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Physicochemical properties and agroecological assessment of digestate from chicken manure

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ABSTRACT

Anaerobic digestion of chicken manure produces both biogas and an organic fertilizing product, the composition of which depends on the properties of the feedstock, digestion conditions, and separation of the material into process fractions. This study aimed to determine the physicochemical and agrochemical properties of products obtained from the anaerobic digestion of chicken manure, identify patterns in the distribution of macro- and micronutrients among process fractions, and assess their agroecological potential. The study was conducted at the industrial Biogas Ladyzhyn facility (Vinnytsia Oblast, Ukraine). Raw chicken manure, products obtained after separation and digestion, the post-digestion product, and the solid fraction were analyzed. The measurements included pH, organic matter, total and ammonium nitrogen, P_2O_5, K_2O, MgO, CaO, SO_3, B, Fe, Mn, Cu, and Zn. The liquid digestate was slightly alkaline (pH 8.4–8.7) and contained, on average, 1.01% N, 0.97% P_2O_5, 0.81% K_2O, and 0.26% CaO on a fresh-weight basis. On a dry-matter basis, the highest contents of total and ammonium nitrogen were recorded in the post-digestion product, at 18.6% and 7.7%, respectively. The maximum P_2O_5 and K_2O contents were 5.5% and 9.7%, respectively. In the post-digestion product, Zn, Cu, and Fe concentrations reached 1,509.7, 296.8, and 623.2 mg/kg dry matter, respectively, whereas Mn concentrations were lower than those in the raw manure. These findings indicate that anaerobic digestion is accompanied by the selective redistribution of nutrients and micronutrients among process fractions. The observed compositional differences characterize the agroecological potential of biogas production by-products and are important for assessing their subsequent use as organic fertilizing products.

Keywords: digestate, chicken manure, anaerobic digestion, biogas, organic fertilizers, nitrogen, macronutrients, micronutrients, zinc, copper, agroecological potential.

INTRODUCTION

Intensive poultry production generates substantial quantities of chicken manure, which is rich in organic matter, nitrogen, and phosphorus. Improper storage and handling can lead to nitrogen losses, emissions of ammonia and greenhouse gases, unpleasant odors, and the release of nutrients into soil and aquatic ecosystems. Accordingly, modern approaches to poultry waste management seek not only to dispose of waste but also to return organic matter and nutrients to agricultural production. Anaerobic digestion is one such approach, as it simultaneously generates biogas and a stabilized organic product known as digestate (Kacprzak et al., 2023). Carbon, nitrogen, and phosphorus cycling during chicken manure processing determines both feedstock utilization efficiency and the subsequent agroecological value of the digestion products.

Digestate is a complex organomineral system whose physicochemical properties depend on feedstock type and composition, the C/N ratio, temperature, duration, and other parameters of anaerobic digestion, as well as subsequent separation and processing methods. During digestion,

some organic matter is degraded and nitrogen compounds undergo transformation, including an increase in the proportion of ammonium nitrogen. This may improve N availability to plants but also requires careful control of application rates and methods. Digestate properties and its potential uses are also strongly influenced by separation, storage, and conditioning technologies (Guan et al., 2024; Lamolinara et al., 2022; Nayak & Ranade, 2025). Recent reviews emphasize that effective digestate utilization requires consideration of its nutrient value, processing method, and potential environmental impacts together.

The assessment of nitrogen compounds is particularly important for digestate derived from chicken manure. A high nitrogen content is a major contributor to its potential agronomic value; however, ammonium nitrogen accumulation may also affect the anaerobic digestion process itself. Based on a synthesis of 55 continuous studies of poultry manure anaerobic digestion, Arriagada et al. (2026) demonstrated the importance of total ammonium nitrogen and free ammonia concentrations for process stability and efficiency. Experimental studies of chicken manure digestate also confirm the substantial contribution of ammonium nitrogen following anaerobic digestion and the potential use of this product as a source of N in crop production (Mórtola et al., 2019; Mousavi et al., 2024).

However, the agroecological value of digestate cannot be determined solely from its major nutrient content. Anaerobic digestion and subsequent separation may change the concentrations of phosphorus, potassium, calcium, magnesium, sulfur, and micronutrients in different process fractions. Particular attention should be paid to Cu and Zn because chicken manure may contain considerable amounts of these elements, and their accumulation in certain processing products affects the feasibility of their safe, long-term application to soil. Digestate assessment should therefore consider both its fertilizer value and the potentially limiting elements it contains (Rizzo et al., 2022; Guan et al., 2024; Zapata-Morales & Moreno-Andrade, 2025; Salomon et al., 2022).

An important consideration is that anaerobic digestion does not necessarily yield a product in which all constituents are uniformly distributed. Mechanical separation and other processing operations can redistribute nutrients and potentially undesirable components between the liquid and solid fractions. For example, Liedl et al. (2006) found that nitrogen was predominantly transferred to the liquid fraction of poultry manure digestate, whereas a substantial proportion of phosphorus was concentrated in the solid fraction. Recent studies also show that digestate composition can vary considerably with the feedstock and processing technology, and that some constituents may become concentrated in particular streams rather than being removed during treatment or separation (Salomon et al., 2022; Proskynitopoulou et al., 2026).

Despite extensive research on digestate, findings from individual studies cannot always be applied directly to specific industrial processing systems because of differences in feedstock composition, anaerobic digestion conditions, process duration, and methods of separation and subsequent product handling. Digestate characteristics and agronomic potential depend strongly on the original feedstock and production technology. Consequently, its quality must be assessed for each specific production process (Guan et al., 2024; Nayak & Ranade, 2025; Chojnacka & Moustakas, 2024; Proskynitopoulou et al., 2026).

At the same time, relatively few studies have characterized chicken manure anaerobic digestion products within a single industrial processing cycle while simultaneously determining the physicochemical properties, nitrogen forms, and macro- and micronutrient composition of individual process fractions. Tracking the distribution of elements between raw chicken manure and the products of separation and digestion is especially important because changes in elemental concentrations do not necessarily reflect the overall mass balance within the processing system.

The scientific novelty of this study lies in its comprehensive characterization of the physicochemical and agrochemical properties of chicken manure anaerobic digestion products collected at different stages of an industrial processing line, including the identification of how nitrogen forms, macronutrients, and micronutrients are redistributed between liquid and solid fractions. Particular attention was given to the combined assessment of digestate nutrient value and concentrations of Cu, Zn, Fe, Mn, and B, thereby providing a basis for characterizing its agroecological potential.

The aim of the study was to determine the physicochemical and agrochemical properties of chicken manure digestate, assess the redistribution of major nutrients and micronutrients among process fractions, and establish its agroecological potential. To achieve this aim, the study sought

to assess interannual variability in pH and key agrochemical indicators of liquid digestate; characterize the contents of organic matter, total and ammonium nitrogen, phosphorus, potassium, magnesium, calcium, and sulfur in raw manure and its anaerobic digestion products; determine the distribution of B, Fe, Mn, Cu, and Zn among process fractions; and identify the indicators that determine the nutrient value and potential agroecological limitations of the products studied.

MATERIALS AND METHODS

The study was conducted at the Biogas Ladyzhyn operating unit, part of Vinnytsia Poultry Farm LLC (Ladyzhyn, Vinnytsia Oblast, Ukraine). Chicken manure was the principal feedstock for anaerobic digestion. Digestion was carried out at approximately 40 °C, with a substrate retention time of 40–45 days. The study examined chicken manure and its anaerobic digestion products sampled at different processing stages: raw chicken manure, digestate after the separator, the post-digestion product, digestate from the fermenter, and solid digestate.

To assess interannual stability in the composition of liquid digestate, analytical results from 2021–2023 were used. The measured parameters were pH, total nitrogen, P_2O_5, K_2O, CaO, Cu, Zn, and Mn. For comparisons among process fractions, moisture content, organic matter, total and ammonium nitrogen, P_2O_5, K_2O, MgO, CaO, SO_3, and B, Fe, Mn, Cu, and Zn were additionally determined.

Chemical and physicochemical parameters were determined using standardized and generally accepted laboratory methods. Dry matter and sample moisture contents were determined gravimetrically according to DSTU ISO 11465:2007. The pH was determined potentiometrically in an aqueous suspension according to DSTU ISO 10390:2022; organic matter was determined according to DSTU 4289:2004; total and ammonium nitrogen according to DSTU 7911:2015; and total potassium according to DSTU 7949:2015.

Calcium and magnesium were determined by titration according to MBB 081/12-0006-01. Sulfates were determined by titration according to MBB 081/12-0177-05, and the results were expressed as SO_3. Phosphorus was determined by a photocolorimetric method, with the results expressed as P_2O_5. For micronutrient analysis, samples were first mineralized according to DSTU 7670:2014. The concentrations of B, Fe, Mn, Cu, and Zn were determined by instrumental methods following the relevant laboratory procedures, including atomic absorption spectrometry using a C-115 spectrophotometer. Results were expressed in the units appropriate to each parameter.

The units used depended on the type of material analyzed and the analytical method. For liquid digestate in the interannual analysis, N, P_2O_5, K_2O, and CaO contents were expressed as percentages of fresh product mass, whereas Cu, Zn, and Mn concentrations were expressed in mg/kg dry matter. For comparisons among process fractions, organic matter, N, NH_4-N, P_2O_5, K_2O, MgO, CaO, and SO_3 were expressed as percentages of dry matter, and B, Fe, Mn, Cu, and Zn concentrations as mg/kg dry matter.

For the liquid digestate parameters measured in 2021–2023, the arithmetic mean, standard deviation (SD), and coefficient of variation (CV, %) were calculated. The coefficient of variation was calculated as the standard deviation divided by the mean, expressed as a percentage. Data for individual process fractions presented in Tables 2 and 3 were assessed descriptively, without statistical comparisons, because they did not contain enough replicate measurements to support statistical testing of differences. Statistical analyses were performed using Statistica 10 and Agrostat.

RESULTS AND DISCUSSION

The liquid digestate produced by anaerobic digestion of chicken manure maintained a consistently slightly alkaline pH during 2021–2023. The pH values were 8.7, 8.5, and 8.4, respectively, with a mean of 8.53 over the study period. The standard deviation was 0.15 and the coefficient of variation was only 1.79%, indicating limited variation in this parameter (Table 1).

The contents of the major nutrients also varied between years, although the magnitude of these changes was relatively small. Total nitrogen content ranged from 0.97% to 1.08% of fresh weight, P_2O_5 from 0.87% to 1.03%, K_2O from 0.74% to 0.92%, and CaO from 0.23% to 0.31%. The corresponding mean values were 1.01%, 0.97%, 0.81%, and 0.26%. Total nitrogen showed the lowest variability among these parameters (CV = 6.02%), whereas the CV values for P_2O_5, K_2O, and CaO were 8.99%, 11.91%, and 16.76%, respectively.

Table 1. Physicochemical and agrochemical properties of liquid chicken manure digestate

Year	pH	Macronutrients, % of fresh weight				Micronutrients, mg/kg dry matter		
		N	P_2O_5	K_2O	CaO	Cu	Zn	Mn
2021	8.7	0.97	1.01	0.74	0.23	10.6	25.6	23.2
2022	8.5	1.08	1.03	0.92	0.24	11.0	34.7	13.6
2023	8.4	0.98	0.87	0.77	0.31	11.4	35.4	17.2
Mean	8.53	1.01	0.97	0.81	0.26	11.0	31.9	18.0
σ	0.15	0.06	0.09	0.10	0.04	0.40	5.47	4.85
CV	1.79	6.02	8.99	11.91	16.76	3.64	17.14	26.94

Note: σ – standard deviation; CV – coefficient of variation.

The micronutrient composition of liquid digestate showed greater interannual variability. Cu concentrations ranged from 10.6 to 11.4 mg/kg dry matter, Zn from 25.6 to 35.4 mg/kg, and Mn from 13.6 to 23.2 mg/kg. Their respective mean concentrations were 11.0, 31.9, and 18.0 mg/kg. Cu had the lowest coefficient of variation (3.64%), whereas those for Zn and Mn were 17.14% and 26.94%, respectively. Thus, pH, Cu, and total nitrogen were the most stable characteristics of liquid digestate over the study period. By contrast, Mn, Zn, and certain macronutrients, particularly CaO and K_2O, showed greater interannual variability. This indicates that the overall chemical characteristics of the digestate remained relatively stable, even though the concentrations of individual elements may have varied with feedstock composition and production conditions.

A comparative characterization of raw chicken manure and its anaerobic digestion products is presented in Table 2. Raw chicken manure had a moisture content of 53.6%, compared with 92.1–93.8% in the liquid anaerobic digestion products. The solid digestate fraction had a lower moisture content of 76.3%.

On a dry-matter basis, the organic matter content of raw manure was 33.4%. This value was 69.4% in digestate after separation and 67.7% in the post-digestion product, whereas the material from the fermenter contained 22.8%. The organic matter content of the solid digestate fraction was 40.9%.

On a dry-matter basis, total nitrogen concentrations in anaerobic digestion products were higher than in raw chicken manure, except in the solid fraction, where the value was 9.7% and was close to the initial level. The highest total N content, 18.6% of dry matter, was recorded in the post-digestion product, which also had the highest ammonium nitrogen content, 7.7% of dry matter. In digestate after the separator, these values were 16.9% and 6.8%, respectively; in material from the fermenter, they were 14.9% and 5.3%. Ammonium nitrogen accounted for approximately 26% of total nitrogen in raw chicken manure, compared with approximately 40% in digestate after separation, 41% in the post-digestion product, and 36% in material from the fermenter. The solid fraction had the lowest proportion of ammonium nitrogen, at approximately 20%.

Phosphorus, potassium, magnesium, calcium, and sulfur contents also differed among fractions. The highest P_2O_5 content, 5.5% of dry matter, was

Table 2. Moisture, organic matter, and macronutrient contents of chicken manure and derived digestate

Product	Moisture, %	Content, % of dry matter							
		Organic matter	Nitrogen		P_2O_5	K_2O	MgO	CaO	SO_3
			Total	Including NH_4-N					
Chicken manure	53.6	33.4	9.2	2.4	4.2	3.7	1.9	10.5	1.0
Digestate (separator)	93.8	69.4	16.9	6.8	3.0	4.3	0.9	6.5	1.5
Digestate (post-digester)	93.8	67.7	18.6	7.7	3.3	9.7	2.0	8.0	1.5
Digestate (fermenter)	92.1	22.8	14.9	5.3	5.5	8.0	2.5	8.0	1.0
Solid digestate	76.3	40.9	9.7	1.9	3.0	2.4	1.5	4.3	0.8

found in digestate from the fermenter. The post-digestion product and digestate after separation contained 3.3% and 3.0% P_2O_5, respectively, and the solid fraction contained 3.0%. The highest K_2O content was recorded in the post-digestion product (9.7% of dry matter), followed by material from the fermenter (8.0%). K_2O content was 4.3% in digestate after the separator and 2.4% in the solid fraction. Raw manure contained 3.7% K_2O on a dry-matter basis.

MgO content ranged from 0.9% in digestate after the separator to 2.5% in material from the fermenter. CaO content in the digestion products ranged from 4.3% to 8.0%, compared with 10.5% in raw manure. SO_3 content ranged from 0.8% in the solid fraction to 1.5% in digestate after the separator and in the post-digestion product. Raw chicken manure and its anaerobic digestion products differed in their concentrations of the micronutrients studied (Table 3). The largest differences were observed for Fe, Cu, and Zn.

Boron concentrations in the liquid anaerobic digestion products ranged from 206.3 to 251.6 mg/kg, exceeding the value of 66.2 mg/kg measured in raw chicken manure. In the solid fraction, the concentration was 63.7 mg/kg, close to that of the original feedstock. The highest Fe concentration was measured in digestate after the separator (639.2 mg/kg), with slightly lower values in the post-digestion product (623.2 mg/kg) and material from the fermenter (495.6 mg/kg). The solid fraction contained 208.4 mg/kg Fe, compared with 57.8 mg/kg in raw manure.

Unlike the other micronutrients studied, Mn concentrations after anaerobic digestion were lower than in raw manure. Concentrations ranged from 3.9 to 5.9 mg/kg in the liquid products and were 8.7 mg/kg in the solid fraction, compared with 36.2 mg/kg in the original material. Cu concentrations in digestate after the separator, the post-digestion product, and material from the fermenter were 277.4, 296.8, and 251.9 mg/kg, respectively. The value was lower in solid digestate (97.0 mg/kg), compared with 117.5 mg/kg in raw chicken manure.

The highest Zn concentration was found in the post-digestion product (1,509.7 mg/kg). Concentrations in digestate after the separator and material from the fermenter were 1,400.0 and 1,293.7 mg/kg, respectively. Solid digestate contained 515.2 mg/kg Zn, less than the 673.1 mg/kg recorded in raw manure. Compared with raw chicken manure, the post-digestion product contained approximately 2.24 times as much Zn, 2.53 times as much Cu, and 10.8 times as much Fe. At the same time, Mn concentrations in the liquid products were several times lower. These results indicate a marked redistribution of micronutrients during anaerobic digestion and subsequent separation of digestate into fractions.

These findings reveal differences in micronutrient concentrations among process fractions and suggest their redistribution during anaerobic digestion and subsequent digestate separation. The most pronounced changes involved nitrogen forms, potassium, phosphorus, and Fe, Cu, and Zn. However, the pattern of change varied among digestate fractions, confirming the importance of assessing not only the feedstock and final product but also the individual stages of processing.

One of the main changes during anaerobic digestion is the conversion of organic nitrogen forms into ammonium nitrogen. In this study, NH_4-N accounted for approximately 26% of total nitrogen in raw chicken manure, increasing to approximately 40–41% in digestate after separation and the post-digestion product, while reaching approximately 36% in digestate from the fermenter. This trend is consistent with studies of poultry manure digestate reporting a substantial proportion of total nitrogen in ammonium form, which contributes to the potential value of digestate as a source of mineral nitrogen for plants (Mórtola et al., 2019; Salomon et al., 2022; Tawfik et al., 2023).

Table 3. Micronutrient contents of chicken manure and derived digestate

Product	Content, mg/kg dry matter				
	B	Fe	Mn	Cu	Zn
Chicken manure	66.2	57.8	36.2	117.5	673.1
Digestate (separator)	251.6	639.2	3.9	277.4	1400.0
Digestate (post-digester)	237.1	623.2	4.8	296.8	1509.7
Digestate (fermenter)	206.3	495.6	5.9	251.9	1293.7
Solid digestate	63.7	208.4	8.7	97.0	515.2

Nevertheless, the exact proportion of NH_4-N may vary among studies. This is associated with differences in feedstock composition, anaerobic digestion conditions, process duration, dry matter content, and subsequent digestate separation or storage. A systematic analysis of digestate separation processes shows that both feedstock type and separation technology affect the characteristics of the resulting liquid and solid fractions, including the distribution of dry matter, nitrogen, and phosphorus (Carraro et al., 2024). A review of current separation approaches likewise confirms that the selected technology influences the properties and potential uses of the resulting fractions (Nowak & Czekała, 2024). The values observed in individual studies should therefore be regarded as characteristics of the specific processing systems examined rather than universal properties of all chicken manure digestates (Guan et al., 2024; Nayak & Ranade, 2025). Elevated ammonium nitrogen content is important both for the fertilizer value of digestate and for the operation of the anaerobic digestion system itself. Ammonium is a plant-available form of nitrogen; however, excessive accumulation of ammonium nitrogen and free ammonia can adversely affect methanogenesis. High concentrations of ammonium nitrogen and free ammonia are recognized as potential constraints on process stability during poultry manure anaerobic digestion (Tawfik et al., 2023; Arriagada et al., 2026). Thus, the increased proportion of NH_4-N in the samples studied should be considered both an indication of potentially greater nitrogen availability and a parameter relevant to assessing process stability.

The distribution of phosphorus and potassium among process fractions differed from that of nitrogen. The highest P_2O_5 content was recorded in digestate from the fermenter (5.5% of dry matter), whereas the highest K_2O content was found in the post-digestion material (9.7% of dry matter). This difference indicates that the elements are not distributed uniformly between the liquid and solid components of the product. Studies of industrial facilities have shown that anaerobic digestion and subsequent separation may alter the chemical forms and partitioning of phosphorus among fractions (Mazzini et al., 2020). Phase separation can yield products with different nutrient ratios, while subsequent technologies, including struvite precipitation, allow targeted recovery of N and P from digestate (Liedl et al., 2006; Mousavi et al., 2024).

Accordingly, the differences observed among process fractions should not be interpreted solely as changes in the concentrations of individual elements. They reflect the redistribution of nutrients within the processing system. Confirming any actual increase or decrease in the total quantity of an element requires a complete mass balance that accounts for the mass of each fraction. This is essential for assessing the flows of N, P, K, and potentially hazardous elements in digestate production and utilization systems (Salomon et al., 2022). A systematic review of industrial separation technologies likewise confirms that the concentrations measured in individual fractions should be considered alongside the mass recovery of elements in the respective streams (Carraro et al., 2024).

Differences in micronutrient distribution were even more pronounced. In the post-digestion product, Zn, Cu, and Fe concentrations were 1,509.7, 296.8, and 623.2 mg/kg dry matter, respectively, compared with 673.1, 117.5, and 57.8 mg/kg in raw chicken manure. Thus, these elements were more concentrated in certain fractions following processing. However, this does not imply an increase in their total quantity within the system, as concentration changes may result from redistribution between fractions and changes in fraction mass.

The importance of considering elemental flows as well as concentrations was similarly demonstrated by Salomon et al. (2022), who found that Cu and Zn inputs from digestate and other organic materials contributed substantially to the overall flows of these elements on farms. Therefore, when assessing the agroecological suitability of digestate, Cu and Zn concentrations should be considered in relation to the application rate, mass of product applied, and duration of repeated use. Recent reviews of digestate agronomic value also emphasize the need to consider both nutrient composition and quality and safety parameters when justifying its use as an organic fertilizer (Senevirathne & Kaparaju, 2025).

Unlike Cu, Zn, and Fe, Mn concentrations in the process fractions studied were lower than in raw chicken manure. This further confirms that different elements may behave differently during anaerobic digestion and subsequent product separation. The observed differences among fractions may be associated both with the properties of the elements themselves and with their partitioning among the organic, mineral, and liquid components of the material. However, without determining the masses of the individual process streams, it is not possible to establish whether the lower

Mn concentration represents an actual decrease in its total quantity within the system.

Elevated Cu and Zn concentrations in some of the fractions studied warrant attention when assessing the long-term application of digestate as an organic fertilizer. However, the total concentration of a metal alone does not allow its environmental risk to be assessed directly. Such an assessment must take into account the chemical form, mobility, and bioavailability of the element, soil properties, application rate, and duration of product use. Recent reviews also emphasize that agroecological assessment of digestate should consider not only the total contents of potentially hazardous elements but also the conditions under which they enter the soil and their potential availability to plants (Sobhi et al., 2024; Rizzo et al., 2022; Senevirathne & Kaparaju, 2025). The Cu and Zn concentrations measured here should therefore be treated primarily as parameters requiring monitoring, rather than as direct evidence that the product poses an environmental hazard.

Another important finding was the stability of the principal characteristics of liquid digestate during 2021–2023. The pH ranged from 8.4 to 8.7, with a coefficient of variation of only 1.79%. Total nitrogen content was also relatively stable (CV = 6.02%). In contrast, K_2O, CaO, Zn, and especially Mn showed greater interannual variability. Thus, a stable pH does not necessarily imply a uniform elemental composition of digestate. The differences observed between years may be related to changes in feedstock composition and production conditions. For practical digestate use, regular monitoring of chemical composition is therefore preferable to assessing its properties from a single analysis. Recent reviews of digestate management emphasize that its characteristics depend on feedstock composition, anaerobic digestion technology, fraction separation, and subsequent utilization methods (Guan et al., 2024; Chojnacka & Moustakas, 2024; Proskynitopoulou et al., 2026). A systematic review of industrial separation technologies also shows that the properties of the resulting fractions depend on digestate type and the separation method (Carraro et al., 2024; Nowak & Czekała, 2024).

Overall, the results demonstrate that chicken manure digestate is not a uniform product: its agrochemical and agroecological properties depend substantially on the process fraction. Anaerobic digestion is accompanied by redistribution of nitrogen, phosphorus, potassium, and micronutrients, and some fractions may contain elevated concentrations of both valuable nutrients and Cu and Zn. Agronomic assessment of this material should therefore consider not only its total nutrient content but also its fraction-specific composition, application rate, and monitoring of potentially problematic elements. This approach is consistent with the contemporary concept of managing digestate as a resource for returning nutrients to agricultural production and for further valorization, provided that product quality and environmental risks are controlled (Chojnacka & Moustakas, 2024; Senevirathne & Kaparaju, 2025; Wang et al., 2023).

CONCLUSIONS

Anaerobic digestion of chicken manure was accompanied by redistribution of nutrients among process fractions and transformation of nitrogen forms. Liquid digestate was slightly alkaline (pH 8.4–8.7) and exhibited low interannual variability in its main characteristics. The highest contents of total and ammonium nitrogen were found in the post-digestion product, indicating a greater proportion of nitrogen in ammonium form.

The distribution of P, K, and micronutrients varied with the processing stage and fraction composition. The most pronounced changes were observed for Fe, Cu, and Zn, whereas Mn concentrations in the digestion products decreased relative to raw manure. These findings confirm the need for comprehensive digestate assessment that accounts for both its nutrient value and the potential accumulation of individual micronutrients.

The results indicate that the products of chicken manure anaerobic digestion have potential for use as organic fertilizing materials. However, their subsequent application requires a fraction-specific approach and justified application rates based on agrochemical composition and agroecological characteristics.

REFERENCES

1. Arriagada, C., Guzmán-Fierro, V., Riveros, G., Leiva, A. M., & Roeckel, M. (2026). Operating conditions and performance analysis of anaerobic digestion of poultry manure. *Bioresource Technology, 458*, Article 135097. https://doi.org/10.1016/j.biortech.2026.135097
2. Carraro, G., Tonderski, K., & Enrich-Prast, A. (2024). Solid-liquid separation of digestate from

biogas plants: A systematic review of the techniques' performance. *Journal of Environmental Management, 356*, Article 120585. https://doi.org/10.1016/j.jenvman.2024.120585

3. Chojnacka, K., & Moustakas, K. (2024). Anaerobic digestate management for carbon neutrality and fertilizer use: A review of current practices and future opportunities. *Biomass and Bioenergy, 180*, Article 106991. https://doi.org/10.1016/j.biombioe.2023.106991
4. Guan, D., Zhao, J., Wang, Y., Fu, Z., Zhang, D., Zhang, H., Xie, J., Sun, Y., Zhu, J., & Wang, D. (2024). A critical review on sustainable management and resource utilization of digestate. *Process Safety and Environmental Protection, 183*, 339–354. https://doi.org/10.1016/j.psep.2024.01.029
5. Kacprzak, M., Malińska, K., Grosser, A., Sobik-Szołtysek, J., Wystalska, K., Dróżdż, D., Jasińska, A., & Meers, E. (2023). Cycles of carbon, nitrogen and phosphorus in poultry manure management technologies: Environmental aspects. *Critical Reviews in Environmental Science and Technology, 53*(8), 914–938. https://doi.org/10.1080/10643389.2022.2096983
6. Lamolinara, B., Pérez-Martínez, A., Guardado-Yordi, E., Guillén Fiallos, C., Diéguez-Santana, K., & Ruiz-Mercado, G. J. (2022). Anaerobic digestate management, environmental impacts, and techno-economic challenges. *Waste Management, 140*, 14–30. https://doi.org/10.1016/j.wasman.2021.12.035
7. Liedl, B. E., Bombardiere, J., & Chatfield, J. M. (2006). Fertilizer potential of liquid and solid effluent from thermophilic anaerobic digestion of poultry waste. *Water Science & Technology, 53*(8), 69–79. https://doi.org/10.2166/wst.2006.237
8. Mazzini, S., Borgonovo, G., Scaglioni, L., Bedussi, F., D'Imporzano, G., Tambone, F., & Adani, F. (2020). Phosphorus speciation during anaerobic digestion and subsequent solid/liquid separation. *Science of the Total Environment, 734*, Article 139284. https://doi.org/10.1016/j.scitotenv.2020.139284
9. Mórtola, N., Romaniuk, R., Cosentino, V., Eiza, M., Carfagno, P., Rizzo, P., Bres, P., Riera, N., Roba, M., Butti, M., Sainz, D., & Brutti, L. (2019). Potential use of a poultry manure digestate as a biofertiliser: Evaluation of soil properties and *Lactuca sativa* growth. *Pedosphere, 29*(1), 60–69. https://doi.org/10.1016/S1002-0160(18)60057-8
10. Mousavi, S. E., Goyette, B., Zhao, X., Couture, C., Talbot, G., & Rajagopal, R. (2024). Struvite-driven integration for enhanced nutrient recovery from chicken manure digestate. *Bioengineering, 11*(2), Article 145. https://doi.org/10.3390/bioengineering11020145
11. Nayak, J. K., & Ranade, V. V. (2025). Valorisation of digestate: Characteristics, products, processes and potential. *Chemical Engineering Journal Advances, 24*, Article 100887. https://doi.org/10.1016/j.ceja.2025.100887
12. Nowak, M., & Czekała, W. (2024). Sustainable use of digestate from biogas plants: Separation of raw digestate and liquid fraction processing. *Sustainability, 16*(13), Article 5461. https://doi.org/10.3390/su16135461
13. Proskynitopoulou, V., Vourros, A., Garagounis, I., Lorentzou, S., Zouboulis, A., & Panopoulos, K. (2026). Integrated digestate management: Contaminant control, valorisation and circular pathways. *Journal of Environmental Management, 405*, Article 129629. https://doi.org/10.1016/j.jenvman.2026.129629
14. Rizzo, P. F., Young, B. J., Pin Viso, N. D., Carbajal, J., Martínez, L. E., Riera, N. I., Bres, P. A., Beily, M. E., Barbaro, L. A., Farber, M. D., Zubillaga, M. S., & Crespo, D. C. (2022). Integral approach for the evaluation of poultry manure, compost, and digestate: Amendment characterization, mineralization, and effects on soil and intensive crops. *Waste Management, 139*, 124–135. https://doi.org/10.1016/j.wasman.2021.12.017
15. Salomon, E., Tidåker, P., & Bergström Nilsson, S. (2022). Flows and budgets of nutrients and potentially toxic elements on four Swedish organic farms using digestate from agricultural residues. *Organic Agriculture, 12*, 279–292. https://doi.org/10.1007/s13165-022-00393-3
16. Senevirathne, N., & Kaparaju, P. (2025). Enhancing the agronomic value of anaerobic digestate: A review of current vs. emerging technologies, challenges and future directions. *Agriculture, 15*(20), Article 2108. https://doi.org/10.3390/agriculture15202108
17. Sobhi, M., Elsamahy, T., Zakaria, E., Gaballah, M. S., Zhu, F., Hu, X., Zhou, C., Guo, J., Huo, S., & Dong, R. (2024). Characteristics, limitations and global regulations in the use of biogas digestate as fertilizer: A comprehensive overview. *Science of the Total Environment, 957*, Article 177855. https://doi.org/10.1016/j.scitotenv.2024.177855
18. Tawfik, A., Eraky, M., Osman, A. I., Ai, P., Zhou, Z., Meng, F., & Rooney, D. W. (2023). Bioenergy production from chicken manure: A review. *Environmental Chemistry Letters, 21*(5), 2707–2727. https://doi.org/10.1007/s10311-023-01618-x
19. Wang, W., Chang, J.-S., & Lee, D.-J. (2023). Anaerobic digestate valorization beyond agricultural application: Current status and prospects. *Bioresource Technology, 373*, Article 128742. https://doi.org/10.1016/j.biortech.2023.128742
20. Zapata-Morales, A. L., & Moreno-Andrade, I. (2025). Valorization of digestates from organic solid waste as fertilizers, soil improvers, and agricultural prebiotics: Panorama and perspectives. *3 Biotech, 15*, Article 333. https://doi.org/10.1007/s13205-025-04507-y