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Original Article

IoT-Controlled Automatic Vermiculture Condo for Organic Waste Management

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***Abstract** - This research proposed the development of a prototype of an IoT-controlled automatic vermiculture (earthworm cultivation) condo for organic waste management. The system was a 5-level condo structure consisting of 2 trays per level and a 6-in-1 soil quality sensor (soil temperature and humidity, pH, and N-P-K) with a relative error between 0-3.136% as well as an environmental sensor (air temperature and humidity), the data for which was transmitted via the Internet of Things (IoT) for remote data display and control. When the humidity dropped below 30%, it was automatically controlled with a water sprinkler. A comparison of the test results from a semi-automatic system and an automatic system revealed that the automatic system produced a higher yield of vermicast (earthworm manure) in every test tray. The tray without organic waste produced the highest yield at 9.5 kilograms, which was 3.26% higher compared to the semi-automatic system. The cucumber tray produced 8.7 kilograms (10.13% higher), the yard-long bean tray produced 9.3 kilograms (4.49% higher), and the carrot tray produced 8.5 kilograms (4.94% higher). The tomato tray produced the lowest yield at 7.3 kilograms, which was still 8.96% higher than that of the semi-automatic system. The yield from the automatic system was on average 6.36% higher. A calculation of the break-even point revealed a fixed cost of 577.80 USD, a variable cost of 14.22 USD/round, and an income of 31.11 USD/round. The break-even point was at 34.24 rounds of cultivation, requiring 35 or more rounds of cultivation to be profitable. This shows that this system could help reduce the problem of organic waste and create economic value through the production of quality vermicompost.*

***Keywords** - Vermiculture condo, Environment sensor, Control system, Organic waste, Application, Internet of Things.*

1. Introduction

Earthworms play a very important role among large soil-dwelling invertebrates. Taxonomically, earthworms belong to the phylum Annelida and the class Oligochaeta. Their distribution covers every region of the world, covering habitats with significant ecological diversity, from arid zones to rainforest ecosystems. According to palaeontological evidence and geological studies, earthworms' evolutionary history on this earth stretches no less than 600 million years. [1]. Earthworms are widely regarded as "farmers' friends" and have been academically referred to as "soil ecosystem engineers". At present, more than 7,000 species of earthworms have been discovered and classified around the world, and they have adapted to survive in various environments [2]. Based on literature review and research on reliable data, it was found that, among all species of earthworms reported, only about 3,000-3,500 species have been confirmed and recognized as valid [3]. Furthermore, about 150 species are classified as introduced species that have migrated and spread around the world [4]. Numerous researchers have studied the diversity of earthworms around the world, such as in Dubai [5], Brazil [6], and Nigeria [7]. According to Singh et al. [8], earthworms can survive within a temperature range of 25°C to 35°C; however, exposure to these extremes may induce oxidative and nitrative stress. Moreover, the use of earthworm fertilizer offers environmental benefits and has the potential to promote sustainable agricultural practices among farmers [9]. In the rising environmental temperatures, which pose significant challenges to many organisms, including earthworms, further investigation into these impacts and potential adaptive strategies could improve the efficiency of vermicompost production and support broader environmental conservation efforts [10]. Organic agriculture is an eco-friendly farming approach that uses natural biodiversity and processes to reduce reliance on synthetic inputs like fertilisers and pesticides [11]. Organic kitchen waste management is a significant environmental issue, especially in Thailand's big cities. The average household kitchen produces approximately 1.1 kg/day of organic waste [12]. This causes pollution and foul odors, serves as a breeding ground for disease vectors, and produces sewage. The cultivation of earthworms in containers, e.g., plastic tubs, plastic drawers, concrete rings, or plant pots, to compost organic kitchen waste as shown in Figure 1, is an efficient management method [13, 14]. When food, vegetables or fruit scraps are produced, they can be placed in a vermicomposting container immediately. The composting process takes about 30-60 days. Next, the vermicast can be extracted, and the vermiwash (liquid extracted from vermicompost) can be used as fertilizer for plants. Moreover, earthworms can be sold to fish farms or used as animal feed, such as for chicken or fish, to create a supplemental income. There are two main ways to cultivate earthworms: with manure and with organic waste.

Vermiculture using organic waste faces issues where the earthworms can die more easily due to unsuitable pH (which should be between 6.0 and 8.0) and humidity that is either too high or too low (the suitable humidity range is 40-70%) [15, 16]. Although vermiculture is widely recognized as an effective method for managing organic kitchen waste, especially in urban areas, there is a lack of automated, space-saving systems that integrate IoT technology for real-time monitoring and environmental control. Existing practices are often manual and face challenges in maintaining suitable conditions for earthworm survival when using organic waste alone. Therefore, there is a need to develop and evaluate a smart vermiculture system that can automatically regulate soil conditions and provide real-time feedback, particularly suited for household use in Thailand.

Fig. 1 Vermiculture in various containers

Based on the concept of using organic waste for vermiculture, the researcher proposed a study consisting of the development of a prototype of an IoT-controlled automatic vermiculture condo for organic waste management for the purpose of providing knowledge about vermiculture and control systems. The containers were designed in the form of a condo to save space. The system used organic waste, manure as the feed, and an application to display results and send notifications to make it easier for farmers. The system relied on the ability to connect data to the IoT in conjunction with a 6-in-1 soil quality sensor, as shown in Figure 1, connected through an RS-485 half-duplex serial communication port with Modbus RTU [17]. For automatic data transmission and humidity control, which helped reduce the mortality of earthworms and the amount of organic kitchen waste.

Fig. 2 SOIL T/H/PH/N/P/K MODBUS RTU sensor

2. Relevant Literature

The development of the prototype for an IoT-controlled automatic vermiculture condo for organic waste management consisted of three main components: 1) earthworms, 2) organic waste, and 3) IoT. The details are as follows:

2.1. Earthworms Species

Earthworms play an essential role in transforming organic matter into good-quality compost [13, 18]. Earthworms are segmented animals belonging to the phylum Annelida, and more than 31 species have been reported in Thailand. Four main species of earthworms often used in vermiculture around the world include the tiger worm, earthworm, blue worm, and African earthworm, as shown in Figure 3. The most popular species used in vermiculture is the “African earthworm” [19, 20].

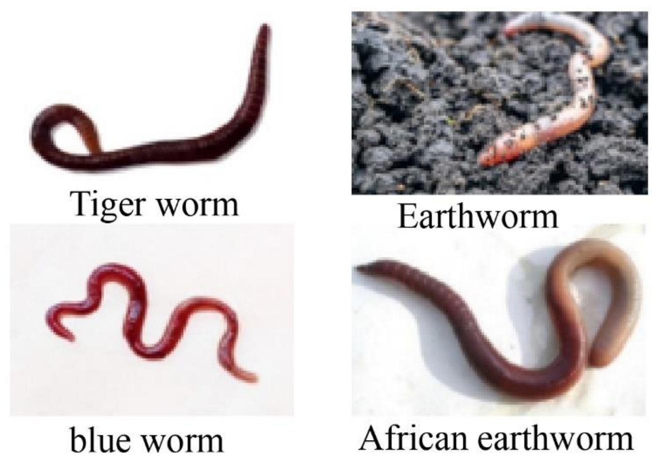


Fig. 3 Popular species used in vermiculture

Earthworms play an important role in conditioning soil structure and loosening soil to improve drainage and aeration. They are considered to naturally till the soil, increase organic matter, and enrich the soil with beneficial microorganisms.

2.2. Organic Waste Management

Organic waste is produced by living organisms that can naturally decompose through biological processes. The sources of organic waste are plants and animals, e.g., food scraps, fruit peels, leaves, hay, and other plant waste. This type of waste can be composted or transformed into natural fertilizer through a process called “composting” [21]. When selecting a means or method of organic waste elimination by composting, there may be variations in terms of the model, method and quality of the compost [22, 23], especially when it comes to food waste from daily household consumption. Organic waste has many benefits in terms of waste management and agriculture. For example: 1. It can be composted into fertilizer to enrich soil; 2. It reduces the amount of waste in landfills 3. It reduces toxic contamination in soil and water; 4. It can be turned into biomass for energy and electricity generation 5. It helps reduce greenhouse gas emissions. There are two main types of organic waste: food waste and agricultural plant waste, as shown in Figure 4.

Fig. 4 Food scraps and agricultural plant waste

2.3. The Internet of Things (IoT)

The Internet of Things (IoT) is the connection of items and devices with electronic circuits, software, sensors and connection with a network [24] that facilitates the storage or real-time transmission of data, allowing the environment to be monitored and the devices to be controlled remotely [25]. The IoT is widely implemented in industry [26], agriculture [27], medicine [28], education [29], and daily living [30] to boost efficiency, reduce costs, and enhance convenience in daily living, as shown in Figure 5.

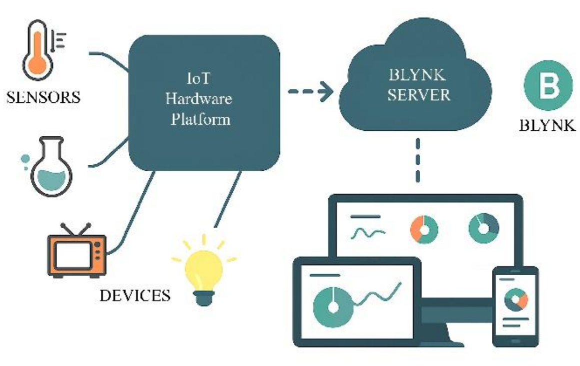


Fig. 5 Working principles of the IoT

The infrastructure of the IoT utilizes 5G network, NB-IoT, LoRaWAN technology, and cloud-based connection. Furthermore, future trends and development will involve the application of AI, machine learning, edge computing, blockchain integration and digital twin technology. The IoT also has an economic impact. It enhances production efficiency, reduces operating costs, and creates new business opportunities. Socially, it can enhance the quality of living, improve security, and reduce environmental impacts. The development of the IoT will involve its application, Blynk IoT via the Blynk Server [31].

3. Proposed System

The proposed system was the development of a prototype of an automatic vermiculture condo system composed of two main parts: the development of vermiculture for organic waste management, and an automatic system with the ability to read the values from various sensors to display results via the IoT and, if unsuitable values were detected, to send alerts and order the system to adjust the environment automatically, i.e., to water to increase soil humidity. The design started with the installation of rectangular vermiculture containers, a 6-in-1 sensor, and an environmental sensor. The structural design included five levels, with two trays/level and a water tray at the bottom for cleaning. The water from the bottom level could be used as vermiwash. A sprinkler was installed on each level to adjust the soil humidity to be suitable for vermiculture, as shown in Figure 6.

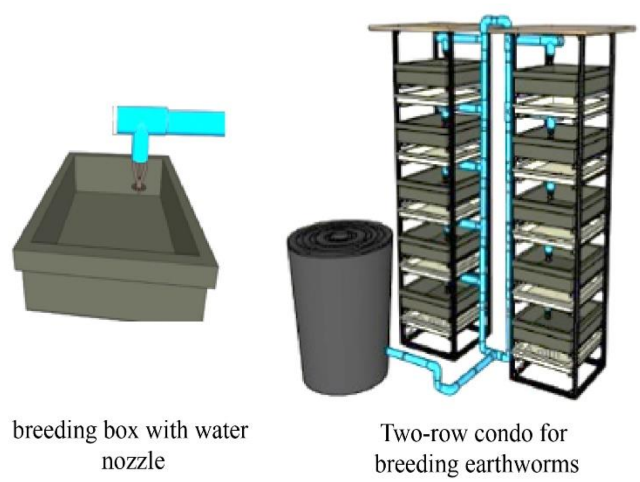


Fig. 6 3D drawing of vermiculture condos

4. Software and Hardware Structure Design

4.1. Software Structure Design

The software design included the design of the program structure to function according to the steps of the automatic vermiculture condo. The function structure was developed using the Arduino IDE software. This started by connecting to the Internet, then waiting to receive the readings from the 6-in-1 and environmental sensors. Next, the data was sent to the Arduino board to process soil humidity values. If the sensors detected a soil humidity reading lower than 30%, the sprinkler system would order the tray to water with low humidity. After checking the Arduino board, the data of the readings would be uploaded to the Internet via the ESP32 board to be displayed in real time on the application Blynk IoT via the Blynk Server and stored on Google Sheets every 5 minutes, as shown in Figure 7.

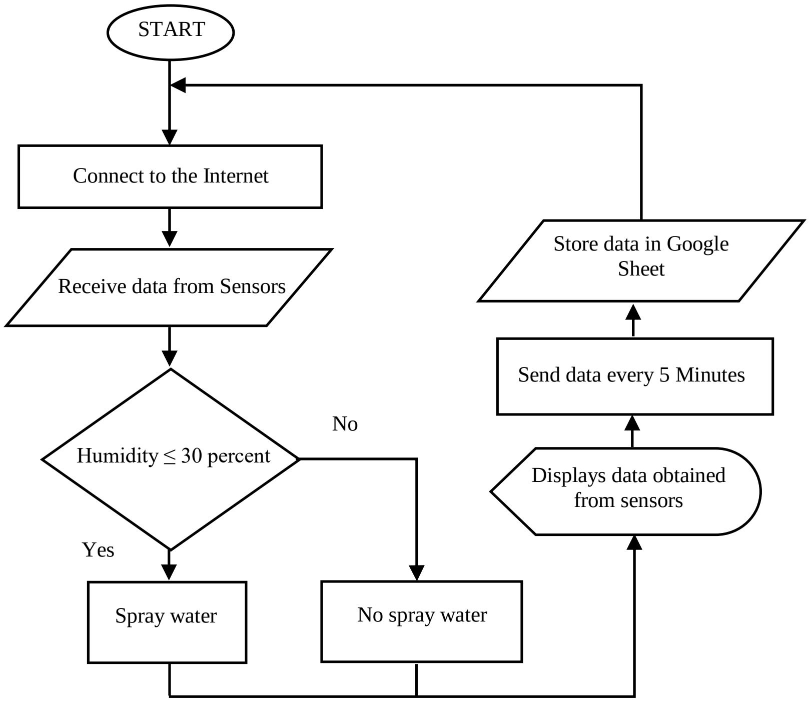


Fig. 7 Flow chart of the system

4.2. Hardware Structure Design

The design of the hardware structure for the vermiculture condo consisted of the following equipment: power switch, ESP32supply board, Arduino Uno R3 board, relays, water pump, solenoid valve, RS485, and soil nutrient sensors. The hardware's functional structure involved the connection between the soil nutrient sensors via the RS485 module and the Arduino board to send the data from the readings to the NodeMCU ESP32. If the soil humidity reading drops below the acceptable range, the system activates the solenoid valve and water pump to irrigate and adjust the conditions of the vermiculture tray with the unsuitable humidity reading, as shown in Figure 8. The input/output connections of each device to the Arduino board are shown in Table 1.

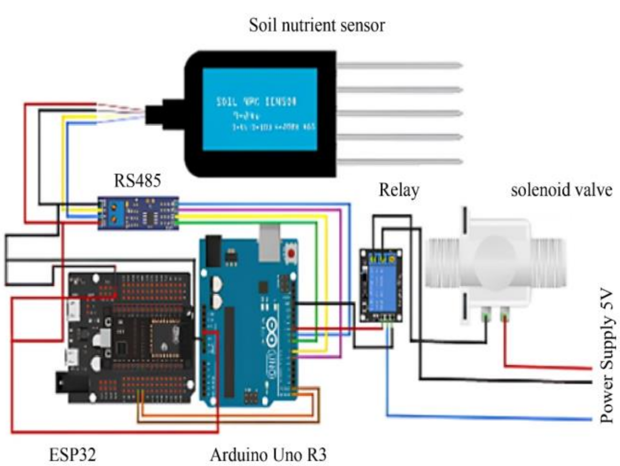


Fig. 8 Hardware diagram

Table 1. Circuit connections

Soil Nutrient Sensor	RS485		Arduino Uno R3	Relay	ESP32
	IN	OUT			
Red	VCC	DI	D9		
Blue	B	DE	D7		
Yellow	A	RE	D6		
Black	GND	R0	D8		
			D10	IN	
			D0		D17
			D1		D16

5. Installation of the System Devices

The automatic vermiculture condo was installed by building and installing the equipment, control box, soil nutrient sensor, and air temperature and humidity sensor, as shown in Figure 9.

Fig. 9 Equipment of the automatic vermiculture breeding condo

The installation of the equipment will be carried out according to the system parameters and specifications as shown in Table 2.

Table 2. The system parameters and specifications

Parameters	Specification
Structure	The structure is made of 1.5-inch perforated steel, assembled into a structure 170 cm x 45 cm x 40 cm, divided into 5 equal levels, totaling 2 sets.
Size of the breeding tray	50 cm x 40 cm x 13 cm
Size of the solenoid valve	Size 1.5 inches
Soil quality sensor	The Soil 6-in-1 sensors creatively measure moisture, temperature, pH, nitrogen, phosphorus and potassium parameters together.
Cow manure volume 1 trays	5 kg
Organic waste volume 1 trays	100 g

6. Results and Discussion

The test results for the IoT-controlled automatic vermiculture condo for organic waste management consisted of the results from testing two types of systems: semi-automatic and automatic vermiculture control systems. The temperature, humidity, pH, nitrogen, phosphorus, potassium, air temperature, and air humidity were tested, including scenarios where organic waste was added or not added to each tray.

1. The test results of the sensor readings were obtained by testing the readings from the soil quality sensors, consisting of the humidity, nutrient, NPK, pH, and soil temperature. The humidity, pH, and temperature readings could be read directly from the sensors. However, the nitrogen, phosphorus, and potassium readings needed to be converted by using Equations (1) and (2).

$$X_{(n,p,k)} = \frac{Measurex5}{1023} \quad (1)$$

In Equation (1), after obtaining the $X_{(n,p,k)}$ value, input it into Equation (2) to find the real value of $Y_{(n,p,k)}$.

$$Y_{(n,p,k)} = \frac{X_{(n,p,k)}x100}{5} \quad (2)$$

Table 3. Measurement results from soil quality sensors

Results	N(mg/L)	P (mg/L)	K (mg/L)	Temp (°C)	pH	Humidity (%)
Sand	0	3.51	2.73	30	7	35
Worm castings	2.93	11.33	10.75	28	6.5	45
Soil	0.87	6.64	5.86	30	6	50
Soil mixed with fertilizer (16-16-16)	11.73	31.76	31.18	30	6.5	45
Soil mixed with fertilizer (24-7-14)	4.88	15.73	15.05	28	7	45

According to Table 3, the nitrogen, phosphorus, and potassium values calculated by using Equations (1) and (2) were compared to the standard value conversion website at https://aesl.ces.uga.edu/soil/fertcalc/, a website developed by the University of Georgia, as shown in Figure 10.

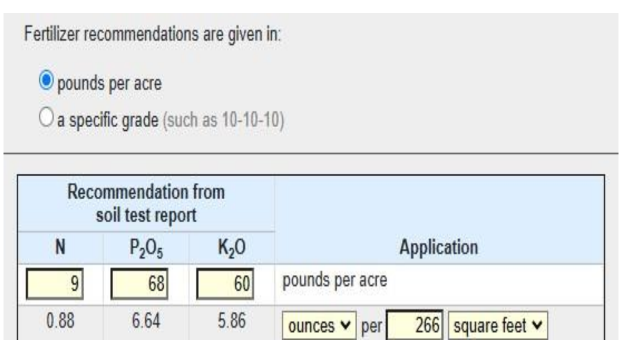


Fig. 10 Example of conversion via website

In Figure 10, after converting the values using the standard value conversion website, the values were compared to the values converted using Equations (1) and (2) in order to find the relative error from Equation (3).

$$E_r = \frac{|X_{measured} - X_{true}|x100}{X_{true}} \quad (3)$$

As shown in Table 3 and Figure 10, the relative error between the sensor readings and the standard reference values from the University of Georgia's website ranged from 0% to 3.136%. This error was calculated by comparing the measured values with the standard values. The result indicates that the sensor provides reliable data for soil quality monitoring and supports accurate system operation.

2. The test results of the semi-automatic vermiculture condo system in which a caretaker would water the condo every five days according to schedule, regardless of the soil humidity, were obtained by testing the soil temperature, soil humidity, pH, nitrogen, phosphorus, potassium, air temperature, and air humidity, as shown in Figure 11.

Fig. 11 Results of the semi-automatic vermiculture condo

3. The test results of the vermiculture condo with automatic watering when the sensors detect soil humidity of less than 30% were obtained by testing the soil temperature, soil humidity, pH, nitrogen, phosphorus, potassium, air temperature, and air humidity, as shown in Figure 12.

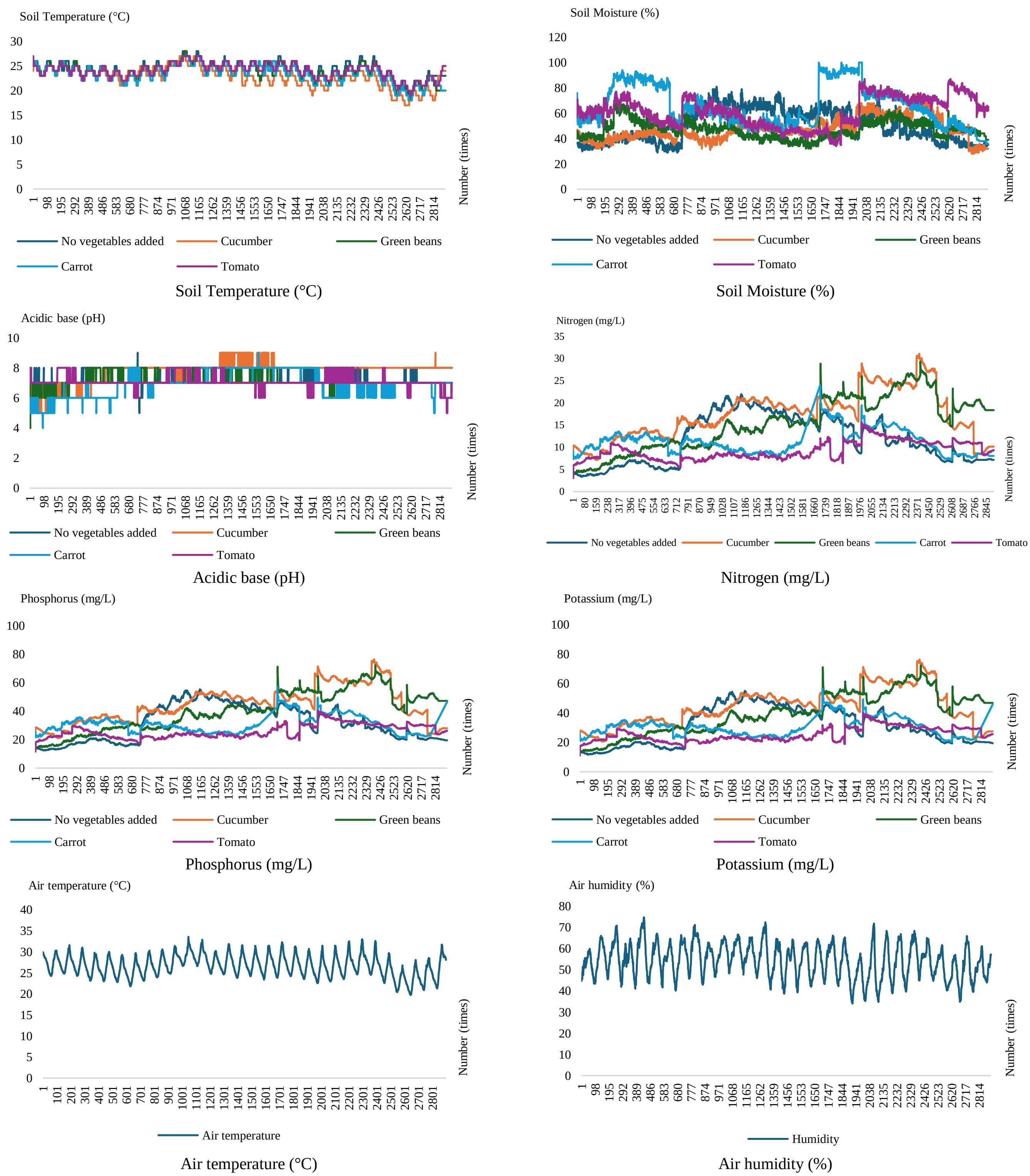


Fig. 12 Results of the automatic vermiculture condo

4. In comparing the vermicast yield from the semi-automatic and automatic vermiculture systems, the vermicast was harvested after one week of cultivation to allow the vermiculture medium to completely dry first. Next, the vermiculture medium was sifted to separate the vermicast and earthworms from the medium, then weighed, as shown in Table 4.

Table 4. Earthworm faeces volume from semi-automatic and automatic farming

	Cow manure added in 2 trays (kg)	Vegetables added in 2 trays (grams)	Worm castings from semi-automatic method (kg)	Worm castings from the automatic method (kg)
No vegetables	10	200	9.2	9.5
Cucumber	10	200	7.9	8.7
Green beans	10	200	8.9	9.3
Carrot	10	200	8.1	8.5
Tomato	10	200	6.7	7.3

Based on Table 4, the semi-automatic vermiculture system that used 10 kg of cattle manure and 200 g of vegetables produced the following vermicast yields: the tray without vegetables produced 9.2 kg, the cucumber tray produced 7.9 kg, the yard-long bean tray produced 8.9 kg, the carrot tray produced 8.1 kg, and the tomato tray produced 6.7 kg. In addition, the automatic vermiculture system that used 10 kg of manure and 200 g of vegetables produced the following vermicast yields: the tray without vegetables produced 9.5 kg, the cucumber tray produced 8.7 kg, the yard-long beans produced 9.3 kg, the carrot tray produced 8.5 kg, and the tomato tray produced 7.3 kg.

5. The test results for the use of an application to display soil quality readings and store data in a database were obtained by using the Blynk IoT application to display the soil quality readings, as shown in Figure 13, and the data was stored in the Google Sheets database, as shown in Figure 14. The data retention period was 30 days.

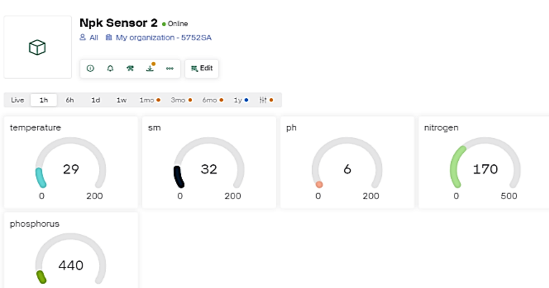
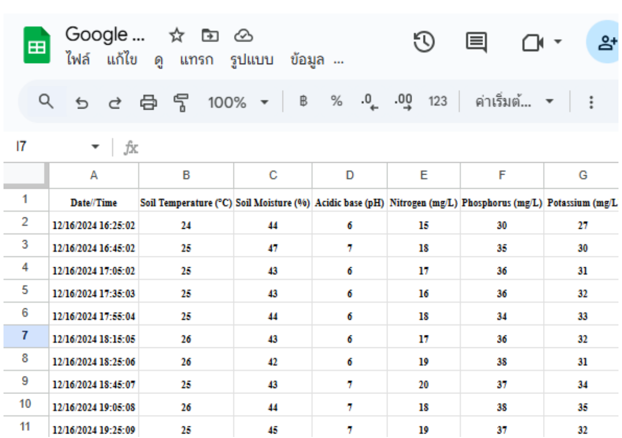


Fig. 13 Blynk of IoT application



	A	B	C	D	E	F	G
1	Date//Time	Soil Temperature (°C)	Soil Moisture (%)	Acidic base (pH)	Nitrogen (mg/L)	Phosphorus (mg/L)	Potassium (mg/L
2	12/16/2024 16:25:02	24	44	6	15	30	27
3	12/16/2024 16:45:02	25	47	7	18	35	30
4	12/16/2024 17:05:02	25	43	6	17	36	31
5	12/16/2024 17:35:03	25	43	6	16	36	32
6	12/16/2024 17:55:04	25	44	6	18	34	33
7	12/16/2024 18:15:05	26	43	6	17	36	32
8	12/16/2024 18:25:06	26	42	6	19	38	31
9	12/16/2024 18:45:07	25	43	7	20	37	34
10	12/16/2024 19:05:08	26	44	7	18	38	35
11	12/16/2024 19:25:09	25	45	7	19	37	32

Fig. 14 Google Sheets database

6. The calculation of the break-even point of the IoT-controlled automatic vermiculture condo system for organic waste management involved the development of a vermiculture system that would help to reduce care time and earthworm mortality. From the analysis to find the break-even point, the details of the costs and incomes are as follows:

The fixed cost was calculated from the cost of the materials and equipment used to build the system, namely, the structure, vermiculture equipment, and control equipment, which amounted to a total of 577.80 USD.

The variable cost per unit, including the vermiculture medium and internet costs amounting to 0.39 USD /round and the cost of 10 electricity units at 0.15 USD/unit amounting to 1.50 USD/round, amounted to a total of 14.22 USD/round.

The income from each sale of vermicast, which depended on the vermicompost yield, was 0.360 USD/kg. The system produced an average vermicast amount of 86.6 kg/round, amounting to 31.11 USD/round.

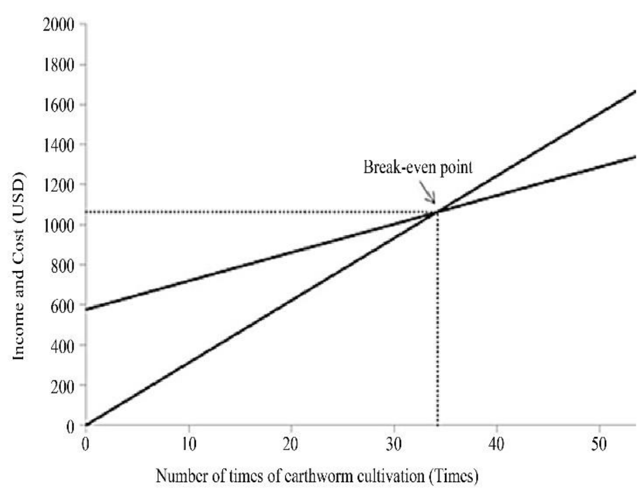


Fig. 15 Break-even point of vermiculture condo

Based on Figure 15, it is evident that the production amount at the break-even point was 34.24 rounds, which was the number of vermiculture rounds that would make the investment equal to the income. In order to make the vermiculture profitable, the material would have to be tested from the 35th round and up.

7. Discussion of the Test Results

Based on the test results of the function of the IoT-controlled automatic vermiculture condo for organic waste management developed according to the steps that were studied theoretically and related research, the automatic vermiculture condo could efficiently raise earthworms. The test results can be explained as follows:

1. The values presented in Table 3 were compared with the converted values obtained from the University of Georgia's online calculator. Using Equation (3) to calculate the relative error, the results showed a 0–3.136% range, indicating acceptable conversion accuracy.

2. Based on Figure 9, the testing of the semi-automatic vermiculture was able to measure the vermiculture medium quality accurately. The test results show that the humidity in the medium gradually decreased until it reached below 30%. However, the humidity did not increase because it was not time to water the medium. As a result, the earthworms either died or escaped the medium. On the other hand, when the medium was watered, the humidity clearly increased and reached 40-80%.

   The soil temperature readings were at 26-31°C, with the pH at 4-8, the nitrogen at 2.5-31 mg/L, the phosphorus at 11-69 mg/L, the potassium at 11-69 mg/L, the air temperature at 26-41°C, and the air humidity at 39-90%. Moreover, the automatic vermiculture testing was able to measure the vermiculture medium quality accurately. The test results show that the humidity in the medium would not reach below 30%, staying between 30%-100%. The soil temperature was low at 17-28°C as water was supplied to maintain soil temperature. The pH was 4-9, the nitrogen at 2.5-31 mg/L, the phosphorus at 10.5-76 mg/L, the potassium at 10.5-76 mg/L, the air temperature at 20-34°C, and the air humidity at 33-76%.

3. According to Table 4, Vermicast Yield from Semi-automatic and Automatic Vermiculture, it can be seen that the vermicast yield from the semi-automatic system was 6.7-9.2 kg. Meanwhile, the vermicast yield from the automatic system was 7.3-9.5 kg, depending on the type of organic waste added to the medium. The vermicast yield from the medium without any added waste was the highest at 9.2 kg (semi-automatic) and 9.5 kg (automatic), and the vermicast yield from the medium with tomatoes was the lowest at 6.7 kg (semi-automatic) and 7.3 kg (automatic) due to the medium having pH values higher than what the earthworms could live in.

4. The break-even point was calculated using a fixed cost of USD 577.80, a variable cost per unit of USD 14.22, and a selling price of vermicast at USD 31.11. The results indicated that the break-even point was 34.24 production rounds. Therefore, a minimum of 35 rounds of vermiculture is required to achieve profitability.

8. Conclusion

This research proposed the development of a prototype of an IoT-controlled automatic vermiculture condo for organic waste management. The system was a 5-level condo structure consisting of 2 trays per level and a 6-in-1 soil quality sensor (soil temperature and humidity, pH, and N-P-K) with a relative error between 0- 3.136%.

The system could automatically control the humidity to prevent it from dropping below 30%. As a result, the average soil temperature of the automatic system was between 22.83 and 24.02°C, resulting in higher vermicast yields than those of the semi-automatic system at an average of 6.36%. It was found that the type of organic waste had an impact on the yield. The maximum yield increase from the tray without any added organic waste was 3.26%. The cucumber tray produced the highest yield increase at 10.13%. The yield from the yard-long bean tray increased by 4.49%, while the carrot tray increased by 4.94%. The tomato tray produced the lowest yield, although the yield still increased by 8.96%, due to unsuitable pH levels.

Economically, the system had a break-even point at 34.24 rounds of cultivation, a fixed cost of 577.80 USD, a variable cost per round of 14.22 USD, and an income per round of 31.11 USD. In addition, the integration of IoT technology enabled real-time monitoring of soil quality through the Blynk IoT application, with data automatically recorded in Google Sheets. This facilitated environmental control within the vermiculture system, improved organic kitchen waste management, and added economic value by reducing manual supervision and enhancing vermicast productivity.

The IoT-controlled vermiculture condo effectively transforms organic waste into nutrient-rich compost, contributing to SDG 12 (Responsible Consumption and Production), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action).

Its smart infrastructure also supports SDG 9 (Industry, Innovation and Infrastructure) by promoting circular economy practices and environmental sustainability. Future work should explore AI-driven control systems, incorporate life cycle assessment (LCA) to quantify environmental benefits, and implement urban-scale pilots to validate scalability and foster wider adoption in smart cities.

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