ETV analysis of earthworm composting technology in municipal sludge

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Abstract: Earthworm composting technology can reduce the excess sludge of sewage treatment plant and treat it with resources. According to the procedure of environmental technology verification, this paper tests and analyzes the environmental protection effect and environmental impact of earthworm composting technology scientifically, objectively and fairly. The results showed that the concentration of heavy metals and the number of fecal coliforms in earthworm dung met the limit requirements of the "Organic Fertilizer"(NY 525-2012), and the moisture content, organic matter concentration and total nutrients in earthworm dung did not meet the limit requirements of the "Organic Fertilizer"(NY 525-2012), so it was not suitable to be used directly. It is used as an organic fertilizer, and the mass reduction rate of the mixture after earthworm composting is more than 45%; the sludge treatment capacity (dry weight meter) of the process is 0.24 kg ꞏm-2ꞏd-1, the yield of earthworm dung (dry weight meter) is 0.06 kgꞏm -2ꞏd-1, and the yield of earthworm (dry weight meter) is 0.02 kgꞏm -2ꞏd-1. The reduction effect of earthworm composting process on organic waste (sludge and straw), the concentration of heavy metals and the number of Fecal coliform, all the indicators can meet the verification statement of the enterprise.

1. Introduction
Environmental Technology Verification (ETV) is entrusted by the government, environmental technology developers (owners), technology users or other interested parties, in accordance with relevant national regulations and standards, and according to the "General Specifications for Environmental Technology Verification Evaluation (Trial)" (T/CSES 1-2015) and "General Specification for Environmental Technology Verification Evaluation Test (Trial)" (T/CSES 2-2015) issued by the Chinese Society of Environmental Sciences require comprehensive use of analytical testing, mathematical statistics, expert-assisted evaluation and other methods to conduct scientific, objective, and fair testing and analysis of the environmental protection effects, environmental impacts, and important performances from other environmental perspectives of the entrusted environmental technology [1-3]. The goal of the ETV plan is to promote the development and promotion of new technologies through technical performance assessment and information release,
so that environmental innovation technologies can be accepted and used by society more quickly, in order to protect the environment better.

The purpose of this technical verification is to evaluate the reduction effect of organic wastes (i.e. sludge and straw), the heavy metal content of earthworm compost products, the number of fecal coliform groups, and the performance of the technology. The promotion of this technology provides technical basis.

2. Overview of verification technology process

With the economic growth, the content of heavy metals in the residual sludge of municipal sewage treatment plants (hereinafter referred to as residual sludge) has increased rapidly. Some developed countries have banned the use of the residual sludge for soil improvement, which highlights the problem of the treatment and disposal of the residual sludge of municipal sewage treatment plants.

The excess activated sludge of a municipal sewage plant is actually a general term for the microbial population and the organic and inorganic substances they depend on. Earthworm composting technology is a new type of organic waste treatment technology. The principle is that earthworms feed on microorganisms in sludge. Bacteria and protozoa are decomposed and absorbed to convert organic pollutants into proteins (live earthworms) [4,5]. Because live earthworms are rich in protein, fat and a large number of vitamins and trace elements needed by the human body, high value can be extracted from them, which has broad market prospects; earthworms use their own rich enzyme system to rapidly decompose organic waste and convert them into easy-to-use nutrients (earthworm dung). Earthworm dung is a highly efficient organic fertilizer and soil conditioner. Fertilizer efficiency is much higher than that of ordinary poultry dung. In addition, the use of earthworm compost as a means to treat excess sludge can effectively reduce the amount of sludge, thereby reducing transportation costs and difficulty. Earthworms can also absorb and enrich heavy metals in sludge during metabolism, effectively reducing the content of heavy metals in earthworm dung, reducing pollution and harm to crops and soil.

3. Validation technology process

The data used in this verification and evaluation were collected from two batches (summer and winter) of earthworm compost experiment process, specifically: June 2017 ~ August 2017, the on-site earthworm compost experiment evaluation process for organic waste (i.e. sludge and straw) reduction effect; from October 2017 to January 2018, the on-site earthworm compost experiment was used to evaluate the reduction effect of the process on organic waste (i.e. sludge and straw), the heavy metal content of earthworm compost products, and fecal coliform groups. Data and technical performance, the verification and testing site is the sludge disposal base of Liaoning Huadian Environmental Protection Technology Co., Ltd.

The earthworm composting process flow chart is shown in Figure 1. This earthworm composting process includes organic waste pretreatment, earthworm composting, earthworm dung air-drying, earthworm dung drying, and product processing processes. Specifically: after the excess sludge is transported to the plant, it is first mixed with straw (broken) in a certain ratio and then added to an earthworm-based bed containing a specific number of earthworms for a certain period of degradation and maturation; during the earthworm composting process, the temperature inside the pile is maintained at 10 ~ 25°C. If the temperature is too high, it is appropriate to add water to reduce the temperature; during the earthworm composting process, the moisture content of the pile is controlled to 50% ~ 60% by supplementing water. The fresh earthworm dung produced by earthworm compost is transported to an air-drying site for air-drying treatment. After air-drying, the moisture content of earthworm dung is controlled to about 45%. After air-drying, the earthworm dung is transported to the drying workshop, and dehydrated and killed the fecal coliform group at 80°C. The drying time is 2 hours. The dried earthworm dung can be processed and packaged for sale after being mixed with auxiliary materials according to different purposes. This time it is only verified to dry the earthworm dung, and it is not responsible for the products after adding auxiliary materials.
4. Determination of verification parameters
The test parameters are divided into three categories: environmental effect parameters, operating process parameters and maintenance management parameters. The test parameters are shown in Table 1. The reasons for selection are as follows:

(1) Selection of environmental effect parameters: The earthworm composting technology is an organic resource waste recycling technology. The main purpose of the treatment is to convert organic waste into nutrients that are easy for plants to absorb and use through the metabolism of earthworms. However, due to the use of this technology verification Organic waste is special. It is excess sludge produced by municipal sewage treatment plants, which contains a wide range of heavy metals. Earthworm dung produced after earthworm composting will still be rich in heavy metals, which may exceed "Organic Fertilizer" (NY 525-2012) standard for heavy metals. Therefore, the selection of environmental effect parameters for technical verification of this project should meet: ① accurately reflect the operation status of earthworm composting process; ② determine the content of heavy metals in earthworm dung, compare and judge whether earthworm dung meets "Organic Fertilizer" (NY 525-2012) standards for heavy metal limit requirements.

Based on this, indicators such as wet weight of the material, moisture content, heavy metals, and fecal coliform groups were selected as environmental effect parameters.

(2) Selection of process operating parameters: The content of heavy metals in earthworm dung is mainly related to the ratio of raw materials and the treatment effect. Therefore, indicators such as the ratio of raw materials, the ratio of earthworm dosing and the treatment cycle are selected as process operating parameters.

(3) Selection of maintenance management parameters: The direct costs of excess sludge and earthworm composting technology mainly include: power consumption, water consumption, manpower and mechanical investment.
Table 1. List of test parameters

| Parameter category          | object                  | Specific parameters                                                                 |
|-----------------------------|-------------------------|--------------------------------------------------------------------------------------|
| Environmental effect        | Excess sludge           | moisture content, organic matter, cadmium, mercury, lead, chromium, arsenic, copper,  |
| parameters                  |                         | zinc, nickel                                                                         |
|                             | Earthworm dung          | moisture content, organic matter, fecal coliforms, total nutrients, cadmium,         |
|                             |                         | mercury, lead, chromium, arsenic, copper, zinc, nickel                                 |
|                             | Earthworm               | moisture content, organic matter, cadmium, mercury, lead, chromium, arsenic, copper,  |
|                             |                         | zinc, nickel                                                                          |
|                             | Working environment     | odor concentration                                                                    |
| Operating process           | Earthworm composting   | raw materials ratio, sludge treatment capacity, earthworm ratio, treatment cycle,    |
| parameters                  | facilities             | earthworm dung and earthworm yield                                                    |
| Maintenance                 | Earthworm composting   | power consumption, water consumption, manpower and mechanical investment             |
| management parameters       | facilities             |                                                                                      |

The verification started on September 26, 2016 and ended on January 25, 2018, with a time span of 487 days. Among them, the two batches of field experiments were conducted from June 2017 to August 2017 and October 2017 to January 2018. The total field experiment cycle is about 145 days.

5. Verification test results

5.1. Environmental effect parameters

5.1.1. Effect of organic waste reduction During the test, the changes of material quality (wet weight meter) are shown in Figure 2 and 3. It can be seen from Figure 2 that the wet weight of the raw materials (with sludge, straw, inoculated earthworms, and earthworm-based beds) in the summer experiment was about 13,497 kg. After being treated with earthworm compost and earthworm dung, the wet weight of the materials was reduced to 9,500 kg and 6850 kg. After the original material was processed by the entire earthworm composting process, the wet weight reduction rate of the material was 49.2%; as shown in Figure 3, the wet weight of the original material (with sludge, straw, inoculated earthworm, and earthworm-based bed) in the winter experiment was about 9797 kg. After the earthworm compost, earthworm dung air-drying and earthworm dung drying treatment, the wet weight of the material was reduced to 7,663, 6171, and 5159 kg, respectively. After the original material was processed by the entire earthworm composting process, the wet weight reduction rate of the material was 47.3%.
5.1.2. Material organic matter change During the test, the total organic mass of the original materials (including sludge, straw, inoculated earthworms, and earthworm-based beds) in the summer experiment was approximately 1814.8 kg. The total organic mass of the materials after earthworm composting and earthworm dung air-drying treatment was reduced to 762.9 kg. After the raw material was processed by the entire earthworm composting process, the total organic matter mass reduction rate of the material was 53.2%; it can be seen from Figure 5 that in the winter experiment, the total mass of organic matter is approximately 712 kg. The total organic matter mass of the material after earthworm composting, earthworm earthworm dung drying, and earthworm dung drying has been reduced to 472, 522, and 453 kg, respectively. After the original material is processed by the entire earthworm composting process, the organic matter mass of the material The total mass reduction rate was 36.3%.

5.1.3. Changes in Total Heavy Metals in Earthworm Products In addition to evaluating the reduction effect of the process on organic waste, the purpose of the technical verification and evaluation of this project also includes: ①judging the operation status of the earthworm composting process by measuring the total mass of heavy metals before and after earthworm composting; ②according to the
test agency, the data of heavy metal concentration and the number of fecal coliforms in earthworm dung. Therefore, this verification and evaluation was conducted to quantify the conservation of the total amount of heavy metals in earthworm compost materials through field earthworm compost experiments during October 2017 to January 2018. At this stage, the heavy metal concentrations of earthworm compost raw materials (not part of the organic fertilizer category) and earthworm dung were tested using relevant solid waste and soil standards.

During the test, the changes in the total mass and concentration of heavy metals in earthworms are shown in Figure 4. It can be seen from Figure 4 that the wet weight of the inoculated earthworms was 75 kg, and the total of cadmium, mercury, lead, chromium, arsenic, copper, zinc, and nickel in the inoculated earthworms was 6, 11, 502, 4064, 340, 1334, 5014.5, 869 mg. After composting by earthworms, the wet weight of commercial earthworms (i.e. earthworm products) was 128.8 kg, of which the total mass of cadmium, mercury, lead, chromium, arsenic, copper, zinc and Nickel was 44, 13, 658, 742, 720, 2251, 11300, and 567.5 mg. The concentrations of chromium, zinc, and nickel in the inoculated earthworms were 118.0, 145.5, and 25.2 mg·kg⁻¹; The concentrations of chromium, zinc, and nickel in earthworm products were 12.1, 185.0 and 9.3 mg·kg⁻¹; The concentrations of chromium and nickel in earthworm products after composting were significantly lower than those of chromium and nickel in inoculated earthworms; The accumulation of zinc was obvious during the composting process of earthworms; the other heavy metal concentrations of the earthworm products did not change significantly compared to the heavy metal concentrations of the inoculated earthworms.

![Figure 4 Total mass and concentration changes of heavy metals in earthworms (experimental data from October 2017 to January 2018)](image)

5.1.4. Changes in heavy metal content and other physical and chemical properties of earthworm compost products

The earthworm dung produced by earthworm compost is air-dried and placed in an oven 2 h. The temperature of the oven is set to 80 oC. Then send the dried earthworm dung to the laboratory for monitoring. The detection method is "Organic Fertilizer" (NY 525-2012) relevant test standards, the test results are shown in Table 2. As can be seen from Table 2, after the excess sludge and straw were composted by earthworms, then air-dried and dried, when the samples were tested by the relevant test standards in "Organic Fertilizer" (NY 525-2012), the concentrations of cadmium, mercury, lead, chromium and arsenic in the dried earthworm dung were 0.15, 0.25, 7.30, 75.85, 5.95 mg·kg⁻¹. The test indicators met the "Organic Fertilizer" (NY 525-2012) for the corresponding index limit requirements. The number of fecal coliforms in air-dried earthworm dung was 688 grams per unit, and the number of fecal coliforms in air-dried earthworm dung after drying treatment was 68 grams per unit. The number of fecal coliforms in earthworm dung after drying treatment met the limit requirements of corresponding indicators in the standard of "Organic Fertilizer" (NY 525-2012). The moisture content, organic matter concentration and total nutrient index in dried earthworm dung did
not meet the requirements of the corresponding indicators in the "Organic Fertilizer" (NY 525-2012) standard, so it should not be directly used as organic fertilizer.

5.1.5. Odor concentration in earthworm composting workshop In two batches of earthworm composting experiments, the odor concentration in the earthworm composting workshop gradually decreased with the progress of the experiment. During the summer experiment, the highest odor concentration in the earthworm composting workshop was 19 and the lowest value was 12; during the winter experiment, the highest odor concentration in the earthworm composting workshop was 28 and the lowest value was 14.

5.2. Maintenance management parameters and process operation parameters

(1) Raw material ratio, earthworm dosing ratio and treatment cycle

According to the analysis of winter test data, the area of the earthworm compost base bed (effective earthworm compost treatment area) in this technical verification was 30 m²; the earthworm compost cycle (without air-drying and drying treatment cycle) span was 52 days; the complete earthworm compost cycle (including air-drying and drying treatment cycles) span was 70 days; during the test, the total wet weight of the excess sludge was 3007 kg and the dry weight was 377.4 kg; the wet weight of the treated straw was 175.4 kg and the dry weight was 153.7 kg; the wet weight of the inoculated earthworm was 75 kg and the dry weight was 34.5 kg.

① The raw material ratio of the excess sludge and earthworm composting technology and the earthworm dosing are as follows:

- Wet weight meter: excess sludge: straw: inoculated earthworm ≈ 40: 2.3: 1;
- Dry weight: excess sludge: straw: inoculated earthworm ≈ 11:4.5:1

② The earthworm dosing per unit earthworm compost treatment area is as follows:

- Wet weight meter: Inoculation with earthworms: treatment area = 75:30 = 2.5 kg·m⁻²;
- Dry weight meter: Inoculated earthworms: treatment area = 34.5:30 = 1.15 kg·m⁻²

(2) Sludge treatment capacity

① By analyzing the winter test data, it is known that the raw material processing capacity per unit processing area and time of the system during the test is as follows:

- Sludge treatment capacity (wet weight meter) for the process of earthworm composting cycle (without air-drying and drying treatment cycle): 3007÷30÷52=1.9 kg·m⁻²·d⁻¹; sludge treatment capacity (wet weight meter) for the process of earthworm composting cycle (with air-drying, drying treatment cycle): 3007÷30÷70=1.4 kg·m⁻²·d⁻¹; Sludge treatment capacity (dry weight meter) for the process of earthworm composting cycle (without air-drying and drying treatment cycle): 377.4÷30÷52=0.24 kg·m⁻²·d⁻¹; Sludge treatment capacity (dry weight meter) for the process of earthworm composting cycle (with air-drying and drying treatment cycle): 377.4÷30÷70=0.18 kg·m⁻²·d⁻¹; processing capacity of materials (with sludge and straw) in the earthworm composting cycle (without air-drying and drying process cycle) (wet weight meter): 3182.4÷30÷52=2.0 kg·m⁻²·d⁻¹; processing capacity of materials (with sludge and straw) in the earthworm composting cycle (with air-drying and drying) (wet weight meter): 3182.4÷30÷70=1.5 kg·m⁻²·d⁻¹; processing capacity of materials (with sludge and straw) in the earthworm composting cycle (without air-drying and drying) (dry weight meter): 531.1÷30÷52=0.34 kg·m⁻²·d⁻¹;

- Earthworm composting cycle (with air-drying and drying process cycle) materials (with sludge and straw) processing capacity (dry weight meter): 531.1÷30÷70=0.25 kg·m⁻²·d⁻¹.

② By analyzing the winter test data, it is known that the raw material handling capacity of the system per unit mass of earthworms per unit time during the test is as follows:

- Sludge treatment capacity per unit time (wet weight meter) of earthworm composting cycle (without air-drying and drying treatment cycle): 3007÷75÷52=0.77 kg·kg⁻¹·d⁻¹; Sludge treatment capacity per unit time (dry weight meter) of earthworm composting cycle (without air-drying and drying treatment cycle): 377.4÷34.5÷52=0.21 kg·kg⁻¹·d⁻¹; Earthworm composting cycle (without air-drying and drying treatment cycle) material handling capacity (with sludge and straw) per unit
mass of earthworm per unit time (wet weight meter): \( \frac{3182.4}{75} \div 52 = 0.82 \text{ kg} \cdot \text{kg}^{-1} \cdot \text{d}^{-1} \); Earthworm composting cycle (without air-drying and drying treatment cycle) material handling capacity (with sludge and straw) per unit mass of earthworm per unit time (dry weight meter): \( \frac{531.1}{34.5} \div 52 = 0.3 \text{ kg} \cdot \text{kg}^{-1} \cdot \text{d}^{-1} \).
### Table 2 Summary of physical and chemical properties of earthworm compost (experimental data from October 2017 to January 2018)

| Materials and standards | Moisture content (%) | Organic matter (% dry) | Cadmium (mg kg\(^{-1}\) dry) | Mercury (mg kg\(^{-1}\) dry) | Lead (mg kg\(^{-1}\) dry) | Chromium (mg kg\(^{-1}\) dry) | Arsenic (mg kg\(^{-1}\) dry) | Copper (mg kg\(^{-1}\) dry) | Zinc (mg kg\(^{-1}\) dry) | Nickel (mg kg\(^{-1}\) dry) | Fecal coliform count (PCS / g) | Total nutrients (% dry) |
|--------------------------|---------------------|-----------------------|-----------------------------|-----------------------------|--------------------------|-----------------------------|--------------------------|--------------------------|--------------------------|--------------------------|---------------------------|-------------------------|
| Excess sludge            | 87.45               | 65.48                 | 0.93                        | 1.42                        | 25.29                    | 58.65                       | 9.58                     | 173.98                   | 602.30                   | 31.61                    | -                         | -                        |
| Straw                    | 12.37               | 90.76                 | 0.06                        | 0.01                        | 1.82                     | 18.77                       | 0.97                     | 7.27                     | 28.59                    | 6.41                     | -                         | -                        |
| Earthworm inoculation    | 54.05               | -                     | 0.18                        | 0.33                        | 14.55                    | 118.00                      | 9.86                     | 38.70                    | 145.50                   | 25.20                    | -                         | -                        |
| Earthworm products       | 52.58               | 68.93                 | 0.72                        | 0.21                        | 10.78                    | 12.14                       | 11.78                    | 36.85                    | 185.00                   | 9.29                     | -                         | -                        |
| Air-dried earthworm droppings | 46.90           | 16.03                 | 0.13                        | 0.26                        | 18.85                    | 55.03                       | 5.94                     | 38.45                    | 138.75                   | 12.58                    | 688.25 a                  | 2.40 a                  |
| Dried earthworm dung (measured according to organic fertilizer standards) | 37.31            | 25.10                 | 0.15                        | 0.25                        | 7.30                     | 75.85                       | 5.95                     | 45.80c                   | 166.10d                  | 16.40e                    | 68.00                     | 3.08g                  |
| Dried earthworm dung (measured according to solid waste standard) | 39.80            | 14.60                 | 0.15                        | 0.25                        | 21.00                    | 62.75                       | 6.24                     | 49.35                    | 196.00                   | 18.20                    | -                         | -                        |
| Dried earthworm dung (measured according to green planting soil standards) | 39.30            | 12.70                 | 0.13                        | 0.22                        | 14.90                    | 137.50                      | 5.89                     | 47.50                    | 132.00                   | 7.65                     | -                         | -                        |
| Green Planting Soil Class I Standard (CJ/T 340-2011) | -                | ≥1.20                  | ≤0.30                       | ≤0.30                       | ≤85.00                   | ≤100.00                     | ≤30.00                   | ≤40.00                   | ≤150.00                  | ≤40.00                   | -                         | -                        |
| Organic fertilizer standard (NY525-2012) | ≤30.00           | ≥45.00                 | ≤3.00                       | ≤2.00                       | ≤50.00                   | ≤150.00                     | ≤15.00                   | -                        | -                        | -                        | ≤100.00                   | ≥5.00                   |

Notes:  
- a Determined according to the standard of <Organic fertilizer NY525-2012>  
- b According to solid waste standard  
- c Determined according to the standard of <Determination method of copper in organic fertilizer NY / T 305.1-1995>  
- d Determined according to the standard of <Determination of zinc in organic fertilizer NY / T 305.2-1995>  
- e Determined according to the standard of <Solid waste determination of 22 metal elements inductively coupled plasma atomic emission spectrometry HJ 781-2016>  
- f Determined according to the standard of <Planting soil CJ / T 340-2011>  
- g The total nitrogen (% calculated on dry basis) is 1.14; Phosphorus (% P2O5, dry basis) is 1.44; Potassium (% K2O, on dry basis) is 0.49  

(3) Earthworm dung yield  
During the winter test, the total dry earthworm dung dry weight was 3106.3 kg, including the initial dry earthworm bed dry weight of 2989.3 kg. Therefore, the net earthworm dung production (dry weight meter) was 117 kg.

The earthworm dung yield per unit area per unit time (dry weight meter) of the system during the earthworm compost cycle (including air-drying and drying treatment cycles) was: 117÷30×70=0.06 kg m\(^{-2}\)d\(^{-1}\). In the earthworm composting cycle (with air-drying and drying treatment cycle), the unit material of the system (with sludge and straw, dry weight meter), the earthworm dung yield (dry weight meter) was: 117÷531.1=0.22 kg kg\(^{-1}\).  
(4) Earthworm yield
During the winter test, the wet weight of the inoculated earthworm was 75 kg and the dry weight was 34.5 kg; the wet weight of the produced earthworm product was 128.8 kg and the dry weight was 61.1 kg. Therefore, the net earthworm yield was 53.8 kg and the dry weight was 26.6 kg.

By analyzing the winter test data, it can be known that the earthworm yield per unit processing area and unit time of the system during the test is as follows:

Earthworm yield per unit area per unit time (wet weight meter) in the earthworm composting cycle (without air-drying and drying treatment cycle): 53.8÷30÷52=0.03 kg m⁻² d⁻¹; Earthworm yield per unit of treated area per unit of time (dry weight meter) in the earthworm composting cycle (without air-drying and drying treatment cycle): 26.6÷30÷52=0.02 kg m⁻² d⁻¹.

According to the analysis of winter test data, the yield of earthworms per unit material (with sludge and straw) of the system is as follows:

The earthworm yield (wet weight meter) of the system during the earthworm composting cycle (without air-drying and drying treatment cycle): 53.8÷3182.4=0.017 kg kg⁻¹; The earthworm yield (dry weight meter) of the system during the earthworm composting cycle (without air-drying and drying treatment cycle): 26.6÷531.1=0.05 kg kg⁻¹.

5.3. Maintenance Management Parameters
Omitted.

6. Verification conclusion
During the verification and evaluation period, the system was stable and there were no major faults affecting the normal operation of the process. This earthworm composting process uses the excess sludge from the municipal sewage treatment plant as raw material and the straw as auxiliary material. The materials are uniformly mixed in a specific ratio and put them into the earthworm composting system. According to the verification evaluation goals and test results, the technical verification evaluation conclusions are as follows:

After the earthworm dung produced by the earthworm composting process was air-dried and dried (80 °C, 2 h), the concentration of heavy metals and the number of fecal coliform groups in the dried earthworm dung met the limits in the "Organic Fertilizer" (NY 525-2012) standard; The moisture content, organic matter concentration and total nutrients in dried earthworm dung did not meet the limit values of the corresponding indicators in the "Organic Fertilizer" (NY 525-2012) standard, so it should not be used directly as organic fertilizers.

The quality of the mixed material (sludge and straw) after earthworm composting, air-drying and drying (wet weight meter) reduction rate was greater than 45%; during the earthworm composting cycle (without air-drying and drying treatment cycles), the sludge treatment process capacity (wet weight meter) was 1.9 kg m⁻² d⁻¹; sludge treatment capacity (dry weight meter) was 0.24 kg m⁻² d⁻¹; during the earthworm composting cycle (with air-drying and drying treatment cycle), the earthworm dung yield (dry weight meter) of the process was 0.06 kg m⁻² d⁻¹; during the earthworm composting cycle (without air-drying and drying treatment cycle), the earthworm dung yield (dry weight meter) of the process was 0.02 kg m⁻² d⁻¹; The water consumption, power consumption and labor hours of raw materials per unit mass (with sludge and straw, dry weight meter) by earthworm composting technology (without air-drying and drying treatment stages) were 0.003 m³ kg⁻¹, 6.89 kw h kg⁻¹, and 0.075 h kg⁻¹.

7. suggestions
(1) The raw materials used in this verification test were the excess sludge and straw of the municipal sewage plant, and the process is stable. The number of heavy metals and fecal E.coli groups in dried earthworm dung met the limit requirements in the "Organic Fertilizer" (NY 525-2012) standard. The verification results do not guarantee that when the nature, ratio or working conditions of the raw materials change, the results are still completely consistent with the verification and evaluation results, and further experiments are required.
(2) After the excess sludge and straw were composted by earthworms, the number of fecal E. coli groups in earthworm dung may still not meet the limit requirements in the "Organic Fertilizer" (NY 525-2012) standard. It is recommended to take necessary measures to kill fecal coliforms before leaving the factory (such as high temperature drying treatment).

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