Exploratory Analysis of Resourceful Treatment through Earthworm Composting of Urban Greening Waste

Xianming Yang

Beijing No.4 High School, Beijing, China

yangxian123465@163.com

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Abstract: Earthworm composting of urban greening waste leaves is employed to achieve resourceful treatment and enhance the efficiency of urban waste management. In this study, we leveraged the controlled variable method test to identify the optimal proportions of leaves and soil, along with the ideal quantity of earthworms for vermicomposting. The selected materials were fermented for eight weeks, followed by composting, and the resulting soil was analyzed using nine indicators, including quick N, P, K, full K, full N, EC, and pH. The indicators of 20 batches were compared to derive the optimal composting conditions. According to our results, the most effective composting was achieved with 50 earthworms and a leaf-to-soil ratio of 7:3. During the testing process, we encountered challenges such as long data monitoring periods, high testing costs, difficulties in collecting the compost's organic liquid, and earthworm escape. To counter these problems, we developed a vermicomposting prototype based on sensor technology, 3D modelling, and Python programming. This prototype, equipped with water pumps, light sensors, soil integrated sensors, and a master controller, enabled spatial isolation of earthworm composting, enhanced the collection of organic liquids, and prevented earthworm escape. Additionally, it facilitated real-time monitoring of temperature, humidity, and pH, ensuring rapid and accurate detection of potassium, phosphorus, nitrogen, and other organic substances. This groundwork paves the way for the future construction of large-scale vermicomposting pond management, operation, and maintenance.

1. Introduction

Urban greening waste, which includes grass clippings, trimmed tree branches, naturally withered branches, and fallen leaves, is an inevitable byproduct of urban greening initiatives. Despite its ubiquity, the transportation and treatment of such waste often remain overlooked in current urban greening practices. Existing research indicates that common methods for managing landscaping waste in China, such as incineration and centralized landfill, have proven to be less than optimal[1]. Incineration not only generates significant amounts of carbon dioxide, contributing to local pollution, but also leads to resource wastefulness. Conversely, centralized landfill utilizes soil-borne microorganisms to decompose greening waste, producing a large quantity of humus for soil use. However, the products of microbial treatment are predominantly wood fibers, and if composting is conducted, both carbon and nitrogen levels become excessively high. Moreover, relying solely on microbial treatment for green waste proves inefficient. Consequently, the development of effective processes for handling urban greening waste has emerged as a pressing contemporary issue.

2. Research Background and Significance

2.1 Background

In China, the utilization of earthworms in managing greening waste is gradually emerging in the field of urban greening. However, this approach has had a late start, is still maturing, and has yet to be fully deployed in greening waste treatment[2]. According to Ma Shule[3], greening waste, rich in organic matter, can be decomposed to produce organic fertilizers and used in creating cultivation

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substrates, soil improvement, and other production applications. This can replace grass charcoal and opens a wide range of application prospects.

Nevertheless, the organic matter in common urban greening waste is difficult to degrade. Furthermore, when conventional methods are employed for ancillary treatment, two main issues arise: composted products easily undergo low humification, and the non-degradable nature of the compost also results in very low humification efficiency of the green waste. These problems have hampered the widespread adoption and application of green waste compost, and are key reasons why current green waste treatments largely consist of combustion and landfill treatments.

Promoting the rapid conversion of the compost's organic matter into compost products and improving the degree of humification in these products are crucial issues to be addressed. However, humus formation is a complex process dependent on numerous factors, including environmental conditions and compost substrate composition. Despite extensive research on the compost formation process and humus structure, the academic community has yet to reach a consensus, complicating the monitoring of humus formation in compost.

Aerobic composting, achieved by artificially controlling conditions such as moisture index, organic matter concentration, pH values, and temperature, could enhance the degradation process of greening waste and generate high-quality humus with optimal physical, chemical, and biological properties. Moreover, the heat produced by microbial activity during this process increases composting temperatures, which results in the inactivation of pathogenic microorganisms and the production of harmless organic products.

Cai Linlin[4] analyzed common measures used for managing garden wastes in China, concluding that aerobic composting is one of the predominant methods. This process involves mixing greening wastes with other excipients and using microbial aerobic fermentation for decomposition. The greening wastes are eventually converted into humus nutrients, resulting in stable and non-polluting composting products.

Wang Yingnan[5] noted that vermicompost, with its ideal pore structure for microbial survival and high content of mineral nutrients, organic carbon, humic acid, and plant hormones, is not only simple to prepare but also suitable for a wide range of applications, including soil improvement, animal husbandry, and crop cultivation.

Liu Wei et al.[6] concluded that earthworm manure could effectively enhance soil microaggregate structure, nutrient content, bacterial colony quantity, and enzyme activity, thereby aiding in soil sloughing problem resolution and alfalfa performance enhancement for improved heavy metal pollution in farmland. Their study showed that the application of vermicompost significantly promoted the heavy metal concentration capacity of alfalfa, increased the total number of organisms and distribution density, and enhanced the soil's organic matter, total nitrogen, and total phosphorus by 13.2%, 28.2%, and 30.6%, respectively. Moreover, there was a significant decrease in the soil's pH value, an increase in cation exchange capacity, and a significant uptick in peroxidase and urease activities in the soil.

Tian Geilin[7] suggested that vermicompost could be used in livestock breeding to remove harmful gases from barns, improve air quality, and as a feed additive to enhance livestock fitness and reduce costs.

2.2 Significance

Utilizing earthworms to consume greening waste and produce vermicompost could potentially address resource wastage and environmental pollution issues. Earthworms are omnivorous annelids capable of consuming up to 1.2 times their own body weight per day. Vermicomposting leverages this characteristic, allowing earthworms to ingest the organic matter in greening waste, mixed with soil, and produce earthworm feces through the combined actions of the microorganisms in their intestinal tracts and the mechanical friction of their gizzards.

Compared to traditional composting, the efficacy of vermicomposting is significantly higher for two main reasons. First, the ingestion process physically breaks down the organic waste, altering the microbial composition and material properties of the greening waste and thereby increasing the

contact surface area between the substrate and the microorganisms within the earthworms' intestinal tracts. Second, the microorganisms within the earthworms' intestinal tracts can accelerate the decomposition of organic matter by secreting organic acid substances and biological enzymes.

The vermicomposting process can therefore be divided into two stages. In the first stage, the earthworms ingest the organic waste, modifying its microbial composition and physical characteristics. In the second stage, the microorganisms within the earthworms' gut aid in further substrate degradation. The earthworm gut harbors numerous microorganisms capable of breaking down the cellulose in organic matter and stimulating the accelerated secretion of extracellular enzymes such as phosphatase, protease, and cellulase. These enzymes expedite the degradation of organic phosphorus, organic carbon, and nitrogen-containing compounds, producing lower molecular weight organic acids, such as acetic acid, citric acid, formic acid, and oxalic acid, in the process. This leads to the mineralization of organic matter, transforming macromolecules that are hard to degrade and absorb into more readily absorbable forms of nitrogen, phosphorus, calcium, and potassium. Under the combined actions of microorganisms and earthworms, organic waste ultimately transforms into earthworm manure with enhanced biological, chemical, and physical properties.

Earthworm composting combines the benefits of both biological and traditional composting methods. Through the combined action of microorganisms and earthworm metabolism, waste is transformed into vermicompost via physical changes and chemical and biological reactions. This process creates vermicompost with favorable physical, biological, and chemical characteristics. In this process, earthworms consume urban greening waste and digest it, forming vermicompost particles. These particles provide a material basis for microbial survival, reproduction, and metabolism, generating organic matter that serves as food for earthworms. Earthworms and microorganisms exist in interdependence, which significantly boosts the decomposition efficiency of organic waste.

When selecting earthworm species, preference should be given to those with high-temperature tolerance and an excellent capacity for decomposing organic matter. As urban waste processing must be managed on a large scale, it is necessary to ensure that earthworms can be cultured en masse. Therefore, the selected species should also meet the following conditions: dense population distribution, robust vitality to maintain rapid growth under high-density conditions, and high environmental adaptability coupled with a high reproduction rate.

In summary, this paper discusses the feasibility of using earthworms in urban gardening waste treatment. Using Eisenia foetida earthworms as an example, it analyzes the efficacy of processing garden wastes, particularly fallen leaves. The paper examines the relationship between the moisture of materials, earthworm density, and the quality of the final compost. It also further analyzes the feasibility of using the products of earthworm treatment to replace peat in floriculture, providing inspiration for interested parties.

3. Test materials and methods

3.1 Experiment 1: Effects of Different Treatments on the Resourceful Treatment of Urban Greening Waste

3.1.1 Test Materials

The test materials comprised naturally fallen leaves from poplar trees in Shunyi Chengao Eco-development Park in Beijing. All the leaves used were withered and dry, with no moisture remaining. The park's soil was selected as the conditioner. The experiment used 1100 Eisenia foetida earthworms and 20 bins, each with a 12L capacity, with no lids.

3.1.2 Test Method

An uncovered bin was filled with raw, uncut dead leaves, soaked with fresh water, and fermented for three weeks. The fermentation was monitored, with weekly rehydration to ensure that the leaves remained moist. This step aimed to ensure the initial fermentation effect on the leaves, making them easier for the earthworms to digest.

A comparative experimental method was used to yield statistically valid data on composting. The composting bins were categorized, and different treatment measures were applied to each. According to the different substance mixtures in the bins, six bins each had 70% leaves + 30% soil, 90% leaves + 10% soil, and 100% leaves + 0% soil. They were divided into three groups. Based on the grouping of substances in the bins, 50 earthworms were introduced to each group, and two additional bins were set up to house 0 and 200 earthworms, respectively.

Composting took place over five consecutive weeks, during which the bins were constantly observed. Fresh water was added regularly, and the leaves stirred to ensure a consistent mix of leaves and soil, maintaining a moist environment within the bin. The growth and reproduction status of the earthworms were recorded weekly, noting the average mass and number of earthworms.

After five weeks of composting, samples of the organic fertilizer from each bin were sent to the Southwest University of Science and Technology for testing. The tests covered organic matter, germination index, quick K, P, N and full K, P, N, EC, pH, among others. After analyzing nine indexes in total, optimal conditions data for composting was obtained.

3.1.3 Test Environment

The experiment was conducted in a greenhouse at the Beijing Shunyi Cheng'aoyuan Agricultural Development Park from May to June 2022. According to meteorological department statistics, the average daytime and nighttime temperatures were 28 degrees Celsius and 14.7 degrees Celsius respectively in May, and 30.7 degrees Celsius and 20.4 degrees Celsius respectively in June.

3.2 Experiment 2: Constructing a Prototype Vermicomposting Machine

After two months, the first phase of the urban greening waste vermicomposting resourceful treatment experiment was completed as scheduled. In this phase, it was found that the organic matter content of the compost reached its maximum value when the compost mixture contained 30% soil + 70% dead leaves, composted in a 12L bucket with 50 earthworms initially added. However, there were several issues that adversely affected the experimental process and results. These issues stemmed from three aspects: first, the experiment was carried out in summer, when the water level in the composting barrels rose rapidly due to precipitation, leading to earthworms escaping from some barrels, and inaccuracies in earthworm count. Second, vermicomposting produces a liquid that can be used as fertiliser, but during the experiment, this liquid could not be collected when water was added to ensure bucket humidity, leading to wastage. Lastly, the measurement period for the organic matter after composting was lengthy and costly, proving to be time-consuming and labour-intensive. Given these issues, the second phase of the project involves designing a prototype vermicomposting machine for the large-scale, resourceful treatment of greening waste.

3.2.1 Technology Optimization

This step involved the application of components such as water pumps, sensors, and the use of Python coding technology, 3D printing technology, etc.

3.2.2 Equipment Optimization

The prototype machine was built with the aforementioned components.

3.2.3 Controller M5Stack

This industrial-grade programmable embedded controller utilizes a Loxin ESP32 chip, with a Wi-Fi solution and a dual-core, low-power Xtensa® 32-bit LX6 processor operating at 240MHz. It has 16M FLASH memory and 8M PSRAM memory on the motherboard, a highly sensitive capacitive touch panel, and a 2.0-inch full-colour HD IPS display panel with an expansion interface to connect to other peripherals as needed. The controller case is waterproof and dustproof, ensuring safe and stable circuit operation under complex environmental conditions. It is ideal for scenarios such as outdoor data acquisition nodes, intelligent buildings, and industrial field control. In this project's second phase, the controller mainly serves as a connector to the soil integrated sensor, water pump, and light sensor, collecting and displaying data.

3.2.4 Light Sensor DLight Unit

This digital ambient light detection sensor uses the BH1750FVI illuminance sensor and employs an IC or I2C interface. It features internal 16bit AD conversion to support illuminance value detection from 1 to 655351x. It is low power, small in size, and can operate stably in a variety of illuminance detection environments.

3.2.5 Watering Pump

This device integrates a measuring pole plate and water pump, acting as a capacitive soil humidity detection and adjustment unit. It can detect soil humidity and control the pump to deliver water, making it ideal for intelligent plant breeding and other applications. Through humidity detection and pump adjustment, intelligent irrigation control is achieved. The measuring pole plate is capacitive, effectively avoiding the problem of pole plate corrosion in high humidity environments.

3.2.6 Soil Integrated Sensor

Operating on a DC4.5-30V power supply and with a maximum power consumption of 0.5W under 24V DC conditions, this sensor supports long-term operation buried in the soil and is resistant to long-term electrolysis. It is vacuum encapsulated, providing strong corrosion resistance, effective waterproofing, and dust-proofing. It can monitor nitrogen, phosphorus, potassium, temperature, and pH value in soil in real-time.

3.2.7 Wire

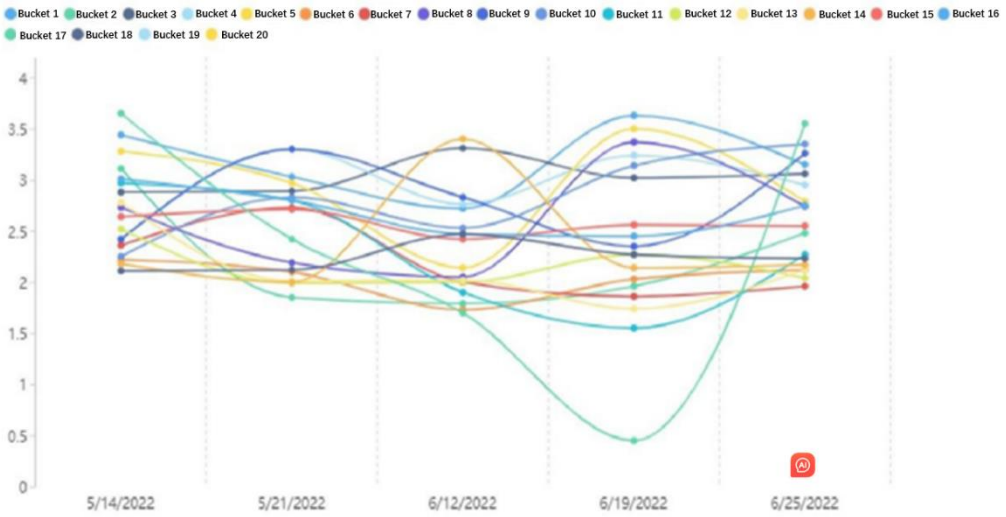
PLA wire was used for 3D printing technology.

4. Test Results and Analyses

4.1 Experiment 1: Effects of Different Treatments on the Resourceful Treatment of Urban Greening Wastes

4.1.1 Effects of Different Treatments on the Average Mass of Earthworms

After five weeks of composting, the earthworms gradually grew and reproduced, laying eggs, which led to an increase in their total number after the larvae hatched. However, since the experiment was conducted in summer, issues such as waterlogging in the buckets and earthworms escaping due to rainfall led to a decrease in the number of earthworms in some experimental groups. The measured average earthworm mass fluctuated over the five-week period, but it remained within a range of 1-20%.



Buckets number / Date	5/14/2022	5/21/2022	6/12/2022	6/19/2022	6/25/2022
Bucket 1	3.44	3.03	2.72	3.63	3.15
Bucket 2	3.11	1.85	1.79	1.96	2.48
Bucket 3	2.88	2.89	3.31	3.02	3.06
Bucket 4	2.42	3.3	2.76	3.24	2.95
Bucket 5	3.28	2.97	2.14	3.5	2.79
Bucket 6	2.22	2.1	1.73	2.03	2.12
Bucket 7	2.36	2.73	2	1.86	1.96
Bucket 8	2.73	2.19	2.05	3.37	2.74
Bucket 9	2.42	3.3	2.83	2.35	3.26
Bucket 10	2.25	2.83	2.53	3.14	3.35
Bucket 11	2.97	2.8	1.9	1.55	2.27
Bucket 12	2.52	1.99	2	2.27	2.04
Bucket 13	2.78	2.01	2.02	1.74	2.12
Bucket 14	2.18	2	3.4	2.14	2.17
Bucket 15	2.64	2.71	2.42	2.56	2.55
Bucket 16	3.01	2.8	2.47	2.45	2.75
Bucket 17	3.65	2.42	#1.7	#0.45	#3.55
Bucket 18	2.11	2.12	2.47	2.27	2.23
Bucket 19					
Bucket 20					

Note : Only one sample was found in the sample where # is located, so the data in the table is the result of the original data after ' 5'

Fig. 1 Effect of different treatments on the average mass of earthworms

4.1.2 Effect of different treatments on soil pH and EC values

Table 1 # pH + EC

Test number	Sample number	pH value	EC(μs/cm)
42	5 Non-soil	7.36	216
43	8 Non-soil	7.61	317
44	13 Non-soil	7.75	244
45	20 Non-soil	7.57	221
46	17 Soil without earthworms	7.54	152
47	1-30% Soil	7.58	169.1
48	3-30% Soil	7.71	166.3
49	7-30% Soil	7.74	159.1
50	2-10% Soil	7.52	242
51	4-10% Soil	7.59	222
52	10-10% Soil	7.44	280
53	21 Leaf	7.41	452

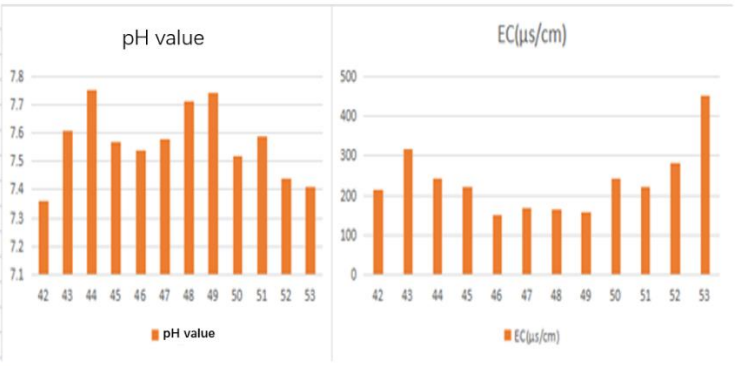


Fig. 2 Schematic diagram of soil pH and EC values

In the Soil-Less and 10% Soil Groups, the soil pH and EC values displayed an inverted U-shaped trend with the increase of earthworms. However, in the 30% Soil Group, soil pH and EC values gradually increased with the increase in earthworms. In the Leaf Treatment Group, the soil pH was significantly lower than in the other treatments, whereas the EC value was significantly higher than in the other treatments.

4.1.3 Effects of different treatments on soil ammonia nitrogen and nitrate nitrogen

Table 2 NH4 + N

Test number	Sample number			5ml extract mg / kg
42	5 Non-soil	0.461	0.7182074	71.82
43	8 Non-soil	0.469	0.7297546	72.98
44	13 Non-soil	0.503	0.7788302	77.88
45	20 Non-soil	0.55	0.84667	84.67
46	17 Soil without earthworms	0.453	0.7066602	70.67
47	1-30% Soil	0.612	0.9361608	93.62
48	3-30% Soil	0.537	0.8279058	82.79
49	7-30% Soil	0.560	0.861104	86.11
50	2-10% Soil	0.781	1.1800954	118.01
51	4-10% Soil	0.539	0.8307926	83.08
52	10-10% Soil	0.620	0.947708	94.77
53	21 Leaf	0.624	0.9534816	57.21

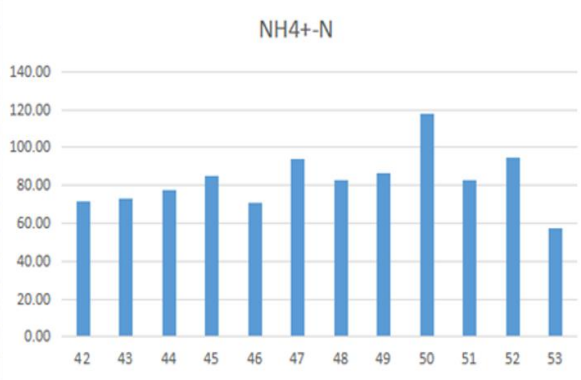


Fig. 3 Effect of different treatments on soil ammoniacal nitrogen

Table3 NO3-N

Test number	Sample number			ug/kg
42	5 Non-soil	0.17	0.071325	285.3
43	8 Non-soil	0.223	0.0741075	296.43
44	13 Non-soil	0.187	0.0722175	288.87
45	20 Non-soil	0.124	0.06891	275.64
46	17 Soil without earthworms	0.297	0.0779925	311.97
47	1-30% Soil	0.130	0.069225	276.9
48	3-30% Soil	0.286	0.077415	309.66
49	7-30% Soil	0.530	0.090225	360.9
50	2-10% Soil	0.103	0.0678075	271.23
51	4-10% Soil	0.246	0.075315	301.26
52	10-10% Soil	0.258	0.075945	303.78
53	21 Leaf	0.176	0.07164	71.64

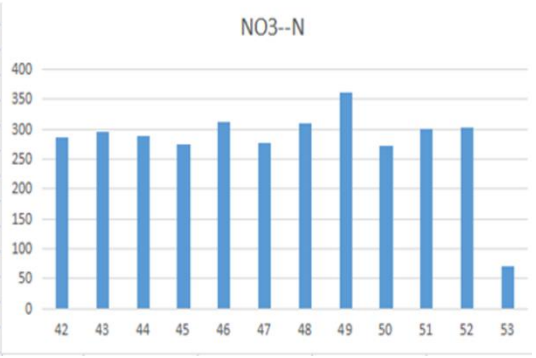


Fig. 4 Effects of different treatments on soil nitrate nitrogen

The levels of soil ammoniacal nitrogen and nitrate nitrogen were significantly lower in the Leaf Treatment Group compared to the other groups. The 2-10% Soil Treatment Group had higher soil ammoniacal nitrogen levels, but there were no significant differences among the other treatment groups. Likewise, soil nitrate nitrogen was higher in the 7-30% Soil Treatment Group, but the differences among the other treatment groups were insignificant.

4.1.4 Effect of different treatments on germination promotion index

Table 4 # Germination number

Test number	Sample number	Germination number root length												GI germination index
42	5 Non-soil	7.15	9.51	9.31	7.68	9.31	5.61	9.78	9.15	9.51		8.56	9	84.626
43	8 Non-soil	7.11	8.85	10.13	8.31	10.21	11.18	11.28	5.78			9.11	8	80.055
44	13 Non-soil	10.21	8.67	9.49	6.61	4.61	7.71	8.91	9.41	10.12		8.42	9	83.231
45	20 Non-soil	10.01	7.01	9.41	7.81	10.21	8.15	8.87	9.15	11.01	9.31	9.09	10	99.934
46	17 Soil without earthworms	5.98	9.71	10.11	9.61	9.39	7.87	5.97	4.51			7.89	8	69.396
47	1-30% Soil	9.11	8.81	10.01	10.35	8.49	7.11	7.12	5.21	9.01		8.36	9	82.659
48	3-30% Soil	9.65	8.21	8.99	10.71	8.61	9.51	11.05	9.31	8.81	10	9.49	10	104.231
49	7-30% Soil	10.21	6.01	5.42	8.99	4.92	5.31	3.21	10			6.76	8	59.418
50	2-10% Soil	11.67	9.51	8.29	9.15	8.01	11.01	10				9.66	7	74.330
51	4-10% Soil	12.08	9.62	11.01	8.72	9.72	12.10	9.12	9.15	10.31		10.20	9	100.912
52	10-10% Soil	9.55	9.01	10.12	9.72	9.51	9.22	8.7	10.71	4.49		9.00	9	89.044
53	21 Leaf	8.61	7.99	6.21	6.11	6.01	8.12	6.64	5.55			6.91	8	60.703
		8.89	8.63	9.96	10.07	8.91	9.88	11.07	8.44	7.46	8.46	9.18	10	100.846

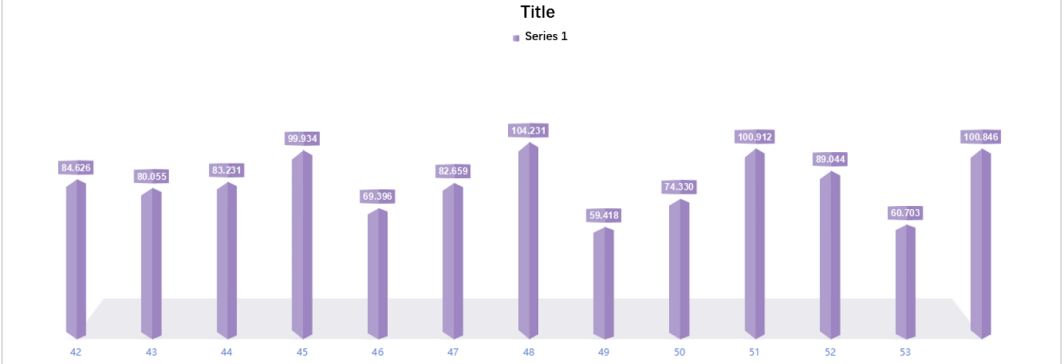


Fig. 5 Effect of different treatments on germination promotion indices

There was no significant difference in the germination indices between the 4-10% Soil, 3-30% Soil, and 20 Non-soil groups, while the germination indices of other treatment groups were lower than those of the Distilled Water Treatment Group. The germination indices of the 17 Soil and Non-Earthworms Group, the 7-30% Soil Group, and the 21 Leaflets Group were significantly lower compared to the other treatments.

4.1.5 Effect of Different Treatments on Total Nitrogen, Phosphorus, and Potassium

The total nitrogen content was higher in the Non-Soil Treatment Group and the 10% Soil Treatment Group, with no significant difference observed between these two groups. The total phosphorus and potassium content in the Soil Treatment Group was lower than that of the Non-Soil Treatment Group. The Leaf Treatment Group had lower total nitrogen, phosphorus, and potassium content compared to the other treatment groups.

Table 5 # Total N-P-K

Test number	Sample number	Sample mass	10ml Total N readings		5ml-50ml Total P readings	Total K readings	Total N content (g/kg)	Total P content (g/kg)	Total P content (g/kg)
42	5 Non-soil	0.1856	2.535		0.915	16.4	14.59590517	9.7765625	8.836206897
43	8 Non-soil	0.2075	2.915	0.763	1.316	19.2	15.61927711	12.96150361	9.253012048
44	13 Non-soil	0.2041	2.795	0.742	1.283	18.8	15.05634493	12.82462518	9.211170995
45	20 Non-soil	0.1822	2.719		1.426	17.3	16.28210757	16.07866081	9.495060373
46	17 Soil without earthworms	0.173	1.793		0.643	11.2	9.65433526	7.057953757	6.473988439
47	1-30% Soil	0.1708	2.087		0.761	12.8	12.18852459	8.656334895	7.494145199
48	3-30% Soil	0.2038	1.934		0.897	15.3	9.163886163	8.710765456	7.507360157
49	7-30% Soil	0.2003	1.987		0.914	14.9	9.694458313	9.048167748	7.438841737
50	2-10% Soil	0.2023	2.958		0.951	16.8	16.3183391	9.357795353	8.30449827
51	4-10% Soil	0.2037	2.844		1.168	15.2	15.42268041	11.61794796	7.461953854
52	10-10% Soil	0.1945	2.876		1.076	14.9	16.38251928	11.13538303	7.66066838
53	21 Leaf	0.1719	1.507		0.479	9.8	7.386852821	5.021396161	5.700988947

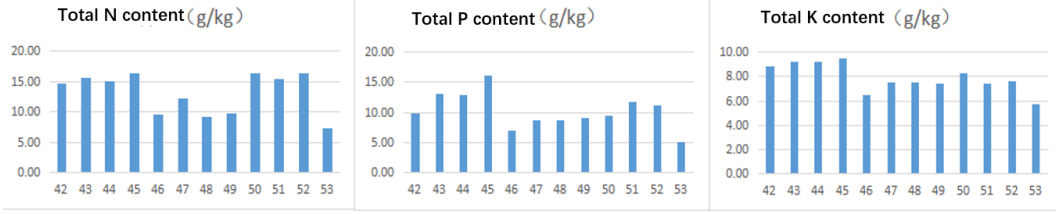


Fig. 6 Effects of different treatments on total nitrogen, phosphorus and potassium

4.2 Experiment 2: Construction of a Prototype Vermicomposting Machine

4.2.1 Modification of Composting Bucket

A bucket with a bottom diameter of 18 cm and a top diameter of 25 cm was chosen as the body of the composting prototype. This was modified to simulate a large-scale composting tank experiment. In a design reminiscent of a household washbasin, a circle of 2 cm diameter holes were drilled into the bucket wall, 7 cm from the bucket surface, with a 5 cm spacing between adjacent holes. A layer of gauze was placed inside the bucket. This design ensured that when the liquid level inside the bucket exceeded two-thirds due to rainfall, some of it could flow out. It also prevented solid materials from escaping and earthworms from leaving the bucket.

4.2.2 Liquid Collection

Liquid is collected via a double-layer structure, which involves a tray and perforated holes approximately 6 cm up from the bottom of the barrel. This divides the barrel into two interconnected yet separate spaces. The tray is lined with a layer of gauze to prevent earthworms from entering the interlayer. The liquid can seep into this interlayer through the small holes and the gauze. Additional small holes are drilled in the bottom of the bucket, where a tap is installed outside the bucket at the perforated area. When the liquid accumulates in large quantities, the tap can be opened to divert the liquid from the bucket into a special container. Figure 7 provides a schematic diagram of the body modeling of the composting prototype.

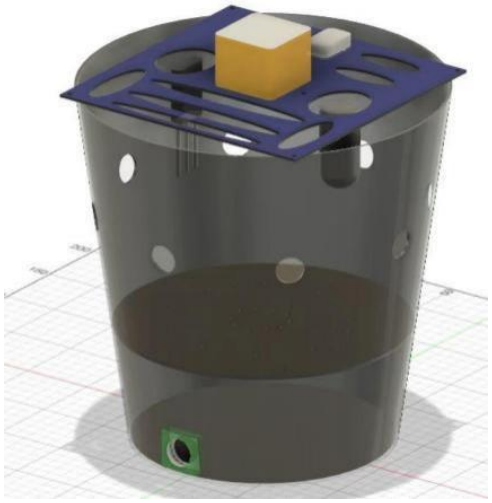


Fig. 7 The composting prototype body model

4.2.3 Data Acquisition

In this study, one master controller and three sensors are used for data acquisition, display, and control. The master controller serves as the central controller, connecting to each sensor, obtaining the data acquired by the sensors, and displaying it on its screen. The integrated soil sensor simultaneously measures the nitrogen, phosphorus, and potassium content in the soil, as well as soil humidity. Meanwhile, the light sensor monitors the external light intensity in real time. The water pump operates in conjunction with the soil sensor, determining whether to add water based on real-time soil humidity. This ensures that soil humidity is always maintained within a certain range, securing the survival conditions for earthworms and sustaining a high decomposition rate. The connection between the master controller and the sensors is established through the master controller expansion interface, and the pump and sensors are controlled by the master controller through Python language programming. The flow chart of the program is shown in figure 8.

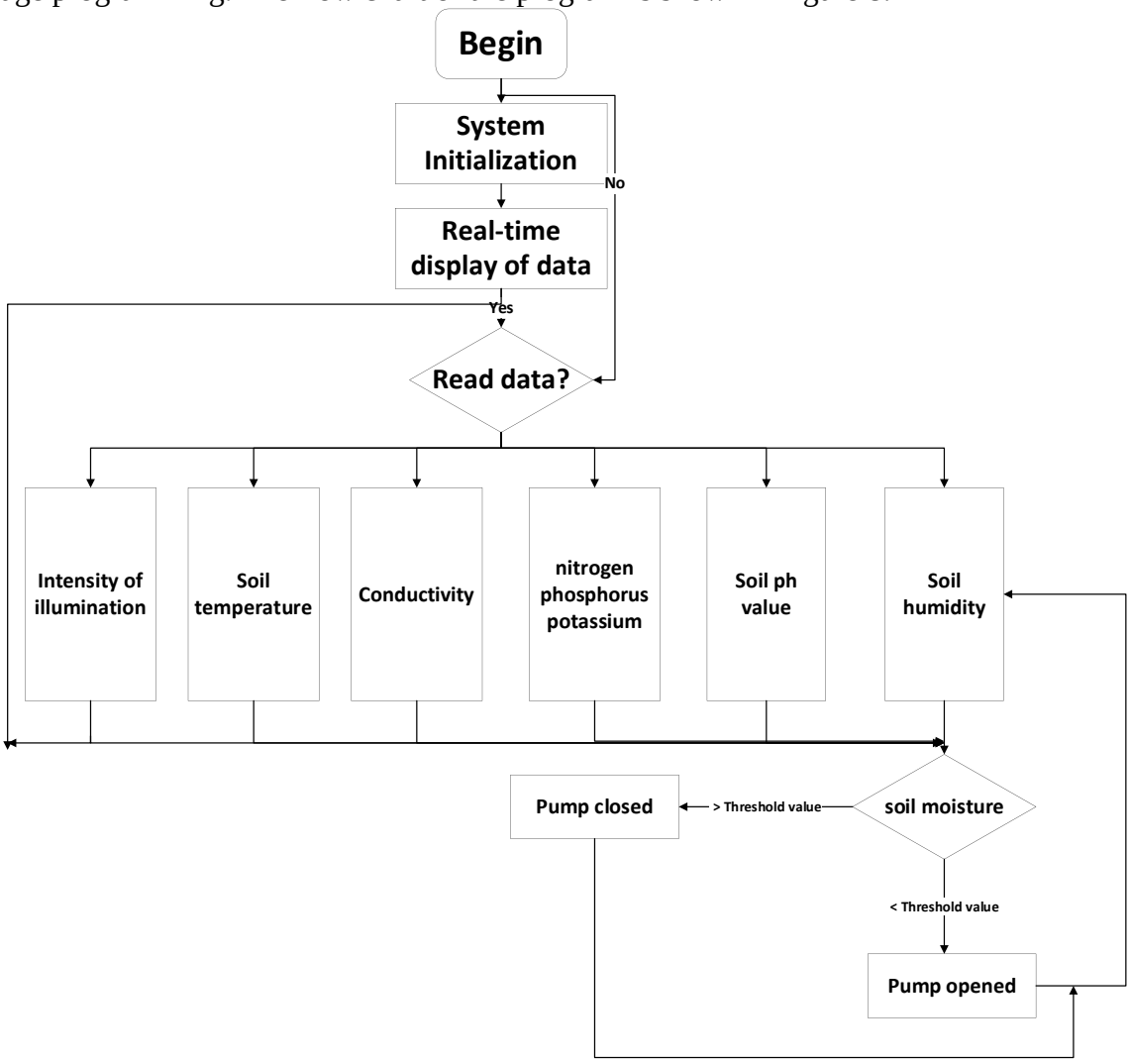


Fig. 8 Procedure flow chart

4.2.4 Model Construction

Upon resolving the data analysis issue, it was found that the placement of the master controller and sensors presented a problem. Specifically, the positioning of these elements reduced the air circulation within the composting bucket, potentially affecting the composting process. In response, we used Fusion software, alongside the actual dimensions of the sensor, to conduct a 1:1 ratio modeling and 3D printing. This resulted in the 3D printed model shown in Figure 9.

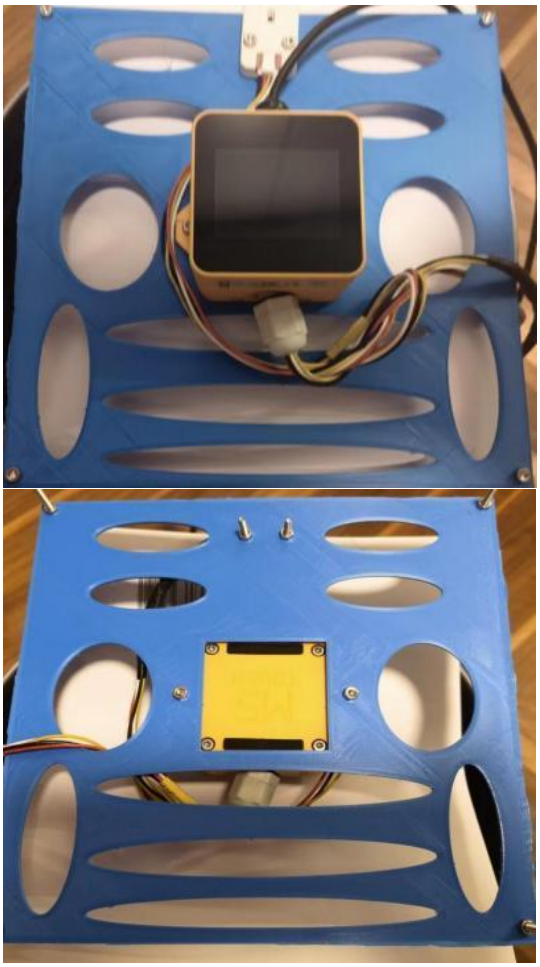


Fig.9 3D printed model

To stabilize the platform and ensure a solid connection with the compost bucket, long screws are positioned at the four corners of the platform. Two additional long screws are set in the middle for securing the light sensor. Holes are made on both sides of the main controller to guarantee direct contact between the water pump, the integrated soil sensor, and the soil underneath. These holes must be spaced apart to prevent the pump from interfering with the soil sensor's data accuracy. As seen in Figure 9, aside from the aforementioned holes and screws, the platform also features a large area of ventilation holes. These are designed to provide earthworms with adequate conditions for survival and to prevent oxygen deficiency, which could lead to a significant decrease in the earthworm population.

5. Discussion

Earthworms are among the largest invertebrates in the soil, both in size and number. They can decompose organic matter such as fallen leaves and residues thanks to various specific enzymes in their bodies, thus contributing to environmental pollution reduction. The earthworms selected for this experiment are surface-dwelling species that reside in the soil's organic layer, feeding on the abundant organic humus. Soil pH greatly impacts the survival rate of earthworms. The lowest survival rate was 8.33% at a pH of 6.72, while the highest was 80.60% at a pH of 7.81, elucidating the decrease in earthworm numbers under the treatments at the experiment's later stage. Soil and organic matter, after passing through the neutral intestinal environment of Eisenia fetida earthworms and being excreted as feces, can improve soil pH. The effectiveness of this improvement is related to the earthworm inoculum density and the nature of the organic material (Figs. 1 and 2). Soil Electrical Conductivity (EC) can indicate the content of mineral nutrients or nutrient salts in the soil. Most crops, and earthworms, prefer a soil EC between 0.4-1 dS-m-1. Soils with high EC are rich in mineral nutrients and favorable for earthworm growth and reproduction [8] (Figs. 1 and 2).

The soil's total nitrogen, phosphorus, and potassium content, as well as nitrate nitrogen and ammoniacal nitrogen, were higher after earthworm inoculation. This suggests that earthworm inoculation can effectively enhance soil fertility (Figs. 3, 4, and 6). Earthworms enhance soil fertility by consuming decomposing organic matter rich in carbon and nitrogen and excreting feces mixed into the soil. This process effectively improves soil organic carbon and total nitrogen content[9]. The germination index was significantly positively correlated with the germination environment's temperature, humidity, and nutrient richness. The lower EC values in the 17 Soil Non-earthworm Group and the 7-30% Soil Group (Fig. 2) suggest that lower nutrient richness in the germination environment adversely affects germination, thereby reducing the germination index (Fig. 5).
Based on the statistical data and the operation of the constructed vermicomposting prototype, it was found that the soil organic matter content reached its peak under the condition of 50 earthworms and 30% conditioner soil. We concluded that the fertility of the fermented composted soil was optimal under the condition of 50 earthworms and 30% conditioner soil.

6. Conclusion and Outlook

Through the modeling of large-scale composting ponds using small composting buckets, this study further clarified the role and application scenario of the vermicomposting project in urban resource regeneration and environmental protection work. This was accomplished after conducting Phase I and II of the urban greening waste vermicomposting resourceful treatment trial, writing the thesis, and practicing scientific and technological innovation. When constructing a large-scale composting tank in the future, the author plans to base the approach on the conditions determined in this paper's tests, specifically introducing 50 earthworms and ensuring conditioner soil accounts for 30%. This involves increasing the quantity of fallen leaves, soil, and earthworms in equal proportions, ensuring uniform sensor installation within the large-scale composting tank to maintain data accuracy, and combining soil sensors with pumps to regulate the composting tank's real-time humidity.

Building upon this, the author intends to integrate ThingJS low-code development technology, Internet of Things technology, and digital connectivity technology. These will cater to the needs of operational and maintenance management work for large-scale composting pond systems. This serves as the third phase of the city's greening waste vermicomposting resourceful treatment experiment. The author believes that with further theoretical analyses, experimental investigations, and practical applications, this work will provide more detailed references for resourceful treatment of urban greening waste, thereby contributing to the improvement of people's living environments.

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Appendix:

Description

		Number of Cases	Mean Value	Criteria Deviation	Criteria Error	95% confidence interval of the mean value		Minimum	Maximum
						Lower Limit	Upper Limit		
Total N content	CK	3	7.39	.000	.000	7.39	7.39	7	7
	T1	4	15.39	.728	.364	14.23	16.55	15	16
	T2	3	16.04	.537	.310	14.71	17.37	15	16
	T3	3	10.35	1.615	.932	6.34	14.36	9	12
	Total	13	12.53	3.771	1.046	10.25	14.81	7	16
Total P content	CK	3	5.02	.000	.000	5.02	5.02	5	5
	T1	4	12.91	2.574	1.287	8.82	17.01	10	16
	T2	3	10.70	1.190	.687	7.75	13.66	9	12
	T3	3	8.81	.212	.123	8.28	9.33	9	9
	Total	13	9.63	3.355	.930	7.61	11.66	5	16
Total K content	CK	3	5.70	.000	.000	5.70	5.70	6	6
	T1	4	9.20	.272	.136	8.77	9.63	9	9
	T2	3	7.81	.440	.254	6.71	8.90	7	8
	T3	3	7.48	.036	.021	7.39	7.57	7	8
	Total	13	7.67	1.347	.373	6.86	8.49	6	9

ANOVA

		Sum of Square	Degree of Freedom	Mean Square	F	Significance
Total N content	Inter-groups	163.294	3	54.431	66.353	.000
	Within-group	7.383	9	.820		
	Total	170.677	12			
Total P content	Inter-groups	112.260	3	37.420	14.776	.001
	Within-group	22.793	9	2.533		
	Total	135.053	12			
Total K content	Inter-groups	21.147	3	7.049	103.501	.000
	Within-group	.613	9	.068		
	Total	21.760	12			

Multiple Comparison

LSD

Dependent Variable	(I) Processing No.	(J) Processing No.	Mean Difference (I-J)	Criteria Error	Significance	95% confidence interval	
						Lower Limit	Upper Limit
Total N content	CK	T1	-8.002*	.692	.000	-9.57	-6.44
		T2	-8.654*	.740	.000	-10.33	-6.98
		T3	-2.962*	.740	.003	-4.64	-1.29
	T1	CK	8.002*	.692	.000	6.44	9.57
		T2	-.653	.692	.370	-2.22	.91
		T3	5.039*	.692	.000	3.47	6.60
	T2	CK	8.654*	.740	.000	6.98	10.33
		T1	.653	.692	.370	-.91	2.22

		T3	5.692*	.740	.000	4.02	7.37
	T3	CK	2.962*	.740	.003	1.29	4.64
		T1	-5.039*	.692	.000	-6.60	-3.47
		T2	-5.692*	.740	.000	-7.37	-4.02
Total P content	CK	T1	-7.889*	1.215	.000	-10.64	-5.14
		T2	-5.682*	1.299	.002	-8.62	-2.74
		T3	-3.784*	1.299	.017	-6.72	-.84
	T1	CK	7.889*	1.215	.000	5.14	10.64
		T2	2.207	1.215	.103	-.54	4.96
		T3	4.105*	1.215	.008	1.36	6.85
	T2	CK	5.682*	1.299	.002	2.74	8.62
		T1	-2.207	1.215	.103	-4.96	.54
		T3	1.899	1.299	.178	-1.04	4.84
	T3	CK	3.784*	1.299	.017	.84	6.72
		T1	-4.105*	1.215	.008	-6.85	-1.36
		T2	-1.899	1.299	.178	-4.84	1.04
Total K content	CK	T1	-3.498*	.199	.000	-3.95	-3.05
		T2	-2.108*	.213	.000	-2.59	-1.63
		T3	-1.779*	.213	.000	-2.26	-1.30
	T1	CK	3.498*	.199	.000	3.05	3.95
		T2	1.390*	.199	.000	.94	1.84
		T3	1.719*	.199	.000	1.27	2.17
	T2	CK	2.108*	.213	.000	1.63	2.59
		T1	-1.390*	.199	.000	-1.84	-.94
		T3	.329	.213	.157	-.15	.81
	T3	CK	1.779*	.213	.000	1.30	2.26
		T1	-1.719*	.199	.000	-2.17	-1.27
		T2	-.329	.213	.157	-.81	.15

*. The significance level for the mean difference is 0.05.

The Total N content was statistically significant according to the ANOVA test with significance less than 0.05. This indicates that there were significant differences in the Total N content between groups. Upon multiple comparisons, the Total N content in T1 and T2 was significantly higher than in the other groups.

The Total P content was also statistically significant according to the ANOVA test with significance less than 0.05, implying a significant difference in Total P content between the groups. By conducting multiple comparisons, it was found that the Total P content in T1 and T2 was significantly higher than that in the other groups.

Lastly, the Total K content showed statistical significance according to the ANOVA test with significance less than 0.05, indicating a significant difference in Total K content between the groups. Upon multiple comparisons, it was determined that the Total K content in T1 was significantly higher than that in the other groups.

Description								
		Number of Cases	Mean Value	Criteria Deviation	Criteria Error	95% confidence interval of the mean value		Minimum	Maximum
						Lower Limit	Upper Limit		
Quick-acting Phosphorus	CK	3	249.4004	.00000	.00000	249.4004	249.4004	249.40	249.40
	T1	4	768.3903	102.69149	51.34575	604.9852	931.7954	645.16	895.24
	T2	3	645.7518	50.11332	28.93294	521.2634	770.2402	608.23	702.66
	T3	3	514.3383	54.95860	31.73036	377.8136	650.8631	469.96	575.81
	Total	13	561.6948	210.97006	58.51257	434.2069	689.1827	249.40	895.24
Quick-acting K	CK	3	6100.0000	.00000	.00000	6100.0000	6100.0000	6100.00	6100.00
	T1	4	15712.5000	862.53019	431.26510	14340.0220	17084.9780	14900.00	16600.00
	T2	3	12650.0000	435.88989	251.66115	11567.1895	13732.8105	12350.00	13150.00
	T3	3	9716.6667	943.83968	544.92609	7372.0389	12061.2944	8900.00	10750.00
	Total	13	11403.8462	3832.34380	1062.90093	9087.9840	13719.7083	6100.00	16600.00

ANOVA						
		Sum of Square	Degree of Freedom	Mean Square	F	Significance
Quick-acting Phosphorus	Inter-groups	491400.181	3	163800.060	34.524	.000
	Within-group	42700.211	9	4744.468		
	Total	534100.392	12			
Quick-acting K	Inter-groups	171848766.026	3	57282922.009	117.342	.000
	Within-group	4393541.667	9	488171.296		
	Total	176242307.692	12			

Multiple Comparison							
LSD							
Dependent Variable	(I) Processing No.	(J) Processing No.	Mean Difference (I-J)	Criteria Error	Significance	95% confidence interval	
						Lower Limit	Upper Limit
Quick-acting Phosphorus	CK	T1	-518.98993*	52.60804	.000	-637.9976	-399.9823
		T2	-396.35140*	56.24036	.000	-523.5759	-269.1269
		T3	-264.93798*	56.24036	.001	-392.1625	-137.7134
	T1	CK	518.98993*	52.60804	.000	399.9823	637.9976
		T2	122.63853*	52.60804	.045	3.6309	241.6462
		T3	254.05195*	52.60804	.001	135.0443	373.0596
	T2	CK	396.35140*	56.24036	.000	269.1269	523.5759
		T1	-122.63853*	52.60804	.045	-241.6462	-3.6309
		T3	131.41342*	56.24036	.044	4.1889	258.6380
	T3	CK	264.93798*	56.24036	.001	137.7134	392.1625
		T1	-254.05195*	52.60804	.001	-373.0596	-135.0443
		T2	-131.41342*	56.24036	.044	-258.6380	-4.1889
Quick-acting K	CK	T1	-9612.50000*	533.63526	.000	-10819.6668	-8405.3332
		T2	-6550.00000*	570.48009	.000	-7840.5156	-5259.4844
		T3	-3616.66667*	570.48009	.000	-4907.1823	-2326.1510
	T1	CK	9612.50000*	533.63526	.000	8405.3332	10819.6668
		T2	3062.50000*	533.63526	.000	1855.3332	4269.6668
		T3	5995.83333*	533.63526	.000	4788.6665	7203.0002
	T2	CK	6550.00000*	570.48009	.000	5259.4844	7840.5156
		T1	-3062.50000*	533.63526	.000	-4269.6668	-1855.3332
		T3	2933.33333*	570.48009	.001	1642.8177	4223.8490
	T3	CK	3616.66667*	570.48009	.000	2326.1510	4907.1823
		T1	-5995.83333*	533.63526	.000	-7203.0002	-4788.6665
		T2	-2933.33333*	570.48009	.001	-4223.8490	-1642.8177
*. The significance level for the mean difference is 0.05.							

The Quick-acting Phosphorus content was statistically significant according to the ANOVA test with significance less than 0.05, indicating a significant difference in Quick-acting Phosphorus content between groups. By conducting multiple comparisons, it was determined that the Quick-acting Phosphorus content in T1 was significantly higher than that in the other groups.

The Quick K content was also statistically significant according to the ANOVA test with significance less than 0.05, signifying a significant difference in Quick K content between the groups. Upon multiple comparisons, it was found that the Quick K content in T1 was significantly higher than that in the other groups.

Description								
Organic Matter								
	Number of Cases	Mean Value	Criteria Deviation	Criteria Error	95% confidence interval of the mean value		Minimum	Maximum
					Lower Limit	Upper Limit		
CK	3	661.4700	.00000	.00000	661.4700	661.4700	661.47	661.47
T1	4	491.1484	25.52845	12.76423	450.5269	531.7698	456.85	513.24
T2	3	546.1185	26.25255	15.15692	480.9035	611.3334	524.85	575.46
T3	3	404.3452	37.55764	21.68391	311.0469	497.6436	372.99	445.97
Total	13	523.1073	96.42558	26.74364	464.8379	581.3767	372.99	661.47

ANOVA					
Organic Matter					
	Sum of Square	Degree of Freedom	Mean Square	F	Significance
Inter-groups	105420.048	3	35140.016	51.386	.000
Within-group	6154.651	9	683.850		
Total	111574.698	12			

Multiple Comparison						
Dependent Variable: Organic Matter						
LSD						
(I) Processing No.	(J) Processing No.	Mean Difference (I-J)	Criteria Error	Significance	95% confidence interval	
					Lower Limit	Upper Limit
CK	T1	170.32165*	19.97279	.000	125.1401	215.5033
	T2	115.35153*	21.35182	.000	67.0504	163.6527
	T3	257.12478*	21.35182	.000	208.8236	305.4259
T1	CK	-170.32165*	19.97279	.000	-215.5033	-125.1401
	T2	-54.97013*	19.97279	.022	-100.1517	-9.7885
	T3	86.80313*	19.97279	.002	41.6215	131.9847
T2	CK	-115.35153*	21.35182	.000	-163.6527	-67.0504
	T1	54.97013*	19.97279	.022	9.7885	100.1517
	T3	141.77326*	21.35182	.000	93.4721	190.0744
T3	CK	-257.12478*	21.35182	.000	-305.4259	-208.8236
	T1	-86.80313*	19.97279	.002	-131.9847	-41.6215
	T2	-141.77326*	21.35182	.000	-190.0744	-93.4721
*. The significance level for the mean difference is 0.05.						

The Organic matter content reached statistical significance as per the ANOVA test, with a significance level less than 0.05, indicating a significant difference in the content of organic matter between the groups. Upon conducting multiple comparisons, it was found that the organic content in the CK group was significantly higher than that in the other groups.