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Physicochemical Characterization of Broiler Poultry Litter from Commercial Broiler Poultry Operation in Semiarid Tropics of India

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Abstract: This study characterized the physicochemical properties of broiler poultry litter (BPL) produced from intensively reared commercial broilers that were collected from 110 commercial poultry farms at the end of the production cycle (sixth week). A further 20 samples were collected from the end use point where BPL was utilized as a soil amendment by the farmers after a period of storage for improving poultry litter management practices, developing new litter treatment technologies, or enhancing its use as a sustainable resource. The dry matter (DM), moisture, ash, organic matter (OM), and organic carbon (OC) from the manure samples were 83.04, 16.96, 27.08, 72.92, and 42.39%, respectively. The pH, electrical conductivity (EC) (dS m^{-1}), and Kjeldahl nitrogen (N) were 8.43, 5.74, and 24.2 g kg^{-1}, respectively. The BPL from the cement floor had higher levels of P and K than the mud floor. The correlation studies revealed that the OM, C, N, and Zn had significant positive correlations; pH, moisture, and ash had positive correlations; and EC, DM, and Ca had positive correlations. The EC level of BPL negatively correlated with pH, Fe, and Mn. The N content was found to have a highly significant ($p < 0.01$) positive correlation with the OM, OC, Ca, and Zn content of BPL, and it was found to have a highly significant ($p < 0.01$) negative correlation with the ash content, pH, and K content of BPL. The P content of BPL showed a positive correlation ($p < 0.01$) with the K content and a negative correlation with the Zn ($p < 0.05$) and Fe ($p < 0.01$) contents of BPL. Zn was found to be negatively ($p < 0.01$) correlated with the ash content; the pH; and the K, Fe, and P content of BPL. According to the findings of this study, BPL as such at the end of the production cycle is rich in OM, nitrogen, macrominerals, and microminerals; however, at the point of utility (after a period of storage of 4 to 6 months), there was a loss of OM, N, and mineral concentrations, highlighting the importance of proper storage and composting. Overall, this study on the physicochemical properties of broiler poultry litter is crucial for improving agricultural practices, protecting the environment, and preserving the health and safety of human beings and livestock.

Keywords: physicochemical properties; broiler; manure; poultry litter

1. Introduction

The Indian poultry industry consists of broiler and egg-type chickens worth INR 1905 billion (USD 22.07) in 2022 with an average growth rate of 10.18%, and the projected value for the year 2028 is INR 3477 billion (USD 41.42 billion) [1]. More than 80% of India's chicken output is produced by contract farming under the organized sector, mainly by vertical integration by major companies, which comprise approximately 60–70% of the total chicken production [2,3].

India is the sixth largest producer in the world [4], and about 331.51 million chicks are slaughtered annually in India. Broiler production is mainly concentrated in the states of Maharashtra (0.726 million tons), West Bengal (0.649 million tons), Haryana (0.619 million tons), Andhra Pradesh (0.592 million tons), Tamil Nadu (0.50 million tons), and Telangana (0.482 million tons) with a total annual production of 4.9 million tons. Tamil Nadu state is the fifth leading state in poultry meat production, which accounts for 10.01% of the poultry meat produced in the country [5].

The major broiler production zone in Tamil Nadu falls under the tropical semiarid zone, the average farm size ranges between 5000 and 20,000 broilers, and the production cycle lasts for 5 to 6 weeks. Coconut cultivation is one of the major agricultural activities in the major broiler production belt (Tirupur, Coimbatore, and Erode districts), and most of the farmers utilize coconut pith waste as bedding material in broiler farming. This is an effective way of recycling agricultural waste by the farmers. Most of the farmers utilize the used litter as a soil amendment after storing it for a short period [6].

The broiler litter is made up of bedding material combined with droppings, feathers, and feed waste. It is high in minor nutrients (mg/kg) such as Fe (1055), Cu (662.0), Mn (556.0), Zn (436.0), and Mg (6.1 g/kg), as well as major plant nutrients like N (32.8 g/kg), P (18.77 g/kg), K (30.3 g/kg), OM, and C/N. Due to its high ammonia nitrogen content, manure cannot be utilized as a soil amendment and must be mineralized. Poultry waste must be processed right away in order to preserve its nutritional qualities and stop it from decomposing too quickly.

One of the challenges facing livestock and poultry industries worldwide is manure management. Improper management and utilization of manure can contribute to environmental degradation and ultimately be detrimental to human and animal populations. The disposal of raw poultry manure without further treatment poses serious environmental problems such as obnoxious odors, the leaching of toxic elements such as heavy metals [7], methane emissions, the eutrophication of waterways, nutrient imbalances when applied to soil, phytotoxicity, and the dissemination of pathogens and weeds. Broiler poultry litter adversely affects plant growth and seed germination [8] due to the production of phytotoxic substances such as phenolic and volatile fatty acids during partial OM decomposition as they have wide C:N ratio. The broiler litter consists of bedding material mixed with droppings, feathers, and feed waste, which is rich in major plant nutrients.

The average daily fresh manure production by broiler chicken is about 43 kg per 1000 kg live weight. On a dry weight basis, poultry litter production ranges from 0.7 to 2.0 tons per 1000 broilers per flock. In Tamil Nadu, it was estimated that broiler chicken litter production per year is about 520,000 MT/year [9]. Large amounts of fertilizer are used in Indian agriculture; during the years 2022–2023, the total fertilizer nutrients consumed were 29.84 million MT (20.21 million MT of N, 7.92 million MT of P_2O_5, and 1.72 million MT of K_2O). When animal waste is properly recycled, especially poultry industry waste, the need for inorganic fertilizer is decreased [10].

Several studies have assessed the efficacy of various systems for handling or processing chicken litter with the aim of reducing environmental effects and/or producing goods with added value. These technologies include burning to produce energy; producing methane through anaerobic digestion; pelletizing to enhance application and transportability; and composting to lessen moisture, smells, and pathogens. The research data regarding the physicochemical properties of broiler litter from commercial broiler farms and the loss of nutrients during storage and further handling are limited.

Heavy bulk densities, manure production in relatively remote areas, and difficulties with long-distance hauling are some of the issues with manure management among chicken farms. Composting is a cost-effective form of manure management, with several methods including pile, passive aeration, active aeration, and in-vessel composting, among others. Broiler chicken litter composting is determined by the methods employed to compost the raw material utilized as litter material, as well as the carbon and nitrogen levels of the broiler chicken litter.

The various litter materials used in the study area's broiler farm are composted using three methods in order to analyze the composting efficacy and nutrient conservation. Under Indian conditions, research data on the physicochemical qualities of broiler poultry litter using various bedding materials are limited, and no attempt has been made to compost poultry broiler litter at the production or use stages. Farmers only perform simple stockpiling for 4–6 months before applying it as a soil supplement. To investigate the gap, this research was conducted with the following objectives:

- To investigate the physical characteristics, chemical makeup, and manure value assessment at the production and usage sites of broiler chicken litter;
- To create appropriate composting plans that will preserve and maintain the broiler chicken litter's manure value;
- To examine the microbial situation during the composting process.

In this study, broiler litter samples were collected from different poultry farms utilizing various bedding materials and were subjected to a laboratory analysis of their physicochemical properties. Manure samples were also collected from the end user level, and the variability in the physicochemical properties was documented. The management factor influencing the BPL quality and the correlation between the physiochemical properties and the loss of plant nutrient during the process of storage were studied.

This study promises to help in knowing the nutrient composition of poultry litter, which will aid in the management of its use as a fertilizer. This ensures that crops receive appropriate nutrients while reducing the risk of over-fertilization, which can result in environmental problems such as nutrient runoff. By evaluating the physical qualities, we can determine how litter impacts soil structure and health. Litter that is properly classified can help with soil aeration, water retention, and general fertility. Furthermore, the classification of litter can help to build effective waste management strategies. This includes determining the most effective methods for composting or treating litter to lessen its environmental impact. Overall, this research investigating the physicochemical features of broiler poultry litter is critical for improving agricultural practices, safeguarding the environment, and ensuring the health and safety of humans and livestock.

2. Materials and Methods

2.1. Study Area

This study was carried out in the Western Agro-climatic zone of Tamil Nadu, India, specifically in the districts of Coimbatore, Tiruppur, and Erode (Figure 1), which have the highest concentration of broiler population. The study area is located between 10°36′ and 11°58′ N latitude, 76°49′ and 77°58′ E longitude with the mean sea level ranging between 177 and 411 m. The selected districts have the highest annual growth rate in broiler population; the greatest number of broiler integrators, broiler parental breeding farms, broiler hatcheries, and commercial broiler farms; and a small number of chicken processing plants, poultry input dealers, and service providers, all of which contribute to a favorable environment for commercial broiler ventures. They are located in a semi-arid tropical climate, with temperatures ranging from 18 to 40 °C. The annual rainfall is approximately 700 mm. The soil is predominantly red sand and gravel, with some red loam and black loam, loamy soil, and clay soil thrown in for good measure.

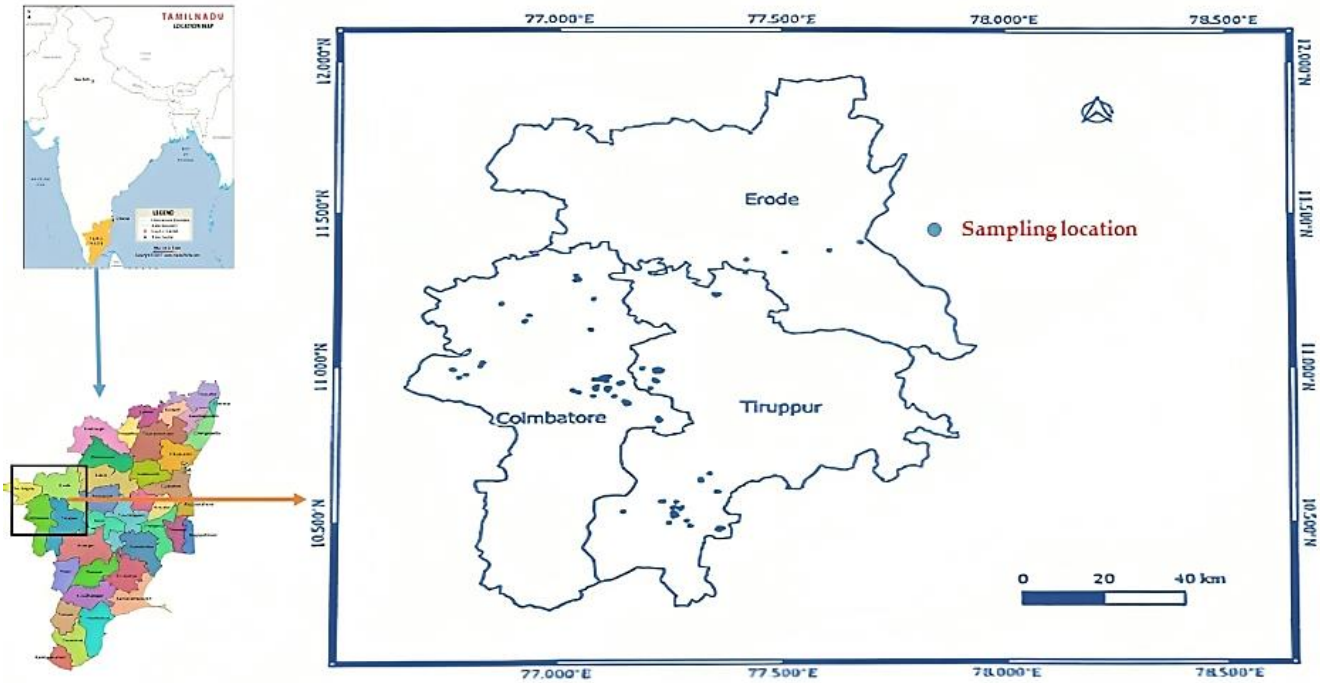

Figure 1. Survey areas in Coimbatore, Tiruppur, and Erode districts of Tamil Nadu, India.

2.2. Sample Collection

The BPL samples were collected following the point sample method [11]. In the current study, to collect a representative in-house litter sample, samples were collected from each of the 110 commercial broiler houses located across the three selected districts of the western agro-climatic zone between March and September 2017 at the end of the production cycle (5 to 7 weeks). To understand the physicochemical properties of BPL at the end use point where BPL was utilized as a soil amendment by the farmers after a period of storage (point of utility), 20 samples were collected from various composting yards (static composting for a period of 4–6 months) and analyzed. A representative BPL sample was carefully collected from various areas proportionately in the production house, and a total of 15 to 20 samples were randomly collected with the spade from the litter pack down to the depth of the litter. After placing the samples in a plastic pail and vigorously mixing them with a spade to break up large clumps, the manure was separated into four pieces. Two opposite pieces of the four were discarded. The remaining two parts were blended and mixed. The above method was repeated until the remaining amount of material (about 0.5 kg) was sufficient for analysis. The well-mixed sub-sample was placed in a plastic bag that was half to two-thirds full. The bag was closed and sealed when the extra air was squeezed out. The date, time, farm name, and number were all labeled on the bags. The samples were immediately used in the laboratory.

2.3. Physicochemical Analysis

The collected BPL samples were homogenized and oven-dried at 105 °C for 24 h to determine the moisture content [12,13]. The pH and EC were determined in 1:10 (w/v) aqueous extracts of the BPL sample using a digital pH and EC meter (Systronics 308 model) [14,15]. The total ash content was determined as the difference between the DM content and the gravimetric loss on ignition produced by the previously dried samples at 550 °C for 5 hr. in a muffle furnace and expressed as a percentage of residues after combustion [12,16]. The total OM/total volatile solids content was calculated with the formula Total OM = [100 − Ash%]. The total OC analysis was performed by the dry combustion method with a Van Bemelem factor of 1.8 using the formula Total OC (%) = [100 − Ash %]/1.8 [16–19]. The total Kjeldahl nitrogen was estimated by using a Keltec2100 nitrogen distillation system (FOSS), digesting the air-dried compost samples in concentrated sulphuric acid at 500 °C, and distilling and trapping the NH_3 in 0.1 N H_2SO_4 titrated against standard 0.1 N NaOH solutions [20]. The C/N ratio was computed based on the concentration of the total OC and the total Kjeldahl nitrogen [20]. The major plant nutrients, viz., total P as per AOAC 965.01 (Spectophotometric, model Lamda 25, Perkin Elmer), Ca (as per AOAC 927.02, titration method), and Mg (Gravimetric, Aoact 962.01), were analyzed as per [20], and the total potassium was analyzed using a Flame photometer [20]. The micronutrients, viz., Cu, Zn, Fe, and Mn, were analyzed using an atomic absorption photometer [20,21].

2.4. Statistical Analysis

The physicochemical properties were statistically analyzed as they were influenced by factors such as geographical location; commercial broiler integrating company; and other management factors such as the floor type, roof type, feeding method, litter material used, form of feed, watering devices used, and population size. The correlation of the physicochemical attributes was also performed. Descriptive statistics were computed for all the studied traits by adopting conventional procedures as described by Snedecor and Cochran [22]. The data on DM, moisture, ash, organic matter, organic C, pH, electrical conductivity, and N at different management conditions were analyzed using least-squares analysis of variance using SPSS software (Version 17.0), as well as using Sigmaplot for Windows (version 11.0) of Systat Software Inc. (San Jose, CA, USA).

2.5. Ethical Approval

In this experiment, no animal or human intervention investigations were conducted.

3. Results

3.1. Dry Matter

The mean ± SE (Table 1) of DM (%) in BPL collected from the surveyed geographical area was 83.04 ± 0.77 (57.85 to 94.59). The DM content of BPL was found to be significantly ($p < 0.05$) affected by the type of drinkers provided in the broiler farm (Table 2). The DM level was found to be positively correlated ($p < 0.05$) with the electrical conductivity of BPL and was found to have a highly significant negative ($p < 0.01$) correlation with moisture, pH, and Mg and Cu contents (Table 3).

Table 1. Mean (± SE) physicochemical characteristics of BPL in commercial broiler farms (n = 110).

Sl. No	Character	Mean (± SE)
1	Dry matter (%)	83.04 ± 0.77
2	Moisture (%)	16.96 ± 0.77
3	Ash (%)	27.08 ± 1.18
4	Organic matter (%)	72.92 ± 1.18
5	Organic carbon (%)	42.39 ± 0.69
6	pH	8.43 ± 0.06
7	EC (dS m^{-1})	5.74 ± 0.13
8	N (g kg^{-1})	24.2 ± 0.84
9	C:N ratio	21.42 ± 1.24

Table 1. *Cont.*

Sl. No	Character	Mean (± SE)
10	Calcium (g kg^{-1})	22.20 ± 0.72
11	Phosphorous (g kg^{-1})	11.3 ± 0.49
12	Potassium (g kg^{-1})	14.90 ± 1.17
13	Magnesium (g kg^{-1})	11.60 ± 0.12
14	Zinc (mg kg^{-1})	276.6 ± 26.50
15	Copper (mg kg^{-1})	25.01 ± 2.05
16	Manganese (mg kg^{-1})	200.3 ± 6.00
17	Iron (g kg^{-1})	2.37 ± 9.81

Table 2. Mean (± SE) of DM, moisture, ash, and organic matter at different management conditions.

Effect.	n	DM (%)	Moisture (%)	Ash (%)	OM (%)
		Mean (± SE)	Mean (± SE)	Mean (± SE)	Mean (± SE)
Overall mean	110	84.58 ± 2.56	15.42 ± 2.56	36.84 ± 3.11	63.16 ± 3.11
Geographical location		NS	NS	NS	NS
Coimbatore	55	84.23 ± 2.44	15.77 ± 2.44	37.65 ± 2.96	62.35 ± 2.96
Erode and Tirupur	55	84.93 ± 2.98	15.07 ± 2.98	36.03 ± 3.63	63.97 ± 3.63
Integrator		NS	NS	*	*
Others	10	89.12 ± 3.93	10.89 ± 3.93	41.88 ± 4.77 ^{c}	58.13 ± 4.77 ^{a}
Shanthi	68	84.79 ± 3.14	15.21 ± 3.13	32.05 ± 3.81 ^{a}	67.95 ± 3.81 ^{b}
RMP	32	79.84 ± 2.64	20.16 ± 2.64	36.59 ± 3.21 ^{b}	63.41 ± 3.21 ^{b}
Floor		NS	NS	**	**
Cement	56	83.78 ± 2.63	16.22 ± 2.63	32.58 ± 3.20 ^{a}	67.42 ± 3.20 ^{b}
Mud	54	85.38 ± 2.82	14.62 ± 2.82	41.10 ± 3.43 ^{b}	58.90 ± 3.43 ^{a}
Roof		NS	NS	NS	NS
Tiles	75	85.06 ± 2.94	14.94 ± 2.94	36.96 ± 3.57	63.04 ± 3.57
Asbestos	14	85.18 ± 3.24	14.82 ± 3.24	40.59 ± 3.94	59.41 ± 3.94
Metal	21	83.51 ± 2.83	16.50 ± 2.83	32.97 ± 3.44	67.03 ± 3.44
Extra feeding		NS	NS	**	**
No	95	84.55 ± 2.47	15.45 ± 2.47	32.07 ± 3.00 ^{a}	67.93 ± 3.00 ^{b}
Yes	15	84.62 ± 3.13	15.39 ± 3.13	41.61 ± 3.81 ^{b}	58.39 ± 3.81 ^{a}
Littering		NS	NS	NS	NS
Coir pith	105	83.51 ± 1.64	16.49 ± 1.64	34.31 ± 1.99	65.69 ± 1.99
Rice husk	5	85.65 ± 4.60	14.35 ± 4.60	39.37 ± 5.59	60.63 ± 5.59
Type of feed		NS	NS	NS	NS
Mash	33	84.65 ± 3.21	15.35 ± 3.21	39.69 ± 3.91	60.31 ± 3.91
Crumble	77	84.52 ± 2.83	15.48 ± 2.83	33.99 ± 3.44	66.01 ± 3.44
Watering		*	*	NS	NS
Automatic	77	86.97 ± 2.92 ^{b}	13.03 ± 2.92 ^{a}	35.98 ± 3.55	64.02 ± 3.55
Nipple	33	82.19 ± 2.60 ^{a}	17.81 ± 2.60 ^{b}	37.70 ± 3.16	62.30 ± 3.16
Population size		NS	NS	NS	NS
<9000	80	83.35 ± 2.41	16.65 ± 2.41	37.28 ± 2.93	62.72 ± 2.93
9001–16,800	18	83.49 ± 3.20	16.51 ± 3.20	37.77 ± 3.89	62.23 ± 3.89
>16,800	12	86.90 ± 3.61	13.10 ± 3.61	35.46 ± 4.39	64.54 ± 4.39

* $p < 0.05$; ** $p < 0.01$; NS—non-significant. Columns with the same superscript do not different significantly ($p > 0.05$).

Table 3. Correlation between different physicochemical characters of BPL.

Character	DM	Moisture	Ash	OM	C	pH	EC	N	K	P	Ca	Mg	Zn	Cu	Mn	Fe
Dry matter	1.00	−1.000 **	−0.019	0.019	0.019	−0.534 **	0.209 *	0.025	0.015	−0.103	0.006	−0.858 **	0.089	−0.248 **	−0.020	−0.088
		0.000	0.843	0.843	0.843	0.000	0.028	0.794	0.879	0.286	0.950	0.000	0.356	0.009	0.836	0.360
Moisture	−1.00 **	1.000	0.019	−0.019	−0.019	0.534 **	−0.209 *	−0.025	−0.015	0.103	−0.006	0.858 **	−0.089	0.248 **	0.020	0.088
	0.000		0.843	0.843	0.843	0.000	0.028	0.794	0.879	0.286	0.950	0.000	0.356	0.009	0.836	0.360
Ash	−0.019	0.019	1.000	−1.000 **	−1.00 **	0.199 *	−0.035	−0.450 **	0.297 **	0.006	−0.123	0.015	−0.319 **	0.175	0.182	0.144
	0.843	0.843		0.000	0.000	0.038	0.714	0.000	0.002	0.952	0.202	0.874	0.001	0.067	0.057	0.135
Organic matter	0.019	−0.019	−1.00 **	1.000	1.000 **	−0.199 *	0.035	0.450 **	−0.297 **	−0.006	0.123	−0.015	0.319 **	−0.175	−0.182	−0.144
	0.843	0.843	0.000		0.000	0.038	0.714	0.000	0.002	0.952	0.202	0.874	0.001	0.067	0.057	0.135
Organic carbon	0.019	−0.019	−1.00 **	1.000 **	1.000	−0.199 *	0.035	0.450 **	−0.296 **	−0.006	0.123	−0.015	0.319 **	−0.175	−0.182	−0.144
	0.843	0.843	0.000	0.000		0.038	0.714	0.000	0.002	0.953	0.202	0.875	0.001	0.067	0.057	0.135
pH	−0.534 **	0.534 **	0.199 *	−0.199 *	−0.199 *	1.000	−0.301 **	−0.322 **	0.102	0.152	−0.190 *	0.360 **	−0.367 **	0.182	0.045	0.054
	0.000	0.000	0.038	0.038	0.038		0.001	0.001	0.288	0.114	0.047	0.000	0.000	0.056	0.639	0.577
EC(MS)	0.209 *	−0.209 *	−0.035	0.035	0.035	−0.301 **	1.000	0.071	0.175	0.168	0.197 *	−0.084	0.132	−0.020	−0.232 *	−0.442 **
	0.028	0.028	0.714	0.714	0.714	0.001		0.464	0.068	0.079	0.039	0.385	0.168	0.834	0.015	0.000
N	0.025	−0.025	−0.450 **	0.450 **	0.450 **	−0.322 **	0.071	1.000	−0.261 **	0.142	0.404 **	−0.054	0.289 **	−0.056	−0.058	−0.091
	0.794	0.794	0.000	0.000	0.000	0.001	0.464		0.006	0.139	0.000	0.576	0.002	0.561	0.550	0.343
K	0.015	−0.015	0.297 **	−0.297 **	−0.296 **	0.102	0.175	−0.261 **	1.000	0.340 **	−0.135	0.015	−0.311 **	0.052	−0.086	−0.093
	0.879	0.879	0.002	0.002	0.002	0.288	0.068	0.006		0.000	0.160	0.878	0.001	0.593	0.371	0.334
P	−0.103	0.103	0.006	−0.006	−0.006	0.152	0.168	0.142	0.340 **	1.000	0.057	0.081	−0.209 *	−0.068	0.050	−0.253 **
	0.286	0.286	0.952	0.952	0.953	0.114	0.079	0.139	0.000		0.557	0.401	0.029	0.480	0.606	0.008
Ca	0.006	−0.006	−0.123	0.123	0.123	−0.190 *	0.197 *	0.404 **	−0.135	0.057	1.000	−0.021	0.489 **	0.034	−0.022	−0.302 **
	0.950	0.950	0.202	0.202	0.202	0.047	0.039	0.000	0.160	0.557		0.826	0.000	0.728	0.821	0.001
Mg	−0.858 **	0.858 **	0.015	−0.015	−0.015	0.360 **	−0.084	−0.054	0.015	0.081	−0.021	1.000	−0.087	0.355 **	0.051	0.046
	0.000	0.000	0.874	0.874	0.875	0.000	0.385	0.576	0.878	0.401	0.826		0.367	0.000	0.594	0.631
Zn	0.089	−0.089	−0.319 **	0.319 **	0.319 **	−0.367 **	0.132	0.289 **	−0.311 **	−0.209 *	0.489 **	−0.087	1.000	−0.149	−0.174	−0.362 **
	0.356	0.356	0.001	0.001	0.001	0.000	0.168	0.002	0.001	0.029	0.000	0.367		0.121	0.069	0.000
Cu	−0.248 **	0.248 **	0.175	−0.175	−0.175	0.182	−0.020	−0.056	0.052	−0.068	0.034	0.355 **	−0.149	1.000	0.390 **	0.324 **
	0.009	0.009	0.067	0.067	0.067	0.056	0.834	0.561	0.593	0.480	0.728	0.000	0.121		0.000	0.001
Mn	−0.020	0.020	0.182	−0.182	−0.182	0.045	−0.232 *	−0.058	−0.086	0.050	−0.022	0.051	−0.174	0.390 **	1.000	0.468 **
	0.836	0.836	0.057	0.057	0.057	0.639	0.015	0.550	0.371	0.606	0.821	0.594	0.069	0.000		0.000
Fe	−0.088	0.088	0.144	−0.144	−0.144	0.054	−0.442 **	−0.091	−0.093	−0.253 **	−0.302 **	0.046	−0.362 **	0.324 **	0.468 **	1.000
	0.360	0.360	0.135	0.135	0.135	0.577	0.000	0.343	0.334	0.008	0.001	0.631	0.000	0.001	0.000	

* $p < 0.05$; ** $p < 0.01$.

3.2. Moisture

The litter moisture content ranged between 5.41 and 42.15% (mean 16.96%). The type of floor (0.01), the provided drinkers ($p < 0.05$), and the integrating companies ($p < 0.05$) were found to have a significant ($p < 0.05$) influence on the moisture content of BPL samples (Table 2). The farms with semi-automatic bell-type drinkers had BPL with lesser moisture content than that found in farms with nipple-type drinkers. The moisture content of BPL was found to have a positive correlation ($p < 0.01$) with pH and Mg and Cu contents (Figure 2) and was found to have ($p < 0.01$) a negative correlation with DM content and EC ($p < 0.05$) (Table 3).

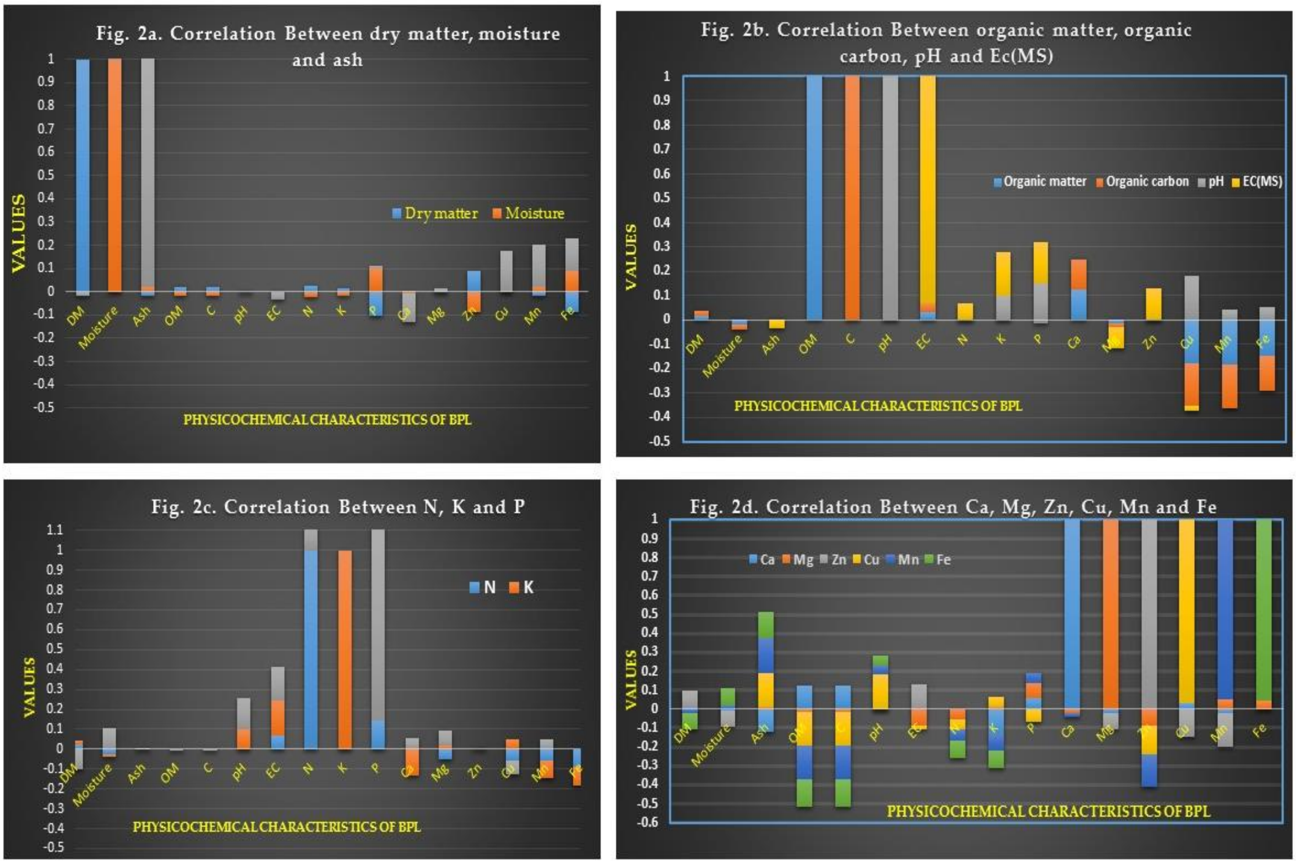

Figure 2. Correlation between different physicochemical characters of BPL. (**a**) Correlation between dry matter, moisture, and ash. (**b**) Correlation between organic matter, organic carbon, pH, and Ec(MS). (**c**) Correlation between N, K, and P. (**d**) Correlation between Ca, Mg, Zn, Cu, Mn, and Fe.

3.3. Total Ash

The mean ash content (%) in BPL was 27.08 ± 1.18. Integrating companies had a significant ($p < 0.05$) influence on ash content. Similarly, the type of floor of the broiler farms and the feeding of extra nutrients were found to have a significant ($p < 0.01$) effect on ash content, and the farms with cement floors had a lesser level of ash than those with mud floors (Table 2). The ash content was found to have a significant ($p < 0.01$) correlation with the K content of BPL and a significant ($p < 0.05$) positive correlation with the pH level of BPL (Figure 2). The ash content of BPL was found to have a highly significant ($p < 0.01$) negative correlation with the OM, OC, N, and Zn contents of BPL (Table 3).

3.4. Total Organic Matter/Total Volatile Solids

The OM of BPL was found to be affected significantly ($p < 0.05$) by integrator companies, and the type of floor and feeding of extra nutrients were found to have a highly significant ($p < 0.01$) effect on the OM of BPL. The farms with cement floors had BPL with higher levels of OM than those with mud floors. Similarly, the practice of feeding extra nutrients to the birds was also found to have a significant ($p < 0.01$) effect on the OM level of BPL (Table 2). The BPL collected from farms with the practice of feeding extra nutrients had a lesser level of OM than that found in farms without extra feeding. The OM was found to have a highly significant positive correlation ($p < 0.01$) with OC, N, and Zn content and found to have a highly significant negative ($p < 0.01$) correlation with ash content, K content (Table 3), and pH ($p < 0.05$).

3.5. Total Organic Carbon

The OC content of BPL was found to be affected by the integrator significantly ($p < 0.05$). The BPL from the farms with cement floors was found to have a significantly ($p < 0.01$) higher level of C than that of those with mud floors (Table 4). The farms with extra nutrient feeding had BPL with lower levels of C than those farms not practicing extra feeding. The C content of BPL was found to have a high positive correlation ($p < 0.01$) with OM, N, and Zn content and a negative correlation (Table 3) with ash content, K ($p < 0.01$), C, and pH ($p < 0.05$).

Table 4. Mean (± SE) of organic C, pH, electrical conductivity, and N at different management conditions.

Effect	n	OC (%)	pH	EC (dS m^{-1})	N (g kg^{-1})
		Mean ± SE	**Mean ± SE**	**Mean ± SE**	**Mean ± SE**
Overall mean	110	36.72 ± 1.81	8.57 ± 0.15	5.62 ± 0.43	19.60 ± 2.20
Geographical location		NS	NS	**	*
Coimbatore	55	36.25 ± 1.72	8.54 ± 0.14	6.07 ± 0.41 ^{b}	21.25 ± 2.10 ^{b}
Erode and Tirupur	55	37.19 ± 2.11	8.60 ± 0.18	5.17 ± 0.51 ^{a}	17.95 ± 2.57 ^{a}
Integrator		*	NS	NS	**
Others	10	33.79 ± 2.77 ^{a}	8.37 ± 0.23	5.74 ± 0.67	16.40 ± 3.38 ^{a}
Shanthi	68	39.50 ± 2.22 ^{b}	8.53 ± 0.18	5.54 ± 0.53	23.96 ± 2.70 ^{b}
RMP	32	36.86 ± 1.87 ^{ab}	8.82 ± 0.16	5.59 ± 0.45	18.44 ± 2.28 ^{a}
Floor		**	NS	NS	NS
Cement	56	39.19 ± 1.86 ^{b}	8.68 ± 0.16	5.68 ± 0.45	21.16 ± 2.27
Mud	54	34.24 ± 1.99 ^{a}	8.47 ± 0.17	5.57 ± 0.48	18.04 ± 2.43
Roof		NS	NS	NS	NS
Tiles	75	36.65 ± 2.08	8.44 ± 0.17	5.36 ± 0.50	20.20 ± 2.53
Asbestos	14	34.54 ± 2.29	8.55 ± 0.19	5.63 ± 0.55	22.13 ± 2.79
Metal	21	38.97 ± 2.00	8.72 ± 0.17	5.87 ± 0.48	16.46 ± 2.44
Extra feeding		**	NS	NS	*
No	95	39.49 ± 1.74 ^{b}	8.57 ± 0.15	5.65 ± 0.42	21.89 ± 2.13 ^{b}
Yes	15	33.95 ± 2.21 ^{a}	8.57 ± 0.18	5.59 ± 0.53	17.30 ± 2.70 ^{a}
Littering		NS	NS	NS	NS
Coir pith	105	38.19 ± 1.16	8.57 ± 0.09	5.61 ± 0.28	18.92 ± 1.42
Rice husk	5	35.25 ± 3.25	8.57 ± 0.27	5.63 ± 0.78	20.28 ± 3.96
Type of feed		NS	**	NS	NS
Mash	33	35.06 ± 2.27	8.85 ± 0.19 ^{b}	5.93 ± 0.54	17.83 ± 2.77
Crumble	77	38.38 ± 1.99	8.29 ± 0.17 ^{a}	5.31 ± 0.48	21.37 ± 2.44
Watering		NS	NS	NS	NS
Automatic	77	37.22 ± 2.06	8.52 ± 0.17	5.92 ± 0.50	18.44 ± 2.52
Nipple	33	36.22 ± 1.84	8.62 ± 0.15	5.33 ± 0.44	20.76 ± 2.24
Population size		NS	NS	NS	NS
<9000	80	36.46 ± 1.70	8.61 ± 0.14	6.08 ± 0.41	21.24 ± 2.08
9001–16,800	18	36.18 ± 2.26	8.58 ± 0.19	5.66 ± 0.54	21.14 ± 2.76
>16,800	12	37.52 ± 2.55	8.51 ± 0.21	5.12 ± 0.61	16.42 ± 3.11

* $p < 0.05$; ** $p < 0.01$; NS—non-significant. Columns with the same superscript do not differ significantly ($p > 0.05$).

3.6. pH

The mean pH level (Table 1) of BPL collected from the sampled geographical location was 8.43 ± 0.057. The pH level of BPL was found to be significantly ($p < 0.01$) affected by the type of feed fed to broilers (Table 4). The farms fed with a mash type of feed had BPL with a higher level of pH than that found in farms fed with a crumble type of feed. The pH level of BPL was found to have a highly significant ($p < 0.01$) positive correlation with moisture, Mg contents of BPL, and ash content ($p < 0.05$) and had a highly significant ($p < 0.01$) negative correlation with the DM content and the EC, N, and Zn content of BPL and also had significant ($p < 0.05$) negative correlation with the OM, OC, and Ca contents of BPL (Table 3).

3.7. Electrical Conductivity (EC)

The mean EC (dS m^{-1}) was 5.74 ± 0.13 (Table 1). The geographical location (Table 4) of the farm was found to have a highly significant influence ($p < 0.01$) on the EC level of BPL, and the BPL collected from Coimbatore district had a higher EC level than that found in BPL collected from farms in Erode and Tirupur districts. The EC level of BPL had a significant positive correlation with DM and Ca contents and was found to have a highly significant ($p < 0.01$) negative correlation with pH and Fe content and a significant ($p < 0.05$) negative correlation with moisture and Mn contents (Table 3).

3.8. Total Nitrogen

The mean N (g kg^{-1}) content in BPL samples collected (Table 1) from the surveyed area was 24.2 ± 0.84 (Figure 3) and ranged between 4.5 and 36.6. The N content was found to be significantly ($p < 0.05$) affected by the geographical location of the farm (Table 4), the practice of feeding extra nutrients to the broiler birds, and the integrator company ($p < 0.01$). The N content was found to have a highly significant ($p < 0.01$) positive correlation with OM, OC, Ca, and Zn content of BPL, and it was found to have a highly significant ($p < 0.01$) negative correlation with the ash content, pH, and K content of BPL (Table 3). The mean C/N ratio of BPL samples collected from the surveyed area was 21.42 ± 1.24, and it ranged from 7.54 to 79.74 (Table 1).

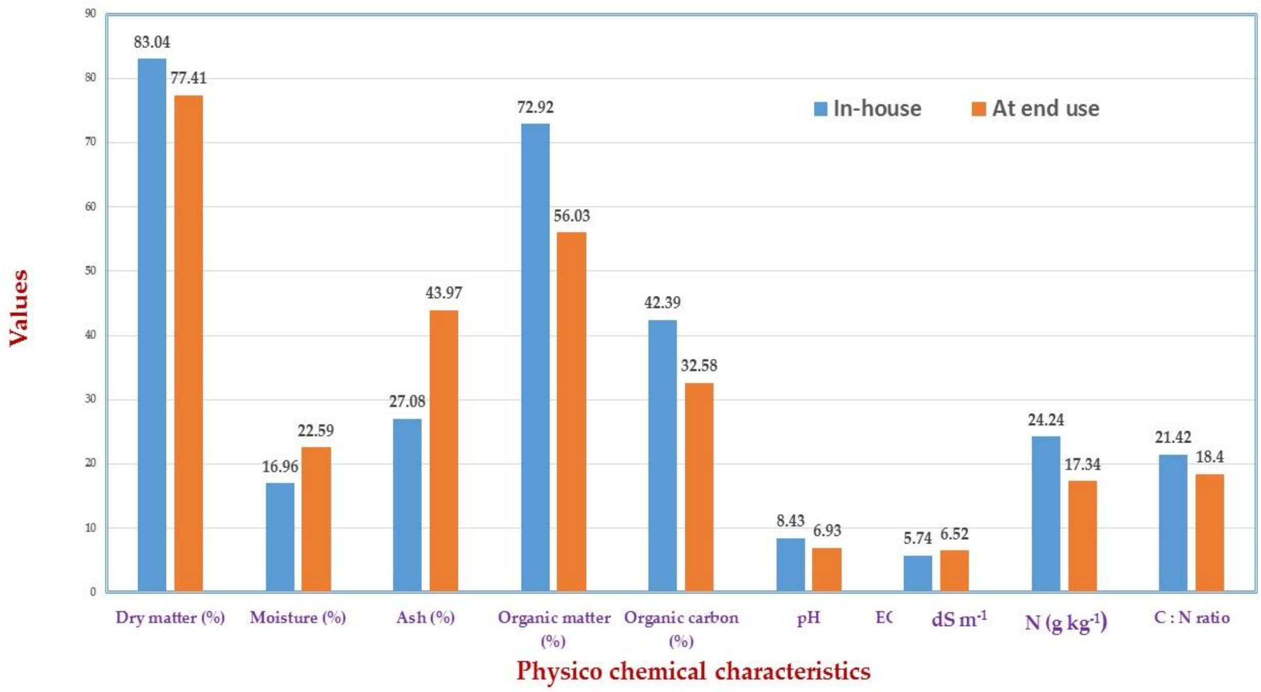

Figure 3. Change in physicochemical characteristics of BPL at various stages.

3.9. Macro Plant Nutrient Analysis

The average calcium (Ca) content in BPL samples collected from the surveyed area was 22.2 g kg^{-1} (Table 1). This Ca content was significantly influenced ($p < 0.01$) by the geographical location of the farm, the integrating company, the type of floor ($p < 0.05$), and the practice of feeding extra nutrients (Table 5). Additionally, the Ca content exhibited a highly significant positive correlation ($p < 0.01$) with N and Zn and with electrical conductivity ($p < 0.05$). Conversely, it had a highly significant negative correlation ($p < 0.01$) with the iron (Fe) content and pH levels ($p < 0.05$) of BPL (Table 3). The phosphorus (P) content in BPL ranged between 4.4 and 31.5 g kg^{-1}, with a mean value of 11.3 g kg^{-1}. The type of feed ($p < 0.01$) and floor ($p < 0.05$) significantly influenced the P content. Litter derived from mash-type feed recorded higher P content (13.95) than that derived from crumble (9.67); similarly, BPL from cement floors recorded higher P content compared with that from mud floors (Table 5). The P content of BPL showed a positive correlation ($p < 0.01$) with K content and a negative correlation with the Zn ($p < 0.05$) and Fe ($p < 0.01$) contents of BPL (Table 3). The mean K content in BPL was 14.9 ± 1.17 g kg^{-1}. Broiler sheds with cement floors had higher K content ($p < 0.01$) than those with mud floors (Table 5). The geographical location of the farm and the type of feed also influenced the variation in K content. The K content displayed a highly significant positive correlation ($p < 0.01$) with the ash and P contents of BPL and a highly significant negative correlation ($p < 0.01$) with the OM, OC, N, and Zn contents of BPL (Table 3). The Mg content in BPL was not significantly affected by any of the factors listed. However, the Mg content showed a significant positive correlation ($p < 0.01$) with the moisture content, pH level, and copper (Cu) content of BPL, while exhibiting a significant negative correlation ($p < 0.01$) with the DM content of BPL (Table 3).

Table 5. Mean (±SE) of phosphorus, potassium, calcium, and magnesium at different management conditions.

Effect	n	Ca (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Mg (g kg^{-1})
		Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Overall mean	110	19.26 ± 2.05	11.80 ± 1.10	12.11 ± 1.59	11.42 ± 0.41
Geographical location		**	NS	*	NS
Coimbatore	55	21.67 ± 1.95 ^{b}	12.34 ± 1.05	13.66 ± 1.51 ^{b}	11.43 ± 0.39
Erode and Tirupur	55	16.84 ± 2.39 ^{a}	11.28 ± 1.28	10.57 ± 1.85 ^{a}	11.41 ± 0.47
Integrator		**	NS	NS	NS
Others	10	15.15 ± 3.15 ^{a}	11.72 ± 1.69	10.96 ± 2.44	10.83 ± 0.63
Shanthi	68	24.28 ± 2.51 ^{b}	12.31 ± 1.35	13.07 ± 1.95	11.36 ± 0.50
RMP	32	18.34 ± 2.12 ^{a}	11.40 ± 1.14	12.31 ± 1.64	12.07 ± 0.42
Floor		*	*	**	NS
Cement	56	17.53 ± 2.11 ^{a}	12.74 ± 1.13 ^{b}	13.28 ± 1.64 ^{b}	11.47 ± 0.42
Mud	54	20.98 ± 2.26 ^{b}	10.88 ± 1.21 ^{a}	10.96 ± 1.75 ^{a}	11.37 ± 0.45
Roof		NS	NS	NS	NS
Tiles	75	20.54 ± 2.35	11.63 ± 1.27	11.50 ± 1.82	11.54 ± 0.47
Asbestos	14	17.89 ± 2.59	10.74 ± 1.40	11.84 ± 2.01	11.26 ± 0.52
Metal	21	19.34 ± 2.27	13.06 ± 1.22	13.02 ± 1.76	11.47 ± 0.45
Extra feeding		*	NS	NS	NS
No	95	20.96 ± 1.98 ^{b}	11.01 ± 1.06	10.77 ± 1.53	11.41 ± 0.39
Yes	15	17.55 ± 2.51 ^{a}	12.61 ± 1.35	13.47 ± 1.95	11.43 ± 0.50

Table 5. *Cont.*

Effect	n	Ca (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Mg (g kg^{-1})
		Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Littering		NS	NS	NS	NS
Coir pith	105	19.69 ± 1.32	10.83 ± 0.71	12.49 ± 1.02	11.48 ± 0.26
Rice husk	5	18.81 ± 3.68	12.79 ± 1.98	11.74 ± 2.85	11.36 ± 0.73
Type of feed		NS	**	*	NS
Mash	33	21.56 ± 2.58	13.95 ± 1.38 ^{b}	14.68 ± 1.99 ^{b}	11.43 ± 0.51
Crumble	77	16.95 ± 2.27	9.67 ± 1.22 ^{a}	9.54 ± 1.75 ^{a}	11.41 ± 0.45
Watering		NS	NS	NS	NS
Automatic	77	19.59 ± 2.34	12.68 ± 1.26	12.05 ± 1.81	11.10 ± 0.46
Nipple	33	18.92 ± 2.09	10.93 ± 1.12	12.18 ± 1.61	11.74 ± 0.41
Population size		NS	NS	NS	NS
<9000	80	19.52 ± 1.93	11.40 ± 1.04	13.03 ± 1.49	11.66 ± 0.38
9001–16,800	18	21.78 ± 2.56	12.65 ± 1.38	12.22 ± 1.98	11.46 ± 0.51
>16,800	12	16.47 ± 2.89	11.38 ± 1.55	11.09 ± 2.24	11.15 ± 0.58

* $p < 0.05$; ** $p < 0.01$; NS—non-significant. Columns with same superscript do not differ significantly ($p > 0.05$).

3.10. Micro Plant Nutrient Analysis

The Zn level of BPL was found to be significantly ($p < 0.01$) affected by the integrator company (Table 6) (Figure 4) and was found to be ($p < 0.01$) positively correlated (Table 3) with the level of OM, C, N, and Ca content. The Zn was found to be negatively ($p < 0.01$) correlated with the ash content; pH; and K, Fe, and P content of BPL ($p < 0.05$). The mean Cu content (mg kg^{-1}) of BPL collected from the surveyed area was 25.01 ± 2.05 (Table 1). It ranged between 1.43 and 135.82 mg kg^{-1}. The manure management factor did not have any influence on the Cu content of BPL.

Table 6. Mean (± SE) of zinc, copper, manganese, and iron at different management conditions.

Effect	n	Zn(mg kg^{-1})	Cu(mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})
		Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Overall mean	110	161.6 ± 81.48	19.48 ± 7.16	217.9 ± 20.30	2435.3 ± 316.435
Geographical location		NS	NS	NS	NS
Coimbatore	55	183.9 ± 77.58	19.26 ± 6.82	204.9 ± 19.33	2176 ± 301.29
Erode and Tirupur	55	139.2 ± 94.95	19.69 ± 8.34	230.9 ± 23.66	2694 ± 368.74
Integrator		**	NS	NS	NS
Others	10	23.43 ± 124.94 ^{a}	17.61 ± 10.98	215.2 ± 31.13	2746 ± 485.20
Shanthi	68	336.9 ± 99.77 ^{c}	16.16 ± 8.77	203.6 ± 24.86	1875 ± 387.45
RMP	32	124.4 ± 84.12 ^{b}	24.67 ± 7.39	235.0 ± 20.96	2683 ± 326.69
Floor		NS	*	NS	NS
Cement	56	127.8 ± 83.79	15.76 ± 7.36 ^{a}	198.7 ± 20.88	2289 ± 325.40
Mud	54	195.3 ± 89.70	23.20 ± 7.88 ^{b}	237.2 ± 22.35	2581 ± 348.35
Roof		NS	NS	NS	NS

Table 6. *Cont.*

Effect	n	Zn(mg kg^{-1})	Cu(mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})
		Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Tiles	75	190.6 ± 93.49	21.27 ± 8.22	217.1 ± 23.29	2739 ± 363.09
Asbestos	14	184.2 ± 103.17	19.83 ± 9.07	230.6 ± 25.71	2252 ± 400.67
Metal	21	109.9 ± 90.19	17.34 ± 7.92	206.2 ± 22.47	2313 ± 350.24
Extra feeding		NS	NS	NS	NS
No	95	209.4 ± 78.56	21.54 ± 6.90	216.6 ± 19.58	2462 ± 305.09
Yes	15	113.8 ± 99.74	17.42 ± 8.76	219.3 ± 24.85	2408 ± 387.33
Littering		NS	NS	NS	NS
Coir pith	105	165.6 ± 52.33	21.44 ± 4.59	200.1 ± 13.04	2278 ± 203.24
Rice husk	5	157.5 ± 146.29	17.52 ± 12.85	235.8 ± 36.45	2591 ± 568.10
Type of feed		NS	*	**	NS
Mash	33	121.7 ± 102.30	18.92 ± 8.99 ^{a}	189.5 ± 25.49 ^{a}	1867 ± 397.30
Crumble	77	201.40 ± 90.04	20.04 ± 7.91 ^{b}	246.4 ± 22.44 ^{b}	3003 ± 349.66
Watering		NS	NS	*	NS
Automatic	77	148.2 ± 92.98	17.89 ± 8.17	216.5 ± 23.17 ^{a}	2122 ± 361.08
Nipple	33	174.9 ± 82.79	21.06 ± 7.28	219.4 ± 20.63 ^{b}	2748 ± 321.55
Population size		NS	NS	NS	NS
<9000	80	110.2 ± 76.73	23.47 ± 6.74	209.1 ± 19.12	2520 ± 297.99
9001–16,800	18	171.0 ± 101.76	21.66 ± 8.94	218.2 ± 25.36	2285 ± 395.20
>16,800	12	203.5 ± 114.90	13.30 ± 10.10	226.5 ± 28.63	2500 ± 446.22

* $p < 0.05$; ** $p < 0.01$; NS—non-significant. Columns with same superscript do not differ significantly ($p > 0.05$).

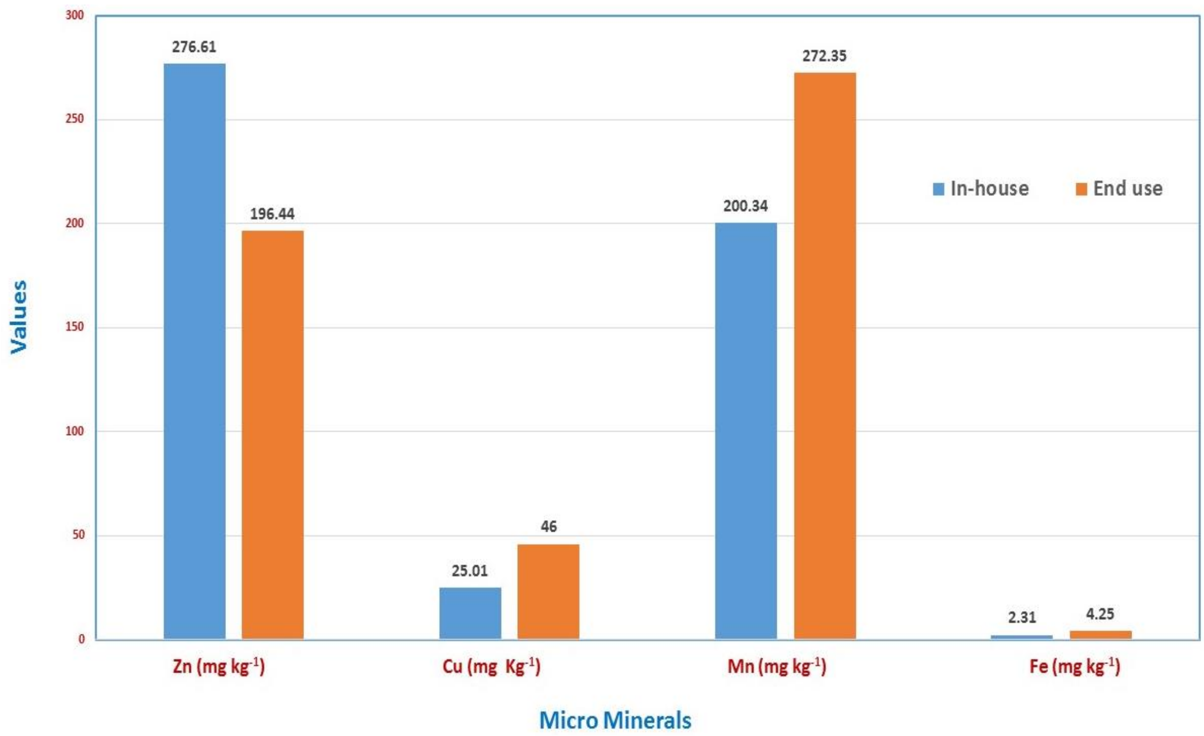

Figure 4. Micromineral profile of BPL at various stages.

The Cu content of BPL was found to be positively ($p < 0.01$) correlated with moisture and Mg, Mn, and Fe contents, and it was found to have a negative ($p < 0.01$) correlation with the DM content of the BPL sample (Table 3). The mean Mn content was 200.34 ± 6.004 mg kg^{-1} and was found to be significantly ($p < 0.05$) influenced by type of the floor in the broiler shed and the type of feed fed to the birds. The Mn content was higher in BPL samples collected from houses with mud floors and farms feeding with the crumble type of feed and was found to be positively ($p < 0.01$) correlated with the Cu and Fe content of the BPL sample. The Fe content of BPL was found to be significantly ($p < 0.01$) affected by the type of feed fed to the birds and the watering system used in the farms ($p < 0.05$). The BPL samples collected from the farms providing the crumble type of feed and semi-automatic bell drinkers had higher Fe content than others. The Fe content of the BPL sample was found to be positively ($p < 0.01$) correlated with the Cu and Mn content, and a negative correlation with EC, P, Ca, and Zn was observed.

3.11. Physicochemical Characteristics of BPL at the Point of Utility

The mean ± physicochemical characteristics of BPL at the point of utility are presented in Table 7. The mean DM and moisture content were 77.41 ± 3.95 and 22.59 ± 3.95%, respectively. The average micromineral contents of Zn, Cu, Mn, and Fe (mg kg^{-1}) at the point of utility were 196.44 ± 13.44, 46 ± 3.55, 272.35 ± 7.13, and 4245.14 ± 343.92, respectively.

Table 7. Mean (±SE) physicochemical characteristics of BPL at point of utility (n = 20).

Sl. No.	Character	Mean (±SE)
1	Dry matter (%)	77.41 ± 3.95
2	Moisture (%)	22.59 ± 3.95
3	Ash (%)	43.97 ± 4.76
4	Organic matter (%)	56.03 ± 4.76
5	Organic carbon (%)	32.58 ± 2.77
6	pH	6.93 ± 0.12
7	EC(dS m^{-1})	6.52 ± 0.82
8	N (g kg^{-1})	17.34 ± 0.63
9	C:N ratio	18.40 ± 1.12
10	Calcium (g kg^{-1})	16.51 ± 1.23
11	Phosphorous (g kg^{-1})	7.37 ± 0.16
12	Potassium (g kg^{-1})	14.52 ± 0.64
13	Magnesium (g kg^{-1})	14.41 ± 2.02
14	Zinc (mg kg^{-1})	196.4 ± 13.44
15	Copper (mg kg^{-1})	46.00 ± 3.55
16	Manganese (mg kg^{-1})	272.4 ± 7.13
17	Iron (g kg^{-1})	4.25 ± 3.43

4. Discussion

4.1. Dry Matter

The mean DM content recorded (83.04%) in this study with a range of 57.85 to 94.59% was found to be concurrent within the range (40 to 60%) reported by Kelleher et al. [23]. The average and the range found in this study were close to the results of Stephenson et al. [24], who reported (6.02 to 95.30) DM % with an average of 80.5%. Chastain et al. and Hersztek et al. [25,26] reported mean DM contents of BPL as 78.5 and 44.5%, respectively. The variation may be due to differences in the watering system, the type of shed, the type of management, and other environmental factors. The DM content of BPL was found to be affected by the type of drinker. Nipple drinkers minimized the water spillage to the litter, which was evident from the higher DM content compared with semi-automatic bell drinkers. The DM was negatively correlated with the moisture, pH, Mg, and Cu contents. Similarly, DM was found to be positively correlated with EC; this may be due to an increase in available mineral contents and consequently an increase in EC.

A negative correlation between DM and moisture indicates that when the moisture content increases, the dry matter content decreases. This is to be expected given that DM is the portion of the litter that remains after the moisture has been removed. The high moisture level dilutes the dry substance. A negative association between DM and pH indicates that when the pH of the litter rises (becomes more alkaline), the dry matter content decreases. This could be due to chemical changes in the litter, which alter its overall makeup and stability. A negative connection with magnesium suggests that higher magnesium levels are linked to reduced dry matter content. This could be because magnesium affects the physical properties of the litter or interacts with moisture. In a comparable direction, a negative association with copper suggests that the dry matter content falls as copper levels rise. This may have to do with how copper affects the stability of the litter or interacts with other materials. A significant association between the electrical conductivity of the litter and its dry matter content indicates that the two variables are positively correlated. EC gauges a solution's capacity to conduct electricity, which is frequently correlated with the amount of ions (such as salts and nutrients) present in the litter. Generally speaking, increased DM corresponds to larger concentrations of these ions, which raises the EC.

4.2. Moisture

The range of moisture content recorded in the present study (Table 1) corresponded closely with the earlier reported values [27,28]. It was not incompatible with the reports of Sistani et al., Ogunwande et al., and Gao et al. [29–31], who reported higher moisture content of 44 to 47.7, 54, 78.2, and 80.9%, respectively. The dirt floor had lower litter moisture (14.62%) than the concrete floor (16.22%), which was in agreement with Kunkle et al. [32], who reported 24.6% litter moisture on the concrete floor and 22.3% on the dirt floor. On the contrary, Abreu et al. [33] observed a similar value between the concrete floor (30.37%) and the mud floor (30.50%); the dirt floor had more possibility to absorb litter moisture than the impervious cement floor, which was the contributing factor. Similarly, the type of drinkers used in the broiler farm was found to impact the moisture content, and the BPL samples collected from the farms with nipple drinkers had higher moisture content and were in agreement with the observations of McMasters et al. [34], indicating higher water spilling with nipple drinkers. A modern nipple with a tray can solve this; even the high flow rate of the nipple may lead to higher litter moisture content [35]. Different companies maintain different production management strategies, particularly nutrient composition in the feed, which influences the moisture content of the excreta and in turn the litter moisture [36].

Significantly positive relationships were detected between the BPL moisture content and pH; Liang et al. [37] indicated that the pH increased as the litter moisture content increased, possibly due to greater NH^3 absorption and retention. Conversely, increased moisture content in litter promotes protonation to NH_4^+, which may be inversely associated with electrical conductivity due to mineral dilution in the BPL. In this analysis, Mg and Cu were the two micronutrients that had a positive correlation with litter moisture; other microminerals or macrominerals did not exert any significant correlation, but van der Hoeven-Hangoor [38] confirmed that dietary Na, protein, P, and Ca had a positive influence on excreta moisture.

4.3. Ash

The mean (27.08%) ash content recorded in BPL samples and its range (Table 1) were found to be in adherence with the ash content reported by Ogunwande et al. and Hersztek et al. [19,26], who recorded 27.32 and 16.6%, respectively. Similarly, Ogunwande et al. and

Fasina [30,39] reported 52.34 and 34.29%, respectively. Stephenson et al. [24] recorded the mean ash content of 24.37 with a range of 8.9 to 54.4%. The observed variation may be due to differences in floor type, quality of the feed ingredients, and other factors. The integrator company, floor type of the broiler farm, and practice of extra feeding had a significant effect on the ash content. This may be due to variations in the quality of the feed formulated by the integrator, the degree of scraping during the clean-out procedure, and imbalanced dilution of nutrients by feeding extra ingredients, respectively. The ash content was found to have a significant ($p < 0.01$) positive correlation with the K content and the pH ($p < 0.05$) level of BPL and have a highly significant ($p < 0.01$) negative correlation with the OM, OC, N, and Zn contents of BPL. Similarly, Stephen et al. [24] reported a positive correlation between broiler litter ash content and N, P, K, Ca, Fe, Mn, and Zn and opined that it might be due to soil contamination, but the present observation revealed that except Ca and P, other properties did not exert any significant difference due to floor type, and hence, it could be concluded that the dietary variation might be the reason for the ash content.

4.4. Organic Matter

The range of OM recorded in this study (Table 1) was consistent with the results obtained by Tiquia et al. and Brodie et al. [13,40], who recorded OM contents of BPL of 78.7 and 50.9%, respectively. The OM of the BPL samples was determined by the integrator company, the type of floor, and the practice of extra feeding, which may be due to an increase or decrease in the OM of the feed, an increase in the ash content, and the dilution effect of the practice of extra feeding, respectively. The OM had a positive correlation with OC, N, and Zn and a negative correlation with ash and K. A strong relationship between OM and OC and ash content was reported by Larney et al. [41] in feedlot manure and compost. Emeterio Iglesias Jimenez and Victor Perez Garcia [42] studied the relationship of OM to OC in municipal solid waste, compost, and city refuse compost and reported a positive correlation between OM and OC. Further, the microbial composting of BPL and the subsequent degradation of OM and mineralization of N were indicated by the positive correlation.

4.5. Organic Carbon

The mean level of OC found in the survey (Table 1) was compatible with the results of Tiquia et al., Kelleher et al., Brodie et al., and Mendonca Costa et al. [13,23,40,43], who recorded 22.72 to 41.8, 45.9, 49.1, and 28 to 40%, respectively. Similarly, Hersztek et al., Katuwal et al., and Ogunwande et al. [26,27,30] reported 32.3, 20.56 and 32.32, and 26.4%, respectively. The OC was found to be affected by the integrator company, the type of floor, and the practice of feeding extra nutrients, and the results indicated a strong relationship between the OM and OC [41].

4.6. pH

The range of pH recorded (Table 1) in the BPL samples was found to be in adherence with the reported results [13,27,28,30] and comparable with the values reported by Ogunwande et al., Kelleher et al., and Ravindran et al. [19,23,44]. The pH of BPL recorded in this study was found to be influenced by the type of feed; BPL from birds fed with mash-type feed recorded a higher pH than those fed with crumble. A strong positive correlation of pH with moisture, ash content, and Mg content was noticed. Higher moisture content favors protonation to NH_4^+, and a subsequent increase in the pH [37] might be the reason for the positivity. A higher amount of exchangeable base in the poultry manure ash was the reason for an increase in the soil pH observed by Azeez Jamiu et al. [45]. The negative correlation of the pH with DM, OM, OC, EC, N, Ca, and ZN was observed. Rogeri et al. [46] found a high negative association between pH and N while describing poultry litter in Brazil, as did Anncarol et al. [47] when composting rice straw with chicken and donkey manure. The parameters DM, OM, and OC are intimately connected, and their negative connection with pH could be attributed to OM breakdown by litter bacteria and N mineralization.

4.7. Electrical Conductivity

The PBL sample analysis revealed that the EC recorded ranged between 1.47 and 10.05 dS m^{-1} with a mean of 6.52, which was compatible with the reports of Ogunwande et al., Kelleher et al., and Katuwal et al. [19,23,27], who reported 2.0 to 9.8, 6.8, and 6.74–9.59 dS m^{-1}, respectively. It did not follow the reports of Gao et al. and Ravindran et al. [31,44], who recorded 12.4 and 2.5 to 12.0 dS m^{-1}, respectively. The geographical location of the farm was found to have a significant impact on the EC. The EC of the BPL had a positive correlation with the DM and Ca contents; dietary inclusion of Ca might influence this positivity. Similarly, EC had a negative correlation with pH, Fe, and Mn.

4.8. Nitrogen

The results found in this study were in accordance with the results of earlier workers [24,26,43,48–51]. However, they differed from the results obtained by Ravindran et al. [44]. The level of N in the BPL was determined by the geographical location of the farm and the integrator company. The N content had a positive correlation with OM, OC, Ca, and Zn contents and a negative correlation with ash, pH, and K. The positivity of TN with K was opposed to the report of Rogeri et al. [46], but the negative correlation with pH and ash content aligned with the reports of Stephen et al. [24] and Rogeri et al. [46].

The C:N ratio arrived in the study range and was found to be in adherence with the results reported by Mendonca Costa et al. and Ravindran et al. [43,44]. However, the meat value was not compatible with the values reported by Tiquia et al., Ogunwande et al., and Gao et al. [13,19,31], who reported lower C:N ratios of about 14, 14.1, and 7.48, respectively. The variation may be due to the difference in bedding material, the reuse of bedding material, and the employed storage methods.

4.9. Major Plant Nutrient Analysis

The range of Ca (10.9–47.9 g kg^{-1}) content (Table 1) found in this study coincided with the earlier reported values of Kelleher et al. (17–37), Stephenson et al. (8.1–61.3), Katuwal et al., Ravindran et al. (5.2–20.9), Bolan et al. (16.2), and Pessoa et al. (16) [23,24,27,44,49,50]. The Ca positively correlated with N, Zn, and EC and negatively correlated with Fe and pH. The level of P content observed (4.4–31.5 g kg^{-1}) was found to be in concomitance with the results reported by Bolan et al. (6.7), Hersztek et al. (18.3), Katuwal et al. (16.3–21.6), Kelleher et al. (17–37), and Stephenson et al. (5.6–39.2) [23,24,26,27,49]. However, it was not similar to the results of Pessoa et al. and Sharpley et al. [50,52], who reported slightly higher values. The lower P excretion in the BPL may be due to development in nutritional concepts such as precise P dispensing mechanisms and phytase enzyme utilization [53]. The P level in the BPL had a positive correlation with K content and a negative correlation with the Zn and Fe contents of BPL. The mean K content of 14.9 g kg^{-1} found in this study (Table 1) conformed with Kelleher et al., Pessoa et al., and Bolan et al. [23,49,50], who recorded 9–20, 7.8, and 10.12 g kg^{-1}, respectively. Stephenson et al. [24] also recorded 7.3 to 51.7, with an average of 23.2 g kg^{-1}. The K content of the BPL had a significant positive correlation with ash and P and a negative correlation with OM, OC, N, and Zn contents. The mean Mg content (10.1–16.6 g kg^{-1}) of the BPL samples from the commercial broiler poultry farms was in concurrence with Sistani et al. and Brodie et al. [29,40], and still lower values were reported by Kelleher et al. and Ravindran et al. [23,44], who reported 0.31 to 4.03, 3.5, and 5 g kg^{-1}, respectively. The factors of broiler farm management did not affect Mg, and it had a significant positive correlation with moisture, pH, and Cu and a negative correlation with DM content.

The Ca, P, and K content in the BLP was influenced by the floor type in which the birds were being reared; mud floors contributed more Ca, and cement concrete floors contributed more P and K. Similarly, the geographical location affected the Ca and K content of BPL. The nutritional aspect was also found to influence macromineral excretion; the farms that practiced feeding with the mash type of feed were found to have more P and K in BPL, and the uniformity and precision in the feeding of P and K in the crumble feed preparation might be the reason. The P had a positive correlation with K, and P and K had a negative correlation with Zn. Ca and P had a negative correlation with Fe; the interrelationship of these minerals in the broiler diet might be the reason for this correlation. The variation in macromineral composition may be attributed to the nutrient composition of the feed and the type of litter material used. The present results indicated that BPL (broiler poultry litter) contained readily available plant nutrients, offering valuable information for effective planning and utilization. The undigested and unabsorbed P, K, Ca, and Mg in the poultry manure is critical, and direct discharge may form insoluble complex such as Ca and Cu complexes, which may result in soil consolidation and water and air permeability decline [54–56]. The data generated from this research can help optimize nutrient application, minimizing excess land application and preventing potential soil and water pollution.

4.10. Micro Plant Nutrient Analysis

The Zn levels observed in the BPL samples were consistent with previous reports [29,50,57,58], who recorded Zn levels ranging between 71 and 436 mg kg^{-1}. Similar findings were also reported by Ravindran et al. and Sturgeon [44,59]. Stephenson et al. [24] recorded Zn levels between 106 and 669 mg kg^{-1}, with an average of 315 mg kg^{-1}. The Cu content of BPL obtained was in line with the findings of Hersztek et al., Tawadchai Suppadit, and Lopez-Mosquera et al. [26,28,57], who reported Cu levels of 42.0, 70.8, and 71.3 mg kg^{-1}, respectively. However, higher concentrations were recorded by Ravindran et al. and Pessoa et al. [44,50], with levels ranging from 621 to 2412 mg kg^{-1}. Stephenson et al. [24], in their survey on broiler litter, recorded Cu levels between 25 and 1003 mg kg^{-1}, with an average of 473 mg kg^{-1}. The manganese (Mn) level in this survey was within the range recorded by Stephenson [24]. Similar findings have also been reported by Tawadchai Suppadit, Lopez-Mosquera et al., and Van Ryssen [28,57,58]. However, slightly higher levels of Mn (500 mg kg^{-1}) were reported by Brodie et al. [40], and a level of 728.3 mg kg^{-1} was reported by Pessoa et al. [50]. The type of floor and feed used in the farms were found to influence the Mn content. The iron (Fe) content in the BPL samples concurred with reports by Sistani et al. and Pessoa et al. [29,50], who recorded Fe levels of 4122 and 1055 mg kg^{-1}, respectively. Lower levels were reported by Sturgeon [59] (695 mg kg^{-1}), while higher ranges were reported by Stephenson et al. [24] (529 to 12,604 mg kg^{-1}, with an average of 2377 mg kg^{-1}). Factors such as the type of feed and the watering system influenced the Fe content. Except for the influence of the integrating company (Zn), floor type (Mn), and feed type (Mn and Fe) watering method (Fe), none of the manure management factors influenced the micromineral profile. Cu, Fe, Mn, and Zn (with Fe) were positively correlated, which might be due to the natural interrelationship of these microminerals. Their relationships with microminerals are discussed in the respective chapter. Fe and Mn had a negative correlation with electrical conductivity (EC), while Zn had a negative correlation with ash, OM, and OC and a positive correlation with the pH and N content.

4.11. Physicochemical Characteristics of BPL at the Point of Utility

The DM, OM, and OC contents in BPL samples collected at the point of utility were found to be lower compared with the results obtained from the in-house BPL samples, which accounted for approximately 6.8, 19.9, and 23.15%, respectively. The reduction in these contents could be attributed to the biodegradation of OM during the storage process. This finding was consistent with the results reported by Xingjun Lin et al. [60], who observed a 20.8% DM loss and a 27% OC loss, and suggested that aerobic digestion and anaerobic decomposition might be the underlying reasons.

The pH of the in-house litter was 8.43, whereas the pH of BPL at the point of utility was 6.93, indicating a 17.79% decline. This decline suggested that the litter material reached the pH stabilization phase. The change in pH could be attributed to the transformation of N and carbon, lignocellulose carbon degradation [61,62], and the production of organic acids and carbon dioxide. However, it is noteworthy that Xingjun Lin et al. [60] observed a higher pH after the storage of chicken manure. The mean electrical conductivity (EC) (dS m^{-1}) was approximately 6.52, which was 13.59% higher than that of the in-house BPL (5.74). The higher EC could be attributed to higher OM loss and concentrations of mineral salts. This highlights the necessity of proper composting of BPL before using it as a soil amendment as safe and stable compost should ideally have an EC of 3 dS m^{-1} [63,64].

Compared with the in-house total Kjeldahl nitrogen (N) content (24.2%), there was a significant reduction in N at the point of utility (17.34%), accounting for a 28.3% loss of TKJN. The long-term storage in the open field and moisture loss during storage, combined with ammonia volatilization, could be the reasons for the N loss. Xingjun Lin et al. [60] reported a 38.6% loss of N from conventionally cage-reared poultry manure stored for 202 days and found a positive correlation between N loss and moisture content. However, in our observation, the mean moisture content of stored manure was 22.59%, which was approximately 33.12% higher than that of the in-house samples, and no significant correlation between the moisture and the N content was observed. The C:N ratio of BPL at the point of utility was 18.4, which was lower than that of the in-house BPL (21.42), accounting for a 14.1% decline. This decline was likely due to the loss of N and OM during the storage period, in agreement with Tittonell et al. [65], who reported a reduction in C:N following long-term open-air storage of cattle manure.

The long-term storage of BPL at the point of utility resulted in a high loss of macrominerals such as Ca, P, K, and Zn, at rates of 25.64, 34.78, 2.55, and 28.0%, respectively. The leaching of minerals during open-field storage may be the reason for this loss, as similarly reported by Xingjun Lin et al. [60], who found an average loss of 11% P and 10.2% K while storing chicken manure for 202 days. On the other hand, high concentrations of Mg (24.22%), Cu (83.93%), Mn (35.94%), and Fe (78.98%) were recorded, which may be attributed to the loss of OM during the long storage period.

The poultry meat industry is expanding rapidly, with an annual growth rate of 14%. Poultry meat now accounts for 40% of the total global meat consumption. However, large-scale poultry operations generate substantial volumes of waste, primarily composed of carbon (C), nitrogen (N), phosphorus (P), potassium (K), and other minerals. If not properly managed, this waste—consisting of feces, litter, feathers, and blood—can contribute to pollution, greenhouse gas emissions, unpleasant odors, and phosphorus buildup in soil (P legacy). Understanding the C, N, and P cycles is crucial when processing poultry manure through common technologies such as composting, anaerobic digestion, or thermal processes like pyrolysis and biochar production [66]. The findings of this study provide valuable insights into the physicochemical characteristics of broiler poultry litter (BPL) at various stages of its availability and utilization. One potential application of BPL is its use as a biofertilizer. By processing BPL into pellets or crumbles, the nutrient content can be precisely determined before soil application. Another promising approach is pyrolysis, which converts BPL into biochar, offering an effective way to manage waste within a circular economy framework. This study highlights the potential for further advancements in poultry litter management, particularly in terms of waste reduction, cost savings, and minimizing environmental impacts, all of which contribute to a more sustainable and circular economy.

5. Conclusions

The study revealed the type of floor in the rearing house played a vital role in the physiochemical properties of BPL, particularly on the ash, OM, OC, Ca, P, and K content; the type of drinker (nipple vs. bell-type) played a major role in litter moisture and DM. The inter-relationship between OM, OC, and N was established by its positive correlation. The BPL after prolonged storage revealed a loss of DM, OM, and OC and a substantial increase in EC, warranting proper composting before using BPL as a soil amendment. The long-term storage leads to a loss of plant nutrients like Ca, P, K, and Zn, while concentration minerals like Mg, Cu, Mn, and Fe tend to escalate.

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