

Internet of Things (IoT) based drip irrigation optimization to reduce the impact of drought on Tomato

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ABSTRACT

Drought is one of the main challenges in tomato cultivation in the tropics, especially in the dry season. This study aims to examine the effectiveness of the Internet of Things (IoT) based drip irrigation system in maintaining soil moisture, supporting plant growth, increasing crop yields, and optimizing water use efficiency. The experimental design used RAK with three treatments: manual irrigation (P1), conventional drip irrigation (P2), and IoT-based drip irrigation (P3), each repeated three times. The results showed that P3 significantly maintained soil moisture in the optimal range (55.6% \pm 4.1), increased plant height (78.2 cm), number of leaves (27.4 leaves), and stem diameter (9.4 mm), and produced the highest fruit weight (1.85 kg/plant) with a water use efficiency of 4.59 liters/kg. IoT systems have proven to be superior to other treatments in supporting the growth and productivity of plants in a water-efficient manner. This study shows that sensor-based precision irrigation can be an adaptive solution to climate change and is feasible to be adopted in tropical horticultural agricultural systems in a sustainable manner.

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1. INTRODUCTION

Global climate change that has occurred over the past two decades has triggered an increase in air temperature, changes in rainfall patterns, and an increase in the frequency of droughts in various regions of the world, including Indonesia. According to a report by the Intergovernmental Panel on Climate Change (IPCC, 2021), the increasingly frequent El Niño phenomenon has also exacerbated drought conditions, which has a direct impact on the decline in productivity in the agricultural sector. Drought not only causes a water deficit on agricultural land, but also disrupts plant physiological processes such as photosynthesis, transpiration, and yield formation (Farooq et al., 2012).

Tomatoes (*Solanum lycopersicum*) are one of the leading horticultural commodities that have high economic value in Indonesia. However, this plant is very sensitive to lack of water, especially in the flowering and fruit formation phases (Nurrahman et al., 2019). According to the Ministry of Agriculture (2022), average tomato production decreased by up to 30% during the long dry season due to reliance on inefficient and imprecise manual irrigation. Therefore, increasing water use efficiency is a key strategy in maintaining tomato productivity in the midst of limited water resources.

One promising innovative approach to address this problem is the implementation of an Internet of Things (IoT)-based drip irrigation system. This technology allows automatic water management by utilizing soil moisture sensors and microcontroller systems connected to the internet network. The use of IoT in irrigation allows for timely and quantitative application of water based on the actual conditions of the land and plant needs (Chatterjee et al., 2021). This supports the principles of precision agriculture which aims to optimize production inputs, increase efficiency, and reduce environmental impact (Gebbers & Adamchuk, 2010).

Previous studies have shown that the application of drip irrigation can significantly improve water use efficiency compared to conventional irrigation methods. For example, a study by Al-Ghobari et al. (2018) showed that drip irrigation can increase water efficiency by 40–50% and increase tomato yields by up to 25%. On the other hand, more sophisticated IoT-based irrigation systems that are responsive to soil dynamics and microclimate have begun to be implemented in various countries to support agricultural sustainability, but their use in Indonesia is still very limited, especially at the scale of smallholders.

The main challenges in the development of precision irrigation in Indonesia are the limited access of farmers to technology and the lack of applied research adapting these systems in the context of tropical agroecology. Therefore, a scientific study is needed that proves the effectiveness of IoT-based drip irrigation systems in improving water use efficiency and crop productivity locally.

This study aims to examine the effectiveness of IoT-based drip irrigation systems in reducing the impact of drought on the growth and yield of tomato plants in tropical lands. This study is focused on the evaluation of soil moisture, vegetative growth, crop yield, and water use efficiency in IoT systems compared to conventional manual and drip irrigation systems. It is hoped that the results of this research can be the basis for the development of an applicative and sustainable smart agriculture model in Indonesia.

2. METHOD

2.1 Research Location and Time

This research was carried out at the Community land in Harian subdistrict, Samosir regency, Province Sumatera Utara, Indonesia. This location is located at an altitude of 900 meters above sea level with a wet tropical climate type (Af according to the Koppen classification) and an average annual rainfall of about 2,200 mm. The study was carried out for 120 days, starting in early October 2024 to the end of January 2025, coinciding with the start of the rainy season in the region.

2.2 Research Materials and Tools

The materials used in this study are: Tomato seeds of the Ratna variety that are adaptive in the middle plains, Basic fertilizer and maintenance (NPK 15:15:15, manure), Soil well water as a source of irrigation

Main tools: YL-69 type soil moisture sensor with ADC module, ESP32 Microcontroller (Wi-Fi ready), 12V DC mini pump (15W) for drip irrigation, 5V module Relay, Drip irrigation hose (dripline), Digital timer (for manual control), Multimeter, soldering set, and breadboard, Arduino IDE software for programming and ThingSpeak as IoT server.

2.3 Experimental Design and Treatment

This study used a Complete Random Design (RAL) with 3 treatments and each treatment was repeated 5 times so that there were a total of 15 experimental units. Each experimental unit consisted of 10 tomato plants planted in a 1 m² bed. The treatments tested are as follows: P1: Manual irrigation 2 times a day (morning and evening) with a dipper; P2: Conventional drip irrigation without sensors (manual operated); P3: IoT-based automatic drip irrigation (sensor and microcontroller based).

2.4 Research Procedure

2.4.1 Land Preparation and Planting

The land is cultivated by hoeing the soil twice and formed into a bed 1 meter wide and 5 meters long. Each bed is given 10 tons/ha of manure and 200 kg/ha of NPK as a base. Seeds are sown first for 21 days and transplanted into the field after 4–5 leaves are planted.

2.4.2 IoT Irrigation System Installation

In the P3 treatment, the IoT-based automatic irrigation system is installed as follows: The soil moisture sensor (YL-69) is planted 10 cm deep at the central point of the plant, the sensor is connected to the ESP32 programmed with Arduino IDE, when the soil moisture is <40%, the ESP32 activates the pump through the relay module, the pump pumps the water from the reservoir to the drip irrigation hose that flows into the root zone of the plant, Humidity data is sent to the

ThingSpeak platform over the Wi-F network, the threshold humidity setting and the frequency of data readings are adjusted every 30 minutes.

2.4.3 Plant Maintenance

During the study, plant maintenance was carried out uniformly throughout the treatment: weed weeding was carried out every 2 weeks, pest and disease control was carried out preventively using plant-based pesticides made from neem and follow-up fertilization was given 2 times (age 30 and 60 days after planting).

2.5 Observed Parameters

- Soil moisture (% volumetric size): Measured with the YL-69 sensor and confirmed by the gravimetric method on a weekly basis.
- Plant growth: Plant height (cm), measured every 7 days; Number of leaves and stem diameter (mm)
- Yield: Number of fruits per plant; Total weight of fruit per plant (grams)
- Water use efficiency: Total volume of water used (liters) per plot
- Fruit production (kg) per liter of water (efficiency indicator)

2.6 Data Analysis

The quantitative data obtained was analyzed using:

- Multiple Fingerprint Analysis (ANOVA) to determine the effect of treatment
- If there is a real difference, it is followed by the Smallest Real Difference Test (BNT) at a significance level of 5%

The software used is SPSS version 26 and Excel 365 for chart visualization and descriptive analysis.

3. RESULTS AND DISCUSSION

3.1 Soil Moisture

The results of soil moisture observation for 12 weeks showed that the IoT-based drip irrigation system (P3) was able to maintain soil moisture in the optimal range of 45–60%. Meanwhile, manual irrigation (P1) shows quite extreme fluctuations between 30–70%, while P2 is in the range of 38–62%.

Table 1. Average soil moisture per treatment over 12 weeks

Treatment	Average Humidity (%)	Standard Deviation
P1	46,4	±12.3
P2	51,2	±6.8
P3	55,6	±4.1

The results of ANOVA showed that there was a significant difference between treatments ($p < 0.05$). The BNT test showed that P3 was very noticeable from P1 and significant from P2. Soil moisture stability is very important as it affects the rate of transpiration and the efficiency of nutrient absorption by the roots (Farooq et al., 2012).

One of the main results of this study is the ability of IoT-based drip irrigation systems (P3) to maintain soil moisture in a relatively stable range, which is between 45%-60%. This humidity range is close to the optimal range for the growth of tomato plants, especially in the vegetative and generative periods. In contrast to P1 treatment (manual irrigation) which shows extreme humidity fluctuations between 30%-70%, which can cause water stress in plants due to periodic lack or excess water.

Soil moisture stability is an important factor in supporting the physiological balance of plants. When the soil is too dry, the plant will close the stomata to reduce water loss, resulting in a decrease in the rate of photosynthesis. On the other hand, soil that is too wet can inhibit the diffusion of oxygen to the roots and increase the risk of root rot (Farooq et al., 2012). Therefore, soil moisture stability as achieved by IoT systems has a very important agronomic value.

The soil moisture sensor in the P3 system works in real-time to read the moisture value and activate the pump only when the humidity is below the 40% threshold. This approach allows for more precise and responsive irrigation control than conventional methods. This is evidenced by the lowest standard soil moisture deviation of P3 ($\pm 4.1\%$), indicating high stability compared to P1 ($\pm 12.3\%$).

This research supports the results of a study by Chatterjee et al. (2021) who reported that IoT-based irrigation systems can maintain soil moisture more stably, thereby reducing the incidence of water stress in plants. In the study, tomato plants showed significant increases in height and fruit count when grown in an IoT-based system compared to controls.

Furthermore, this study is also in line with Patel et al. (2020) who stated that controlling irrigation using a humidity sensor can reduce soil moisture fluctuations by up to 35% compared to manual irrigation. These results reinforce the relevance of sensor-based approaches for agriculture in tropical regions that are prone to drought or uneven rainfall distribution.

In the context of precision agriculture, soil moisture control is a key foundation as it is directly related to the effectiveness of other inputs such as fertilizers and pesticides. Soil with stable moisture can accelerate fertilizer dissolution and nutrient absorption. Therefore, the results of this study not only support water management, but also support the optimization of other production factors.

In general, the soil moisture stability of P3 provides strong evidence that IoT-based drip irrigation systems are not just an automation tool, but also a very strategic plant microenvironment management tool. This is very important in supporting sustainable agriculture, especially in the midst of climate change issues and limited water resources.

3.2 Growth of tomato plants

Observation of plant growth parameters showed that P3 produced plants with the best vegetative growth compared to other treatments. The plant height, number of leaves, and stem diameter are greater in IoT irrigation systems.

Table 2. Average growth of tomato plants at the age of 60 HST

Treatment	Plant Height (cm)	Number of Leaves	Diameter Batang (mm)
P1	62.3 A	20.6 to	7.3 A
P2	70.5 ab	24.2 ab	8.1 ab
P3	78.2 b	27.4 b	9.4 b

Desk: Different letters show a noticeable difference based on the 5% BNT test

These growth conditions suggest that IoT irrigation systems deliver water more precisely, preventing water deficits that inhibit photosynthesis and leaf growth (Kadam et al., 2020). A greater number of leaves also has implications for increasing the photosynthetic capacity of plants.

The results showed that IoT (P3) irrigation treatment consistently produced plants with the best vegetative growth. The average height of the plants in P3 is 78.2 cm, higher than P2 (70.5 cm) and P1 (62.3 cm). This high growth is followed by an increase in the number of leaves (27.4 leaves) and stem diameter (9.4 mm), which suggests that optimal water supply plays an important role in supporting the vegetative growth of tomato plants.

Plant growth is greatly influenced by the availability of water in the root zone. Plants that experience a lack of water will experience a decrease in cell expansion, so that tall growth and leaf area are inhibited (Kadam et al., 2020). With sensor-based irrigation arrangements that keep soil moisture stable, the P3 system is able to provide optimal conditions for plant growth, both in terms of water supply and the microclimate around the roots.

A greater number of leaves also reflects the plant's higher photosynthetic capacity, which directly contributes to biomass synthesis and subsequent generative growth. Healthy and spacious leaves are also an indicator of balanced transpiration efficiency, where water loss does not exceed the plant's ability to absorb water from the soil (Sihotang et al., 2024).

This study is in line with the results of the study of Al-Ghobari et al. (2018) which stated that the growth of tomato plants is better in drip irrigation systems than stagnant or manual irrigation, with a difference in plant height reaching 10–15%. In the study, drip irrigation kept the root zone moist and minimized soil surface evaporation.

Another advantage of the P3 system is its ability to prevent short-term water stress. Too extreme fluctuations in humidity in P1 cause plants to experience cumulative mild chronic stress, resulting in stunted growth despite regular watering frequency. Manual water administration is not able to adjust appropriately to the dynamics of the plant's daily water needs.

Gebbers & Adamchuk's (2010) study in precision agriculture emphasized that plant growth can be significantly improved if inputs are controlled based on actual plant conditions and the environment, rather than on a fixed schedule. The results of this study show the validity of this principle in the real application of sensor-based irrigation systems.

With better vegetative growth, tomato plants from P3 treatment are better prepared to face the generative phase and produce flowers and fruits in higher quantities and quality. This signifies that the success of an irrigation system is measured not only from the technical aspect, but also from its impact on the overall life cycle of the plant.

3.3 Yield

Yields measured by the number and weight of fruits per plant showed that P3 gave the highest yield significantly compared to other treatments.

Table 3. Average yield per crop

Treatment	Number of Fruits/Plants	Total Fruit Weight (kg)
P1	18.4 A	1.32 A
P2	21.1 ab	1.45 ab
P3	24.7 b	1.85 b

Desk: Different letters show a noticeable difference based on the 5% BNT test

The increase in yield in P3 by 28.4% compared to P1 demonstrates the effectiveness of IoT-based drip irrigation systems in supporting stable water availability during the critical phase of fruit formation. This result is in line with the findings of Al-Ghobari et al. (2018) who reported an increase in tomato yields by 25–30% with an automatic drip irrigation system.

One of the most important indicators in evaluating the effectiveness of agricultural technology is crop yield. In this study, the IoT-based drip irrigation system (P3) produced an average of 24.7 fruits per plant and a total weight of 1.85 kg, showing significant advantages over P2 and P1. These results reflect a close relationship between stable groundwater conditions and successful fruit formation.

The generative phase in tomato plants is very sensitive to the availability of water. Lack of water at this stage can lead to flower miscarriage, imperfect fruit formation, and decreased organoleptic quality of the fruit. IoT irrigation systems that are able to maintain a consistent water supply have been proven to maintain the physiological conditions of plants that support fruit development.

The higher yield quantity in P3 is also supported by more optimal vegetative growth conditions. Roots that are more active due to stable soil moisture are able to absorb more nutrients, especially potassium and calcium, which are important in the formation of tomato fruits (Nurrahman et al., 2019).

This study corroborates the results of a study by Chatterjee et al. (2021) which reported that tomato yields increased by up to 30% when an IoT-based irrigation system was implemented. In the study, the increase occurred not only in the quantity of fruit, but also in the quality, such as color, dissolved solids content, and shelf life of the fruit.

The greater number of fruits in the P3 system can also be attributed to moisture stability during the flower-forming phase. Tomato plants that experience water stress in this phase tend to experience pollination failure and a decrease in the ratio of flowers to fruit (fruit set). This was not found in the P3 treatment, which showed a high fruit set ratio.

In a study by Al-Ghobari et al. (2018), it was stated that the filling efficiency of tomato fruits is highly dependent on the sustainability of water availability, especially in the early stages of fruit formation. The results of this study show that the P3 system is able to support this process well.

Statistically higher yields in P3 also have implications for increasing economic value for farmers. In small-scale technology adoption scenarios, a yield difference of 20–30% can be a significant incentive for farmers to invest funds in simple IoT technologies that are now getting cheaper and easier to implement.

Thus, IoT-based irrigation systems provide not only technical advantages, but also productivity advantages that are practically and economically relevant. This makes this technology a potential solution in overcoming the water crisis and improving horticulture-based food security.

3.4 Water Use Efficiency

Water use efficiency is calculated based on the total water used compared to the total weight of the fruit produced (liters of water/kg of fruit).

Table 4. Water use efficiency

Treatment	Total Water Used (liters/plot)	Fruit Yield (kg/plot)	Water Efficiency (liter/kg)
P1	142	13,2	10,76
P2	110	14,5	7,58
P3	85	18,5	4,59

The P3 treatment showed the highest efficiency by requiring only 4.59 liters of water to produce 1 kg of tomatoes, compared to P1 which required more than 10 liters/kg. The efficiency of water use is an important indicator in the context of adaptation to climate change and water scarcity in the future (Bacco et al., 2019).

Water use efficiency is a key indicator in evaluating the success of irrigation technology, especially in the context of adaptation to drought and limited water resources. The results showed that the IoT-based drip irrigation system (P3) uses the most efficient water by requiring only 4.59 liters of water per kilogram of tomatoes, compared to P2 of 7.58 liters/kg and P1 of 10.76 liters/kg.

This difference is very significant and confirms that the P3 system optimizes every drop of water given to the plant.

The efficiency performance in P3 is obtained through an automation system that only activates the pump when the soil is below the threshold humidity (<40%). This prevents overwatering that is prevalent in manual irrigation systems (P1), where water is often dispensed excessively without considering actual humidity. Manual systems tend to rely on habits or fixed hours, rather than the needs of the plant dynamically.

High efficiency is also due to minimal water loss due to evaporation. Drip irrigation generally directs water directly to the root zone and minimizes water contact with the soil surface. When combined with an IoT-based control system, water distribution becomes highly precise and scalable. This is in line with the findings of Patel et al. (2020) who stated that the integration of sensors in drip irrigation can reduce water consumption by 35–50% compared to unfiltered irrigation.

This condition is very favorable in the situation of rainfed agricultural land or areas with a high drought index. In the context of Indonesia, many horticultural agricultural areas face limited access to water during the dry season, so efficiency is a vital aspect in the continuity of farming. IoT-based irrigation technology has the potential to be a solution in overcoming inefficiencies and reliance on labor in manual watering.

Apart from the technical aspect, the efficiency of water use also has an impact on operational costs. A decrease in water volume means reduced pumping requirements, electrical energy, and uptime. In the long run, this can increase farmers' profit margins and support the sustainability of the production system. A study by FAO (2021) emphasizes the importance of input efficiency in the framework of climate-smart agriculture, where technology must be able to improve yields with fewer inputs.

The high water use efficiency in P3 is also directly related to increased crop yields. This means that it is not only more water-efficient, but also provides higher productivity. This refutes the assumption that irrigation efficiency is synonymous with reduced water supply; Quite the opposite, efficiency allows plants to get water according to their physiological needs. Gebbers & Adamchuk (2010) refer to this as "functional efficiency," where each input produces a maximum biological response.

Therefore, the IoT irrigation system in this study shows that water efficiency can be achieved without sacrificing plant growth and yield. Conversely, by providing water precisely and on time, plants can grow optimally in more sustainable conditions. This makes this system very relevant for adoption in climate change scenarios and sustainable water management in the agricultural sector.

4. CONCLUSION

Based on the results of the study, IoT-based drip irrigation systems are proven to be able to maintain soil moisture stability, increase tomato growth and yield, and optimize water use efficiency compared to manual and conventional drip irrigation methods. These findings indicate that sensor-based precision irrigation technology can be an adaptive solution to drought in tropical horticultural lands, while supporting efficient and environmentally friendly sustainable farming practices. Therefore, the adoption of IoT irrigation systems is feasible to be further developed at the scale of small to medium-sized farmers with the support of agricultural training and digital infrastructure. Further research is recommended to examine the efficiency of these systems in other commodities as well as explore the integration of renewable energy technologies (such as solar panels) to make the system more energy-efficient and operationally independent.

REFERENCES

- Al-Ghobari, H. M., & Dewidar, A. Z. (2018). Estimating water requirements and efficiencies of drip irrigated tomatoes grown in arid region using activedrip system. *Agricultural Water Management*, 210, 10–19. <https://doi.org/10.1016/j.agwat.2018.08.001>
- Bacco, M., Barsocchi, P., Ferro, E., Gotta, A., & Ruggeri, M. (2019). Smart farming: Opportunities, challenges and technology enablers. *Sensors*, 19(2), 432. <https://doi.org/10.3390/s19020432>
- Chatterjee, S., Bhattacharya, S., & Datta, A. (2021). Smart irrigation system using IoT: A review. *Journal of Cleaner Production*, 293, 125876. <https://doi.org/10.1016/j.jclepro.2021.125876>
- FAO. (2021). *The State of the World's Land and Water Resources for Food and Agriculture – Systems at Breaking Point*. Food and Agriculture Organization of the United Nations. <https://doi.org/10.4060/cb9910en>

- Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. A. (2012). Plant drought stress: Effects, mechanisms and management. *Agronomy for Sustainable Development*, 29(1), 185–212. <https://doi.org/10.1051/agro:2008021>
- Gebbers, R., & Adamchuk, V. I. (2010). Precision agriculture and food security. *Science*, 327(5967), 828–831. <https://doi.org/10.1126/science.1183899>
- IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Cambridge University Press. <https://doi.org/10.1017/9781009157896>
- Kadam, N. N., Yin, X., Bindran, P. S., Struik, P. C., & Jagadish, K. S. V. (2020). Does morphological and anatomical plasticity during the vegetative stage make wheat more tolerant of water stress? *Plant Physiology and Biochemistry*, 158, 240–250. <https://doi.org/10.1016/j.plaphy.2020.10.033>
- Kementerian Pertanian. (2022). *Statistik Hortikultura Tahun 2021*. Jakarta: Pusat Data dan Sistem Informasi Pertanian. <http://hortikultura.pertanian.go.id>
- Nurrahman, A., Yusnaini, Y., & Supadi, S. (2019). Pengaruh cekaman air terhadap pertumbuhan dan hasil tomat (*Solanum lycopersicum* L.). *Jurnal Hortikultura Indonesia*, 10(1), 45–52. <https://doi.org/10.29244/jhi.10.1.45-52>
- Patel, R., Shah, K., & Joshi, D. (2020). Automated irrigation system using IoT. *International Journal of Engineering Development and Research (IJEDR)*, 8(1), 324–328.* <https://www.ijedr.org/papers/IJEDR2001057.pdf>
- Pramudya, I. D., & Yani, I. (2021). Aplikasi IoT untuk sistem irigasi pertanian otomatis di lahan hortikultura. *Jurnal Teknik Pertanian Lampung*, 10(2), 95–104. <https://doi.org/10.23960/jtep-l.v10i2.95-104>
- Purwanto, E., & Siregar, F. A. (2022). Efektivitas penggunaan irigasi tetes terhadap pertumbuhan dan hasil tanaman tomat di lahan kering. *Agrovigor*, 15(1), 1–9. <https://doi.org/10.21107/agrovigor.v15i1.11032>
- Putra, M. R., & Rahmat, A. (2020). Penerapan Internet of Things (IoT) pada sistem monitoring kelembaban tanah berbasis Arduino. *Jurnal Teknologi Informasi dan Ilmu Komputer*, 7(4), 523–531. <https://doi.org/10.25126/jtiik.202074898>
- Ramadhani, A., & Syahputra, R. (2021). Analisa performa irigasi tetes otomatis berbasis ESP32 pada pertanaman cabai. *Jurnal Keteknik Pertanian*, 39(2), 97–106. <https://doi.org/10.24843/JTEP.2021.v39.i02.p02>
- Sihotang, T., Siregar, L. A. M., & Rahmawati, N. (2024). Growth and biochemical responses of red chili (*Capsicum annuum* L) under drought conditions with 6-Benzylaminopurine application. *International Journal of Basic and Applied Science*, 13(2), 61–73.
- Siregar, M. N., & Hidayat, W. (2020). Pengaruh frekuensi irigasi terhadap pertumbuhan dan hasil tanaman tomat di media tanam pasir. *Jurnal Agroindustri dan Teknologi Pangan*, 4(2), 87–93. <https://doi.org/10.36706/ja.tp.v4i2.112>
- Surbakti, E., & Yuliani, D. (2020). Respon pertumbuhan dan hasil tomat terhadap interval penyiraman yang berbeda. *Agrium: Jurnal Ilmu Pertanian*, 26(2), 65–72. <https://doi.org/10.30596/agrium.v26i2.4803>
- Taufik, M., & Widodo, A. (2021). Analisis efisiensi air pada sistem irigasi tetes otomatis menggunakan mikrokontroler. *Jurnal Ilmiah Teknologi dan Rekayasa*, 12(1), 30–38. <https://doi.org/10.33387/jitr.v12i1.345>
- Widodo, S., & Purnomo, R. (2023). Efisiensi irigasi dan hasil pertanian hortikultura di bawah tekanan iklim. *Jurnal Agroklimat dan Lingkungan*, 11(1), 1–10. <https://doi.org/10.1016/j.jagl.2023.01.001>