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EFFECT OF PACKAGING MATERIALS ON NITROGEN RETENTION AND AMMONIA EMISSION DURING STORAGE OF PELLETIZED POULTRY DROPPINGS AMENDED WITH SINGLE SUPERPHOSPHATE

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ABSTRACT

Ammonia volatilization during storage of single superphosphate (SSP) amended pelletized poultry droppings reduces agronomic value by causing significant nitrogen loss and lowering fertilizer efficiency. This study evaluated the effect of packaging materials on nitrogen retention and ammonia emission of pelletized poultry droppings amended with SSP over six-months, using a completely randomized design (CRD) with three treatments (T_1) – black polyethylene (300-gauge), (T_2) – transparent polyethylene (300-gauge), and (T_3) – high-density polyethylene (500-gauge), each with 4 replicates. The experiment was conducted at the Faculty of Agriculture, University of Ruhuna, from February to July 2025. Initial pellets contained 2.2% total nitrogen (TN), 10.34% phosphorus, 2.82% potassium, pH 8.4, and electrical conductivity (EC) 6.13 mS/cm. TN, phosphorus, potassium, pH, EC, and ammonia emission were measured every two months. Data were analyzed using ANOVA in SAS software (version 9.1.3), with mean separation by Duncan's multiple range test at $p<0.05$. Results showed that a decline in TN was observed in all treatments, with T_2 and T_3 showing significantly higher values at 2 months (2.15% and 2.18%), while T3 maintained significantly highest TN at 4 and 6 months (2.14% and 2.11%). pH increased in all treatments with significantly higher values in T_2 (8.87 and 9.02) and T_3 (8.85, 9.07) at 2 and 4 months, while T_3 recorded the significantly highest pH (9.40) at 6 months. EC increased over time, with T_3 consistently showing the significantly highest values at all sampling intervals (7.59, 8.81, and 10.22 mS/cm). Ammonia emission decreased during storage, with T_3 exhibiting the significantly lowest values (5.67, 1.47, and 1.43 mg at 2, 4, and 6 months). These results indicate that high-density polyethylene- 500-gauge (T_3) effectively preserves nitrogen, maintains physicochemical stability, and minimizes ammonia volatilization during storage.

Keywords: Ammonia emission, Nitrogen retention, Poultry droppings, Single superphosphate, Storage

INTRODUCTION

The rapid expansion of commercial poultry production has generated large volumes of manure that require effective management to avoid environmental pollution while preserving their agronomic value. Poultry droppings are widely recognized as nutrient-rich organic amendments, typically containing 2–4% nitrogen, 1–3% phosphorus and 1–3% potassium on a dry-weight basis (Agori *et al*., 2023). They can be effectively recycled into crop production systems to improve soil health and supply essential nutrients, supporting sustainable nutrient management, particularly in regions where mineral fertilizers are costly or limited.

Among the nutrients present in poultry manure, nitrogen is the most valuable yet most vulnerable during processing and storage. Poultry manure is rich in uric acid, urea and ammonium, which are rapidly mineralized to NH_4^+ and subsequently volatilized as NH_3 under aerobic conditions (Kacprzak *et al*., 2023). During composting, ammonia volatilization is frequently the dominant nitrogen-loss pathway, accounting for up to 79–94% of total nitrogen loss (Zhao *et al*., 2025), and unamended poultry litter can lose 17–60% of its nitrogen as NH_3 alone (Agyarko-Mintah *et al*., 2017). Such losses reduce fertilizer value and contribute to atmospheric pollution and secondary particulate formation, creating both agronomic and environmental concerns. Consequently, considerable attention has been given to mitigation strategies such as moisture management, aeration control and chemical amendments (Chang *et al*., 2020; Ma *et al*., 2022; Xue *et al*., 2025; Anderson *et al*., 2020).

Phosphatic and acidifying additives have shown particular promise in conserving nitrogen during manure stabilization. SSP, a mixture of monocalcium phosphate and gypsum (Powlson and Dawson, 2022), can reduce ammonia volatilization by lowering pH and promoting the formation of relatively stable ammonium-phosphate complexes (Luo *et al*., 2012). Studies on pig and poultry manures indicate that phosphatic amendments can significantly suppress gaseous nitrogen losses while improving the phosphorus content of the final product (Wu *et al*., 2019). However, while the benefits of such amendments during composting are increasingly documented, far less attention has been directed toward nitrogen stability after stabilized materials are converted into marketable fertilizer forms.

Pelletization has become an important upgrading technology for organic residues because it improves bulk density, flowability and ease of mechanical application (John *et al*., 1996). The process typically involves drying to low moisture contents and mechanical densification, which can restrict microbial activity and slow nutrient transformations (Widyowanti *et al.*, 2021; Monaci *et al.*, 2022). Nevertheless, pelletized fertilizers are not chemically inert, and continued mineralization or volatilization during storage particularly under warm and humid conditions may compromise nutrient quality prior to field application. Pawłowska et al. (2019) demonstrated that storage conditions can alter moisture content, enzymatic activity and nitrogen status in pelletized waste-derived fertilizers, indicating ongoing biological and chemical processes during shelf life.

Packaging and storage environment therefore represent critical control points in the post-processing phase of organic fertilizers. Materials with high permeability to water vapor and oxygen may allow moisture ingress and microbial activity, accelerating nitrogen loss, whereas dense multi-layer materials can restrict gas exchange and prolong shelf life (Pawlowska *et al*., 2019). Despite their importance for commercialization, systematic evaluations of packaging effects on ammonia emissions and nutrient retention in pelletized poultry manure remain scarce, particularly in tropical production systems.

Accordingly, the present study investigates the influence of different packaging materials on ammonia volatilization, nutrient dynamics and physicochemical stability of pelletized poultry droppings amended with single superphosphate during six months of storage. Identifying storage systems that maximize nitrogen conservation and preserve fertilizer quality will contribute to more efficient poultry-waste recycling and support the development of reliable organic fertilizer products for sustainable crop production.

MATERIALS AND METHODS

The experiment was conducted at the Faculty of Agriculture, University of Ruhuna, Sri Lanka, from February to July, 2025. Storage trials were maintained in a cool, dry, and dark environment. Poultry droppings were collected from layer hens within seven days and 5 kg of droppings per pile were used. SSP was added at 30% of the dry weight of poultry droppings, as identified in a previous experiment as the optimum level (Sampath *et al*., 2025). The mixture was decomposed for 42 days under a cool, dark environment. The piles were turned on the 14th, 28th, and 42nd days, and moisture content was maintained at 55– 60% using water. Moisture content of the stabilized material was adjusted before pelletization using a die and roller type pelleting machine. Uniform pellet size and compression pressure were maintained throughout the process. The experiment was arranged in a completely randomized design (CRD) with four replicates per treatment. Equal quantities of pellets (50 g per replicate) were sealed in three types of packaging: black polyethylene bags (300-gauge), transparent polyethylene bags (300-gauge), and high-density polyethylene bags (500-gauge). All samples were stored for six months, during which nitrogen content, phosphorus, potassium, pH, electrical conductivity, and ammonia emission were monitored at two-month intervals. Pellet pH and electrical conductivity were measured in a 1:10 pellet-to-water suspension using a pH meter (HANNA) and an EC meter (EUTECH, PC 700). Ammonia emission was quantified using an enclosure venting method (Yang *et al.*, 2018), total nitrogen was determined by the Kjeldahl procedure (Bremner and Mulvaney, 1982), phosphorus was measured using the Olsen method (Olsen, 1954), and potassium was analyzed with a flame photometer (Dharmakeerthi *et al*., 2007). Data were analyzed using analysis of variance (ANOVA) in SAS 9.1.3, and means were separated using Duncan's multiple range test (DMRT) at $p < 0.05$

RESULTS AND DISCUSSION

Immediately after pelletization, the pelletized poultry droppings contained 2.2% Total nitrogen (TN), 10.34% available phosphorus (P), 2.82% potassium (K), a pH of 8.4, and an Electrical conductivity (EC) of 6.13 mS/cm.

Available phosphorus and potassium

Available P and K contents remained essentially unchanged (10.34% and 2.82%) during the six-month storage period, indicating their stability.

Total Nitrogen Variation

Packaging material significantly influenced TN retention during storage ($p<0.05$) (Table 1). A gradual decline in TN was observed in all treatments over the six-month period. At the 2nd month of storage, TN was significantly higher in T_2 (Transparent polyethylene, 300 gauge) at 2.15% and T_3 (High-density polyethylene, 500 gauge) at 2.18%. By the 4th and 6th months, T_3 consistently retained the significantly highest TN (2.14% and 2.11%, respectively). The enhanced TN retention observed in T_3 is primarily attributed to the thicker and denser high-density polyethylene (HDPE) film, which provides an effective barrier against gas and water-vapor exchange. This may limit ammonia (NH_3) volatilization and potentially slow nitrification–denitrification reactions, which could contribute to the reduced conversion of organic nitrogen into gaseous forms (Manka'abusi *et al*., 2025). In addition, the stable moisture environment and reduced aeration associated with HDPE packaging suppress microbial activity and nitrogen mineralization, preserving a larger proportion of organic nitrogen within the pellets (Monaci *et al.*, 2022). The combination of low permeability and microenvironment stability not only reduces nutrient losses but also prolongs the shelf life and fertilizer quality of the stored pellets. In contrast, black 300-gauge polyethylene may absorb more solar radiation, potentially raising the internal temperatures and accelerating the breakdown of organic nitrogen into NH_4^+ and NH_3. The relatively thin and more permeable film further exacerbates nitrogen loss by allowing greater ammonia diffusion into the environment, resulting in the highest observed TN loss among all treatments (Qiu *et al.*, 2021)

Table 1. Total Nitrogen (%) of pelletized poultry droppings under different storage packaging over six months of storage

Treatment	2 months	4 months	6 months
T_1 (Black polyethylene-300 gauge)	2.09 ± 0.01^{b}	1.94 ± 0.02^{c}	1.83 ± 0.01^{c}
T_2 (Transparent polyethylene-300 gauge)	2.15 ± 0.04^{a}	2.07 ± 0.01^{b}	2.02 ± 0.02^{b}
T_3 (High-density polyethylene-500 gauge)	2.18 ± 0.05^{a}	2.14 ± 0.02^{a}	2.11 ± 0.04^{a}

Values represent mean ± standard error. Means followed by the same superscripts in a same column are not significantly different at 0.05 probability level according to DMRT at $P<0.05$.

pH Variation

Pellet pH increased progressively during the six-month storage period in all treatments (Table 2). At the 2nd month, higher pH values were observed in T_2 (8.87) and T_3 (8.85). By the 4th month, T_2 (9.02) and T_3 (9.07) remained higher pH. At the 6th month, T_3 recorded the highest pH (9.40). The gradual rise in pH can be attributed to ongoing microbial decomposition of uric acid, urea, and proteins present in poultry droppings. Urea and uric acid hydrolysis produce ammonium (NH_4^+) and ammonia (NH_3), both of which contribute to alkalinity and increase pH (Buoio *et al.*, 2025). Similarly, protein degradation by spoilage microorganisms generates amines and ammonia, which are basic compounds that further elevate pH during storage (Takma and Korel, 2019). The accumulation of these volatile basic nitrogen compounds (NH_3 and amines) results in an upward shift in pH, a pattern commonly observed in stored organic materials (Akbari and Mehregan, 2025). The highest pH recorded in T_3 (high-density polyethylene, 500 gauge) can be explained by its thicker and denser film structure, which has very low gas permeability. This property limits the diffusion of ammonia and amines to the external environment, causing these alkaline compounds to accumulate within the packaging and thereby increasing the measured pH of the pellets (Guzman-Puyol *et al*., 2022). In contrast, the thinner 300-gauge films used in T_1 and T_2 exhibit higher permeability, allowing more NH_3 to escape and moderating the internal pH increase (Douglas *et al*., 2025).

Table 2. pH of pelletized poultry droppings under different storage packaging over six months of storage

Treatment	2 months	4 months	6 months
T_1 (Black polyethylene-300 gauge)	8.72 ± 0.05^b	8.87 ± 0.02^b	9.02 ± 0.02^c
T_2 (Transparent polyethylene-300 gauge)	8.87 ± 0.05^a	9.02 ± 0.04^a	9.27 ± 0.01^b
T_3 (High-density polyethylene-500 gauge)	8.85 ± 0.02^a	9.07 ± 0.03^a	9.40 ± 0.02^a

Values represent mean± standard error. Means followed by the same superscripts in a same column are not significantly different at 0.05 probability level according to DMRT at P<0.05.

EC Variation

Electrical conductivity (EC) increased significantly ($p < 0.05$) over the six-month storage period in all treatments (Table 3). T_3 consistently recorded the highest EC values (7.29, 8.81 and 10.22 mS/cm, respectively).

Table 3. Electrical conductivity (mS/cm) of pelletized poultry droppings under different storage packaging over six months of storage

Treatment	2 months	4 months	6 months
T_1 (Black polyethylene-300 gauge)	6.00 ± 0.05^c	7.52 ± 0.09^c	8.93 ± 0.05^c
T_2 (Transparent polyethylene-300 gauge)	6.67 ± 0.04^b	8.19 ± 0.08^b	9.60 ± 0.01^b
T_3 (High-density polyethylene-500 gauge)	7.29 ± 0.06^a	8.81 ± 0.06^a	10.22 ± 0.02^a

Values represent mean ± standard error. Means followed by the same superscripts in a same column are not significantly different at 0.05 probability level according to DMRT at P<0.05.

The increase in EC can be attributed to microbial degradation of organic carbon and nitrogen compounds into soluble inorganic ions such as NH_4^+, NO_3^-, PO_4^{3-}, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-}. The accumulation of these ions increases the ionic strength of the solution phase, thereby elevating EC. Similar trends have been reported in composts and poultry litter, where EC rises during composting due to the formation and accumulation of soluble ammonium and other nutrient salts as organic matter decomposes (Masin *et al.*, 2020).

Ammonia Emission

Ammonia emission differed significantly ($p < 0.05$) among packaging treatments throughout the storage period (Table 4). At two months, the highest emission was observed in T_1 (Black polyethylene, 300 gauge) at 7.12 mg, and T_2 (Transparent polyethylene, 300 gauge) at 6.56 mg. Although ammonia emission declined at four months in all treatments, T_1 still showed the significantly highest value (3.94 mg), and this trend continued at six months, where T_1 again recorded the highest emission (4.85 mg). Ammonia volatilization is primarily governed by the production of ammonium (NH_4^+) during organic nitrogen mineralization and the ease with which ammonia (NH_3) can diffuse from the material to the surrounding air (Oliveira *et al.*, 2021). The superior performance of T_3 can be attributed to the barrier properties of 500-gauge high-density polyethylene, which has low gas permeability. This thicker film restricts NH_3 diffusion, allowing a portion of the ammonia formed inside the pellets to remain within the package, dissolve back into moisture, or convert to NH_4^+, thereby reducing net emission. Additionally, reduced water vapor loss in HDPE packaging maintains slightly higher internal humidity, favoring the ionic NH_4^+ form over gaseous NH_3 and further suppressing volatilization.

Table 4. Ammonia Emission (mg) from Pelletized Poultry Droppings under Different Storage Packaging over Six Months of Storage

Treatment	2 months	4 months	6 months
T_1 (Black polyethylene-300 gauge)	7.12 ± 0.36^a	3.94 ± 0.19^a	4.85 ± 0.23^a
T_2 (Transparent polyethylene-300 gauge)	6.56 ± 0.45^{ab}	2.54 ± 0.19^b	2.37 ± 0.23^b
T_3 (High-density polyethylene-500 gauge)	5.67 ± 0.56^b	1.47 ± 0.08^c	1.43 ± 0.07^c

Values represent mean ± standard error. Means followed by the same superscripts in a same column are not significantly different at 0.05 probability level according to DMRT at P<0.05.

CONCLUSIONS

Packaging material significantly influenced the nutrient retention and ammonia emissions of pelletized poultry droppings over six months. High-density polyethylene (HDPE, 500-gauge) consistently retained the highest total nitrogen, maintained higher pH and electrical conductivity, and minimized ammonia losses compared with 300-gauge black or transparent films. These results indicate that HDPE packaging is the most effective for preserving fertilizer quality during storage. Practical significance is that using HDPE bags can improve nitrogen retention, reduce environmental ammonia emissions, and enhance the shelf life and usability of pelletized poultry droppings as an organic fertilizer.

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