUSION

Based on the research, the following conclusions can be drawn:

1. An automation of a combustion engine-powered sprinkler irrigation system had been successfully developed and was capable of controlling water application to prevent over-irrigation, thereby effectively reducing bulb rot in shallot cultivation.
2. The automated sprinkler irrigation system operated for 10–28 minute to achieve the desired soil moisture level.
3. System testing yielded an average Coefficient of Uniformity (CU) of 84.34%, indicating good water distribution uniformity and confirming the feasibility of the system for practical use.

REFERENCES

Abd El-Wahed, M. H., Medici, M., & Lorenzini, G. (2016). Sprinkler irrigation uniformity: Impact on the crop yield and water use efficiency. *Journal of Engineering Thermophysics*, *25*(1), 117–125. https://doi.org/10.1134/S1810232816010112

Ali, M. I., Suhardi, & Haerani. (2024). Effectiveness of the Application of Drip Irrigation In Some Planting Media for Caisim

(Barassica juncea L .). *Salaga Journal*, *02*(1), 1–9. https://doi.org/10.70124/salaga.v2i1.1354
Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration – Guidelines for computing crop water requirements*. Food and Agriculture Organization of the United Nations. https://www.fao.org/4/x0490e/x0490e00.htm
Ayusari, Waris, A., & Sapsal, M. T. (2024). Application of Fuzzy Control and IoT Monitoring on Small Scale Biofermentor for Making Virgin Coconut Oil. *Salaga Journal*, *02*(2), 58–64. https://doi.org/10.70124/salaga.v2i2.1776
Bagaskara, K. F., Mahmudi, A., & Pranoto, Y. A. (2023). Sistem Kontrol Dan Monitoring Pada Tanaman Bawang Merah Berbasis Iot. *JATI (Jurnal Mahasiswa Teknik Informatika)*, *7*(1), 873–880. https://doi.org/10.36040/jati.v7i1.6177
Chaube, U. C., Pandey, A., & Singh, V. P. (2023). Canal Irrigation Systems in India: Operation, Maintenance, and Management. In U. C. Chaube, A. Pandey, & V. P. Singh (Eds.), *Water Science and Technology Library* (pp. 471–483). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-42812-8_19
Darmayati, F. D., & Sutikto, T. (2019). Estimasi Total Air Tersedia Bagi Tanaman Pada Berbagai Tekstur Tanah Menggunakan Metode Pengukuran Kandungan Air Jenuh. *Berkala Ilmiah Pertanian*, *2*(4), 164–168. https://doi.org/10.19184/bip.v2i4.16317
Faridah, N. S., Sapsal, T. M., Jamaluddin, A. T. A., Dani Achmad, A., & Surya, A. M. (2025). Stability of soil moisture sensors for agricultural crop cultivation. *Research in Agricultural Engineering*. https://rae.agriculturejournals.cz/artkey/rae-000004-1828.php
Fauziah, R., Susila, A. D., & Sulistyono, E. (2016). Shallot (Allium ascalonicum L.) Cultivation on Dry Land Using Sprinkler Irrigation on Various Volume and Frequency. *Jurnal Hortikultura Indonesia*, *7*(1), 1–8. https://doi.org/10.29244/jhi.7.1.1-8
Gultom, M. A., Agustina, H., & Mursidi, R. (2012). Effect of Nozzle Diameter and Watering Height of Sprinkler Irrigation on the Soil Compaction. *Jurnal Teknik Pertanian Sriwijaya*, *1*(2), 119–126.
Laba, A., Musa, W., & Abdussamad, S. (2024). Rancang Bangun Model Alat Pengering Indoor Otomatis Hasil Pertanian Berbasis Arduino Uno. *Jambura Journal of Electrical and Electronics Engineering*, *6*(1), 01–06. https://doi.org/10.37905/jjeee.v6i1.21554
Manurung, G. P., Kusumiyati, & Hamdani, J. S. (2022). Effect of watering interval to the growth and adaptation of three commercial cultivars of shallot. *Jurnal Kultivasi*, *21*(1), 24–32. https://doi.org/10.24198/kultivasi.v21i1.34836
Musthafa, A., Utama, S. N., & Harmini, T. (2018). Rancang Bangun Sistem Kontrol Penyiraman Tanaman Bawang Merah pada Greenhouse Menggunakan Smartphone. *Seminar Nasional Teknik Elektro*, 195–198.
Pien, M. R., Haerani, & Munir, A. (2024). Comparative Analysis of the Performance of Gasoline and LPG-Powered Water Pumps in Shallow Wells. *Salaga Journal*, *01*(1), 1–7. https://doi.org/10.70124/salaga.v1i1.1102
Rafikul, A. (2024). *Analisis kebutuhan air tanaman bawang merah untuk penjadwalan musim tanam di Nagari Koto Gadang Guguak Kecamatan Gunung Talang dengan aplikasi Cropwat 8.0* [Universitas Andalas]. http://scholar.unand.ac.id/483288/
Ramsari, N., & Hidayat, T. (2022). Monitoring System and Hydroponic Plant Automation Using Microcontroller Internet of Things Based (IoT). *Compiler*, *11*(2), 59–74. https://doi.org/10.28989/compiler.v11i2.1365
Ravikumar, V. (2023). *Uniform Irrigation with Sprinklers BT - Sprinkler and Drip Irrigation: Theory and Practice* (V. Ravikumar (ed.); pp. 25–46). Springer Nature Singapore. https://doi.org/10.1007/978-981-19-2775-1_2
Shalsabillah, H., Amri, K., & Gunawan, G. (2019). Analisis Kebutuhan Air Irigasi Menggunakan Metode Cropwat Version 8.0. *Inersia, Jurnal Teknik Sipil*, *10*, 61–68. https://doi.org/10.33369/ijts.10.2.61-68
Susanawati, L. D., Rahadi, B., & Tauhid, Y. (2018). The Determination of the Rate of Infiltration Using the Measurement of the Double Ring Infiltrometer and Calculation of Horton Model on The Tangerine Orange 55 (Citrus Reticulata) Garden In The Selorejo Village, Malang. *Jurnal Sumberdaya Alam Dan Lingkungan*, *5*(2), 28–34. https://doi.org/10.21776/ub.jsal.2018.005.02.4
Tusi, A., & Lanya, B. (2016). Design of Portable Sprinkler For Pakchoy Plant. *Jurnal Irigasi*, *11*(1), 43–54. https://doi.org/10.31028/ji.v11.i1.43-54
Wahyuni, L. T., Tusi, A., & Amien, E. R. (2023). Uji Kinerja Sistem Fertigasi Tanaman Bawang Merah (Allium cepa L.). *Jurnal Agricultural Biosystem Engineering*, *2*(3), 461–469. https://doi.org/10.23960/jabe.v2i3.8060
Wicaksono, S. A. W., Ridwan, & Asmara, S. (2023). Geografis Study of Malaya Watershed Irrigation Planning in Lemong District , Pesisir Barat Regency , Lampung Province Based on Geographic Information. *Jurnal Agricultural Biosystem Engineering*, *2*(4), 608–618.
Yudhaprakosa, P., Akbar, S. R., & Maulana, R. (2019). Sistem Otomasi dan Monitoring Tanaman Hidroponik Berbasis Real Time OS. *Jurnal Pengembangan Teknologi Informasi Dan Ilmu Komputer*, *3*(4), 3285–3293. http://j-ptiik.ub.ac.id/index.php/j-ptiik/article/view/4914
Yustiana, F., & Sitohang, G. A. (2019). Perhitungan Evapotranspirasi Acuan untuk Irigasi di Indonesia. *RekaRacana: Jurnal Teknil Sipil*, *5*(2), 39–49. https://doi.org/10.26760/rekaracana.v5i2.39