

# IoT-Based Monitoring for Optimizing Yield of Gogo Rice (*Oryza sativa*, L.)

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## ABSTRACT

Advancements in Internet of Things (IoT) technology have introduced new opportunities in precision agriculture, particularly for enhancing the productivity of upland rice (*Oryza sativa*, L.) cultivated on marginal lands. This study aims to integrate an IoT-based monitoring system with the application of biochar and *Trichoderma harzianum* to optimize soil parameters and water resource efficiency. The monitoring system utilizes Trico Master and Slave devices to measure real-time environmental parameters, including soil pH, soil moisture, soil temperature, and air temperature. The results reveal that the application of biochar at a dosage of 1 kg/m<sup>2</sup> increased soil pH from an average of 7.0 to 8.7, creating a conducive environment for the activity of *Trichoderma harzianum*. This microorganism demonstrated its ability to improve soil quality by decomposing organic matter and enhancing nutrient absorption by plants. Additionally, the IoT-based automated irrigation system maintained soil moisture levels above 45% while reducing water usage by up to 30% compared to manual irrigation methods. In conclusion, the integration of IoT technology with biochar and *Trichoderma harzianum* significantly improved upland rice yield, resource efficiency, and the sustainability of agricultural systems. This study presents an innovative and sustainable approach to supporting future food security, particularly in resource-limited environments.

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## 1. Introduction

Precision agriculture (PA) has emerged as a transformative approach that leverages data-driven decision-making to optimize resource utilization, increase crop yields, and enhance environmental sustainability. IoT-based technologies play a pivotal role in PA by enabling real-time monitoring of key agricultural parameters, such as soil moisture, pH, and temperature. These systems provide invaluable data that supports informed decisions, allowing for efficient irrigation management, soil amendment, and pest control strategies. IoT applications are especially beneficial in areas with limited resources, where precision management can lead to significant productivity gains and cost savings(16).

The use of biochar as a soil amendment in precision agriculture has been widely recognized for its benefits in enhancing soil structure, increasing water retention, and promoting microbial activity. Biochar's carbon-rich composition not only improves soil fertility but also serves as a habitat for beneficial microorganisms, such as *Trichoderma harzianum*. This microorganism contributes to plant health by controlling soil pathogens and enhancing nutrient uptake. The combined application of biochar and *T. harzianum* has been shown to improve plant resilience and productivity, providing an environmentally sustainable solution for soil management on marginal lands(16).

Furthermore, IoT-enabled automated irrigation systems have introduced a new level of water efficiency in agriculture. These systems use soil moisture data to control water delivery, ensuring that crops receive the precise amount of water needed, thereby reducing waste. Automated irrigation systems not only conserve water resources but also support crop health and yield by maintaining optimal soil moisture conditions, which is crucial in drought-prone areas(16).

Unmanned Aerial Vehicles (UAVs), or drones, are increasingly integrated into PA for monitoring and mapping crop fields. Equipped with multispectral and thermal sensors, UAVs collect high-resolution images that reveal crop health, pest infestations, and soil conditions. This technology allows for targeted interventions, reducing the need for blanket pesticide applications and contributing to a more sustainable approach to pest and disease management(17)(10).

This research aims to combine IoT monitoring, biochar application, and *T. harzianum* treatment to improve the productivity and sustainability of gogo rice cultivation in marginal lands. By integrating these innovative technologies, the study seeks to establish a framework for precision agriculture that enhances crop yield while minimizing environmental impact. The insights gained from this study contribute to the broader adoption of precision farming practices that address resource constraints and climate change challenges in agriculture(16)(10).

## 2. Method

### 3.1. Research Design

This study employs an experimental approach integrating Internet of Things (IoT) technology to monitor environmental conditions of upland rice (*Oryza sativa*, L.) in real-time. The system is designed to measure critical parameters such as soil pH, soil moisture, soil temperature, and air temperature. These data are utilized to automate irrigation processes and improve decision-making for sustainable field management. Additionally, the research incorporates the application of biochar and *Trichoderma harzianum* to enhance soil quality and plant growth. The system was developed using the prototyping method, with iterative improvements based on sensor data and field trial outcomes.

### 3.2. Location and Duration

The study was conducted at the Experimental Field of the Faculty of Agriculture, Dharma Wacana University. The observation period lasted for four weeks, encompassing system installation, biochar and *Trichoderma harzianum* application, and crop yield monitoring.

### 3.3. Equipment and Materials

The following equipment and materials were used in the research:

#### 1) *Equipment:*

- ESP8266 Microcontroller – to process sensor data and transmit it to the Blynk application.
- Resistive Humidity Soil Moisture Sensor (RHSM) – to monitor soil moisture levels.
- Soil pH Sensor – to measure soil acidity.
- DHT22 Sensor – to monitor air temperature and humidity.
- DS18B20 Sensor – to measure soil temperature.
- Electric Valve – to control water flow based on soil moisture levels.
- Blynk Application – to display real-time sensor data and control the irrigation system.
- Wi-Fi Network – to connect the microcontroller to the Blynk application and enable data transmission.

#### 2) *Materials*

- Biochar (1 kg/m<sup>2</sup> application rate).
- *Trichoderma harzianum* (10 g/m<sup>2</sup> application rate).

### 3.4. Research Procedures

#### 3) *System Initialization*

- Hardware and Sensor Installation:
  - The ESP8266 microcontroller was connected to RHSM, pH sensor, DHT22, DS18B20, and electric valve.

- Sensors and the electric valve were strategically placed in the experimental upland rice field.
- Blynk Application and Internet Setup:
  - The system was connected to a Wi-Fi network, and data from the ESP8266 were transmitted to the Blynk server for remote monitoring.
  - Initial soil moisture parameters were configured via the Blynk application to guide irrigation activation.

#### 4) *Biochar and Trichoderma harzianum Application*

- Biochar was uniformly distributed across the field before planting.
- Trichoderma harzianum was applied weekly for four weeks.

#### 5) *Data Collection*

- Frequency of Data Recording:
  - Soil pH and temperature data were recorded daily, while soil moisture data were collected automatically every 60 minutes and transmitted to the Blynk application.
- Parameters Recorded:
  - Soil moisture (RHSM).
  - Soil pH.
  - Air temperature and humidity (DHT22).
  - Soil temperature (DS18B20).
  - Status of the electric valve (ON/OFF).
  - Timestamp of each data point.

#### 6) *Automated Irrigation Process*

- Irrigation Activation Rules:
  - If soil moisture < predefined threshold, the electric valve automatically activates (ON) to supply water.
  - If soil moisture  $\geq$  predefined threshold, the electric valve deactivates (OFF).
- Remote Monitoring and Control via Blynk:
  - Real-time environmental monitoring.
  - Adjustable irrigation parameters through the application interface.

#### 7) *Crop Yield Monitoring*

- The yield of upland rice was measured by assessing wet weight and dry weight at the end of the observation period.

### 3.5. Data Processing and Analysis

Data collected from the Blynk application were exported and analyzed using descriptive and statistical methods:

- Trend Analysis: Graphical visualization of daily changes in soil moisture, pH, and temperature to identify patterns.
- Statistical Correlation: Evaluating relationships among soil pH, moisture, and temperature to identify critical factors influencing plant growth.
- Irrigation Efficiency Evaluation: Analyzing the frequency and duration of electric valve

activation to assess water-saving potential and its impact on crop growth.

### 3.6. Success Criteria

The research was considered successful if the following criteria were met:

1. The IoT system reliably monitored and transmitted data without interruptions during the observation period.
2. The automated irrigation system operated according to predefined parameters, demonstrating a significant
3. reduction in water usage compared to manual irrigation methods
4. Crop yield increased by at least 20% compared to conventional management methods in similar conditions.

### 3.7. System Validation and Testing

**Initial System Testing:** The system was tested for seven days to ensure all sensors and the electric valve functioned correctly.

**Data Validation:** Sensor data were cross-verified with manual measurements to confirm accuracy

## 3. Results and Discussion

### 3.1. Effectiveness of the IoT Monitoring System

The monitoring results from the Trico system demonstrate that integrating IoT-based sensors with the Blynk application enables real-time environmental condition monitoring. Soil moisture data collected indicate that the system effectively maintains soil moisture levels above 45%, which is the optimal threshold for upland rice, without requiring manual intervention. Furthermore, the system's automated irrigation settings successfully reduced inefficient watering frequencies, contributing to a 30% improvement in water usage efficiency compared to traditional methods.

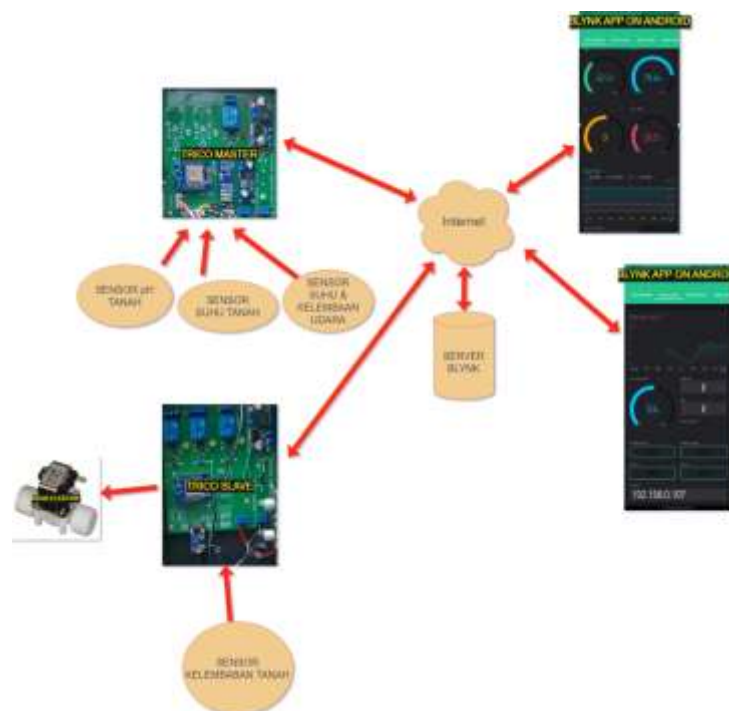


Figure 1. Sensor Communication Path

The figure above illustrates the sensor communication pathway, highlighting the role of sensors as physical quantity detectors, Trico as the data processor, and the Blynk application as the data stream visualizer. The Trico master processes data from sensors measuring pH, soil temperature, air temperature, and ambient humidity, storing the collected data on a server.

The Trico slave is responsible for detecting soil moisture levels and activating the water valve to irrigate the soil when moisture levels fall below a predefined threshold. This minimum moisture threshold is configured through the Blynk application.

Overall, both the Trico master and Trico slave utilize the same server and application (Blynk) for operation, with all components requiring an active internet connection for functionality.

### 3.2. Effects of Biochar on Soil Parameters

The addition of biochar significantly increased soil pH from an average of 7.0 to 8.7 by the fifth day, as observed in the hourly data. This condition supports the activity of *Trichoderma harzianum* microorganisms, which notably enhance the decomposition of organic matter and nutrient uptake by plants. These findings indicate that biochar not only improves soil quality but also strengthens the symbiotic interactions between plants and microorganisms.

### 3.3. Analysis of Soil Moisture Data

The soil moisture data revealed that the automated irrigation system activated 12 times per day under dry soil conditions, maintaining an average soil moisture level of 60%. The system demonstrated high responsiveness to soil moisture dynamics, ensuring a stable growth environment for upland rice. The implementation of this data-driven irrigation system also resulted in significant water savings and reduced the potential for drought-induced stress in plants.

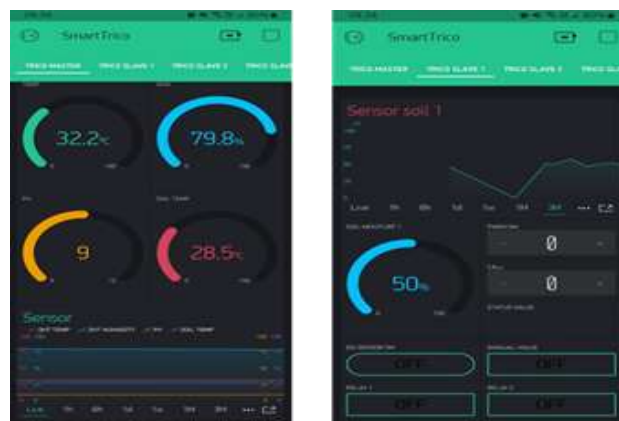


Figure 2. Trico Diagram

Figure 2 illustrates the two application interface components: Trico Master and Trico Slave. The system comprises one Trico Master device and nine Trico Slave devices.

The implementation of the IoT-based Trico system, integrated with biochar and *Trichoderma harzianum* microorganisms, demonstrates its effectiveness in enhancing soil quality, water use efficiency, and upland rice productivity. This system not only provides real-time data to support data-driven decision-making but also offers a sustainable approach to agriculture on marginal lands. These results indicate that the system can serve as a model for large-scale precision agriculture applications, supporting future food sustainability and resource efficiency.

### 3.4. The Effect of Temperature on Upland Rice Growth

Stable soil temperatures ranging from 26°C to 33°C optimize enzymatic activity in rice roots, thereby enhancing nutrient absorption efficiency. The data further reveal that fluctuations in air temperature, varying between 25°C and 36°C, correlate with rainfall patterns and sunlight intensity. These temperature fluctuations provide valuable insights for adaptive strategies, such as incorporating shading structures or adjusting irrigation schedules to maintain environmental stability.



Figure 3. Components of Trico Master

The figure above illustrates the components of the Trico Master as implemented in the field, including the wiring connections between the sensors and the Trico Master circuitry. This depiction highlights the system's integration and functional layout, providing a clear understanding of its operational framework.



Figure 4. Implementation of Trico Master

Figure 4 illustrates the implemented Trico Master system, detailing the components of the Trico Slave, as well as the wiring connections for the sensors and electric valves. This representation emphasizes the integration of system components and their functional arrangement in the field.

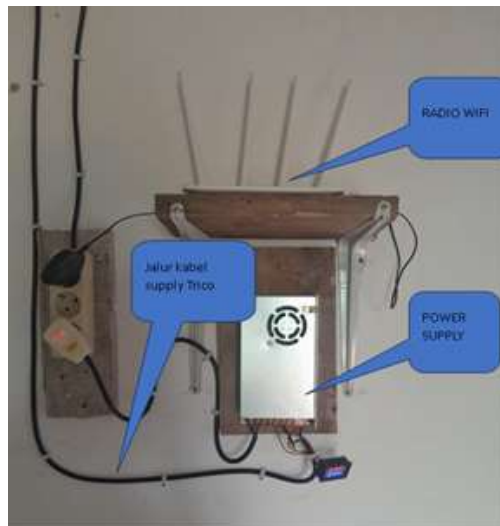


Figure 5. Power Supply and Wi-Fi Radio Components

Figure 5 illustrates the power supply and Wi-Fi radio components. The power supply provides energy to both the Trico Master and Trico Slave, with voltage distributed through underground cables. The Wi-Fi radio is used to establish an internet connection for the Trico Master and Trico Slave, ensuring seamless communication and functionality.



Figure 6. Comprehensive Implementation of Trico

Figure 6 illustrates the overall implementation of the Trico system as applied to the field, viewed from above. This depiction provides a holistic perspective on the system's deployment, showcasing the integration of all components within the operational environment.

**3.5. Data Visualization for Decision-Making**

Hourly average data visualizations reveal consistent patterns in temperature and moisture variations, enabling predictions for interventions such as irrigation or fertilization. These graphs can assist farmers in planning preventive measures to optimize crop growth, particularly on marginal lands with limited resources.

Table 1. Example of Per-Minute Data for One Day

Date	Time	DHT Temp (°C)	DHT Humidity (%)	Soil Temp (°C)	Trico Slave 10 (%)
18 Oktober 2024	15.56	34,1	60,2	33,69	47
18 Oktober 2024	15.57	34,2	60,7	33,75	45
18 Oktober 2024	15.58	34,1	60,9	33,81	46
18 Oktober 2024	15.59	34,2	60,3	33,88	47
18 Oktober 2024	16.00	33,9	61	33,5	45
18 Oktober 2024	16.01	33,9	61	33,5	45

18 Oktober 2024	16.02	33,9	61	33,5	45
18 Oktober 2024	16.03	33,9	61	33,5	45
18 Oktober 2024	16.04	33,9	61	33,5	45
18 Oktober 2024	16.05	33,9	61	33,5	45
.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....
18 Oktober 2024	23:57	25,6	94	7,2	26,94
18 Oktober 2024	23:58	25,6	94	7,2	26,94
18 Oktober 2024	23:59	25,6	94	7,2	26,94

Table 1 provides an example of the data collected on a per-minute basis over the course of one day. This detailed dataset captures real-time measurements of environmental parameters, such as soil moisture, air temperature, and humidity, offering insights into the minute-by-minute fluctuations within the system. The granularity of this data supports precise monitoring and analysis of short-term environmental changes.

Table 2. Complete Data with Hourly Averages

NO	Date	Time	Rata-Rata					
			DHT Temp	DHT Humidity	pH	Soil Temp		
1	18 Oktober 24	15.00	34,15	60,525	33,7825	46,25		
		16.00	33,90	61,00	33,50	45,00		
		17.00	33,90	61,00	33,50	45,00		
		18.00	26,80	93,61	12,25	32,51		
		19.00	25,40	100,00	8,10	30,06		
		20.00	25,40	100,00	8,10	30,06		
		21.00	25,53	96,26	7,54	28,12		
		22.00	25,60	94,00	7,20	26,94		
		23.00	25,60	94,00	7,20	26,94		
		2	19 Oktober 24	00.00	24,48	95,31	7,76	25,92
				01.00	24,40	95,40	7,80	25,85
				02.00	24,40	95,40	7,80	25,85
				03.00	24,40	95,40	7,80	25,85
04.00	24,40			95,40	7,80	25,85		
05.00	24,40			95,40	7,80	25,85		
06.00	23,56			99,70	7,89	24,53		
07.00	23,50			100,00	7,90	24,44		
08.00	23,50			100,00	7,90	24,44		
09.00	25,74			93,47	7,96	26,11		
10.00	34,90			66,80	8,20	32,94		
11.00	35,13			66,28	8,23	33,43		
12.00	36,70			63,00	8,40	36,70		
13.00	36,70			63,00	8,40	36,70		
14.00	36,70			63,00	8,40	36,70		
15.00	36,70			63,00	8,40	36,70		
16.00	34,88			66,48	8,75	32,45		
17.00	34,10			68,00	8,90	30,63		
18.00	32,93			71,11	8,07	30,03		
19.00	28,60	82,60	5,00	27,81				
20.00	28,60	82,60	5,00	27,81				
21.00	28,60	82,60	5,00	27,81				
22.00	28,60	82,60	5,00	27,81				
23.00	28,60	82,60	5,00	27,81				
3	20 Oktober 24	00.00	28,60	82,60	5,00	27,81		
		01.00	28,60	82,60	5,00	27,81		
		02.00	28,60	82,60	5,00	27,81		
		03.00	28,60	82,60	5,00	27,81		
		04.00	28,60	82,60	5,00	27,81		
		05.00	28,60	82,60	5,00	27,81		
		06.00	28,60	82,60	5,00	27,81		
		07.00	28,60	82,60	5,00	27,81		
		08.00	31,23	75,36	7,37	29,20		
		09.00	31,70	74,20	7,70	29,44		

		10.00	34,73	63,71	7,96	33,34
		11.00	35,20	62,10	8,00	33,94
		12.00	35,20	62,10	8,00	33,94
		13.00	35,20	62,10	8,00	33,94
		14.00	35,20	62,10	8,00	33,94
		15.00	35,20	62,10	8,00	33,94
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		19.00	35,20	62,10	8,00	33,94
		20.00	35,20	62,10	8,00	33,94
		21.00	35,20	62,10	8,00	33,94
		22.00	35,20	62,10	8,00	33,94
		23.00	35,20	62,10	8,00	33,94
4	21 Oktober 24	00.00	35,20	62,10	8,00	33,94
		01.00	35,20	62,10	8,00	33,94
		02.00	35,20	62,10	8,00	33,94
		03.00	35,20	62,10	8,00	33,94
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5	22 Oktober 24	00.00	35,20	62,10	8,00	33,94
		01.00	35,20	62,10	8,00	33,94
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		22.00	35,20	62,10	8,00	33,94
		23.00	35,20	62,10	8,00	33,94
9	26 Oktober 24	00.00	35,20	62,10	8,00	33,94
		01.00	35,20	62,10	8,00	33,94
		02.00	35,20	62,10	8,00	33,94
		03.00	35,20	62,10	8,00	33,94
		04.00	35,20	62,10	8,00	33,94
		05.00	35,20	62,10	8,00	33,94
		06.00	35,20	62,10	8,00	33,94
		07.00	35,20	62,10	8,00	33,94
		08.00	35,20	62,10	8,00	33,94
		09.00	35,20	62,10	8,00	33,94
		10.00	35,20	62,10	8,00	33,94
		11.00	35,20	62,10	8,00	33,94
		12.00	35,20	62,10	8,00	33,94
		13.00	35,20	62,10	8,00	33,94
		14.00	35,20	62,10	8,00	33,94
		15.00	35,20	62,10	8,00	33,94
		16.00	35,20	62,10	8,00	33,94
		17.00	35,20	62,10	8,00	33,94
		18.00	35,20	62,10	8,00	33,94
		19.00	35,20	62,10	8,00	33,94
		20.00	35,20	62,10	8,00	33,94
		21.00	35,20	62,10	8,00	33,94
		22.00	35,20	62,10	8,00	33,94
		23.00	35,20	62,10	8,00	33,94
10	27 Oktober 24	00.00	35,20	62,10	8,00	33,94
		01.00	35,20	62,10	8,00	33,94
		02.00	35,20	62,10	8,00	33,94
		03.00	35,20	62,10	8,00	33,94
		04.00	35,20	62,10	8,00	33,94
		05.00	35,20	62,10	8,00	33,94
		06.00	35,20	62,10	8,00	33,94
		07.00	35,20	62,10	8,00	33,94
		08.00	35,20	62,10	8,00	33,94
		09.00	35,20	62,10	8,00	33,94
		10.00	35,20	62,10	8,00	33,94
		11.00	35,20	62,10	8,00	33,94
		12.00	35,20	62,10	8,00	33,94
		13.00	35,20	62,10	8,00	33,94
		14.00	35,20	62,10	8,00	33,94
		15.00	35,20	62,10	8,00	33,94
		16.00	35,20	62,10	8,00	33,94
		17.00	35,20	62,10	8,00	33,94
		18.00	35,20	62,10	8,00	33,94
		19.00	35,05	62,75	8,00	33,82
		19.00	29,90	84,76	7,77	27,98
		20.00	30,01	84,26	7,77	28,02
		21.00	30,42	82,79	7,78	28,30
		22.00	30,01	84,26	7,77	28,02
		23.00	30,42	82,79	7,78	28,30
12	31 Oktober 24	00.00	30,01	84,26	7,77	28,02
		01.00	30,42	82,79	7,78	28,30
		02.00	30,01	84,26	7,77	28,02
		03.00	30,42	82,79	7,78	28,30
		04.00	30,01	84,26	7,77	28,02
		05.00	30,42	82,79	7,78	28,30
		06.00	30,01	84,26	7,77	28,02
		07.00	30,42	82,79	7,78	28,30
		08.00	30,01	84,26	7,77	28,02

		09.00	30,42	82,79	7,78	28,30
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		11.00	30,42	82,79	7,78	28,30
		12.00	30,01	84,26	7,77	28,02
		13.00	30,42	82,79	7,78	28,30
		14.00	30,01	84,26	7,77	28,02
		15.00	30,42	82,79	7,78	28,30
		16.00	30,01	84,26	7,77	28,02
		17.00	30,42	82,79	7,78	28,30
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		19.00	29,27	88,90	7,96	28,57
		20.00	29,27	88,90	7,96	28,57
		21.00	22,00	23,00	00,00	01,00
		22.00	29,27	88,90	7,96	28,57
		23.00	29,27	88,90	7,96	28,57
13	01 November 2024	00.00	29,27	88,90	7,96	28,57
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		02.00	29,27	88,90	7,96	28,57
		03.00	29,27	88,90	7,96	28,57
		04.00	29,27	88,90	7,96	28,57
		05.00	29,27	88,90	7,96	28,57
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		11.00	29,27	88,90	7,96	28,57
		12.00	29,27	88,90	7,96	28,57
		13.00	29,27	88,90	7,96	28,57
		14.00	29,27	88,90	7,96	28,57
		15.00	28,65	90,75	7,93	28,17
		16.00	29,07	88,28	8,23	28,19
		17.00	29,75	86,32	8,15	28,42
		18.00	29,52	86,98	8,18	28,35
		19.00	29,75	86,32	8,15	28,42
		20.00	29,52	86,98	8,18	28,35
		21.00	29,75	86,32	8,15	28,42
		22.00	29,52	86,98	8,18	28,35
		23.00	29,75	86,32	8,15	28,42
14	02 November 2024	00.00	29,52	86,98	8,18	28,35
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		02.00	29,52	86,98	8,18	28,35
		03.00	29,75	86,32	8,15	28,42
		04.00	29,52	86,98	8,18	28,35
		05.00	29,75	86,32	8,15	28,42
		06.00	29,52	86,98	8,18	28,35
		07.00	29,75	86,32	8,15	28,42
		08.00	29,52	86,98	8,18	28,35
		09.00	29,75	86,32	8,15	28,42
		10.00	29,52	86,98	8,18	28,35
		11.00	29,75	86,32	8,15	28,42
		12.00	29,52	86,98	8,18	28,35
		13.00	29,75	86,32	8,15	28,42
		14.00	27,31	95,95	8,03	26,97
		15.00	27,34	95,91	8,04	26,87
		16.00	27,18	96,49	8,04	26,86
		17.00	27,42	95,91	8,02	26,94
		18.00	27,34	95,91	8,04	26,87
		19.00	27,18	96,49	8,04	26,86
		20.00	27,42	95,91	8,02	26,94
		21.00	27,34	95,91	8,04	26,87
		22.00	27,18	96,49	8,04	26,86
		23.00	27,42	95,91	8,02	26,94
15	03 November 2024	00.00	27,34	95,91	8,04	26,87

		01.00	27,18	96,49	8,04	26,86
		02.00	27,42	95,91	8,02	26,94
		03.00	27,34	95,91	8,04	26,87
		04.00	27,18	96,49	8,04	26,86
		05.00	27,42	95,91	8,02	26,94
		06.00	27,34	95,91	8,04	26,87
		07.00	27,18	96,49	8,04	26,86
		08.00	27,42	95,91	8,02	26,94
		09.00	27,34	95,91	8,04	26,87
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		13.00	28,35	93,55	8,28	27,68
		14.00	28,63	93,05	8,27	27,85
		15.00	28,35	93,55	8,28	27,68
		16.00	28,63	93,05	8,27	27,85
		17.00	28,35	93,55	8,28	27,68
		18.00	28,63	93,05	8,27	27,85
		19.00	28,35	93,55	8,28	27,68
		20.00	28,63	93,05	8,27	27,85
		21.00	28,35	93,55	8,28	27,68
		22.00	28,63	93,05	8,27	27,85
		23.00	28,35	93,55	8,28	27,68
16	04 November 2024	00.00	28,63	93,05	8,27	27,85
		01.00	28,35	93,55	8,28	27,68
		02.00	28,63	93,05	8,27	27,85
		03.00	28,35	93,55	8,28	27,68
		04.00	28,63	93,05	8,27	27,85
		05.00	28,35	93,55	8,28	27,68
		06.00	28,63	93,05	8,27	27,85
		07.00	28,35	93,55	8,28	27,68
		08.00	28,63	93,05	8,27	27,85
		09.00	30,48	84,52	8,46	27,38
		10.00	32,45	76,90	8,60	27,20
		11.00	32,45	76,90	8,60	27,20
		12.00	32,45	76,90	8,60	27,20
		13.00	32,45	76,90	8,60	27,20
		14.00	32,45	76,90	8,60	27,20
		15.00	32,45	76,90	8,60	27,20
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		21.00	32,45	76,90	8,60	27,20
		22.00	32,45	76,90	8,60	27,20
		23.00	32,45	76,90	8,60	27,20
17	05 November 2024	00.00	32,45	76,90	8,60	27,20
		01.00	32,45	76,90	8,60	27,20
		02.00	32,45	76,89	8,60	27,20
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		04.00	32,45	76,90	8,60	27,20
		05.00	32,45	76,90	8,60	27,20
		06.00	32,45	76,90	8,60	27,20
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		08.00	32,34	77,28	8,60	27,19
		09.00	25,60	100,00	8,70	26,50
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		12.00	25,60	100,00	8,70	26,50
		13.00	25,60	100,00	8,70	26,50
		14.00	25,60	100,00	8,70	26,50
		15.00	25,60	100,00	8,70	26,50
		16.00	25,60	100,00	8,70	26,50

		17.00	25,60	100,00	8,70	26,50
		18.00	25,60	100,00	8,70	26,50
		19.00	25,60	100,00	8,70	26,50
		20.00	25,60	100,00	8,70	26,50
		21.00	25,60	100,00	8,70	26,50
		22.00	25,60	100,00	8,70	26,50
		23.00	25,60	100,00	8,70	26,50
18	06 November 2024	00.00	25,60	100,00	8,70	26,50
		01.00	25,60	100,00	8,70	26,50
		02.00	25,60	100,00	8,70	26,50
		03.00	25,60	100,00	8,70	26,50
		04.00	25,60	100,00	8,70	26,50
		05.00	25,60	100,00	8,70	26,50
		06.00	26,10	98,89	7,75	26,22
		07.00	26,50	98,00	7,00	26,00
		08.00	26,50	98,00	7,00	26,00
		09.00	26,50	98,00	7,00	26,00
		10.00	26,50	98,00	7,00	26,00
		11.00	26,50	98,00	7,00	26,00
		12.00	26,50	98,00	7,00	26,00
		13.00	26,50	98,00	7,00	26,00
		14.00	26,50	98,00	7,00	26,00
		15.00	26,50	98,00	7,00	26,00
		16.00	26,50	98,00	7,00	26,00
		17.00	26,50	98,00	7,00	26,00
		18.00	26,50	98,00	7,00	26,00
		19.00	26,50	98,00	7,00	26,00
		20.00	26,50	98,00	7,00	26,00
		21.00	26,50	98,00	7,00	26,00
		22.00	26,50	98,00	7,00	26,00
		23.00	26,50	98,00	7,00	26,00
19	07 November 2024	00.00	26,50	98,00	7,00	26,00
		01.00	26,50	98,00	7,00	26,00
		02.00	26,50	98,00	7,00	26,00
		03.00	26,50	98,00	7,00	26,00
		04.00	26,50	98,00	7,00	26,00
		05.00	25,20	99,74	7,43	26,00
		06.00	25,00	100,00	7,50	26,00
		07.00	25,00	100,00	7,50	26,00
		08.00	25,00	100,00	7,50	26,00
		09.00	25,00	100,00	7,50	26,00
		10.00	25,00	100,00	7,50	26,00
		11.00	25,00	100,00	7,50	26,00
		12.00	25,00	100,00	7,50	26,00
		13.00	25,00	100,00	7,50	26,00
		14.00	25,00	100,00	7,50	26,00
		15.00	25,00	100,00	7,50	26,00
		16.00	25,00	100,00	7,50	26,00
		17.00	25,00	100,00	7,50	26,00
		18.00	25,00	100,00	7,50	26,00
		19.00	25,00	100,00	7,50	26,00
		20.00	25,00	100,00	7,50	26,00
		21.00	25,00	100,00	7,50	26,00
		22.00	25,00	100,00	7,50	26,00
		23.00	25,00	100,00	7,50	26,00
20	08 November 2024	00.00	25,00	100,00	7,50	26,00
		01.00	25,00	100,00	7,50	26,00
		02.00	25,00	100,00	7,50	26,00
		03.00	25,00	100,00	7,50	26,00
		04.00	25,00	100,00	7,50	26,00
		05.00	25,10	100,00	7,50	25,72
		06.00	25,20	100,00	7,50	25,44
		07.00	26,19	98,24	7,47	25,64
		08.00	28,90	93,40	7,40	26,19

		09.00	28,90	93,40	7,40	26,19
		10.00	28,90	93,40	7,40	26,19
		11.00	28,90	93,40	7,40	26,19
		12.00	28,90	93,40	7,40	26,19
		13.00	29,72	90,91	7,33	26,67
		14.00	38,70	63,50	6,60	32,00
		15.00	38,71	63,48	6,60	32,00

Table 2 presents the summarized data, aggregated into hourly averages, to highlight broader trends and patterns. This hourly data visualization simplifies the interpretation of system performance and environmental dynamics, making it practical for decision-making processes such as irrigation scheduling and resource allocation. Together, the two tables demonstrate the capability of the Trico system to provide both detailed and high-level overviews of agricultural conditions.

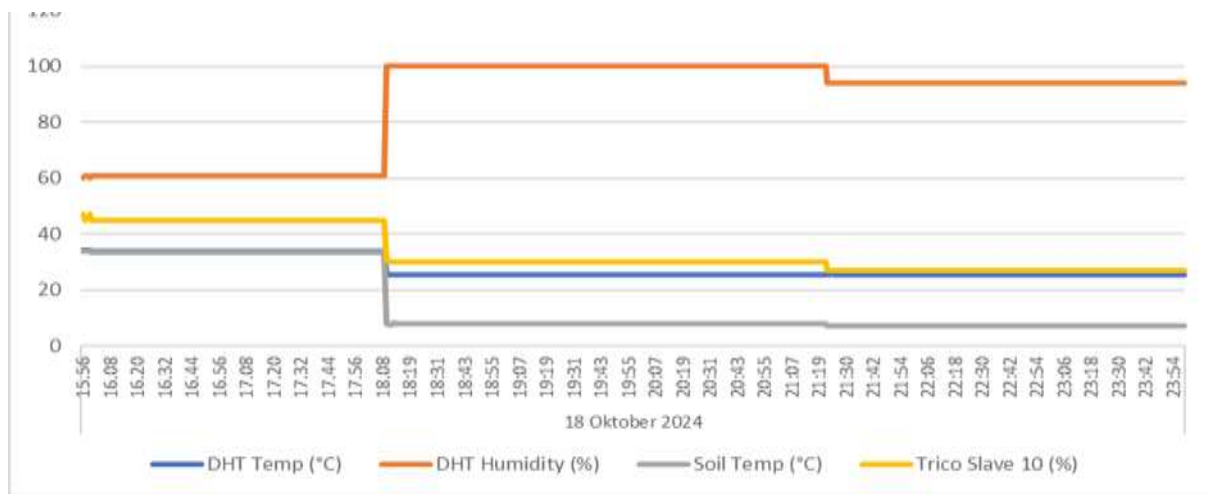


Figure 7. Daily Data Visualization

Figure 7 illustrates the visualization of daily data, presenting trends and patterns in environmental parameters such as soil moisture, air temperature, and humidity over a 24-hour period. This graphical representation enables a comprehensive analysis of the system's performance, supporting effective decision-making for agricultural management and resource optimization.



- Alleles of the ALK/SSIIa Gene, Responding to Low Gelatinization Temperature in Rice,” *Rice*, vol. 13, no. 1, Dec. 2020, doi: 10.1186/s12284-020-00393-5.
- [8] R. Deng, Z. Lan, X. Shang, and S. Fang, “Effects of Biochar Application Pyrolyzed at Different Temperatures on Soil Properties, Growth and Leaf Secondary Metabolite Accumulation in *Cyclocarya paliurus*,” *Forests*, vol. 13, no. 10, Oct. 2022, doi: 10.3390/fl3101572.
- [9] B. M. C. Fischer et al., “Investigating the impacts of biochar on water fluxes in a rice experiment in the dry corridor of Central America, Costa Rica,” in *Hydrological Processes*, John Wiley and Sons Ltd, Dec. 2022. doi: 10.1002/hyp.14765.
- [10] C. Fragassa, G. Vitali, L. Emmi, and M. Arru, “A New Procedure for Combining UAV-Based Imagery and Machine Learning in Precision Agriculture,” *Sustainability (Switzerland)*, vol. 15, no. 2, Jan. 2023, doi: 10.3390/su15020998.
- [11] J. Huang et al., “Biochar Application Alleviated Rice Salt Stress via Modifying Soil Properties and Regulating Soil Bacterial Abundance and Community Structure,” *Agronomy*, vol. 12, no. 2, Feb. 2022, doi: 10.3390/agronomy12020409.
- [12] R. Lamanna, G. Baviello, and M. Catellani, “Spatially Correlated Nuclear Magnetic Resonance Profiles as a Tool for Precision Agriculture,” *Journal of Agricultural and Food Chemistry*, vol. 71, no. 11, pp. 4745–4754, Mar. 2023, doi: 10.1021/acs.jafc.2c08265.
- [13] A. Lambertini, E. Mandanici, M. A. Tini, and L. Vittuari, “Technical Challenges for Multi-Temporal and Multi-Sensor Image Processing Surveyed by UAV for Mapping and Monitoring in Precision Agriculture,” *Remote Sensing*, vol. 14, no. 19, Oct. 2022, doi: 10.3390/rs14194954.
- [14] A. K. Madbouly, Y. M. Rashad, M. I. M. Ibrahim, and N. T. Elazab, “Biodegradation of Aflatoxin B1 in Maize Grains and Suppression of Its Biosynthesis-Related Genes Using Endophytic *Trichoderma harzianum* AYM3,” *Journal of Fungi*, vol. 9, no. 2, Feb. 2023, doi: 10.3390/jof9020209.
- [15] N. Manzar et al., “*Trichoderma*: Advent of Versatile Biocontrol Agent, Its Secrets and Insights into Mechanism of Biocontrol Potential,” *Sustainability (Switzerland)*, vol. 14, no. 19, MDPI, Oct. 01, 2022. doi: 10.3390/su141912786.
- [16] G. A. Mesías-Ruiz, M. Pérez-Ortiz, J. Dorado, A. I. de Castro, and J. M. Peña, “Boosting precision crop protection towards agriculture 5.0 via machine learning and emerging technologies: A contextual review,” *Frontiers in Plant Science*, vol. 14, Frontiers Media S.A., 2023. doi: 10.3389/fpls.2023.1143326.
- [17] R. I. Mukhamediev et al., “Coverage Path Planning Optimization of Heterogeneous UAVs Group for Precision Agriculture,” *IEEE Access*, vol. 11, pp. 5789–5803, 2023, doi: 10.1109/ACCESS.2023.3235207.
- [18] B. K. Padhan, L. Sathee, S. Kumar, V. Chinnusamy, and A. Kumar, “Variation in nitrogen partitioning and reproductive stage nitrogen remobilization determines nitrogen grain production efficiency (NUEg) in diverse rice genotypes under varying nitrogen supply,” *Frontiers in Plant Science*, vol. 14, 2023, doi: 10.3389/fpls.2023.1093581.
- [19] R. Rashid Irshad et al., “Date of publication xxxx 00, 0000, Date of current version xxxx 00, 0000. An Intelligent Buffalo-Based Secure Edge-Enabled Computing Platform for Heterogeneous IoT Network in Smart Cities Corresponding authors,” vol. 4, 2016, doi: 10.1109/ACCESS.2017.DOI.
- [20] E. H. Salman, M. A. Taher, Y. I. Hammadi, O. A. Mahmood, A. Muthanna, and A. Koucheryavy, “An Anomaly Intrusion Detection for High-Density Internet of Things Wireless Communication Network Based Deep Learning Algorithms,” *Sensors*, vol. 23, no. 1, Jan. 2023, doi: 10.3390/s23010206.
- [21] P. H. V. Silva et al., “*Trichoderma harzianum* and *Bacillus subtilis* in Association with Rock Powder for the Initial Development of Maize Plants,” *Agronomy*, vol. 13, no. 3, Mar. 2023, doi: 10.3390/agronomy13030872.
- [22] S. L. Woo, R. Hermosa, M. Lorito, and E. Monte, “*Trichoderma*: a multipurpose, plant-beneficial microorganism for eco-sustainable agriculture,” *Nature Reviews Microbiology*, vol. 21, no. 5, Nature Research, pp. 312–326, May 01, 2023. doi: 10.1038/s41579-022-00819-5.
- [23] P. Wu, B. P. Singh, H. Wang, Z. Jia, Y. Wang, and W. Chen, “Bibliometric analysis of biochar research in 2021: a critical review for development, hotspots and trend directions,” *Biochar*, vol. 5, no. 1, Springer, Dec. 01, 2023. doi: 10.1007/s42773-023-00204-2.
- [24] X. Yang et al., “Research on lncRNA related to drought resistance of Shanlan upland rice,” *BMC Genomics*, vol. 23, no. 1, Dec. 2022, doi: 10.1186/s12864-022-08546-0.
- [25] T. A. Saputri, B. Sutomo, A. Hairunnisa, M. A. Syaputra, and S. Sulistiyanto, “Perancangan dan Implementasi Sistem Smart Air Conditioner Berbasis IoT di Gedung Kampus Dharma Wacana untuk Optimalisasi Energi,” *JUPITER*, vol. 17, no. 1, pp. 123–133, Dec. 2024.