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Overview of Resource Utilization of Livestock and Poultry Manure

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Abstract: In recent years, with the development of animal husbandry, more and more livestock and poultry manure has been generated. Currently, the most common methods for treating livestock and poultry manure are anaerobic fermentation and aerobic composting. Aerobic composting is a technology that uses animal manure for high-temperature composting and fermentation to degrade organic matter and convert it into humic substances. Anaerobic fermentation is an energy utilization technology that converts organic matter into combustible gases such as CH4 through the action of anaerobic microorganisms and produces biogas slurry and sludge. This article reviews two treatment methods for livestock and poultry manure, aerobic composting and anaerobic digestion, in order to provide reference for the research of humic acid organic fertilizers.

Keywords: Livestock and poultry manure; Aerobic composting; Anaerobic digestion; humus.

1. Introduction

In recent years, with the development and promotion of modern industrial breeding models, the intensive scale of breeding has led to the treatment of livestock and poultry manure becoming an important factor restricting the development of modern breeding industry. Animal manure contains a large amount of pollutants. If not handled properly, it will seriously affect air quality, soil and water safety, and damage the ecosystem [1]. The pungent odor produced by animal manure, harmful gases such as ammonia (NH_3) and hydrogen sulfide (H_2S), as well as dust, are important factors threatening air quality [2]; In addition to nitrogen and phosphorus, which are potential pollutants in soil, antibiotics and heavy metals caused by feed addition in animal manure are also a major cause of soil pollution [3]; Direct discharge of feces and improper treatment of livestock and poultry manure can lead to the entry of nutrients, antibiotics, heavy metals, insect eggs, pathogenic microorganisms, etc. into the water environment, resulting in eutrophication and numerous other pollution situations in the water body [4]. If the decomposition products from these processes enter the natural environment, it not only affects human health, but in severe cases, it will damage the local ecological environment.

However, livestock and poultry manure contains abundant organic matter and a large amount of growth elements such as nitrogen, phosphorus, and potassium, making it a good bioavailable resource. Reasonable disposal and resource utilization of livestock and poultry manure can not only reduce environmental pollution, but also turn waste into treasure. Further development of its economic value can promote sustainable development of agriculture.

2. Animal Manure Treatment Technology

In order to achieve harmless treatment of livestock and poultry manure and reduce environmental pollution, the commonly used treatment methods currently include anaerobic fermentation and aerobic composting[5]. Anaerobic fermentation treatment of livestock and poultry manure to produce biogas is a technology for energy utilization of livestock and poultry manure. Through the action of anaerobic microorganisms, organic matter is converted into combustible gases such as CH_4, and the generated biogas slurry can be used as organic fertilizer. Anaerobic fermentation technology is relatively mature, but this method has high cost, complex process, and difficult operation, making it difficult to start at low temperatures[6].

Aerobic composting, on the other hand, involves selecting appropriate excipients and mixing them with animal manure, and then undergoing high-temperature composting fermentation to degrade and transform the macromolecular organic matter into stable humic substances, known as the humification process [7]. This process can remove harmful substances from livestock and poultry manure. The humified livestock and poultry manure products can be used as organic fertilizers for returning to the field, improving soil fertility and achieving the goal of improving soil environment. Compared to anaerobic fermentation, aerobic composting has a simpler fermentation process and is easier to operate, package, and transport.

2.1. Overview of High Temperature Aerobic Composting

High temperature aerobic composting utilizes the fermentation process of aerobic microorganisms to decompose and convert organic matter into CO_2, heat, and humus. At present, the main composting methods include stack composting, static aeration composting, and closed fermentation bin composting[8]. Both stack composting and static aeration composting belong to open-air composting methods. These two methods can timely process a large amount of livestock and poultry manure, and facilitate observation and mastery of fermentation conditions during the composting process, however, these two composting methods require a significant amount of space and require a longer composting time, making them unsuitable for larger scale aquaculture farms [6].

Closed fermentation bin composting is the use of modern equipment such as closed fermentation tanks or large fermentation tanks to complete the composting process, Closed fermentation tanks include box type fermentation tanks, vertical drum type fermentation tanks, and horizontal drum type fermentation tanks. Among them, box type and vertical fermentation tanks are the main types commonly used to achieve rapid composting [9]. Stable temperature and humidity can promote the growth and metabolism of microorganisms in the compost and accelerate the decomposition and transformation of organic matter, thereby improving the maturity and stability of compost [10]. Aeration can provide sufficient oxygen for composting, thereby increasing the enzyme activity of microorganisms in the compost, further accelerating the degradation of organic matter, and improving the maturity of compost [11].

High temperature aerobic composting is generally divided into heating stage, high temperature stage, and maturation stage [12], transforming organic waste into mineralized products and stable organic matter through the action of microorganisms, mainly generating humus [12]. Therefore, it can be divided into two processes: mineralization and humification[13], and the humification stage takes a long time and is a critical period for the aggregation of a large amount of humus[14]. During this process, the highest temperature during the high-temperature period of composting can reach over 65 ℃. Maintaining this temperature for 3-4 days can kill pathogenic microorganisms and insect eggs in feces, reduce the spread of pathogenic microorganisms, and convert livestock and poultry manure into harmless organic fertilizer for agricultural production [15]. After the high temperature period, the organic matter is basically degraded, making it difficult for thermophilic bacteria to continue metabolizing and growing, which leads to a decrease in compost temperature and enters the stage of composting and solidification. After the high temperature period, the organic matter is basically degraded, making it difficult for thermophilic bacteria to continue metabolizing and growing, which leads to a decrease in compost temperature and enters the stage of composting and solidification. The purpose of aerobic composting is to promote the stabilization and humification of organic waste. Specialized and facultative aerobic microorganisms undergo complex biochemical processes to oxidize, decompose, and synthesize organic waste for utilization. In the process of oxidative decomposition, macromolecular substances are decomposed, releasing heat and energy, and releasing gases such as CO_2 and NH_3; In the synthesis and utilization stage, microorganisms utilize organic matter that is decomposed into small molecules to meet their own growth and metabolic needs, and humify organic waste to generate HS. Microbial metabolites and HS can be used as excellent organic fertilizers for agricultural production.

Returning chicken manure compost to the field can increase soil fertility, stimulate crop growth and increase crop yield, and protect the environment. However, the use of immature and unstable compost can cause many adverse effects such as plant nitrogen deficiency and plant toxicity[16], so it is necessary to evaluate the stability and maturity of compost. To ensure the stability of composting, various physicochemical and biological parameters such as compost temperature, moisture content, pH, electrical conductivity (EC), C/N ratio, NH_4^+-N/NH_3^--N ratio, and organic matter content should be controlled. C/N ratio is considered one of the key factors affecting the composting process and composting quality [17]. A high C/N ratio results in a very slow composting process due to the excessive biodegradable substrate of microorganisms. When the C/N ratio is low, excess nitrogen elements will be lost from the compost as ammonia through leaching or volatilization. The low C/N ratio can be adjusted by adding biochar such as bacterial residue, straw, etc.

Microorganisms and their enzyme activity are also important indicators of composting, as they play a crucial role in the decomposition of organic matter during composting. In the biochemical degradation process of composting, about 75% of the biochemical reactions are carried out by bacteria. Bacteria have a large specific surface area and decompose and degrade organic matter through their own metabolism and enzyme production. Therefore, bacteria are the microbial community that plays a major role in the composting fermentation process [18]. Previous studies have shown that adding various microbial agents during aerobic composting can improve the overall quality of the compost, significantly improving its stability and maturity [19]. Adding exogenous microorganisms can produce various enzymes to decompose organic matter in compost, providing more humus precursors and obtaining more HS. Microbial agents can be specific strains, multiple strains, or even composted piles [20].

2.2. Overview of anaerobic fermentation

Anaerobic digestion is a technology that can effectively treat organic waste and convert it into clean energy. In principle, all organic matter can undergo anaerobic digestion. Anaerobic digestion not only reduces the volume of organic waste, but also generates a large amount of methane and hydrogen for utilization [21]. Organic waste such as livestock and poultry manure becomes more stable after anaerobic digestion, and the organic fertilizers contained in it can be used to improve soil quality [22]. In addition, the utilization technology of biogas produced by anaerobic digestion has become more mature, such as burning CH_4 and H_2 for power generation to achieve energy conservation and emission reduction. Due to the different substrates and reaction conditions of anaerobic digestion, it can be classified based on temperature, solid content, reaction phase, feeding method, and type.

According to different fermentation temperatures, anaerobic digestion at 35-40 ℃ belongs to a medium temperature reaction system, while anaerobic digestion at 50-55 ℃ belongs to a high temperature reaction system. According to the difference in solid content in anaerobic digestion systems, those with TS>30% belong to dry fermentation systems, while those with TS between 2-19% belong to wet fermentation systems. According to the different stages of anaerobic digestion reaction, it can be divided into single-phase systems with the combination of acid and methane production phases, while multiphase systems with the separation of acid and methane production phases. According to the feeding method, it is divided into continuous feeding with multiple consecutive feedings and sequential batch feeding with one feeding. According to the type of feed, it is divided into separate digestion systems with a single substrate and co digestion systems with multiple substrates.

In the anaerobic digestion process of sludge, the degradation of organic matter is usually divided into the following stages: hydrolysis, acidification, and methane production [23, 24]. The first stage is the degradation of organic matter, during which carbohydrates, proteins, and lipids are broken down by microorganisms into monomers such as amino acids, long-chain fatty acids, and alcohols [25]. In the second stage of acidification, the long-chain fatty acids and amino acids produced by hydrolysis are used as substrates by fermenting microorganisms, producing organic acids such as acetic acid, propionic acid, butyric acid, and other short chain fatty acids, alcohols, H_2 and CO_2[26].Finally, methane producing bacteria mainly utilize H_2, CO_2 and acetic acid to produce methane. Methanogenic bacteria can also utilize a limited number of other substrates during anaerobic processes to form CH_4, such as methanol [27].

Important environmental factors in anaerobic digestion include temperature, pH value, buffering system, C/N, nutrients, and the presence of toxic components during the process. The anaerobic digestion process is strongly influenced by temperature and can be divided into the following categories: low-temperature (0-20 ° C) digestion, medium-temperature (20-42 ° C) digestion, and high-temperature (42-75 ° C) digestion [5]. Anaerobic digestion reactors usually choose medium to high temperature digestion systems. High temperature anaerobic digestion can increase gas production and efficiently degrade lignin [28]. The anaerobic digestion process is highly dependent on pH value, as the microorganisms involved in the reaction have a specific pH range for their optimal growth. For example, the optimal pH value for methane producing microorganisms is 6.8-7.2, while the optimal pH value for acid producing bacteria is about 6[29, 30]. The buffering system is designed to maintain the optimal pH range throughout the entire anaerobic digestion process.

All living organisms require the basic components necessary for growth, including nutrients such as nitrogen and phosphorus, as well as trace elements (potassium, calcium, magnesium, iron, etc.) that are essential for efficient anaerobic digestion systems [31]. The most important nutrients in anaerobic digestion are nitrogen and phosphorus. The optimal C: N: P ratio for high methane production is 100:3:1. If the carbon to nitrogen ratio is high, it will lead to nutrient deficiency, while when the nitrogen content is high, ammonia inhibition will occur [32]. In addition, the presence of heavy metal ions and toxic compounds in anaerobic digestion systems can inhibit the activity of microorganisms, thereby affecting the anaerobic digestion process.

3. Overview of Humus

The formation of humic substances (HS) is accompanied by aerobic composting and anaerobic digestion processes, and the formation of HS is influenced by many environmental factors. The specific reasons for its formation are not yet clear. However, currently, there are mainly Maillard reaction theory, polyphenol theory, sugar amine condensation Maillard theory, polyphenol Maillard joint theory, lignin polyphenol theory, cell autolysis theory, microbial synthesis theory, and lignin theory for the formation of HS in the humification process [33].The formation of different theories is due to the use of different raw materials, research methods, and research directions in the process of humification. However, in fact, the formation pathways of these HS may not occur singly, and under different conditions, these pathways may jointly affect the process of humification. The formation of HA is mainly through the polyphenol humification pathway formed by the condensation of polyphenols and amino groups, as well as the Maillard humification pathway formed by the condensation of sugars and amino groups.

HS is not a single substance, it has a complex polymer structure, mainly composed of humic acid (humic acid, HA), humic acid (fulvic acid, FA), and insoluble humic acid (HM). The molecular weight of HS is generally between 0.5 and 1000 KDa, the molecular weight of HA is generally between 10 and 100 KDa, and the molecular weight of FA is concentrated between 0.5 and 1.5 KDa. The content of humin is extremely low and it is difficult to decompose, so the concentration of humin is usually not considered in research [34]. The structure of HS contains a large number of functional groups such as hydroxyl, carboxyl, quinone, amino, methoxy, alcohol hydroxyl, sugars, carbonyl, and phenolic hydroxyl. These functional groups are mainly based on aromatic benzene rings and are connected by chemical bonds and intermolecular forces, resulting in HS exhibiting stable chemical structure, ion exchange, coordination, redox, and physiological activities, among many other chemical properties [35].

The reason for the complex structure of humic substances is not only due to their complex macromolecular structures, but also due to differences in their structural characteristics caused by different sources of humic substances. For example, humic substances formed from different starting materials have significant differences in molecular weight, and humic substances formed in water generally have smaller molecular weights [36]. In addition, there are significant differences in molecular structure between humic substances formed through different pathways and humic substances with different humification processes.

4. Application of Humus

Due to the presence of redox functional groups such as carboxyl, phenol, hydroxyl, and quinone in HA, it can mediate redox reactions, which is beneficial for environmental pollution control. In addition, the oxygen-containing functional groups of HA can adsorb metal ions and form colloidal aggregates. HA can also stimulate plant growth by promoting nutrient absorption and metabolism [37, 38]. The higher the content of HA, the higher the stability of organic matter. HA/FA is also widely used as a good indicator for judging the maturity of compost [39].

HS is a soil amendment that helps maintain soil moisture, pH stability, and nutrient dynamics [40]. According to research, soil humus has a certain degree of cohesiveness, which can improve soil porosity and aeration, and enhance soil water retention and drought resistance. Mature HS also has a certain inhibitory effect on plant pathogenic microorganisms [41].

5. Conclusion

Humus takes an aromatic structure as its backbone, and through polymerization or condensation, it combines with intermediate products generated during the degradation of organic matter to synthesize macromolecular polymers [42], its formation process is extremely complex. Humus is generated during both aerobic composting and anaerobic digestion processes. In addition, the biogas residue produced after anaerobic digestion is often further harmless treated through aerobic composting technology. Previous studies have mainly focused on exploring aerobic composting or anaerobic digestion of livestock and poultry manure under different conditions, with few studies comparing the two in combination. Therefore, the analysis of humic substances in samples obtained from aerobic composting or anaerobic digestion of livestock and poultry manure is of great significance for the resource utilization research of livestock and poultry manure.

References

[1] GAO M, LI B, YU A, et al. The effect of aeration rate on forced-aeration composting of chicken manure and sawdust [J]. Bioresource Technology: Biomass, Bioenergy, Biowastes, Conversion Technologies, Biotransformations, Production Technologies, 2010, (6): 101.

[2] CHYNOWETH D P, OWENS J M, LEGRAND R. Renewable methane from anaerobic digestion of biomass [J]. Renewable Energy, 2001, 22(1): 1-8.

[3] GUJRE N, MITRA S, SONI A, et al. Speciation, contamination, ecological and human health risks assessment of heavy metals in soils dumped with municipal solid wastes [J]. Chemosphere, 2021, 262: 128013.

[4] GAO M, LI B, YU A, et al. The effect of aeration rate on forced-aeration composting of chicken manure and sawdust [J]. Bioresource Technology, 2010, 101(6): 1899-903.

[5] PARAWIRA W. Anaerobic Treatment of Agricultural Residues and Wastewater - Application of High-Rate Reactors [J]. siv holmqvist department of biotechnology, 2004.

[6] KHOSHNEVISAN B, DUAN N, TSAPEKOS P, et al. A critical review on livestock manure biorefinery technologies: Sustainability, challenges, and future perspectives [J]. Renewable and Sustainable Energy Reviews, 2021, 135: 110033.

[7] LI H, ZHANG T, TSANG D C W, et al. Effects of external additives: Biochar, bentonite, phosphate, on co-composting for swine manure and corn straw [J]. Chemosphere, 2020, 248: 125927.

[8] DAVID, CHADWICK R, JOHN, et al. Strategies to reduce nutrient pollution from manure management in China [J]. Frontiers of Agricultural Science and Engineering, 2020, v.7(01): 52-62.

[9] YIN J, XIE M, YU X, et al. A review of the definition, influencing factors, and mechanisms of rapid composting of organic waste [J]. Environmental Pollution, 2024, 342: 123125.

[10] PAJURA R. Composting municipal solid waste and animal manure in response to the current fertilizer crisis - a recent review [J]. Science of The Total Environment, 2024, 912: 169221.

[11] TANG R, LIU Y, MA R, et al. Effect of moisture content, aeration rate, and C/N on maturity and gaseous emissions during kitchen waste rapid composting [J]. Journal of Environmental Management, 2023, 326: 116662.

[12] QIAN X, SHEN G, WANG Z, et al. Co-composting of livestock manure with rice straw: Characterization and establishment of maturity evaluation system [J]. Waste Management, 2014, 34(2): 530-5.

[13] KONG X, LUO G, YAN B, et al. Dissolved organic matter evolution can reflect the maturity of compost: Insight into common composting technology and material composition [J]. Journal of Environmental Management, 2023, 326: 116747.

[14] GAO X, TAN W, ZHAO Y, et al. Diversity in the Mechanisms of Humin Formation during Composting with Different Materials [J]. Environmental Science & Technology, 2019, 53(7): 3653-62.

[15] CHEN W, LIAO X, WU Y, et al. Effects of different types of biochar on methane and ammonia mitigation during layer manure composting [J]. Waste Manag, 2017, 61: 506-15.

[16] GAO M, LIANG F, YU A, et al. Evaluation of stability and maturity during forced-aeration composting of chicken manure and sawdust at different C/N ratios [J]. Chemosphere, 2010, 78(5): 614-9.

[17] MICHEL F C, FORNEY L J, HUANG A J F, et al. Effects of turning frequency, leaves to grass mix ratio and windrow vs. Pile configuration on the composting of yard trimmings [J]. Compost Science and Utilization, 1996, 4(1): 26-43.

[18] DE GANNES V, EUDOXIE G, HICKEY W J. Prokaryotic successions and diversity in composts as revealed by 454-pyrosequencing [J]. Bioresource Technology, 2013, 133: 573-80.

[19] ZHOU X, LI J, ZHANG J, et al. Bioaugmentation mechanism on humic acid formation during composting of food waste [J]. Science of The Total Environment, 2022, 830.

[20] CERDA A, ARTOLA A, FONT X, et al. Composting of food wastes: Status and challenges [J]. Bioresource Technology, 2018, 248: 57-67.

[21] WANG X, ATIFLYU, TAODONG, RENJIELIU, HONGTAOWU, SHUBIAO. Mechanisms of genuine humic acid evolution and its dynamic interaction with methane production in anaerobic digestion processes [J]. Chemical engineering journal, 2021, 408(1).

[22] PLAZA C, SENESI N, BRUNETTI G, et al. Evolution of the fulvic acid fractions during co-composting of olive oil mill wastewater sludge and tree cuttings [J]. Bioresource Technology, 2007, 98(10): 1964-71.

[23] DA ROS C, CAVINATO C, PAVAN P. Optimization of thermophilic anaerobic digestion of winery bio-waste by micro-nutrients augmentation [J]. Environmental Engineering & Management Journal, 2015, 14(7): 1535-42.

[24] GERARDI M H. Microbiology of Anaerobic Digesters [J]. 2004.

[25] APPELS L, BAEYENS J, DEGRèVE J, et al. Principles and potential of the anaerobic digestion of waste-activated sludge [J]. Progress in Energy and Combustion Science, 2008, 34(6): 755-81.

[26] KALYUZHNYI S, VEEKEN A, HAMELERS B. Two-particle model of anaerobic solid state fermentation [J]. Water Science and Technology, 2000, 41(3): 43-50.

[27] HWANG S, LEE Y, YANG K. Maximization of acetic acid production in partial acidogenesis of swine wastewater [J]. Biotechnology and Bioengineering, 2001.

[28] XIANG-LIN G, JIAN-E Z, XU-CHUAN S, et al. Mesophilic and Thermophilic Anaerobic Co-Digestion of Food Waste and Straw [J]. Environmental Science, 2017.

[29] MOOSBRUGGER R E, WENTZEL, M.C.*, EKAMA, G.A., MARAIS G V. Weak acid/bases and pH control in anaerobic systems -A review [J]. Water SA, 1993.

[30] DINAMARCA C, BAKKE R. Process parameters affecting the sustainability of fermentative hydrogen production: A short-review [J]. International Journal of Energy & Environment, 2011, 2(6): 1067-78.

[31] RAJESHWARI K V, BALAKRISHNAN M, KANSAL A. State-of-the-art of anaerobic digestion technology for industrial wastewater treatment [J]. Renewable & sustainable energy reviews, 2000, (2): 4.

[32] KRISHANIA M, KUMAR V, VIJAY V K, et al. Opportunities for improvement of process technology for biomethanation processes [J]. Green Processing and Synthesis, 2012, 1(1): 341-4.

[33] WU J, ZHAO Y, ZHAO W, et al. Effect of precursors combined with bacteria communities on the formation of

humic substances during different materials composting [J]. Bioresour Technol, 2017, 226: 191-9.

[34] BAI Y, WU F, XING B, et al. Isolation and characterization of Chinese standard fulvic acid sub-fractions separated from forest soil by stepwise elution with pyrophosphate buffer [J]. Sci Rep, 2015, 5: 8723.

[35] GUO X, HUANG J, LU Y, et al. The influence of flue gas desulphurization gypsum additive on characteristics and evolution of humic substance during co-composting of dairy manure and sugarcane pressmud [J]. Bioresour Technol, 2016, 219: 169-74.

[36] AIKEN G R, MCKNIGHT D, WERSHAW. An introduction to humic substances in soil, sediments, and water [J]. 1985.

[37] CANELLAS, LUCIANO P, OLIVARES, et al. Humic and fulvic acids as biostimulants in horticulture [J].

[38] ZHAO X, TAN W, PENG J, et al. Biowaste-source-dependent synthetic pathways of redox functional groups within humic acids favoring pentachlorophenol dechlorination in composting process [J]. Environment International, 2020, 135: 105380.

[39] ZHANG Z, ZHAO Y, WANG R, et al. Effect of the addition of exogenous precursors on humic substance formation during composting [J]. Waste Management, 2018, 79: 462-71.

[40] GUO X, HUANG J, LU Y, et al. The influence of flue gas desulphurization gypsum additive on characteristics and evolution of humic substance during co-composting of dairy manure and sugarcane pressmud [J]. Bioresource Technology, 2016, 219: 169-74.

[41] LOFFREDO E, SENESI N. In vitro and in vivo assessment of the potential of compost and its humic acid fraction to protect ornamental plants from soil-borne pathogenic fungi [J]. Scientia Horticulturae, 2009, 122(3): 432-9.

[42] BRADY N C, WEIL R R. Elements of the Nature and Properties of Soils [J]. Prentice Hall, 2010.