

Article

A Staged Resource-Recovery Pathway for Breeder Chicken Manure Under Intensive Farming Conditions: A Practice-Based Case Evaluation

Mengtang Yuan , Yang Yu, Wenqi Liu and Fanke Kong *

Yantai Institute of China Agricultural University, No. 2006, Binhai Mid-Rd, High-tech Zone, Yantai 264670, China; yuanmengtang@cau.edu.cn (M.Y.); 2023505520127@cau.edu.cn (Y.Y.); 2023505520125@cau.edu.cn (W.L.)

* Correspondence: kfk2000@sina.com

Abstract

Large-scale breeder chicken farms generate high-moisture manure, and all-in/all-out management can constrain continuous manure handling, especially during cold northern winters. This study proposed and evaluated a staged resource-recovery pathway for breeder chicken manure under all-in/all-out farm management. The pathway consisted of an implemented on-farm primary aerobic fermentation stage for rapid reduction and sanitization, an implemented centralized secondary aerobic fermentation stage for standardized organic fertilizer production, and a proposed solar-greenhouse-assisted low-temperature module for seasonal continuity support. System performance was assessed through a practice-based case evaluation using enterprise operational records, field investigations, and routine monitoring data on manure generation, process parameters, product quality, and logistics/cost indicators. The primary stage showed a relatively stable operational window across case farms, with fresh manure moisture contents of 85–90%, compost temperatures increasing from approximately 30 °C to 60 °C before declining to about 40 °C, and pH values ranging from 7.0 to 9.5, while batch duration and moisture-control pathways varied among farms. The secondary stage demonstrated standardized downstream processing capacity; the tested organic fertilizer complied with NY/T 525-2021, while the bio-organic fertilizer specifications met the benchmark requirements of NY 884-2012. The conceptual winter continuity-support module was discussed as a conceptual engineering supplement requiring future operational validation. Overall, the evaluated pathway may provide a practice-based reference for sustainable manure management, standardized fertilizer production, and circular agricultural resource recovery under intensive breeder chicken production conditions.



Academic Editor: Jose Navarro Pedreño

Received: 6 May 2026

Revised: 28 June 2026

Accepted: 30 June 2026

Published: 14 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

Keywords: breeder chicken manure; resource recovery; sustainable manure management; organic fertilizer; circular agriculture

1. Introduction

The green transformation of animal husbandry has become an important issue in the high-quality development of agriculture in China. Large-scale livestock and poultry production ensures a stable agricultural supply, but it also generates substantial organic waste streams that require reliable and continuous management [1–3]. Among them, livestock manure is rich in organic matter and nutrients and therefore represents an important recyclable agricultural resource when appropriately treated and reutilized. Composting and related

aerobic treatment technologies provide a practical basis for converting manure into fertilizer products through stabilization, sanitization, and humification processes [4–6]. Recent reviews have further emphasized composting as an important organic-waste valorization route within circular resource management, with final product quality and management conditions being critical to its practical value [7,8]. More broadly, livestock manure has increasingly been framed as a recoverable resource within circular-economy and sustainable management pathways, rather than solely as a waste-disposal problem [9,10].

Breeder chicken farms present a particularly challenging manure-management scenario. Under the all-in/all-out production model, manure generation, temporary accumulation, and routing are strongly affected by production organization rather than by a uniform continuous flow [11]. In addition, breeder chicken manure usually has high moisture content, and its treatment continuity can be further constrained during cold northern winters. These features make it difficult to maintain a stable treatment chain from on-farm handling to downstream resource recovery. As a result, the key challenge is not only how to treat manure at an individual process unit, but how to maintain a continuous and operable management pathway that links on-farm pretreatment, material transfer, and downstream utilization.

1.1. Challenges and Research Gap

Existing studies and engineering practices on poultry manure management have mainly focused on composting parameter optimization, process emissions, and related treatment-performance evaluation [12–15]. These studies have examined operational variables such as aeration intensity, turning management, and reactor structure, and have also reported gaseous emissions, fertilizer quality, and maturity indicators of composted products. Together, they provide valuable evidence for understanding specific treatment units and improving composting performance.

However, relatively few studies have addressed how breeder chicken manure can be organized into a staged resource-recovery pathway under real farm and enterprise operating conditions. Recent studies have emphasized that organic-waste and manure-management systems should be evaluated from a circular-resource perspective rather than only by the performance of individual treatment units [16–19]. In particular, waste-derived fertilizer production and nutrient recovery have been increasingly discussed as important routes for fertilizer substitution and agricultural reuse [20–23]. Studies on manure redistribution, resource-transfer logistics, farm-level composting strategies, and downstream fertilizer utilization have emphasized the importance of coordinating material flows across multiple management stages rather than focusing solely on the optimization of individual treatment units [24–27]. Nevertheless, system-level evidence on how breeder-farm manure can be coordinated across on-farm pretreatment, centralized fertilizer production, and seasonal continuity support remains limited. This gap is particularly evident for breeder chicken farms operating under all-in/all-out management in northern regions, where seasonal low temperatures can disrupt treatment continuity and reduce the stability of manure-to-resource conversion. In such cases, the practical challenge lies not only in improving an individual composting step, but also in organizing a staged treatment pathway that can maintain material flow, support downstream standardization, and improve the continuity of the overall waste management chain.

Accordingly, there remains a need for a practice-based management framework that connects on-farm pretreatment, centralized processing, and winter continuity support under real breeder-farm operating conditions. Such a framework is relevant to manure handling continuity and resource-oriented management [9,10,19], as well as to nutrient recovery, fertilizer substitution, and circular agricultural resource utilization [17,20,22,23,28].

1.2. Objectives and Contributions

To address this need, this study proposes a case-based management framework for breeder chicken manure in northern China. The framework integrates on-farm primary treatment, centralized secondary processing, and a conceptual winter continuity-support module, thereby linking manure pretreatment, standardized fertilizer production, and downstream agricultural utilization under all-in/all-out farm management.

Specifically, the study evaluates the implemented primary and secondary stages using enterprise operational records, field investigations, and routine monitoring data, and discusses a conceptual solar-greenhouse-assisted low-temperature module as a seasonal supplementary option for winter operation. The objectives of this study are to:

- (1) Establish a staged resource-recovery pathway adapted to the production characteristics and operational organization of breeder chicken farms;
- (2) Evaluate the operational characteristics and engineering roles of the implemented primary and secondary stages using enterprise operational records, field investigations, and routine monitoring information;
- (3) Assess product-quality indicators and benchmark compliance of secondary-stage fertilizer products based on available testing data and enterprise product specifications;
- (4) Examine operational constraints related to material routing, data coverage, logistics, and seasonal continuity under practical farm and enterprise conditions;
- (5) Discuss the potential function and evidence boundary of a conceptual winter continuity-support module under low-temperature conditions.

The contribution of this study lies in providing a practice-based reference for organizing breeder chicken manure management under real farm and enterprise conditions. First, it clarifies the engineering roles of on-farm pretreatment and centralized secondary processing in material routing, product formation, and resource recovery. Second, it incorporates product-quality benchmarking into the evaluation of downstream fertilizer production. Third, it discusses the evidence boundary and potential role of a conceptual winter continuity-support module for low-temperature treatment continuity. In this sense, the study responds to recent calls for more practice-oriented evidence on organic-waste valorization and circular resource management [16,17,19,23], waste-derived fertilizer production and utilization [20,22,29], and deployable manure-management strategies linking resource transfer, farm-level composting, and downstream fertilizer reuse [24–27].

2. Materials and Methods

2.1. Study Design and Analytical Boundary

This study was designed as a practice-based case evaluation of a staged breeder chicken manure resource-recovery pathway under farm and enterprise conditions. The analysis focused on system organization, operational characteristics, product outcomes, and engineering adaptability in actual breeder-farm operations.

Within the proposed pathway, the primary and secondary stages were implemented modules evaluated using enterprise operational records, field investigations, and routine monitoring data. The winter continuity-support module was included as a conceptual engineering component for supporting treatment continuity during low-temperature periods and was discussed in terms of design rationale and intended operational role.

The analytical boundary was defined around stage-specific evidence and functional compatibility among the pathway components, rather than around a fully traceable mass balance from manure generation to final fertilizer output. Specifically, the study examined on-farm primary pretreatment, transport arrangements to the centralized processing facility,

secondary fermentation, aging, granulation, packaging, and the conceptual role of the proposed winter continuity-support module.

Functional integration was defined as the operational coordination among on-farm pretreatment, transportation, centralized processing, and downstream fertilizer-utilization stages of the proposed staged pathway. It was assessed qualitatively based on field investigations, enterprise operational records, transportation arrangements, processing-flow organization, and documented links between pretreatment, centralized fertilizer production, and downstream utilization pathways. However, full batch-to-batch traceability across the primary-to-secondary chain and downstream fertilizer application was not available. Therefore, the analysis evaluated stage-specific functions and functional compatibility, rather than a quantitatively verified whole-chain material balance.

Because the case datasets were derived from actual operations and were not fully synchronized across farms and treatment stages, the analysis was conducted using descriptive comparison and engineering interpretation.

2.2. Study Area and Case Background

The study was conducted in Yantai City, Shandong Province, China, a typical agricultural region in northern China characterized by a temperate monsoon climate and cold winters. Fruit tree cultivation coexists with large-scale livestock and poultry farming in this region, creating practical conditions for evaluating manure-to-fertilizer resource recovery. Winter low temperatures in the region may constrain aerobic treatment continuity and were therefore considered in the pathway design.

This study analyzed the generation, treatment, and utilization processes of breeder chicken manure using multiple large-scale breeder chicken farms and their supporting organic fertilizer production facilities under Shandong Yisheng Breeding Livestock Co., Ltd. (Yantai, China) as case subjects. Enterprise production records and field survey data were integrated for the analysis. The equipment described in this study refers to enterprise-operated composting facilities and generic equipment types. Detailed manufacturer and model information could not be disclosed due to enterprise confidentiality and information-disclosure review requirements and was not used as an analytical variable. Table 1 summarizes the data coverage windows for each case-study farm and the on-site survey period for the secondary processing center.

Table 1. Data coverage windows for case-study farms and on-site survey period for the secondary processing center.

Research Subject	Breeder Chicken Farm					Secondary Fermentation Center (Fertilizer Plant)
	A	B	C	D	E	
Data Coverage Period	July 2023–May 2025	September 2023–October 2024	October 2023–December 2024	February 2024–January 2025	February 2024–November 2024	November 2024

Note: A–E denote anonymized breeder chicken farm codes. The periods shown represent the operational data coverage windows for each farm, whereas “November 2024” for the secondary processing center corresponds to the on-site survey period.

Data were collected through a combination of field investigations, structured questionnaires, enterprise operational records, and interviews with farm managers. Information obtained included flock size, feed consumption, water use, manure generation, composting process parameters (e.g., moisture content, temperature, pH, composting duration, and turning intervals), transportation distance, logistics costs, product output, and fertilizer utilization pathways. Because the farms operated under different production schedules and record-keeping periods, the data coverage windows were not fully synchronized.

Accordingly, the study was designed as a descriptive engineering case evaluation rather than a statistically synchronized comparative study.

All case-study farms covered at least part of the winter operational period, including months between December and mid-February of the following year. This made it possible to identify continuity constraints under low-temperature conditions and to assess their implications for staged system operation.

2.3. Configuration of the Staged Resource-Recovery Pathway

As shown in Figure 1, the staged resource-recovery pathway for breeder chicken manure was organized as a simplified functional framework linking manure generation, on-farm pretreatment, centralized secondary processing, downstream fertilizer utilization, and seasonal continuity support. The pathway consisted of three functionally differentiated components: an implemented primary stage for on-farm pretreatment, an implemented secondary stage for centralized processing and product formation, and a conceptual winter continuity-support module.

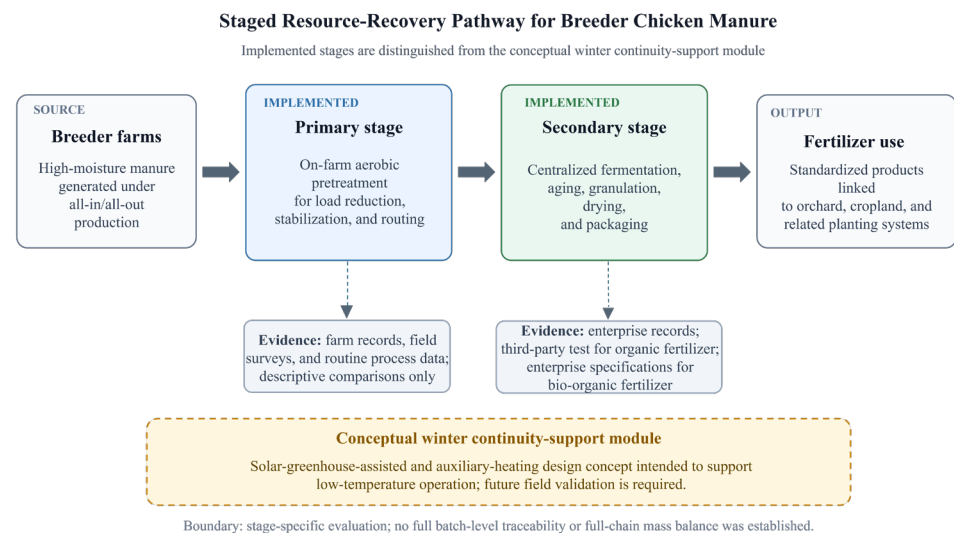


Figure 1. Simplified overview of the staged resource-recovery pathway for breeder chicken manure. Arrows indicate material and functional flow, dashed elements denote evidence links or conceptual components, and colors distinguish pathway components. Detailed operational parameters, evidence categories, and validation boundaries for each stage are provided in Supplementary Figure S1.

- Primary stage: on-farm pretreatment and load reduction;
- Secondary stage: centralized processing, standardization, and product formation;
- Conceptual winter continuity-support module: seasonal support under low-temperature conditions.

To address the characteristics of large-scale manure generation, high moisture content, and seasonal processing constraints in breeder chicken farms, the pathway was organized as “on-farm reduction—centralized value-oriented processing—seasonal continuity support.” Compared with a single-site manure treatment route, this staged pathway emphasized material routing and functional coordination among breeder farms, the centralized fertilizer-production facility, and downstream agricultural utilization. In the primary stage, fresh manure generated from breeder chicken farms was pretreated on farm through aerobic fermentation to achieve preliminary reduction, moisture decrease, and stabilization. This stage was designed to alleviate on-site accumulation pressure and provide pretreated materials suitable for subsequent local utilization or transfer to the centralized processing facility.

In the secondary stage, pretreated materials entered a centralized processing system for further aerobic fermentation, aging, granulation, drying, packaging, and standardized fertilizer production. This stage functioned as the value-oriented processing node of the pathway, supporting the transformation of manure-derived materials into commercial organic fertilizer or bio-organic fertilizer products for agricultural use.

The conceptual winter continuity-support module was included as a seasonal engineering supplement intended to support treatment continuity when low temperatures constrain conventional operation. In the pathway configuration, this module was positioned as an auxiliary conceptual component rather than an independently validated treatment stage.

The primary and secondary stages were evaluated using enterprise operational records, field survey data, and routine monitoring indicators. By contrast, the winter continuity-support module was included as a concept-level engineering component supported by literature evidence and design logic. Therefore, the analytical focus of this study was placed on the implemented primary and secondary stages, while the winter module was discussed in terms of its potential role in seasonal continuity support. The pathway configuration shown in Figure 1 should be interpreted as a functional organization of stage roles rather than as evidence of a fully traceable mass balance across the entire manure-to-fertilizer chain.

2.3.1. Primary Stage: On-Farm Pretreatment and Load Reduction

Primary fermentation was conducted within the breeding farm, primarily aiming to achieve rapid reduction, stabilization, and sanitization of manure. This stage employed trough-type or tank-type aerobic fermentation equipment. Under controlled key process parameters—including fermentation temperature, moisture content, and fermentation cycle—fresh chicken manure was converted into a primary compost product. The resulting product could be applied locally to surrounding farmland for basic fertilization or transported to secondary processing centers for further treatment.

To characterize the operational features and functional role of the primary stage within the staged pathway, this study selected five large-scale breeder chicken farms under Shandong Yisheng Breeding Livestock Co., Ltd. as case subjects. Sample selection considered farm scale, primary-treatment equipment type, data availability, and connectivity with the centralized processing center so as to capture operational variation under different on-farm arrangements. The statistical time windows for each case study were determined according to actual production batches and record availability, as detailed in Table 1.

Data for the primary stage were derived mainly from field visits, enterprise production ledgers, and routine process records. These data covered breeder chicken production processes, manure generation patterns, primary-stage operational parameters, and product utilization. Because the case-study time windows were not fully synchronized, cross-farm comparisons in this study were descriptive and intended for engineering adaptability assessment rather than for strictly synchronized comparative trials. On this basis, the primary-stage indicators across the five farms were organized and compared to identify shared parameter ranges and site-specific operational characteristics. Process-relevant operational factors reported in chicken manure composting studies, such as substrate balance and carbon-to-nitrogen regulation, were considered in interpreting variation among on-farm pretreatment systems [30].

2.3.2. Secondary Stage: Centralized Processing, Standardization, and Product Formation

Secondary fermentation was conducted at specialized manure treatment centers for the further decomposition, stabilization, and standardized processing of poultry manure-based organic materials into commercial organic fertilizers. The process flow mainly included

large-scale trough aerobic fermentation, aging, granulation, and packaging, enabling scaled-up production and quality control through centralized treatment.

Within the staged pathway, the secondary stage functioned as the centralized node for deep processing, product standardization, and fertilizer product formation. To evaluate its engineering role, this study examined the biofertilizer production line at Shandong Yisheng Breeding Livestock Co., Ltd., with particular attention to equipment configuration, process flow, and commercial production organization. Information on the secondary stage was obtained primarily from field survey data and process/production details provided by company personnel.

The secondary stage was evaluated as the enterprise-level downstream processing node of the regional manure management pathway. The assessment focused on equipment configuration, process flow, product standardization, and industrial handling capacity.

2.4. Conceptual Design Basis for Winter Continuity Support

To address seasonal continuity constraints during northern winters, this study discussed a conceptual winter continuity-support module as a supplementary component to the implemented primary and secondary stages. The module was intended to support relatively stable thermal conditions during cold seasons and to reduce the potential risk of treatment interruption caused by low ambient temperatures.

The proposed configuration involved constructing a solar greenhouse above the fermentation tank and using solar-converted thermal energy as the primary heat source [31]. During periods of insufficient solar input, such as nighttime or consecutive cloudy days, auxiliary heating was considered as a supplementary design option to support treatment conditions [32]. The temperature-control logic and design considerations were further informed by previous studies on solar-assisted composting and low-temperature operation [23,31–33].

Key design parameters and intended operational roles of the winter continuity-support module are summarized in Table 2.

Table 2. Key design parameters and intended operational targets of the conceptual winter continuity-support module.

Design Parameter	Parameter Description	Reference Basis	Expected Function
Target Temperature Range	Designed to help maintain the reactor body or reaction system within the target fermentation temperature range	Low-temperature organic-waste management and solar-assisted composting literature [23,31,33]	Potential mitigation of slow winter temperature rise and support for fermentation activity
Auxiliary Heating Trigger Conditions	Designed to activate supplemental heating during periods of insufficient solar heating, such as at night or during consecutive cloudy days	Solar greenhouse heat-collection strategy and auxiliary heating logic [31,32]	Temperature-stability support and reduced risk of fermentation interruption
Thermophilic-phase support	Monitoring of the high-temperature phase duration to support sanitization and decomposition requirements	Temperature-control logic and stabilizing treatment conditions [23,31]	Support for pathogen inactivation and organic-matter stabilization
Changes in the maturation cycle	Evaluation of extended maturation cycles during low-temperature seasons and optimization potential	Low-temperature continuity-support rationale and engineering design objectives [22,23,31]	Potential reduction in maturation delays and support for processing efficiency

Table 2. *Cont.*

Design Parameter	Parameter Description	Reference Basis	Expected Function
Key regulatory parameters	Temperature, humidity, turning/ventilation frequency, timing of heating switching, etc.	Integrated control factors reported for organic-waste treatment systems [23,31–33]	Basis for subsequent parameter optimization
System operational positioning	Supplementary conceptual winter continuity-support module positioned to support primary and secondary fermentation	Staged pathway coordination and circular management logic [22,28]	Support for processing-chain continuity and stability

Note: The expected functions listed in this table represent intended design roles of the conceptual winter continuity-support module and require future field validation.

2.5. Data Sources and Evaluation Indicators

This study relied primarily on enterprise production records, field surveys, and routine operational monitoring data. The collected data included manure generation volumes, moisture content, temperature profiles, fermentation cycle duration, product information, transport-related records, and selected cost items. These data were organized to evaluate process characteristics, operational continuity, and downstream processing suitability across the implemented primary and secondary stages, together with the intended role of the conceptual winter continuity-support module.

System performance assessment was based on three main categories of evidence: (1) enterprise operational ledgers and production records; (2) technical communications and site survey materials provided by company personnel; and (3) routine monitoring results from treatment facilities. The evaluation included stage-specific information on on-farm primary treatment, transport arrangements to the centralized processing facility, secondary fermentation, aging, granulation, and packaging, as well as the design rationale of the conceptual winter continuity-support module. It did not establish continuous batch-level traceability or a full-chain mass balance from manure generation to final fertilizer output.

Because the case datasets were derived from actual operations and were not fully synchronized, the analysis emphasized descriptive comparison and engineering interpretation rather than inferential statistical testing. For selected farm-level economic indicators, mean, standard deviation (SD), and coefficient of variation (CV) were calculated across the five case-study farms using WPS Spreadsheets (v12.1.0.25225; Kingsoft Office Software, <https://www.wps.cn/>, accessed on 4 July 2026) to summarize inter-farm variability. The key indicators included treatment-continuity support, process parameter ranges, product standard-compliance information, and major logistics/cost items relevant to management decisions.

To further improve methodological transparency, Table 3 summarizes the evidence types and inference boundaries used in the staged pathway evaluation.

Because the study relied on routine enterprise records rather than a pre-designed experimental sampling protocol, sampling frequency and monitoring intervals differed among farms and process stages. Product-quality data for the organic fertilizer were obtained from a third-party testing report, whereas routine process indicators were checked against enterprise operational records and field-survey information for consistency. These evidence sources were used to support a practice-based evaluation of stage-specific functions and functional compatibility, rather than a quantitatively verified full-chain material balance.

Table 3. Evidence categories and analytical boundaries used in the evaluation of the staged pathway.

Evaluation Item	Data Source	Process Stage	Analytical Purpose	Boundary or Limitation
Manure generation characteristics	Enterprise production records; field observations	Upstream farm operation	Describe manure generation context and handling demand at breeder farms	Data windows differed among case-study farms
Primary-stage equipment configuration	Field visits; enterprise equipment records	Primary stage	Identify the main pretreatment modes used at farm level	Equipment configuration varied across farms
Primary-stage operating parameters, including fresh manure moisture content, batch duration, temperature trajectory, moisture evolution, and pH range	Routine process records; enterprise ledgers	Primary stage	Summarize key operating ranges and site-specific variation across Farms A–E	Cross-farm comparisons were descriptive rather than statistically synchronized
Primary-stage product destination and utilization mode	Enterprise records; field survey information	Primary stage	Describe whether products were locally utilized or transferred downstream	Material routing was evaluated functionally rather than by full batch-level traceability
Secondary-stage process flow and equipment organization	Field surveys; process descriptions provided by company personnel	Secondary stage	Characterize downstream centralized processing, including aerobic fermentation, aging, granulation, and packaging	Evaluated as an enterprise-level downstream processing node
Product quality and standard-compliance documentation	Product testing records; company documentation	Secondary stage	Assess standardized product formation and compliance with relevant fertilizer standards	Based on available documentation and test records provided by the enterprise
Transport-related information and selected cost items	Enterprise logistics and cost records	Between primary and secondary stages	Evaluate management-relevant logistics characteristics of the staged pathway	Cost and transport information were interpreted at case level
Winter continuity-support design parameters	Literature sources; engineering design logic	Conceptual winter support module	Summarize the proposed design basis for low-temperature continuity support	Conceptual module; not evaluated through full-scale operational validation
Stage coordination and functional compatibility	Integrated analysis of operational records, field survey materials, and stage-specific information	Integrated pathway interpretation	Evaluate stage coordination, treatment-continuity support, and downstream processing suitability	No continuous batch-level traceability or full-chain mass balance; engineering-oriented interpretation only

Note: Numerical ranges for primary-stage operating parameters were summarized from structured farm surveys, enterprise operational records, and routine process information. Farm-specific values are further detailed in Section 3.1.1.

2.6. Use of Generative Artificial Intelligence

During manuscript preparation, ChatGPT (OpenAI, <https://chatgpt.com/>, accessed on 4 July 2026) was used only to assist with English language polishing, text organization, formatting consistency, and improving the clarity of expression. The tool was not used to generate research data, design the study, collect data, conduct analyses, interpret results, create figures, or draw scientific conclusions. All AI-assisted outputs were reviewed, edited, and verified by the authors, who take full responsibility for the content of the manuscript.

3. Results

3.1. Primary-Stage Operational Characteristics and Routing Role

Based on production records and field survey data from five breeder chicken farms during their respective case-study periods (Table 1), the primary stage was evaluated in terms of basic production indicators, hatchability-related by-product burden, economic characteristics of compost products, and fermentation parameter ranges. Variations were observed among farms in manure output, compost yield rate, product price, and transport cost. In contrast, relatively consistent ranges were observed for key operating parameters such as temperature trajectory and pH. These results indicate that the primary stage functioned as an on-farm pretreatment and routing node within the staged pathway, while retaining site-dependent variation in economic and organizational performance.

Because the data coverage windows across farms were not fully synchronized and were derived from routine engineering operations, the comparisons presented in this section should be interpreted as descriptive comparisons of farm-level operational patterns rather than statistically synchronized treatment effects. Differences among farms may reflect not only treatment performance, but also production-cycle timing, flock structure, seasonal conditions, record-keeping periods, equipment configuration, and management practices. Therefore, the results are used to characterize operational variability and engineering adaptability under real production conditions, rather than to infer causal differences among farms. Where applicable, descriptive statistics were used only to summarize inter-farm variability and were not used for hypothesis testing.

3.1.1. Descriptive Analysis of Basic Farming Indicators

As shown in Figure 2, descriptive comparisons were conducted for per-bird feed intake, water consumption, and daily manure production across five breeder chicken farms. Daily manure output per bird showed the most pronounced inter-farm variation, whereas feed intake and water consumption did not display fully aligned trends across the farms. These results indicate that differences existed among farms in the relationship between material input and manure output during the evaluated production periods. Previous research has also reported seasonal variation in laying-hen manure production and pollutant-emission characteristics, providing contextual support for production-related variation under different farm and seasonal conditions [34]. Related studies have further shown that seasonal or thermal conditions can affect laying-hen performance, including feed intake and water intake, which may in turn contribute to variation in manure generation patterns under practical production conditions [35,36].

Evaluation of hatching efficiency of breeding eggs

As shown in Figure 3, hatchability varied across breeder farms during one production cycle at each farm. In this study, hatchability was used mainly as an indicator associated with the scale of unhatched eggs and related by-products within the farm system. Farm D showed the highest hatchability, at approximately 88.9%, whereas Farms B and C showed lower and broadly comparable values. Farm E was excluded from this comparison because its eggs were primarily sold as commercial products rather than used for hatching. Within

the studied system, unhatched eggs, after pretreatment, can be used as auxiliary materials in co-composting during the primary stage, and previous work has demonstrated the feasibility of composting poultry litter together with eggshell waste [37]. This is also consistent with previous studies showing that hatchery-associated wastes can be incorporated into co-composting systems with poultry litter and other organic materials [38,39].

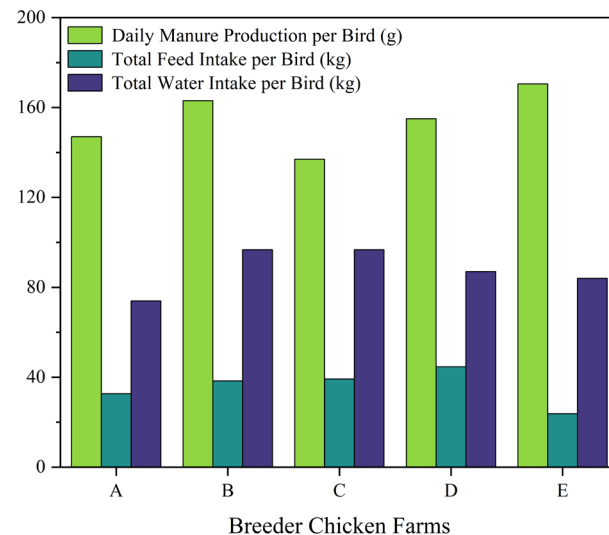


Figure 2. Per-bird feed intake, water consumption, and daily manure production across breeder farms (A–E). Note: Descriptive comparison; $n = 1$ production or recording cycle per farm. Feed and water are per-bird cumulative totals over the cycle; daily manure production is reported as $\text{g bird}^{-1} \text{d}^{-1}$. Case coverage windows are listed in Table 1.

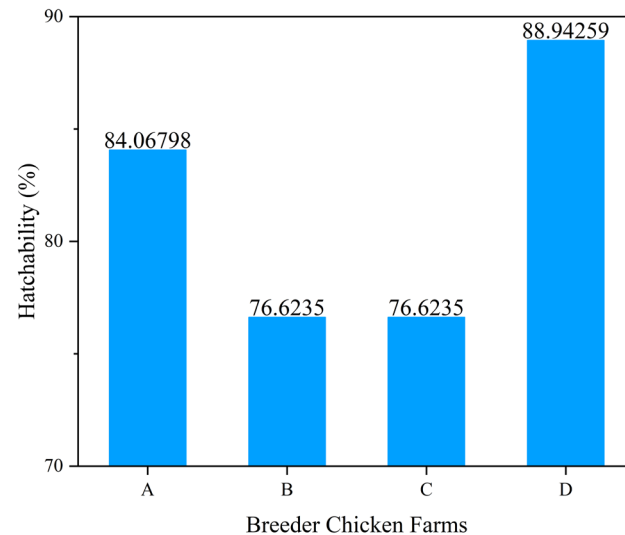


Figure 3. Egg hatchability across breeder farms (A–D). Note: Descriptive comparison; $n = 1$ production cycle per farm. Hatchability = hatched chicks/total eggs. Farm E was excluded because eggs were primarily sold as commercial products rather than used for hatching. Case coverage windows are listed in Table 1.

Case-level output, price, and logistics observations of compost products

Figure 4 shows variation in compost product yield rate across breeder farms. Figure 5 presents differences in the market price of primary-stage compost products, and Figure 6 shows the corresponding transport cost to the centralized treatment facility. Based on manure generation and compost output during one production cycle at each

farm, compost yield rate was calculated. Product prices and transport costs were then summarized descriptively.

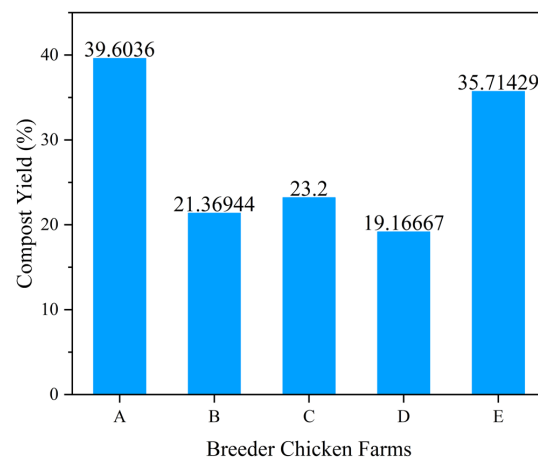


Figure 4. Compost product yield rate across breeder farms (A–E). Note: Descriptive comparison; $n = 1$ production or recording cycle per farm. Yield rate = compost output/manure generation (%). Case coverage windows are listed in Table 1.

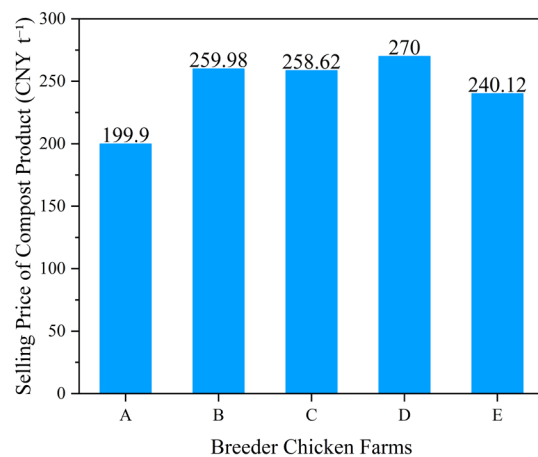


Figure 5. Market price of primary-stage compost products across breeder farms (A–E). Note: Descriptive comparison; $n = 1$ production or recording cycle per farm. Prices are reported in CNY/t based on enterprise records and/or technical communications. Case coverage windows are listed in Table 1.

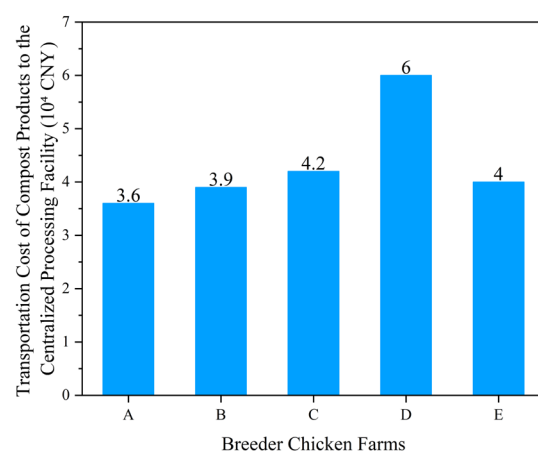


Figure 6. Transport cost of primary-stage compost products to the centralized facility across breeder farms (A–E). Note: Descriptive comparison; $n = 1$ production or recording cycle per farm. Costs are reported as total transport cost per cycle (10,000 CNY/cycle) based on enterprise records and/or technical communications. Case coverage windows are listed in Table 1.

The results indicate clear inter-farm variation in yield rate, market price, and transport cost. As summarized in Table 4, different farms exhibited distinct combinations of output, price, and logistics cost characteristics. The descriptive statistics further indicated that compost yield rate showed the greatest inter-farm variability, followed by transport cost, whereas market price was relatively less variable. This pattern is consistent with previous studies showing that case-level economic outcomes of manure recycling may depend not only on treatment performance, but also on recycling pathway, scale, and cost structure [24]. Transport and centralized redistribution can further influence the practicality and efficiency of manure-based resource utilization [25]. In addition, the economic value of poultry-litter-based fertilizer products is closely related to their downstream agricultural use and on-farm agro-economic performance [40]. These findings show that the routing and disposition of primary-stage products differed among farms and could not be represented by a single economic indicator alone.

Table 4. Case-level primary-stage output, price, and logistics indicators across breeder farms.

Farm	Yield Rate (%)	Market Price (CNY/t)	Transport Cost (10,000 CNY/Cycle)
A	39.60	199.90	3.60
B	21.37	259.98	3.90
C	23.20	258.62	4.20
D	19.17	270.00	6.00
E	35.71	240.12	4.00
Mean	27.81	245.72	4.34
SD	9.20	27.79	0.95
CV (%)	33.09	11.31	21.96

Note: Values for Farms A–E are summarized at the farm-cycle level ($n = 1$ cycle per farm; see Table 1 for coverage windows). Mean, standard deviation (SD), and coefficient of variation (CV) were calculated across the five farms as descriptive statistics only. These statistics were used to summarize inter-farm variability and were not intended for inferential comparison, because the data were derived from non-synchronized operational records. These indicators describe case-level output, price, and logistics characteristics and should not be interpreted as evidence of general economic feasibility under broader deployment conditions.

Because each farm contributed one production or recording cycle, these indicators should be interpreted as case-level economic and logistical observations rather than as evidence of broader deployment feasibility.

Fermentation parameter characteristics

Table 5 summarizes key operating parameters of the primary stage across the five breeder chicken farms. Although all farms adopted aerobic composting as the core treatment principle, differences were observed in equipment configuration, processing capacity, and operational management. Farms A, C, D, and E primarily employed trough-type composting systems, whereas Farm B adopted a tank-type fermentation system.

Fresh manure moisture content ranged from 85% to 90% across all farms. Composting temperatures generally followed a similar phased trajectory of approximately $30\text{ }^{\circ}\text{C} \rightarrow 60\text{ }^{\circ}\text{C} \rightarrow 40\text{ }^{\circ}\text{C}$, corresponding to the heating, thermophilic, and cooling stages of aerobic fermentation. Compost pH values generally increased from approximately 7–8 before treatment to 8.5–9.5 after treatment, indicating progressive stabilization during the composting process.

Inter-farm variation was more evident in fermentation duration and moisture-evolution pathways. Farm B exhibited a shorter fermentation cycle (7–10 d), whereas the other farms generally ranged from 15 to 21 d. Moisture evolution followed two principal patterns: $50\text{--}55\% \rightarrow 35\text{--}40\%$ and $55\text{--}60\% \rightarrow 35\text{--}40\%$. These differences likely reflect variation in equipment type, process management, and site-specific operational conditions.

Table 5. Comparison of key operating parameters of the primary stage across five breeder farms.

Parameter	Farm A	Farm B	Farm C	Farm D	Farm E
Fresh manure moisture content (%)	85–90	85–90	85–90	85–90	85–90
Batch duration (d)	15–21	7–10	15–21	15–21	15–21
Temperature profile (°C)	30 → 60 → 40	30 → 60 → 40	30 → 60 → 40	30 → 60 → 40	30 → 60 → 40
Moisture evolution (%)	50–55% → 35–40%	55–60% → 35–40%	50–55% → 35–40%	50–55% → 35–40%	55–60% → 35–40%
pH range during fermentation	7.0–9.5	7.0–9.5	7.0–9.5	7.0–9.5	7.0–9.5

Note: This table provides a descriptive summary of the range and trajectory characteristics of key operating parameters at the primary stage across case-study farms. Values were compiled from structured farm surveys, enterprise operational records, and interviews with farm managers conducted at Farms A–E. Statistical cycles for each site are detailed in Table 1. The temperature trajectory “30 → 60 → 40 °C” indicates the phased transition from heating to thermophilic and cooling stages.

Previous studies have shown that moisture content is a key factor influencing composting performance and stabilization in poultry-manure systems [41,42]. In addition, process-management factors such as turning frequency can affect composting efficiency and nutrient conservation during aerobic treatment [43]. The relatively consistent temperature trajectories and pH ranges observed across the surveyed farms therefore suggest the existence of a shared operational window for primary-stage composting under practical production conditions.

Taken together, these results indicate that the primary stage operated within a relatively consistent basic process window across farms, while fermentation duration and moisture-control trajectories remained adjustable operational parameters under different engineering conditions.

3.1.2. Process Characteristics of the Primary Stage

Primary fermentation employed trough-type or tank-type equipment as the main treatment unit and achieved preliminary composting and stabilization of chicken manure through the control of temperature, moisture, and cycle duration. The two equipment types differed in their operating context: trough systems were used in relatively larger-scale settings with sufficient site conditions, whereas tank systems were more suitable for small-to-medium-scale or space-constrained conditions. Overall, the primary stage functioned as an on-farm pretreatment and load-reduction step and as a routing node for subsequent local use or transfer to the centralized downstream stage.

3.2. Secondary Stage as the Standardization and Product-Output Node

The secondary stage operated at the centralized enterprise treatment center and further decomposed, stabilized, and standardized poultry-manure-derived materials into commercial fertilizer products. In the staged pathway, the secondary stage was characterized as the standardization and product-output node, where pretreated manure-derived and related organic materials were centrally processed into differentiated commercial fertilizer products under enterprise process control. Based on enterprise operational records, field survey information, and product specifications, this stage was evaluated in terms of equipment configuration, processing flow, product system, and benchmark compliance with relevant fertilizer standards.

It should be noted that the secondary production line described here represents an enterprise-level downstream processing system for chicken-manure-based resource utilization. Although its feedstock originated from chicken manure systems, the available

records did not establish a continuously traceable batch-to-batch input sequence from the five primary-stage farms included in this study. Accordingly, the results in this section are used to characterize the engineering role of the secondary stage in centralized processing, standardization, and commercial output formation, rather than to verify complete material traceability or a full-chain mass balance across the entire primary-to-secondary pathway.

3.2.1. Fermentation Equipment

The secondary stage used large-scale trough-type aerobic fermentation equipment. The fermentation tanks were reinforced concrete structures measuring 100 m × 25 m × 2 m, with an approximate total volume of 5000 m³, indicating a large-capacity centralized treatment configuration. Materials underwent about 30 days of aerobic fermentation in the tanks. A chain-track turning machine was used for mechanized turning, moving continuously along the longitudinal axis of the tank at approximately 3–4 m per day. This configuration supported regular turning and aeration during the fermentation process. Previous studies have shown that turning frequency and mixing ratio affect trough aerobic composting performance in chicken manure systems [44,45], and that turning management can further influence organic matter degradation, nitrogen transformation, and compost stabilization [46,47].

3.2.2. Fermentation Process

The secondary-stage fermentation process used pretreated chicken-manure-derived materials, supplemented with auxiliary materials such as straw and composite microbial inoculants. Dynamic aerobic fermentation was conducted using a chain-track turning machine. During the initial phase, pile temperature increased rapidly to approximately 70 °C, and then declined to 40–50 °C during the subsequent decomposition stage. At the end of fermentation, moisture content was controlled at 27–28%. Parameters including temperature, time, pH, and C/N ratio were monitored during the process. pH decreased to 5.0–6.0 in the initial stage, increased to above 8.5 during the high-temperature phase, and returned to 7.0–7.5 in the later stage. Before transfer to the aging silo, sugar residue with pH 5.0 was added to adjust material acidity and alkalinity into a suitable range. After fermentation, the material was tested for organic matter content, moisture content, and relevant hygienic indicators. Materials meeting internal requirements entered the aging stage, whereas non-compliant materials were returned for reprocessing. The use of straw as a Supplementary Material is consistent with previous reports that wheat straw can improve pore structure and composting conditions in poultry manure systems [48], while microbial inoculation has also been reported to regulate nitrogen transformation and microbial community dynamics during livestock manure composting [49].

3.2.3. Aging

Aging served as a stabilization step for the post-fermentation material. The aging warehouse used a ventilated design, with pile height controlled between 1.5 and 2.0 m. During aging, pile temperature was maintained at approximately 65 °C and moisture at 25–26%. Mechanical turning was carried out weekly to improve material uniformity. The aging cycle lasted approximately 30 days. During operation, temperature gradients between upper and lower pile layers were monitored, and pile inversion was conducted when necessary to improve uniformity before granulation. This stage was consistent with previous process-optimization studies emphasizing the importance of post-fermentation stabilization and controlled reactor operation in composting systems [50].

3.2.4. Granulation, Drying, and Packaging System

After aging, the material underwent crushing and screening before granulation. Two granulation modes were used to produce differentiated particle forms: extrusion granulation for cylindrical granules and disc granulation for spherical micro-granules. Following granulation, the products entered a waste-heat recovery drying system and then proceeded to rapid quality testing and packaging.

The enterprise packaging line had an annual capacity of 60,000 tons. Granulated and dried materials were sorted and packaged into two product systems: basic organic fertilizer and bio-organic fertilizer. Basic organic fertilizer was packaged at 40 kg per bag and sold at 50 CNY per bag (equivalent to 1250 CNY/t). Its product specification included organic matter $\geq 35\%$ and total nutrients ($N + P_2O_5 + K_2O$) $\geq 6.0\%$. Bio-organic fertilizer was packaged at 40 kg per bag and sold at 60 CNY per bag (equivalent to 1500 CNY/t). It included composite functional microbial agents, such as *Bacillus subtilis* and *Bacillus amyloliquefaciens*, with organic matter $\geq 60\%$ and viable microbial count $\geq 5 \times 10^8$ CFU g⁻¹. Based on enterprise production information, this configuration indicates that the secondary stage served as a centralized product-output node capable of producing differentiated fertilizer product types.

3.2.5. Product-Quality Evidence and Benchmark Comparison

Table 6 summarizes the available product-quality evidence for secondary-stage fertilizer products and compares it with the applicable quality benchmarks. The organic fertilizer column reports third-party testing results and was evaluated against NY/T 525-2021 [51] (Organic Fertilizer). By contrast, the bio-organic fertilizer column reports enterprise product specifications only and was benchmarked against NY 884-2012 [52] (Bio-Organic Fertilizer), because independent third-party testing data for this product were not available during the study period.

Table 6. Available product-quality evidence and applicable benchmark comparison for secondary-stage fertilizer products.

Indicator	Standard Requirement	Organic Fertilizer (Third-Party Tested)	Bio-Organic Fertilizer (Enterprise Specification Only)
Organic matter (%)	≥ 30 (NY/T 525-2021)	36	≥ 60
Total nutrients (%)	≥ 4.0 (NY/T 525-2021)	9.0	-
Moisture (%)	≤ 30 (NY/T 525-2021)	21	-
pH	5.5–8.5 (NY/T 525-2021)	8.4	-
As (mg/kg)	≤ 15 (NY/T 525-2021)	1	-
Cd (mg/kg)	≤ 3 (NY/T 525-2021)	1	-
Pb (mg/kg)	≤ 50 (NY/T 525-2021)	23	-
Cr (mg/kg)	≤ 150 (NY/T 525-2021)	10	-
Hg (mg/kg)	≤ 2 (NY/T 525-2021)	0.1	-
Fecal coliforms	$\leq 100/g$ (NY/T 525-2021)	<3	-
Helminth egg mortality (%)	≥ 95 (NY/T 525-2021)	100	-
Viable microbial count (CFU g ⁻¹)	$\geq 0.2 \times 10^8$ (NY 884-2012)	-	$\geq 5 \times 10^8$

Note: Organic fertilizer data were obtained from a third-party quality inspection report and evaluated against NY/T 525-2021 (Organic Fertilizer) [51]. Bio-organic fertilizer values represent enterprise product specifications only and were not independently tested during the study period. They are shown only for benchmark comparison with NY 884-2012 (Bio-Organic Fertilizer) [52]. The viable microbial count criterion is applicable only to bio-organic fertilizer according to NY 884-2012.

Based on the third-party testing report, the organic fertilizer complied with the applicable requirements of NY/T 525-2021 for organic matter, total nutrients, moisture, heavy metals, and hygienic indicators. For the bio-organic fertilizer, the available enterprise

specifications indicated benchmark values for organic matter and viable microbial count that were consistent with the corresponding criteria in NY 884-2012. However, these values should be interpreted as enterprise-reported specifications rather than independently verified testing results.

These results support the characterization of the secondary stage as the standardization and product-output node within the proposed staged pathway. However, the evidence basis differed between the two products: compliance of the organic fertilizer was supported by third-party testing, whereas the bio-organic fertilizer was evaluated only through enterprise specifications benchmarked against NY 884-2012.

Taken together, the available evidence supports a staged functional differentiation within the proposed breeder chicken manure resource-recovery pathway. The primary stage operated as an on-farm pretreatment and routing node, characterized by a relatively shared basic operational window but farm-dependent variation in economic and organizational parameters. The secondary stage was characterized as the centralized standardization and product-output node, supporting differentiated fertilizer production and benchmark comparison with relevant product-quality requirements, while the evidence basis for product quality differed between third-party testing and enterprise-reported specifications.

4. Discussion

4.1. Functional Roles of the Staged Pathway

The staged pathway examined in this study differentiated breeder chicken manure management into functionally connected but distinct stages under practical farm and enterprise conditions. Rather than treating manure management as a single composting operation, the pathway organized manure handling, pretreatment, centralized processing, and downstream utilization into a coordinated resource-recovery route. This organization is particularly relevant for intensive breeder chicken production, where concentrated manure generation, high initial moisture content, and all-in/all-out management can increase short-term handling pressure.

The primary stage mainly served as an on-farm pretreatment and material-routing node, where fresh manure was preliminarily reduced and stabilized before either local utilization or transfer to downstream processing routes. Its main contribution was therefore not the formation of a fully standardized end product at the farm level, but the reduction in local accumulation pressure and the improvement of material transferability under practical production conditions. This role is consistent with farm-level manure composting studies showing that composting can function not only as a treatment technology, but also as an operational strategy for converting livestock manure into a more manageable and reusable resource under practical farm conditions [26].

The secondary stage was characterized as the centralized standardization and product-output node. Under enterprise-level process control, semi-finished manure-derived and related organic materials were further stabilized, cured, granulated, dried, and packaged into differentiated fertilizer products. Third-party testing showed that the organic fertilizer complied with the corresponding requirements of NY/T 525-2021 [51], whereas the bio-organic fertilizer was evaluated based on enterprise specifications benchmarked against NY 884-2012 [52]. These results support the role of centralized processing in product standardization and commercial output formation, while not establishing full batch-level traceability across the primary-to-secondary chain. In this sense, the staged pathway should be understood not simply as consecutive fermentation steps, but as a division of engineering roles between decentralized pretreatment and centralized resource recovery. Previous studies have likewise shown that microbial inoculation and co-composting conditions can influence compost quality formation and process performance in chicken-manure-

based systems [53,54]. The centralized granulation and packaging steps also align with studies on pelletized compost from animal manure, which suggest that product form, transport convenience, and end-user acceptance can influence the practical reuse of manure-derived fertilizers [27].

The third-stage component should be interpreted differently from the first two stages. In the present study, the conceptual winter continuity-support module was not evaluated as an implemented treatment stage supported by operational data. Instead, it was introduced as a conceptual engineering component intended to support pathway continuity under low-temperature conditions. Its expected role is not direct product formation, but potential seasonal continuity support when conventional biological treatment performance is constrained during northern winters. Engineering studies on livestock and poultry manure composting equipment with vented heating indicate that heating, ventilation, and process-control configurations may affect composting efficiency and can provide useful references for future validation of winter continuity-support strategies under constrained operating conditions [55].

4.2. Management Implications for Manure Resource Recovery

A key implication of this study lies in framing breeder chicken manure management as a staged resource-recovery pathway rather than as an isolated treatment unit. Within this pathway, manure generated at breeder farms first entered on-farm pretreatment, after which semi-finished products were either utilized locally or transferred to downstream processing routes for further standardization and product formation. The resulting fertilizer-use routes were then linked to downstream agricultural application scenarios, thereby forming a more organized “breeding–fertilizer–cropping” connection at the management level.

Based on the present case evaluation, this pathway provides management implications for manure resource recovery in two main ways. First, it supports the organization of manure-derived material routing under concentrated production conditions. Instead of requiring all materials to be handled through a single uniform route, the system allows differentiated routing according to local use conditions, transport feasibility, and downstream processing capacity. This flexibility may help reduce short-term accumulation pressure at farm level and support the continuity of manure handling across different production cycles.

Second, the secondary stage supports resource recovery by processing semi-finished manure-derived and related organic materials into fertilizer products with clearer product identities and broader utilization scenarios. Compared with farm-level semi-finished compost alone, such standardized outputs may be more compatible with commercial distribution, quality control, and crop-specific fertilizer use. Therefore, the value of the pathway lies not only in manure stabilization, but also in its potential to connect waste treatment with fertilizer production and agricultural nutrient recycling. This interpretation is supported by broader discussions on transforming biomass waste, including animal manure, into sustainable organic fertilizers as a route for waste reduction, nutrient recovery, and agricultural reuse [29].

From a broader perspective, this staged organization is consistent with recent discussions of integrated crop–livestock circular agriculture and ecological farm management, which emphasize the coupling of waste treatment, nutrient recycling, and downstream agricultural use within coordinated resource cycles [56,57]. In addition, studies on soil responses to organic fertilizer inputs suggest that resource-return pathways of this kind may contribute to soil fertility improvement and beneficial microbial regulation when the recovered products are appropriately applied [58]. However, such agronomic benefits were

not directly tested in this study and should be further verified through long-term field application trials.

It should also be emphasized that this study did not directly monitor NH_3 , CH_4 , N_2O , VOC emissions, nutrient losses, or life-cycle environmental impacts. Therefore, the resource-recovery implications discussed here should be interpreted as management-oriented and product-utilization implications rather than as demonstrated evidence of overall environmental superiority.

Product quality and safety are also important considerations in evaluating the practical value of manure-resource recovery pathways. Based on the third-party testing results summarized in Table 6, the tested organic fertilizer product complied with the requirements of NY/T 525-2021 [51] with respect to organic matter content, total nutrients, moisture, heavy metals (As, Cd, Pb, Cr, and Hg), and hygienic indicators. The measured heavy metal concentrations were substantially below the corresponding regulatory limits, indicating that the tested organic fertilizer met the applicable quality and safety requirements under the investigated operating conditions. By contrast, the bio-organic fertilizer was evaluated only using enterprise product specifications benchmarked against NY 884-2012 [52], because independent third-party testing data were not available during the study period.

Nevertheless, the present study did not include phytotoxicity assessment indicators such as germination index (GI), nor did it evaluate long-term soil accumulation risks associated with repeated field application. Therefore, the safety assessment presented here should be interpreted as a product-quality verification of the tested organic fertilizer and a benchmark comparison for the bio-organic fertilizer based on enterprise specifications, rather than a comprehensive environmental risk evaluation. Further studies incorporating phytotoxicity testing, long-term field trials, direct emission monitoring, nutrient-loss assessment, and life-cycle or environmental impact assessment would help provide a more complete assessment of agronomic performance, environmental performance, and transferability.

4.3. Applicability and Deployment Conditions

The applicability of the staged pathway should be interpreted as conditional and case dependent, depending on whether the logistical, utilization, and operational conditions required for staged routing can be met. Based on the present case-level observations, the pathway may be more applicable where breeder farms generate manure in concentrated cycles, where local pretreatment can reduce short-term accumulation pressure, and where downstream processing or fertilizer-utilization scenarios are available to receive semi-finished or standardized products.

Several conditions may support deployment under comparable contexts. Stable fertilizer application scenarios or market demand are important, such as orchards, protected cultivation systems, nearby cropland, or other planting systems capable of absorbing organic fertilizer products. Access to a centralized processing facility is likewise important when standardized secondary outputs are a management objective. Supplementary Materials such as straw, pruning residues, or similar bulking agents can support moisture regulation and fermentation organization. The pathway may also be relevant in regions where winter low temperatures constrain continuous biological treatment and where seasonal support measures are needed to support operational continuity. In this regard, equipment designs incorporating vented heating and process monitoring may provide useful technical references for designing and evaluating winter continuity-support strategies under unfavorable ambient conditions [55].

At the same time, broader deployment should be approached cautiously when transport distance is excessive, logistics cost is high, downstream fertilizer demand is unstable, or auxiliary-heating costs are difficult to justify. Under such conditions, case-level economic

and operational conditions may become less favorable, even if the staged organization remains technically implementable. The transferability of the system should therefore be assessed not only by composting performance itself, but also by the interaction among manure generation pattern, pretreatment capacity, transport conditions, downstream processing access, and end-use demand. Previous work on pelletized compost reuse has also suggested that transport, handling, market value, and stakeholder acceptance can influence the practical adoption conditions of manure-derived fertilizer products [27].

4.4. Evidence Boundary, Limitations, and Future Validation Needs

The evidence provided in this study should be interpreted within the boundary of a practice-based case evaluation. The primary and secondary stages were assessed using enterprise operational records, field investigations, and routine monitoring information, but the study did not establish full batch-to-batch traceability or a full-chain mass balance across the entire primary-to-secondary and downstream utilization chain. Similarly, inter-farm comparisons were descriptive rather than based on synchronized experimental designs. The findings should therefore be understood as system-level and engineering-oriented rather than as inferential proof derived from controlled experiments.

Another important boundary concerns gaseous emissions and environmental performance. Continuous monitoring data for NH_3 , CH_4 , N_2O , volatile organic compounds (VOCs), and other atmospheric emissions were not available from the participating farms during the study period. Therefore, this study could not quantify emission fluxes from either the primary or secondary treatment stages. From a process perspective, the primary stage involved high-moisture manure pretreatment at farm level, where moisture reduction and thermophilic development may influence NH_3 release, odor formation, and short-term emission risks. The secondary stage involved larger-scale aerobic fermentation, turning, auxiliary material addition, aging, and product formation, where aeration, moisture control, C/N regulation, and process scale may further affect greenhouse gas emissions and nutrient losses. Previous studies have shown that aeration, reactor configuration, substrate composition, turning management, and additives can substantially influence NH_3 , CH_4 , N_2O , VOC emissions, compost quality, and life-cycle environmental performance during poultry-manure and organic-waste composting [12,14,54,59].

Consequently, the environmental implications discussed in this study should be interpreted as management-oriented inferences associated with more organized material routing, potential reduction in accumulation pressure, and documented downstream utilization routes, rather than as directly quantified environmental outcomes. The present study should therefore be regarded as a practice-based pathway evaluation rather than a complete environmental sustainability assessment, and it does not provide direct evidence of overall environmental superiority.

The conceptual winter continuity-support module has an even more explicit evidence boundary. In the present study, this component was discussed as a concept-level engineering supplement rather than an empirically validated treatment unit. Its expected role is to support pathway continuity during northern winters by providing supplementary insulation and heating options under low-temperature conditions, with the intended aim of reducing interruption risks associated with slow heating, insufficient maintenance of the thermophilic phase, and prolonged maturation. However, no direct operational data were available to validate its full-scale performance. Although previous equipment-oriented research provides technical references for heating, ventilation, and monitoring strategies in livestock and poultry manure composting [55], the actual effects of the proposed module on temperature stability, thermophilic-phase duration, maturation time, product stability, energy demand, cost-effectiveness, and operational reliability still require full-scale field

validation. Accordingly, the winter continuity-support module should be interpreted as a conceptual engineering option intended to support pathway continuity rather than as a demonstrated treatment technology.

Future work should therefore focus on four priorities: first, evaluating whether the conceptual winter continuity-support module can support temperature stability and heating-switching strategies under real engineering conditions; second, assessing its potential influence on thermophilic-phase duration, composting cycle, and product-quality stability; third, quantifying its auxiliary-heating energy demand, cost-effectiveness, and logistical performance; and fourth, incorporating environmental impact monitoring or life cycle assessment to clarify the practical deployment boundary of the module.

In addition, long-term field trials are needed to evaluate the agronomic performance, soil fertility effects, and nutrient-recycling efficiency of fertilizer products associated with the staged pathway. Additional priorities include direct monitoring of gaseous emissions (e.g., NH_3 , CH_4 , N_2O , and VOCs), nutrient losses, and environmental trade-offs associated with different pathway configurations, as well as phytotoxicity assessment and long-term soil-monitoring programs to further evaluate product safety and environmental performance.

With these additional data, the staged pathway proposed here could be further refined and more fully assessed for its practical contribution to sustainable manure management and circular agricultural resource recovery.

5. Conclusions

This study addressed the manure-management needs of large-scale breeder chicken farms in northern China under all-in/all-out production systems and winter low-temperature conditions. A staged resource-recovery pathway organized as “on-farm reduction—centralized value-oriented processing—seasonal continuity support” was examined as a practice-based engineering case. The implemented primary and secondary stages were evaluated using enterprise operational records, field investigations, and routine monitoring information, while the winter continuity-support module was discussed as a conceptual engineering supplement.

Within the investigated cases, the implemented primary stage showed a relatively consistent operational window in terms of fresh manure moisture content, temperature evolution, and pH range. However, fermentation duration and moisture-control pathways varied among farms, indicating that these parameters remain adjustable under different equipment configurations and management conditions. The implemented secondary stage was characterized as a centralized standardization and product-output node. Third-party testing results showed that the organic fertilizer product complied with the applicable requirements of NY/T 525-2021, while the bio-organic fertilizer was evaluated based on enterprise product specifications and benchmarked against NY 884-2012.

The proposed winter continuity-support module should be interpreted as a conceptual engineering supplement rather than an empirically validated treatment technology. Its expected role is to provide a potential continuity-support option under low-temperature conditions, but its actual effects on temperature stability, maturation duration, treatment continuity, energy demand, cost-effectiveness, and environmental performance require field-scale validation.

Overall, this study provides a practice-based reference for organizing breeder chicken manure management into a staged resource-recovery pathway that functionally coordinates on-farm pretreatment, centralized fertilizer production, and downstream agricultural utilization. However, the findings should be interpreted within the boundary of a case evaluation of stage-specific functions and functional compatibility, rather than as inferen-

tial proof from controlled experiments or as a quantitatively verified full-chain material balance. Because gaseous emissions, nutrient losses, phytotoxicity, long-term soil effects, and life-cycle environmental impacts were not directly assessed, the results should not be interpreted as direct evidence of overall environmental superiority. Future research should incorporate synchronized long-term monitoring, full-chain material tracing, direct gaseous-emission assessment, nutrient-loss monitoring, phytotoxicity testing, field application trials, and life-cycle or environmental impact assessment to further assess the environmental performance, operational reliability, and transferability of the proposed pathway.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/su18147186/s1>, Figure S1: Detailed operational parameters, evidence categories, and validation boundaries of the staged resource-recovery pathway for breeder chicken manure.

Author Contributions: Conceptualization, M.Y. and F.K.; methodology, M.Y. and F.K.; investigation, M.Y., Y.Y. and W.L.; resources, F.K.; data curation, M.Y., Y.Y. and W.L.; formal analysis, M.Y.; validation, M.Y. and F.K.; visualization, M.Y., Y.Y. and W.L.; writing—original draft preparation, M.Y.; writing—review and editing, F.K.; supervision, F.K.; project administration, F.K.; funding acquisition, F.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Key Research and Development Program of Shandong Province, grant number 2024TZXD080; the 2025 Yantai Municipal Major Agricultural Technology Collaborative Extension Program, project “Integration and Collaborative Extension of Key Technologies for Comprehensive Prevention and Control of Major Diseases in Green and High-Quality White-Feather Broiler Production”; and the 2024 Undergraduate Research Training Program of Yantai Institute of China Agricultural University, grant number X20255053070. The APC was supported by the corresponding author’s research funds.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request. Some enterprise operational records are not publicly available due to confidentiality restrictions.

Acknowledgments: The authors thank the participating enterprise and field personnel for their assistance with field investigations and provision of operational information. The authors also acknowledge the use of ChatGPT (GPT-5.5; OpenAI, <https://chatgpt.com/>, accessed on 4 July 2026) for language polishing and formatting assistance during manuscript preparation. All AI-assisted outputs were reviewed and edited by the authors, who take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

APC	Article Processing Charge
C/N	Carbon-to-nitrogen ratio
GB/T	Recommended National Standard of the People’s Republic of China
GenAI	Generative Artificial Intelligence
LCA	Life Cycle Assessment
NY	Agricultural Industry Standard of the People’s Republic of China

References

1. Sun, L.; Liu, T.; Zhang, L. Current status of large-scale livestock and poultry farming in China and its impact on the ecological environment. *J. South China Agric. Univ. Soc. Sci. Ed.* **2016**, *15*, 23–30.
2. Shi, S.; Sun, W.; Tang, J.; Wang, D.; Zhou, Y.; Yuan, Y.; Fang, B.; Liu, P. Research progress on aerobic composting technology for organic solid waste. *Mod. Chem. Eng.* **2024**, *44*, 62–67. [[CrossRef](#)]
3. Wu, G.Y.; Liao, X.D.; He, D.C.; Li, J. Current status and countermeasures for pollution prevention and control in livestock and poultry farming in China. *J. Agric. Environ. Sci.* **2014**, *33*, 1261–1264.
4. Wichuk, K.M.; McCartney, D. A review of the effectiveness of current time-temperature regulations on pathogen inactivation during composting. *J. Environ. Eng. Sci.* **2007**, *6*, 573–586. [[CrossRef](#)]
5. Wang, K.; He, C.; You, S.; Liu, W.; Wang, W.; Zhang, R.; Qi, H.; Ren, N. Transformation of organic matters in animal wastes during composting. *J. Hazard. Mater.* **2015**, *300*, 745–753. [[CrossRef](#)] [[PubMed](#)]
6. Chen, L.; Chen, Y.; Li, Y.; Liu, Y.; Jiang, H.; Li, H.; Yuan, Y.; Chen, Y.; Zou, B. Improving the humification by additives during composting: A review. *Waste Manag.* **2023**, *158*, 93–106. [[CrossRef](#)] [[PubMed](#)]
7. Huzir, N.M.; Ahmad Asmadi, A.; Rosly, M.B.; Tamunaidu, P.; Amin, A.N.R. Composting as a pathway for organic waste valorization: Substrate performance, process strategies, and quality benchmarks. *J. Mater. Cycles Waste Manag.* **2026**, *28*, 815–833. [[CrossRef](#)]
8. Pajura, R. Composting municipal solid waste and animal manure in response to the current fertilizer crisis: A recent review. *Sci. Total Environ.* **2024**, *912*, 169221. [[CrossRef](#)] [[PubMed](#)]
9. Sadeghpour, A.; Afshar, R.K. Livestock manure: From waste to resource in a circular economy. *J. Agric. Food Res.* **2024**, *17*, 101255. [[CrossRef](#)]
10. Zhang, L.; E, R.; Ali, M.M.; Lin, H.; Zhang, S.; Jin, S.; Zhu, Z.; Hu, J.; Yao, Y.; Sun, Y.; et al. Livestock and poultry manure management from the perspective of carbon neutrality in China. *Front. Agric. Sci. Eng.* **2023**, *10*, 341–362. [[CrossRef](#)]
11. Cui, S.; Pang, L. Empty-lot management plan under the “all-in, all-out” rearing model in layer farms. *China J. Anim. Sci. Technol.* **2013**, *49*, 63–64.
12. Shen, Y.; Ren, L.; Li, G.; Chen, T.; Guo, R. Influence of aeration on CH₄, N₂O, and NH₃ emissions during aerobic composting of a chicken manure and high C/N waste mixture. *Waste Manag.* **2011**, *31*, 33–38. [[CrossRef](#)] [[PubMed](#)]
13. Qasim, W.; Moon, B.E.; Okyere, F.G.; Khan, F.; Nafees, M.; Kim, H.T. Influence of aeration rate and reactor shape on the composting of poultry manure and sawdust. *J. Air Waste Manag. Assoc.* **2019**, *69*, 633–645. [[CrossRef](#)] [[PubMed](#)]
14. Jiang, Y.; Yao, Y.; Liu, H.; Zhang, S.; Bai, X.; Ma, X.; Wang, Y.; Ren, Q. Volatile organic compounds conversion pathways and odor gas emission characteristics in chicken manure composting process. *Front. Ecol. Evol.* **2023**, *11*, 1192132. [[CrossRef](#)]
15. Shang, B.; Zhou, T.; Tao, X.; Chen, Y.; Dong, H. Simultaneous removal of ammonia and volatile organic compounds from composting of dead pigs and manure using pilot-scale biofilter. *J. Air Waste Manag. Assoc.* **2021**, *71*, 378–391. [[CrossRef](#)] [[PubMed](#)]
16. Gotowska, M.; Jakubczak, A. Sustainable biodegradable waste management for circular economy: Comparative assessment of composting technologies. *Sustainability* **2025**, *17*, 8978. [[CrossRef](#)]
17. Peng, J.; Baležentis, T.; Streimikiene, D.; Dabkiene, V.; Agnusdei, G.P. Circular economy in agriculture: A systematic literature review. *Sustain. Dev.* **2025**, *33*, 501–516. [[CrossRef](#)]
18. Vasmaras, C.; Martini, A. Transforming livestock and aquaculture waste into renewable energy and materials—A review. *Sustainability* **2025**, *17*, 10590. [[CrossRef](#)]
19. Velthof, G.L.; Cals, T.C.A.; van 't Hull, J.P.; Lesschen, J.P.; Lessmann, M.; Porre, R.J.; Ros, M.B.H.; Rietra, R.P.J.J.; Schoumans, O.F.; Veenemans, L.; et al. Managing organic resources in agriculture: Future challenges from a scientific perspective. *Front. Sustain. Food Syst.* **2024**, *8*, 1393190. [[CrossRef](#)]
20. Babcock-Jackson, L.; Konovalova, T.; Krogman, J.P.; Bird, R.; Díaz, L.L. Sustainable fertilizers: Publication landscape on wastes as nutrient sources, wastewater treatment processes for nutrient recovery, biorefineries, and green ammonia synthesis. *J. Agric. Food Chem.* **2023**, *71*, 8265–8296. [[CrossRef](#)] [[PubMed](#)]
21. Kuligowski, K.; Tran, Q.B.; Nguyen, C.C.; Kaczyński, P.; Konkol, I.; Świerczek, L.; Cenian, A.; Nguyen, X.C. Analyzing and predicting the agronomic effectiveness of fertilizers derived from food waste using data-driven models. *Appl. Sci.* **2025**, *15*, 5999. [[CrossRef](#)]
22. Hidalgo, D.; Martín-Marroquín, J.M.; Corona, F.; Verdugo, F. Waste-derived fertilizers: Conversion technologies, circular bioeconomy perspectives and agronomic value. *Agronomy* **2025**, *15*, 2167. [[CrossRef](#)]
23. Bhatia, T.; Sindhu, S.S. Sustainable management of organic agricultural wastes: Contributions in nutrients availability, pollution mitigation and crop production. *Discov. Agric.* **2024**, *2*, 130. [[CrossRef](#)]
24. Kung, C.C.; Hu, S.; Lee, T.J.; Li, J. An economic and environmental evaluation of Taiwan's manure to energy applications. *iScience* **2025**, *28*, 113492. [[CrossRef](#)] [[PubMed](#)]
25. Kamilaris, A.; Engelbrecht, A.; Pitsillides, A.; Prenafeta-Boldú, F.X. Transfer of manure as fertilizer from livestock farms to crop fields: The case of Catalonia. *Comput. Electron. Agric.* **2020**, *175*, 105550. [[CrossRef](#)]

26. Palese, A.M.; Persiani, A.; D'Adamo, C.; Pergola, M.; Pastore, V.; Sileo, R.; Ippolito, G.; Lombardi, M.A.; Celano, G. Composting as manure disposal strategy in small/medium-size livestock farms: Some demonstrations with operative indications. *Sustainability* **2020**, *12*, 3315. [\[CrossRef\]](#)
27. Pampuro, N.; Caffaro, F.; Cavallo, E. Reuse of animal manure: A case study on stakeholders' perceptions about pelletized compost in Northwestern Italy. *Sustainability* **2018**, *10*, 2028. [\[CrossRef\]](#)
28. Arsic, M.; Abdalla, A.L.; Dong, H.; Loyon, L.; Packer, A.P.C.; Saha, C.K.; Si, B.; Meo Zilio, D.; Amon, B.R. Circular bioeconomy approaches for livestock manure and post-consumer wastes: Opportunities for biofertilizers and bioenergy. *Anim. Front.* **2025**, *15*, 54–64. [\[CrossRef\]](#) [\[PubMed\]](#)
29. Chew, K.W.; Chia, S.R.; Yen, H.-W.; Nomanbhay, S.; Ho, Y.-C.; Show, P.L. Transformation of biomass waste into sustainable organic fertilizers. *Sustainability* **2019**, *11*, 2266. [\[CrossRef\]](#)
30. Cai, S.; Ma, Y.; Bao, Z.; Yang, Z.; Niu, X.; Meng, Q.; Qin, D.; Wang, Y.; Wan, J.; Guo, X. The impacts of the C/N ratio on hydrogen sulfide emission and microbial community characteristics during chicken manure composting with wheat straw. *Agriculture* **2024**, *14*, 948. [\[CrossRef\]](#)
31. Su, J.J.; Huang, H.C.; Chen, Y.C.; Shih, M.Y. A design of a solar fermentation system on chicken manure by fuzzy logic temperature control. *Appl. Sci.* **2021**, *11*, 10703. [\[CrossRef\]](#)
32. Alexopoulos, S. Biogas systems: Basics, biogas multifunction, principle of fermentation and hybrid application with a solar tower for the treatment of waste animal manure. *J. Eng. Sci. Technol. Rev.* **2012**, *5*, 48–55. [\[CrossRef\]](#)
33. Chen, Y.; Yu, F.; Liang, S.W.; Wang, Z.; Liu, Z.; Xiong, Y. Utilization of solar energy in sewage sludge composting: Fertilizer effect and application. *Waste Manag.* **2014**, *34*, 2014–2021. [\[CrossRef\]](#) [\[PubMed\]](#)
34. Chen, W.; Zhang, Y.; Zhao, H.; Ning, Z.; Wang, Y.; Wu, Y.; Liao, X.; Mi, J. Seasonal variation in egg-laying hen manure production and pollutant emission characteristics. *J. Domest. Anim. Ecol.* **2023**, *44*, 50–54.
35. Oguntunji, A.O.; Aderemi, F.A.; Lawal, T.E.; Alabi, O.M. The influence of seasonal variation on performance of a commercial laying strain in a derived savanna environment in Nigeria. *Niger. Poult. Sci. J.* **2008**, *5*, 75–82.
36. Xin, H.; Gates, R.S.; Puma, M.C.; Ahn, D.U. Drinking water temperature effects on laying hens subjected to warm cyclic environments. *Poult. Sci.* **2002**, *81*, 608–617. [\[CrossRef\]](#) [\[PubMed\]](#)
37. Kemper, N.P.; Goodwin, H.L., Jr. Feasibility and production costs of composting breeder and pullet litter with eggshell waste. *J. Appl. Poult. Res.* **2009**, *18*, 172–184. [\[CrossRef\]](#)
38. Das, K.C.; Minkara, M.Y.; Melear, N.D.; Tollner, E.W. Effect of poultry litter amendment on hatchery waste composting. *J. Appl. Poult. Res.* **2002**, *11*, 282–290. [\[CrossRef\]](#)
39. Glatz, P.; Miao, Z.; Rodda, B. Handling and treatment of poultry hatchery waste: A review. *Sustainability* **2011**, *3*, 216–237. [\[CrossRef\]](#)
40. Harmel, R.D.; Harmel, B.; Patterson, M.C. On-farm agro-economic effects of fertilizing cropland with poultry litter. *J. Appl. Poult. Res.* **2008**, *17*, 545–555. [\[CrossRef\]](#)
41. Petric, I.; Šestan, A.; Šestan, I. Influence of initial moisture content on the composting of poultry manure with wheat straw. *Biosyst. Eng.* **2009**, *104*, 125–134. [\[CrossRef\]](#)
42. Li, M.X.; He, X.S.; Tang, J.; Li, X.; Zhao, R.; Tao, Y.Q.; Wang, C.; Qiu, Z.P. Influence of moisture content on chicken manure stabilization during microbial agent-enhanced composting. *Chemosphere* **2021**, *264*, 128549. [\[CrossRef\]](#) [\[PubMed\]](#)
43. Bryndum, S.; Muschler, R.; Nigussie, A.; Magid, J.; de Neergaard, A. Reduced turning frequency and delayed poultry manure addition reduces N loss from sugarcane compost. *Waste Manag.* **2017**, *65*, 169–177. [\[CrossRef\]](#) [\[PubMed\]](#)
44. Liu, X.; Li, H.; Ding, M.; Zhang, J.; Wang, F.; Yu, H.; Zha, D. Effects of turning frequency and mixing ratio on trough aerobic composting of chicken manure. *Agric. Eng.* **2023**, *13*, 35–41. [\[CrossRef\]](#)
45. Ogunwande, G.A.; Osunade, J.A.; Adekalu, K.O.; Ogunjimi, L.A.O. Nitrogen loss in chicken litter compost as affected by carbon to nitrogen ratio and turning frequency. *Bioresour. Technol.* **2008**, *99*, 7495–7503. [\[CrossRef\]](#) [\[PubMed\]](#)
46. Zhou, J. Effect of turning frequency on co-composting pig manure and fungus residue. *J. Air Waste Manag. Assoc.* **2017**, *67*, 313–321. [\[CrossRef\]](#) [\[PubMed\]](#)
47. Manga, M.; Muoghalu, C.; Camargo-Valero, M.A.; Evans, B.E. Effect of turning frequency on the survival of fecal indicator microorganisms during aerobic composting of fecal sludge with sawdust. *Int. J. Environ. Res. Public Health* **2023**, *20*, 2668. [\[CrossRef\]](#) [\[PubMed\]](#)
48. Petric, I.; Šestan, A.; Šestan, I. Influence of wheat straw addition on composting of poultry manure. *Process Saf. Environ. Prot.* **2009**, *87*, 206–212. [\[CrossRef\]](#)
49. Cao, R.; Huang, Y.; Li, R.; Li, K.; Ren, Z.; Wu, J. Regulation of nitrogen transformation and microbial community by inoculation during livestock manure composting. *Environ. Microbiol. Rep.* **2024**, *16*, e13256. [\[CrossRef\]](#) [\[PubMed\]](#)
50. Liu, Z.; Wang, X.; Cao, Y.; Ma, L. Research on process optimization of vertical silo reactor composting technology. *Chin. J. Ecol. Agric. Chin. Engl.* **2020**, *28*, 1979–1989. [\[CrossRef\]](#)
51. NY/T 525-2021; Organic Fertilizer. China Agriculture Press: Beijing, China, 2021.

52. NY 884-2012; Bio-Organic Fertilizer. China Agriculture Press: Beijing, China, 2012.
53. Wan, L.; Wang, X.; Cong, C.; Li, J.; Xu, Y.; Li, X.; Hou, F.; Wu, Y.; Wang, L. Effect of inoculating microorganisms in chicken manure composting with maize straw. *Bioresour. Technol.* **2020**, *301*, 122730. [[CrossRef](#)] [[PubMed](#)]
54. García-Rández, A.; Orden, L.; Marks, E.A.N.; Andreu-Rodríguez, J.; Franco-Luesma, S.; Martínez-Sabater, E.; Saéz-Tovar, J.A.; Pérez-Murcia, M.D.; Agulló, E.; Bustamante, M.Á.; et al. Monitoring of greenhouse gas emissions and compost quality during olive mill waste co-composting at industrial scale: The effect of N and C sources. *Waste Manag.* **2025**, *193*, 33–43. [[CrossRef](#)] [[PubMed](#)]
55. Ren, K.; Su, L.; Zhang, Y.; He, X.; Cai, X. Optimization and experiment of livestock and poultry manure composting equipment with vented heating. *Sustainability* **2023**, *15*, 11353. [[CrossRef](#)]
56. He, K.; Liu, Y.; Zheng, J. Development of integrated crop–livestock circular agriculture under the “dual carbon” goals. *J. Zhongnan Univ. Econ. Law* **2024**, *6*, 28–39. [[CrossRef](#)]
57. Liu, W.; Xu, S.; Liang, S.; Feng, X.; Lu, P.; Zhang, H.; Cao, L.; Sha, Z. Carbon footprint and nitrogen flux analysis of an integrated crop–livestock ecological farm in Shanghai. *Chin. J. Ecol. Agric. Chin. Engl.* **2025**, *33*, 1732–1747. [[CrossRef](#)]
58. Hou, J.; Xing, C.; Yang, L.; Wu, C.; Zhao, H.; Duan, Y.; Yan, X. Differences and relationships in soil fertility and bacterial community structure following carbon inputs from biochar and organic fertilizers. *Environ. Sci.* **2024**, *45*, 4218–4227. [[CrossRef](#)] [[PubMed](#)]
59. Zhang, B.; Fu, T.; Guan, C.-Y.; Cui, S.; Fan, B.; Tan, Y.; Luo, W.; Wei, Q.; Li, G.; Peng, Y. Environmental life cycle assessments of chicken manure compost using tobacco residue, mushroom bran, and biochar as additives. *Sustainability* **2022**, *14*, 4976. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.