Smart Innovation, Systems and Technologies 397

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Agriculture Digitalization and Organic Production

Proceedings of the Fourth International Conference on Agriculture Digitalization and Organic Production (ADOP 2024), Minsk, Belarus, June 05–08, 2024

Springer

Smart Innovation, Systems and Technologies

Volume 397

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ISSN 2190-3018 ISSN 2190-3026 (electronic)
Smart Innovation, Systems and Technologies
ISBN 978-981-97-4409-1 ISBN 978-981-97-4410-7 (eBook)
https://doi.org/10.1007/978-981-97-4410-7

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

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Chapter 24
Utilization and Recycling of Agricultural Waste with the Help of Biological Objects

Yan Li, Viktar Lemiasheuski, and Svetlana Maksimova

Contents

Abstract Currently, the poultry industry is showing an intensive development trend, which has led to a high concentration of poultry manure. Due to imperfect disposal methods and the lack of processing technology, handling poultry manure is difficult. If measures are not taken to dispose of feces effectively and promptly, large amounts of feces can accumulate near poultry farms, causing potential harm to the environment and human health. To study the effects of earthworm rearing using different bird droppings as base material on the survival, growth, and development of earthworms,

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A. Ronzhin et al. (eds.), *Agriculture Digitalization and Organic Production*, Smart Innovation, Systems and Technologies 397,
https://doi.org/10.1007/978-981-97-4410-7_24

this paper uses bird droppings with different fermentation periods as experimental factors to conduct earthworm survival and chicken and duck droppings analysis. The study also examined goose manure during different periods of fermentation. An acute toxicity test was carried out, based on which the possibility of using cattle manure and crop waste as a breeding substrate was tested. Experimental results show that chicken manure (depending on the fermentation period) is suitable for earthworm colonization and can serve as a substrate when adding cow manure and other crop wastes. At the same time, 100% fermented goose and duck manure can also be used as a substrate for earthworm breeding. And through the vermicomposting process, an efficient and long-lasting organic fertilizer (bio humus) is obtained.

24.1 Introduction

The livestock and poultry manure are a general term for the feces and urine discharged from the livestock and poultry farming process [1]. With the economic development, people's demand for livestock and poultry products soared, the farming industry in various countries is more and more presenting the development trend of scale, intensification, and specialization, and at the same time of development, the natural environment has been subjected to enormous pollution pressure [2]. The Food and Agriculture Organization of the United Nations listed intensive livestock and poultry farming as one of the world's three major sources of environmental pollution [3]. In the traditional agricultural production process, livestock and poultry manure is the main source of natural fertilizers, with the intensive aquaculture brought about by the characteristics of "planting and raising plant separation", resulting in the application of livestock and poultry manure in a timely manner, the treatment cost increases, and other problems are becoming more and more serious.

There are serious reasons for this problem. It is estimated that a chicken produces 80–100 g of manure per day, which is about 3–4% of its body weight [4], and an average-sized chicken farm (400,000 laying hens and 10 million broilers) produces up to 35,000 and 83,000 tons of manure per year and generates more than 400,000 m3 of wastewater with a high concentration of hazardous substances. The average litter size (considering the annual shrinkage of up to 65–70%) is 62 kg per adult bird and 42 kg per young bird, respectively. There are more than 67 poultry farms in Belarus. According to statistics, the stock of poultry on all types of farms in Belarus is 31.2 million birds. More than 1.56 million tons of chicken manure are produced, and there are existing technologies for semi-liquid and liquid manure treatment, but they mainly suffer from high costs, high energy consumption, and the need for special equipment. Thus, the problem of pollution from a wide range of sources of livestock manure and the development of new technologies for chicken manure treatment have become major constraints to the sustainable development of the Belarusian farming industry.

Like other livestock manures, poultry is a nutrient-rich organic waste. The content and nature of its chemical composition depend on the type of poultry, rearing methods, feeding practices, and accumulation conditions that determine their reusability. The author's investigation found that laying hen manure has a moisture content of 68–78%, specific gravity between 6.8– and .4, and density of 1.04–1.15 g/cm ~ 3. Poultry manure has different physical, mechanical, and chemical properties depending on the method of poultry rearing (bedding or non-bedding), species of birds (hen, broiler, duck, goose, turkey), and rearing cycle [5]. And, solid manure is composed of 80% organic matter (4.1% — crude fat, 14.3% — crude fiber, 46.9% — non-nitrogenous extracts, 9.3% — amino acids, and 7.3% — mixtures), and the rest is: 4.6% — total nitrogen, 2% — total phosphorus, 1.7% — potassium oxide, 8.6%— calcium, 0.03% — copper, 0.03% — iron, 0.02% — zinc, 0.7% — magnesium, and 0.3% — magnum [6]. Meanwhile, according to Whitehead D. C, the average nitrogen content (total N) in poultry manure was 1.5%, the average ammonium nitrogen (total N) in poultry manure was 7%, and N protein (total N) was 40%. Nitrogenous organic matter is decomposed by urobacteria to produce ammonia. Phosphorus in poultry manure is not fixed in the soil in the form of iron, aluminum, or calcium phosphate, so it is more readily absorbed by plants than phosphorus in mineral fertilizers. The assimilable forms contain up to 50% nitrogen, almost 20% phosphorus, and almost 70% calcium [7].

However, overuse of such natural fertilizers can lead to ecological pollution such as deterioration of air quality, increase in greenhouse gas emissions, accumulation of harmful heavy metals, eutrophication of water bodies, soil acidification, and loss of soil nutrients (nitrogen and phosphorus). Leaching, erosion, and runoff result from lack of consideration of nutrient requirements of crops [8]. Moreover, the unpleasant odor that untreated chicken manure can produce can be of concern to flies, pests, and rodents and poses a clear threat to human health in addition to pathogen colonization and antibiotic resistance [9]. These factors have prompted the need to investigate alternatives for the treatment and use of chicken manure to use it sustainably and economically.

Vermicomposting has gained global attention in the last few decades due to its technical simplicity and effectiveness [10]. Various wastes such as animal manure [11], agricultural wastes [12], industrial wastes [13], and municipal wastes [14] can be used as feedstock for vermicomposting. Vermicomposting is a bio-oxidative, thermophilic, natural decomposition process in which earthworms and microorganisms synergistically mineralize the organic waste substrate and convert it into nutrient-rich organic fertilizer [15]. In this process, two useful products are obtained, i.e., vermicompost, and bio humus . Vermicompost can be used as a soil conditioner and earthworms can be used in pharmaceuticals and fishpond feed. Vermicompost has several advantages over chemical fertilizers and is useful for crops. Vermicompost contains nutrients (in plant usable form), humic acids, and growth hormones, and hence, it is widely used as organic fertilizer in organic farming [16]. Studies conducted by different authors have shown that the use of vermicompost can increase seed germination, nutrient growth, and yield of crops without compromising soil health. Intensive agriculture has seriously affected the soil health and fertility. Application of vermicompost helps to improve the physical, chemical, and biological properties of the soil, thereby maintaining soil health and fertility [10, 13]. Various reports indicate that vermicomposting can also be used in other areas such as wastewater treatment, soil remediation, and energy production [17, 18].

Eisenia foetida is a type of earthworm that belongs to the class of fecal earthworms. This type of earthworm has a very wide range of feeding habits, a high reproductive rate, is more active, and is highly adaptable, which makes it "stand out" in the treatment of livestock manure and has attracted a lot of attention. Its intestinal cellulose has a strong enzyme activity, and decomposition ability is outstanding. Similarly, the feeding capacity of this type of earthworm is considerable, and the weight of the manure it consumes can be equal to its own weight. Thus, 100 million earthworms in 1 min can handle 40~50 t of organic waste and in the process produce 20 t of vermicompost organic fertilizer [19]. According to the author's investigation, earthworms feed on agricultural wastes, plant wastes, sewage treatment plant residues, fruit wastes, and so on. Therefore, the use of earthworms to treat manure can not only solve the current problem and can play a positive role in the green development of agriculture, but also produce organic fertilizer and animal manure in the process of decomposition. Vermicomposting technology is an important part of a country's circular economy, which generates energy from waste and promotes the greening of the environment and the economy.

Research purpose. We took into account the characteristics of poultry farms, such as large emission of livestock and poultry manure, low treatment rate, serious pollution, low comprehensive utilization, etc., combined with the advantages and operability of vermicomposting technology. Therefore, this study explores the method of vermicomposting technology to treat poultry manure, in order to solve the problem of environmental pollution and waste of resources caused by the lack of proper treatment of poultry manure, and to provide a reasonable and feasible technological route for the resourceful utilization of poultry manure.

24.2 Materials and Methods

24.2.1 Materials

To study the possibility of using guano in vermitechnology, composted manure from chickens, geese, turkeys, and ducks was collected from poultry farms (Minsk, Borisov, and Brest oblasts) and placed on site. Experiments on biological humus production were carried out. Earthworms (*Eisenia foetida*, Sav) were provided by the vermitechnology laboratory of the Scientific and Practical Center for Biological Resources of the National Academy of Sciences of Belarus. In addition, the substrate suitability process was carried out in homemade vermiculture containers ($20 \times 30 \times 10$ cm). Physico-chemical analyses were carried out at the Scientific and Practical Center for Bioresources of the National Academy of Sciences of Belarus, and vermiculture experiments were carried out at the above-mentioned poultry farm. Samples of chicken, goose, and duck manure from different composting periods were subjected to visual analysis, and physicochemical analyses of all samples were also carried out; data on the physicochemical composition are presented in Table 24.1.

24.2.2 Methods

Physico-chemical Methods of Analysis

Physico-chemical analysis methods are performed according to the following methods:

- Determination of color and odor — visually and organoleptically.
- Determination of the qualitative composition of bio humus is carried out by methods of laboratory analysis, used in the quality control of organic fertilizers, according to "Methodological guidelines for the analysis of organic fertilizers", M: Kolos, 1984, in accordance with GOST 27980-88.
- Mass fraction of moisture according to GOST 26713-85.
- Mass fraction of organic matter according to GOST 27980-88.
- Acidity (hydrogen ion activity index of salt suspension) according to GOST 27979-88.
- Bulk density according to GOST 24701-81.
- Mass fraction of nutrient elements is determined by:
- Total nitrogen according to GOST 26715-85.
- Total phosphorus according to GOST 26717-85.
- Total potassium according to GOST 26718-85.

Experimental Design of Vermicultivation and Vermicomposting

Worm survival and acute toxicity studies were conducted on chicken, goose, and duck manure at different fermentation periods.

The essence of the experiment: We placed five worms in each box in a prepared container containing droppings of different fermentation periods. We also experimented with the bases at different stages of fermentation, adding cow manure to some of the containers. The experiment lasted 60 days. Worms in containers were counted daily.

After testing the substrate and survival of more than 90% of the worm population, the vermicomposting process began. This process for chicken manure lasted more than six months. At the same time, physicochemical analyses were carried out every month to determine the quality of the final product and the population density was determined to determine the required number of biological objects for processing.

Table 24.1 Physico-chemical parameters of droppings of different species of birds of different fermentation periods

	No. material	pH	Zola (%)	Moisture (%)	Total nitrogen (%)	Total phosphorus (%)	Total potassium (%)	Organic material (%)	CaO (%)
	Chicken droppings 2 years	6.83 ± 1.25	9.98 ± 1.15	52.34 ± 1.53	0.84 ± 0.12	1.47 ± 0.21	1.01 ± 0.16	37.68 ± 1.32	1.10 ± 0.11
	Chicken droppings 1 years	7.72 ± 1.23	9.45 ± 1.41	58.90 ± 2.51	1.17 ± 0.16	0.92 ± 0.13	1.33 ± 0.18	31.65 ± 1.84	0.90 ± 0.14
	Goose droppings, 6 months	7.50 ± 1.37	3.86 ± 0.95	69.58 ± 3.71	0.32 ± 0.07	0.17 ± 0.03	0.35 ± 0.09	28.56 ± 2.47	0.60 ± 0.10
	Duck droppings, 6 months	7.40 ± 1.14	7.10 ± 1.09	71.0 ± 4.16	0.62 ± 0.07	0.85 ± 0.10	0.52 ± 0.04	30.7 ± 2.49	1.0 ± 0.08

24.3 Results and Discussions

24.3.1 Worm Survival and Acute Toxicity Tests

- Option 1: Chicken Litter 1 Year (100%)

As a result of the experiments, it was revealed that dung earthworms released into 1-year-old chicken droppings died on the 2nd day of the experiment. The mortality rate was 100%. When adding 39% soil and 23% cattle manure to chicken manure for 1 year, it turned out that earthworms died on the 2nd day of the experiment. The worm mortality rate was 100%. When adding another 20% of cattle manure to the substrate, it turned out that worm mortality reached 60% on the third day. Continuation of the experiment showed that after 5 days, juveniles (juvenile stages) of earthworms were found in the container and no further mortality of earthworms was observed. Further observation of the life activity of earthworms in this container showed that the mortality rate was 0%, the number of adult worms in the container and juveniles increased by 100%, and the appearance of cocoons was noted. Thus, adding 60% cattle manure to chicken manure for 1 year, as well as 40% soil, promotes the growth and development of dung worms.

- Option 2: Chicken Manure 2 Years (100%)

As a result of the experiment, it was revealed that dung worms released into chicken droppings for 2 years turned out to be lethargic on the second day of the research and died on the 5th day of the experiment. Reintroduction of earthworms into chicken droppings for 2 years showed that by the end of the experiment, the worms were alive, but no growth or development of the population was observed. It should be noted that the addition of 20% cattle manure stimulated the worms to further their growth and development.

- Option 3: Goose Droppings (100%)

As a result of the experiment, it was revealed that dung worms released into goose droppings (100%) survived throughout the entire experiment. The mortality rate was 0%. Moreover, a month after the experiment, the number of worms increased by 50% and the presence of cocoons was revealed. Further observation of earthworms in the container showed that they did not die, but there was an increase in the number of cocoons. Thus, goose droppings can be a substrate for the growth and development of earthworms.

- Option 4: Duck Droppings 100%

As a result of the experiment, it was revealed that dung worms released into duck droppings (100%) survived throughout the entire experiment. The mortality rate was 0%. Moreover, a month after the experiment, the number of worms increased by 20% and the presence of cocoons was revealed. Further observation of earthworms in the container showed that they did not die, but the number of cocoons increased and juveniles appeared. Thus, duck droppings can be a substrate for the growth and development of earthworms.

24.3.2 Experiments with Base Material Additions at Different Stages of Fermentation Vermicomposting Process and Production of Vermicompost

In addition, we conducted an experiment with litter of different fermentation periods. Straw and peat were added to the chicken manure. We have found that the composition of substrates significantly affects the population size of earthworms. Thus, if peat was used instead of straw, the population size of earthworms decreased significantly. The largest number of laid cocoons was recorded in substrates based on chicken manure for 2 years with the following ratios of ingredients: 50% manure — 50% straw and 75% manure — 25% straw. The latter option is preferable not only in terms of processing volume, but also a significant increase in the weight of worms, which in the future can be used as a protein feed additive in the diets of animals and birds. The negative effect of fresh droppings on earthworms can be eliminated if the substrate is presented with droppings along with straw, peat, and sawdust in a 3:1 ratio.

24.3.3 Vermicomposting Process and Production of Vermicompost

As a result of vermicomposting process, a highly effective organic fertilizer of prolonged action —"bio humus"—was obtained.

The fertilizer—"bio humus", is obtained by biotechnological processing of organic wastes of livestock and poultry farming, as well as any organic wastes by vermicomposting (technological line "Belarusian ploughman" dung earthworm species Eisenia foetida (Sav). "Bio humus" is intended for use in agricultural production, horticulture, horticulture, horticulture, floriculture, for growing seedlings of vegetable and ornamental crops, on homestead plots as an organic fertilizer and as a component for the preparation of soil mixtures, organ mineral fertilizers, and soils.

Organic fertilizer BIOGUMUS can be applied to the soil:

- By area method, i.e., by spreading over the soil surface.
- Locally, i.e., in a hole under each plant.
- In the form of a solution.

When preparing soil mixtures, it is recommended:

- For vegetable and flower seedlings: 1 part of "bio humus" mixed with 3–5 parts of sod earth or peat; for flowers in pots: 1 part of "bio humus" mixed with 4–5 parts of soil.
- When planting tomatoes, peppers, eggplant, put 100–200 g of "bio humus" under each plant.
- When sowing green crops (parsley, lettuce, dill, spinach, etc.) in the beds, it is necessary to spread "bio humus" evenly over the surface of the bed on the pre-moistened soil, mix it with the soil, water it, and then sow the seeds. Apply 0.5–1.0 kg of "bio humus" per 1 square meter of bed.
- When planting potatoes, it is advisable to apply 100–200 g of "bio humus" under each tuber.
- When planting strawberries, it is recommended to put 150–200 g of "bio humus" in each well.
- When planting winter garlic, add 0.5 kg of "bio humus" per 1 square meter of bed, mix the soil to a depth of 10 cm.
- When planting shrubs (gooseberries, currants, etc.), 1.5 kg of "bio humus" should be added to the planting hole, thoroughly mixed with soil, watered, and planted.
- When planting fruit trees, 2 kg of "bio humus" should be added to the planting pit for each seedling (apples, pears, cherries, plums, etc.) and mixed with soil.
- To feed vegetable and berry plants during the growing season once a month, sprinkle "bio humus" around the stems of plants or in the inter-row at the rate of 0.5 kg of "bio humus" per 1 square meter, and mix with soil and water.
- To feed shrubs and fruit trees, "bio humus" is spread under the crown at the rate of 0.5 kg/m^2.
- When fertilizing flowers and ornamental plants in the open ground, "bio humus" should be applied monthly at the rate of 150–200 g for each plant or 0.5 kg/m^2 of flowerbed, lawn.
- When fertilizing indoor flowers, "bio humus" should be applied under the plant once every 2 months 2–3 tablespoons.

24.4 Conclusions

During the research, it was found that chicken manure (depending on the fermentation period) is suitable for the colonization of earthworms and can be used as a substrate when adding cow manure and other agricultural wastes. At the same time, 100% fermented feces of geese and ducks can be used as a substrate for the life of earthworms. Moreover, through the vermicomposting process, a high-quality organic fertilizer (biological humus) can be obtained, which can make good use of biotechnology to process organic waste from livestock and poultry breeding. It is suitable for agricultural production, horticulture, floriculture, vegetable, and ornamental crop seedlings, where it is used as an effective organic additive for preparing soil mixtures and soils.

Immediately, we can see that earthworms can efficiently process agricultural waste and obtain beneficial nutrients by efficiently breaking down the materials in their feces. Moreover, the cost of earthworm farming is relatively low, the required technology is relatively simple, and the final benefits and feed benefits are better. Thus, earthworms can be used to improve the environment of livestock and poultry farms, reduce feeding costs, increase economic income, eliminate environmental pollution, and realize resource utilization of livestock and poultry manure, which is a necessity for sustainable development.

Acknowledgements The first corresponding author and PhD student, Yan Li, would like to thank the China Scholarship Council for providing a living grant.

References

1. Xie, G., Bao, W., Liu, J., et al.: Review on the status of livestock and poultry manure resources research in China. J. China Agric. Univ. **23**(04), 75–87 (2018)
2. Tang, W., Sun, X., Gao, H., et al.: Isolation and identification of multidrug-resistant bacteria in feces from large-scale livestock and poultry farms and their resistance characteristics. J. Agric. Environ. Sci. **39**(01), 207–216 (2020)
3. Li, Z., Zhang, Q.W., Zhang, A.P., et al.: Spatiotemporal characteristics of the bearing capacity of cropland based on manure nitrogen and phosphorus load in mainland China. J. Clean. Prod. **233**, 601–610 (2019)
4. Abdeshahian, P., Lim, J.S., Ho, W.S., Hashim, H., Lee, C.T.: Potential of biogas production from farm animal waste in Malaysia. Renew. Sustain. Energy Rev. **60**, 714–723 (2016). https://doi.org/10.1016/j.rser.2016.01.117
5. Ostatochnyi proekt DSTU Poslid ptytsi. Tekhnolohii biolohichnoho pererobliannia. Zahalni vymohy. Kyiv, Ukraine (2012)
6. Pinchuk, V.O., Tertychna, O.V., Borodai, V.P., Mineralov, O.I.: Rozrakhunok azotnoho balansu ptakhopidpryiemstv [Calculation of the nitrogen balance of poultry enterprises]. Ahroekolohichnyi zhurnal **4**, 35–39 (2016). (In Ukrainian)
7. Whitehead, D.C.: Nutrient Elements in Grassland: Soil-Plant-Animal Relationships. Wallingford, United Kingdom (2000)
8. Zhang, L., Li, L., Pan, X., Shi, Z., Feng, X., Gong, B., Li, J., Wang, L.: Enhanced growth and activities of the dominant functional microbiota of chicken manure composts in the presence of maize straw. Front. Microbiol. **9**, 1131 (2018). https://doi.org/10.3389/fmicb.2018.01131
9. Duan, Y., Awasthi, S.K., Liu, T., Zhang, Z., Awasthi, M.K.: Response of bamboo biochar amendment on volatile fatty acids accumulation reduction and humification during chicken manure composting. Biores. Technol. **291**, 121845 (2019). https://doi.org/10.1016/j.biortech.2019.121845
10. Hussain, N., Abbasi, S.A.: Efficacy of the vermicomposts ofdifferent organic wastes as "Clean" fertilizers: state-of-the-Art. Sustainability **10**(4), 1205 (2018)
11. Sharma, K., Garg, V.K.: Vermimodificaion of ruminant excreta using Eisenia fetida. Environ. Sci. Pollut. Res. **24**(24), 19938e45 (2017)
12. Sharma, K., Garg, V.K.: Comparative analysis of vermicompost quality produced from rice straw and paper waste employing earthworm Eisenia fetida (Sav.). Biores. Technol. **24**(8), 7829e36 (2018)
13. Lee, L.H, Yeong, W.T., Shak, K.P.Y., Lim, S.L., Ng, K.Y., Nguyen, M.N., Teoh, W.H.: Sustainable approach to bio-transform industrial sludge into organic fertilizer via vermicomposting: a mini-review. J. Chem. Technol. Biotechnol. **93**, 925e35 (2017)

14. Soobhany, N., Gunasee, S., Rago, Y.P., Joyram, H., Raghoo, P., Mohee, R., Garg, V.K.: Spectroscopic, thermogravimetric, and structural characterization analyses for comparing municipal solid waste composts and vermicomposts stability and maturity. Biores. Technol. **263**, 11e9 (2017). https://doi.org/10.1016/j.biortech.2017.03.161
15. Pramanik, P., Chung, Y.R.: Changes in fungal population of fly ash and vinasse mixture during vermicomposting by Eudrilus eugeniae and Eisenia fetida: documentation of cellulase isozymes in vermicompost. Waste Manag. **31**, 1169e75 (2011)
16. Dominguez, J., Edwards, C.A.: Biology and ecology of earthworm species used for vermicomposting. In: Vermiculture Technology: Earthworms, Organic Wastes, and Environmental Management. Boca Raton, FL, USA, pp. 27–40 (2011)
17. Pereira, M.G., Neta, L.C.S., Fontes, M.P.F., Souza, A.N., Matos, T.C., Sachdev, E.L., Santos, A.V., Souza, M.O.G., Andrade, M.A.V.S., Paulo, G.M.M., Ribeiro, J.N., Ribeiro, A.V.F.N.: An overview of the environmental applicability of vermicompost: from wastewater treatment to the development of sensitive analytical methods. Sci. World J. **2014**, 917348 (2014)
18. Li, Y., Lemiasheuski, V., Maksimova, S.: The simulated experimental design and study of the synergistic treatment of chicken manure and traditional chinese medicine residues on earthworm growth and soil quality. In: E3S Web of Conference, vol. **497**, p. 03012, 5th International Conference on Energetics, Civil and Agricultural Engineering (ICECAE 2024) (2024). https://doi.org/10.1051/e3sconf/202449703012
19. Zhiqi, M., Jipeng, S., Jiale, X., et al.: A preliminary study on the effect of earthworms in treating livestock manure. Tianjin Agric. Forest. Sci. Technol. **6**, 1–2 (2020)

Part IV
Organic Livestock Farming: Poultry and Dairy Production

Contents