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Review and Analysis of Present Situation and Issues in Livestock and Poultry Waste Resource Utilization

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Abstract Animal husbandry is an essential pillar sector in China. However, the wastewater including a mixture of feces, urine, and flushing water from livestock and poultry farming poses serious environmental risks if not properly managed or over-applied. This paper analyzes the existing challenges in the utilization of livestock manure, focusing on source control, process management, and end-use treatment. To address these issues, it proposes establishing a sustainable long-term mechanism. Key recommendations include enhancing source control, strengthening policy support to alleviate the financial burden on enterprises, aligning with market demands, intensifying the promotion of technologies and equipment development, and improving manure quality. In addition, advocating for grain-efficient animal husbandry and promoting diversified utilization through bio-chain approaches are essential.

Key words Livestock and poultry manure, Resource utilization, Present situation, Analysis

0 Introduction

Data from the *Bulletin of the Second National Census on Pollution Sources* (2020, No.33) reveals that by the end of 2017, a total of 2 981 districts and counties in China were surveyed for livestock and poultry farming, with 378 800 large-scale operations undergoing direct on-site inspections. The census identified the agricultural sector as the leading contributor to water pollution, accounting for 10.671 3 million t of Chemical Oxygen Demand (COD), 1.414 9 million t of Total Nitrogen (TN), and 212 000 t of Total Phosphorus (TP). These volumes represented 49.77%, 46.52%, and 67.22% of the national totals for these pollutants, respectively. Despite a decline since the 2007 census, agriculture's share still significantly exceeded that of industrial and domestic sources, solidifying its position as the top polluter[1]. The discharge of water pollutants from the livestock and poultry sector included 10.005 3 million t of COD, 110 900 t of Ammonia Nitrogen (AN), 596 300 t of TN, and 119 700 t of TP. Of these totals, large-scale farms were responsible for 6.048 3 million t of COD[2], along with 75 000 t of AN, 370 000 t of TN, and 80 400 t of TP[3]. In regions with concentrated animal operations or large-scale farms, if the manure produced should exceed the land's assimilation capacity and be over-applied or managed improperly, it is destined to become the most critical non-point pollution source in the countryside.

The livestock and poultry industry plays a vital role in providing food and nutrition, generating employment, and boosting the rural economy. However, it also generates substantial amounts of manure. Against the backdrop of increasing emphasis on the coordinated development of agriculture and the ecological environment, a critical challenge has emerged in the context of modern, scientific, and intensive farming practices: how to balance its dual identity as both a "source of pollution" that threatens soil, water, and air quality, and a "valuable resource" that can drive circular agriculture. To ensure food security and sustainable societal development, the resource utilization of livestock manure presents an effective solution. By converting waste into fertilizer or energy through efficient treatment technologies, the industry can achieve waste reduction, harmless treatment, and resource recovery. This approach not only mitigates environmental pollution but also generates economic benefits, providing solid support for circular agriculture and sustainable development[4].

1 Present situation of livestock and poultry manure treatment

In recent years, guided by a commitment to ecological protection, local authorities have followed the governance principle of "source reduction, process control, and end-use"[5]. This principle is executed through multifaceted approaches: reducing output at the source via optimized farm siting, improved animal genetics, rainwater-sewage diversion, dry-wet separation, and enhanced feed formulations; controlling the process through selected equipment and recycling methods for manure, wastewater, and air emissions; and promoting end-use via vermicomposting, biogas electricity generation, biomass energy production, and irrigation for crop farming. Centered on large-scale operations and championing land application as the primary route, this strategy has continuously improved the efficiency of converting livestock waste into resources.

1.1 Livestock and poultry breeding scale continuing to expand In recent years, driven by national policies and market demand, the livestock and poultry population has increased across various regions. Besides, traditional backyard farming has gradually diminished, while capable farmers have been transitioning toward developing operations of a certain scale. As a result, the

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proportion of scaled farming has continued to rise. Taking Suining City as an example, statistics show that the number of scaled farms reached 1 175 in 2022 and increased to 1 201 in 2023. By the end of 2023, the number of slaughtered hogs reached 3.807 million, a year-on-year increase of 1.97%; cattle stood at 37 900 head, up by 0.06%; and poultry totaled 26.632 8 million birds, rising by 1.39%.

1.2 Livestock and poultry manure emissions increasing The livestock sector is expanding rapidly to meet the increasing demand for animal products. While this growth is positive, it comes with a parallel rise in manure production, which amplifies the challenges associated with its safe disposal and recycling. Taking Suining City as an example, it produced 10.133 2 million t of manure in 2022, of which 9.702 3 million t were repurposed, achieving a utilization rate of 95.75%. In 2023, despite a lower production of 9.180 7 million t, the utilization rate remained stable at 95.75%, with 8.790 6 million t being effectively used.

1.3 Environmental problems caused by improper treatment of livestock and poultry manure

1.3.1 Water source pollution. Livestock and poultry manure contains abundant nutrients essential for plant growth, such as nitrogen, phosphorus, and potassium[6]. However, improper management or over-application can lead to these nutrients being washed into surrounding water bodies through irrigation or rainfall. The subsequent excess of nitrogen and phosphorus can cause eutrophication[7], which stimulates the overgrowth of algae and aquatic plants[8]. In addition, manure often harbors numerous pathogens, including *Escherichia coli*, *Salmonella*, coccidia, and tapeworms. These pathogens can disrupt the natural balance of microbial communities and cause health issues, such as gastrointestinal diseases in animals. Without proper treatment and management, they may enter water sources via runoff or seepage, thereby polluting the water, disturbing aquatic ecosystems, and posing risks to human health[9].

1.3.2 Air pollution. The livestock and poultry sector is a notable source of air pollutants, including carbon dioxide, sulfur dioxide, and ammonia. During decomposition, manure releases significant amounts of ammonia and hydrogen sulfide, alongside minor levels of methane and indole, contributing substantially to air pollution. The primary concern is ammonia, which stems from the breakdown of nitrogenous compounds in manure. This gas is highly irritating, damaging the respiratory tracts of animals, compromising their immunity, and predisposing them to respiratory diseases, ultimately hindering growth performance (Table 1)[10]. Specific studies show that elevated ammonia levels markedly impair poultry growth rates, egg production, and egg quality[11-12]. Recovery of production levels in chickens previously exposed to high ammonia concentrations can take as long as 12 weeks[13]. Accordingly, Chinese hygiene standards mandate that ammonia concentrations be maintained below 15 mg/m^3 in houses for adult birds and less than 10 mg/m^3 for young birds[14]. Another significant gas is hydrogen sulfide, produced under anaerobic conditions from sulfur-containing organic matter in manure. Digestive disorders or diets rich in sulfur proteins can lead to its excessive release through the intestines. Since hydrogen sulfide is denser than air, it accumulates near the floor and animal breathing zones, creating high-concentration pockets in lower areas of the barn. This issue is particularly acute in layer houses, where microbial spoilage of damaged or unprocessed eggs can further elevate ambient hydrogen sulfide levels[15].

Table 1 Harms of different concentrations of ammonia to animals

Concentration of ammonia	Animal	Harm
20 mg/L	Poultry	Respiratory tract congestion, edema, lacrimation, and sneezing.
25 - 35 mg/L	Broiler	Lacrimation, ocular inflammation, lethargy, and head twitching.
50 mg/L	Chick	Viral resistance greatly reduced, anemia
75 mg/L	Pig	Atrophic rhinitis, central nervous system paralysis
15.2 mg/m^3	Grower pig	Feed intake decreased by 15.6% and weight gain decreased by 20%
7.7 - 11.6 mg/m^3	Little sow	Failure to show estrus
35 mg/m^3	Piglet	Decreased resistance to lung disease
38 mg/m^3	Human	Lachrymation, conjunctival hyperemia, expiratory dyspnoea, continuous flow of tear

In addition, the hydrosulfuric acid formed when hydrogen sulfide reacts with water can irritate and corrode the mucous membranes of livestock and poultry. When dissolved into these membranes, hydrogen sulfide rapidly combines with sodium ions to form sodium sulfide, which irritates the ocular and respiratory mucosa, leading to corneal and tracheal inflammation, severe pulmonary edema, and intoxication (Table 2)[10]. Furthermore, hydrogen sulfide can inhibit the respiratory center of animals, causing asphyxiation and death[16]. It is also absorbed into the bloodstream through the alveolar wall, where it binds to iron ions and disrupts cytochrome oxidase, impairing cellular respiration and inducing tissue hypoxia. Chronic exposure to low concentrations of hydrogen sulfide can trigger autonomic nervous system dysfunction, weakening the animals' constitution and compromising their immune response[17]. Besides ammonia and hydrogen sulfide, carbon dioxide also impacts air quality. Animal respiration releases large amounts of carbon dioxide, and elevated concentrations due to inadequate ventilation can create a hypoxic environment in the barn, resulting in lethargy and reduced appetite among the animals. Also, livestock houses produce minor quantities of methane and indole. Methane, a potent greenhouse gas, is primarily generated during the anaerobic fermentation of manure. Indole, a product of protein putrefaction, emits a distinctive foul odor, further contributing to air quality deterioration.

Table 2 Harms of different concentrations of hydrogen sulfide to animals

Hydrogen sulfide concentration	Animal	Harms
18 mg/m^3	–	Liquefaction of tracheal mucosa and increased mucus secretion
20 mg/m^3	Broiler	Apoptosis of tracheal cells
46 mg/m^3	–	Myocardial Injury
300 mg/m^3	–	Epithelial loss of nasal and respiratory tract
975 – 1 125 mg/m^3	–	Hypothalamic neurodegeneration
30 mg/m^3	Weaned piglet	Lung injury

2 Problems in treatment and resource utilization of livestock and poultry manure

2.1 Inadequate equipment for farm scale and insufficient source control In accordance with the overarching principle of "source reduction, process control, and end utilization," farms must be equipped with appropriate treatment facilities, equipment, and manure storage ponds. The necessary measures include implementing separate drainage systems for rainwater and sewage, shifting from water-flushing to dry manure removal, replacing open ditches with enclosed culverts, and transitioning to water-saving drinking facilities. The ultimate goal is to achieve source reduction. (i) While large-scale farms generally exhibit a high facility matching rate, many pig farms still rely on water-intensive flushing systems, which generate massive amounts of effluent that is difficult to treat and dispose of, leading to significant pollution[18]. Furthermore, the adoption of advanced treatment methods remains limited. The lengthy composting cycle for solid manure and the high cost of high-temperature sterilization deter many farms from using these techniques. For liquid biogas slurry fermentation, challenges include low biogas utilization rates and a lack of purification facilities. In addition, the market for products derived from harmless treatment is underdeveloped, the land area available for its application is insufficient, and the overall resource utilization rate remains low. (ii) Small and medium-scale farms face financial constraints, resulting in low rates of supporting facilities. Their treatment facilities are often undersized, water-saving equipment is outdated, and rainwater and sewage systems are frequently combined[19]. (iii) Owners of small, scattered operations often lack strong environmental awareness and sufficient capital. Consequently, their environmental protection facilities are often incomplete, and the primary responsibility for pollution control is not adequately fulfilled. (iv) The operation and management of environmental facilities on some individual farms are deficient. Damaged equipment is not repaired or replaced in a timely manner, and the pipeline networks for returning manure to the field are often aged, damaged, or suffer from human interference.

2.2 High costs of recycling equipment and inadequate process control Achieving the resource utilization of livestock and poultry manure requires substantial capital investment. However, many farms operate on a small scale with limited financial capacity, making it difficult for them to bear high operational costs. As a result, they often show little willingness to invest, which can lead to the arbitrary piling up or discharge of manure. Facilities for manure treatment and resource recovery are generally underdeveloped, and the primary products derived from such processes are mostly unprofitable. Even when relevant equipment is in place, sustainable operation remains challenging, creating significant financial pressure from both investment and daily operations of pollution control facilities. Moreover, small and medium-sized farms and individual farmers are constrained by their scale and conditions. Only a few opt to treat manure by purchasing third-party services, yet having to pay for such services tends to reduce their income and raise overall costs[20].

2.3 Inadequate implementation of manure treatment and constrained end-use Effective manure treatment serves as a crucial foundation for realizing its resource utilization, and it is essential that livestock and poultry farming operations prioritize proper manure management. In China, while many large-scale farms have adopted reasonable treatment practices, such as storing manure in drying yards, some free-range farmers still lack sufficient environmental stewardship. However, even on larger farms, limited land resources often prevent existing drying yards from meeting actual needs, leading to inadequate storage capacity and a heightened risk of secondary pollution[16]. In addition, the primary methods for manure resource utilization involve liquid fertilizing or solid manure returning to the field. These approaches not only occupy extensive farmland but also frequently draw complaints from nearby residents due to odor issues. In practice, the large volumes of manure generated by pig and cattle farms are commonly returned to fields, partly due to logistical challenges such as transportation difficulties. Nevertheless, variations in seasonal and crop-specific nutrient demands can lead to excessive application, which may adversely affect soil structure and crop growth[21].

3 Countermeasures and recommendations for promoting the resource utilization of livestock and poultry manure

3.1 Establishing and improving a long-term mechanism to further strengthen source control The "land-based carrying capacity" principle should be fully implemented to determine the appropriate scale of animal farming and achieve crop-livestock balance. Accordingly, plans for regional circular agriculture development and livestock manure recycling must be optimized, with the government playing a leading role. A long-term management system featuring coordinated operations should be established. This system will strengthen hierarchical management, technical monitoring, and enforcement supervision, while legally addressing environmental pollution caused by improper manure handling and standardizing recycling practices among relevant enterprises. Besides, publicity and guidance efforts should be intensified. Through expert guidance, training sessions, and other means, relevant laws, regulations, and policies on manure recycling should be vigorously promoted. These measures aim to enhance the initiative and enthusiasm of market entities to participate jointly, thereby fostering a favorable social atmosphere.

3.2 Strengthening policy support to reduce the financial pressure of enterprises Current capital investments and policy frameworks are insufficient to meet the demands for high-quality development from both the market and enterprises. It is recommended that, building upon existing support policies, the policy system for the resource utilization of livestock and poultry manure be further refined in terms of project support, taxation, and financing. First, increased support should be directed toward third-party manure treatment agencies and organic fertilizer producers, encouraging the inflow of social capital through measures such as tax incentives, industrial subsidies, and project funding. Second, the scope of policy support should be expanded from large-scale farming enterprises to include small and medium-sized farmers. By implementing favorable loan policies and increasing subsidies for agricultural machinery purchases and facility construction, the financial pressure on small and medium-sized operations can be alleviated, thereby enhancing the coverage and inclusiveness of the policies[20].

3.3 Orienting towards the market demand and strengthening the research and development of technology and equipment It is recommended to support existing enterprises in adopting integrated crop-livestock farming, ecological recycling, and other sustainable models. Efforts should be made to strengthen the promotion and application of practical technologies, such as anaerobic fermentation, aerobic composting, and biological treatment, to enhance the resource utilization rate of livestock and poultry manure. Guided by market demand, the leading role of new-type environmental enterprises in the research and development of new technologies and equipment should be fully leveraged. Increased financial investment and support should be directed toward the development of manure resource utilization equipment and fertilizer-oriented technologies. Encouragement should be given to capable and well-established research teams to focus on key technical challenges, including odor control during manure fermentation, accelerated compost maturation, screening of microbial agents, and the development of land-application equipment. Furthermore, deep cooperation between research institutions, universities, and enterprises should be promoted to enhance the recruitment and training of professionals specializing in manure resource utilization and to facilitate the rapid transformation of research outcomes into practical applications[20].

3.4 Advocating grain-saving animal husbandry and promoting multipolar utilization of biological chain It is necessary to firmly set up the great food concept, diversify food supply channels, and vigorously promote the cultivation of high-quality forage. Practical technologies for planting, harvesting, storage, and processing should be extended in line with local conditions. Efforts must be made to establish a grain-saving animal husbandry system centered on the breeding of cattle, sheep, and rabbits, using crop straw as the primary feed. Through straw feeding and returning manure to fields, this approach not only improves soil moisture and reduces pests but also increases the supply of livestock products such as meat and milk, achieving a win-win outcome for both ecological sustainability and economic benefits. Furthermore, it is recommended to promote the use of livestock manure as feed, such as utilizing earthworms and black soldier flies to convert manure into animal protein feed, will continuously enhance resource utilization efficiency.

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4 Analysis and management suggestions on water pollution in the lower reaches of the Nenjiang River

4.1 Water quality pollution evaluation The correlation analysis of water quality indicators and socio-economic factors in the Nenjiang River Basin reveals that TP, NH_4-N, and chlorophyll exhibit positive correlations with the proportion of the primary industry, negative correlations with population density and the proportion of the tertiary industry, and positive correlations with the proportion of the secondary industry. Notably, the correlation between TP and the proportion of the primary industry is the most pronounced, which may be attributed to the impact of agricultural activities. Agricultural activities contribute to soil erosion, resulting in increased turbidity of water bodies. Phosphorus nutrients from the soil subsequently enter these water bodies, thereby influencing the TP concentration. NH_4-N and chlorophyll exhibit a relatively strong correlation with the proportion of the secondary industry, with the correlation between two variables and the proportion of the secondary industry being the most pronounced. It is hypothesized that during industrial production, the discharge of domestic sewage and industrial wastewater increases, leading to elevated nutrient salt concentrations in water bodies. This, in turn, promotes the proliferation of aquatic phytoplankton, causing an increase in chlorophyll density. Furthermore, COD and DO show a positive correlation with the proportion of the tertiary industry, while exhibiting a negative correlation with both the proportion of the secondary industry and per capita GDP.

4.2 Suggestions for water quality management

4.2.1 Controlling the ecological water demand of rivers and reducing human control over runoff. Based on the climatic and hydrological characteristics of the basin, the status of water resource development and utilization, the types and functions of aquatic ecosystems, the importance and sensitivity of protected objects, and the relative positions of control nodes within the ecosystem, ecological base flows for rivers and minimum ecological water levels for lakes should be maintained by relying on critical control sections. The construction of unnecessary dams should be minimized. Furthermore, during environmental impact evaluations, the effects of water diversion on downstream ecological water requirements must be thoroughly evaluated to prevent increased concentrations of water pollutants resulting from improper runoff regulation.

4.2.2 Reducing soil erosion and restoring the ecological functions of wetlands. The western region of Jilin Province is characterized as a typical area affected by wind erosion, where soil erosion is notably severe. Wind erosion dislodges rock and soil debris, which are subsequently transported into water bodies, lakes, and reservoirs by rainfall. This process results in elevated concentrations of characteristic pollutants in river water. Consequently, while maintaining ecological flow, it is imperative to enhance investment in water diversion projects, reinforce efforts to remediate soil salinization, and progressively restore the original ecological functions of wetlands.

4.2.3 Strengthening comprehensive control over non-point source pollution. In agricultural regions, the adoption of scientifically based planting methods is essential, alongside the rational application of pesticides and chemical fertilizers. Strict pollution control measures must be enforced for small-scale livestock farmers and enterprises. Additionally, it is essential to reinforce local legal oversight, elevate public environmental awareness, and concurrently advance initiatives for water conservation and increased grain production. The vigorous promotion of water-saving irrigation technologies is necessary to regulate agricultural water consumption, reduce pollutant runoff, and increase the volume of clean water entering rivers and reservoirs, thereby mitigating non-point source pollution at its origin.

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