Chapter 3

Nitrogen Emissions and Mitigation Strategies in Chicken Production

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Additional information is available at the end of the chapter

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Abstract

Air emissions from feeding operations and manure management in chicken production are among the major sources of environmental concerns globally. Nitrogen emissions in chicken production occur in several forms but mainly ammonia can contribute directly or indirectly to several environmental and public health hazards. Chicken production also contributes to some extent to climate change through the emissions of nitrous oxide, fine particulate matters, and methane. Emissions and nutrient losses take place in different systems and at every stage of chicken production operations. To effectively reduce the environmental impact of chicken production, appropriate measures should be taken across the chicken supply and manure management chain. Nutritional and manure management strategies for mitigating nitrogen emissions in chicken production are discussed. Challenges associated with the adoption of some of the mitigation strategies are identified and measures to address them are suggested. Co-benefits of mitigating nitrogen emissions in chicken production to the planet, the people and the producers are numerous.

Keywords: nitrogen, emissions, chicken, manure, feeding strategies

1. Introduction

Chicken production is an important source of nutrition and livelihood all over the world. Over the years, significant improvement has been achieved in chicken production, and it is one of the fastest growing sub-sectors of the livestock industry. Chicken production therefore holds great potentials in meeting the increasing demand for animal protein, such as meat and egg, arising from population growth and changing consumer preferences. However, in addition to the production objectives of ensuring profitability and quality, environmental sustainability must be given paramount consideration so as to ensure that production practices benefit the people, the planet, and the business without jeopardizing future utilization of resources.

Air emissions and manure handling in chicken production are among the major sources of environmental concerns globally. Ammonia, nitrous oxide (N_2O), and other oxides of nitrogen (NO_x) are nitrogenous emissions of concern in broiler and layer production systems, while methane, particulate matters, and black carbon emissions also occur. The potential sources of environmental footprint (particularly relating to carbon, nitrogen, phosphorous, particulate matters and micro-organisms) in the animal feeding operations include the animal, type of feed, manure, and housing accessories including bedding and heating materials [1]. Although poultry supply chain is not the main source of greenhouse gases (GHGs) emissions, emissions intensity or emissions per unit of output is significant and needs to be mitigated through adequate measures. This is because the growth forecast in global demand for chicken meat and egg between 2005 and 2030 is 61 and 31%, respectively [2]. This means if appropriate measures are not taken to reduce the emission intensities of these products, production increases required to meet the risen demand will be proportionate to GHGs emissions growth, and this kind of trend is not desirable.

Improved feeding practices, utilization of specific agents, long-term management practices, and animal breeding strategies are some categories of measures that could be employed to mitigate emissions from animal production operations, including chickens [3]. Feed management practices including those that reduce the oversupply of protein and amino acids in the diets are perhaps the most important measure to mitigate nitrogen emissions in chicken production. Reduction of dietary supply of protein and amino acids to chicken is possible because birds have been selected and bred for improved feed conversion efficiency and growth over the years. Also, feeding feed supplements that could enhance the utilization of the diets thereby reducing nutrient excretions by the chicken is also an effective emission mitigation strategy. Enzymes can also contribute to nutrient excretion reduction in chickens. Enzymes reduced the variability in the nutritive values between feedstuffs and improved the accuracy of feed formulation, thereby aiding management and profitability of poultry feeding operation [4]. Specific agents could also be used for manure amendments in order to reduce the volatilization of already excreted nutrients, particularly nitrogen in from of NH_3 and N_2O. This chapter discusses nitrogenous emissions, associated hazards, and some emissions mitigation strategies, particularly feeding and manure management approaches, in chicken production. Some reported undesirable effects of feeding low-protein diets, and measures taken to correct them are also presented.

2. Emissions in poultry supply chain

Emissions of different types and magnitude take place throughout the entire chicken supply chain. Therefore, for emission mitigation strategies to be effective, the important sources across the chicken value chain must be taken into account. Nutrient losses from chicken supply chains can be air emissions such as CH_4, N_2O, and NH_3 or to water sources by leaching of e.g. NO_3^- and P_2O_5 through the soil and by run-off (including intended discharge) [5], and some of these important emissions are briefly discussed (**Table 1**).

Agricultural sector ammonia emission is mainly from livestock operations manure management and chemical fertilizers. Globally, chickens are among the most important contributors to ammonia emissions. Significant portions of nitrogen excreted in chicken production are emitted into the atmosphere in the form of ammonia, which is formed as a result of microbial activities, although limited losses in form of N_2O and NO_3 also occur [6]. Poultry excretions contain high concentration of uric acid which is transformed into urea through aerobic decomposition. When mixed with urease present in the fecal material, urea N can quickly be transformed into highly volatile ammonia and easily diffused into the surrounding air. High temperatures, pH, wind velocity, and urease activity, as well as large surface area for emissions, enhance the volatilization of ammonia in chicken manure [7]. Without taking measures to modify nutrient excretion, as much as 18–41% of fecal N could be lost into the atmosphere in the form of NH_3 and other nitrogenous compounds [8].

Concentrations of ammonia are usually considerably high near the animal facilities due to increased deposition. However, ammonia concentration in the atmosphere reduces as the distance away from the animal facilities increases. Reduction in atmospheric ammonia concentration can be up to 50–70% at a distance of 0.4–4 km away from the animal facility [9]. Accordingly, the mass of ammonia nitrogen expected to be deposited in the soil around sources such as chicken and manure storage facility decreases as the distance increases.

Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are also emitted in chicken production, although the contributions are significantly lower than

Emissions	Remarks
Methane (CH_4)	This is a combustible greenhouse gas, and it is 28 times more powerful than CO_2. It is produced from the decaying organic matter in manure stored under oxygen-free conditions
Nitrous oxide (N_2O)	This is a greenhouse gas, and it is 265 times more powerful than CO_2. It is an intermediate product during the nitrification of NH_4^+ into NO_3^-; and during the denitrification of NO_3^- in manure applied to soils low in oxygen (e.g. waterlogged areas)
Ammonia (NH_3)	An aggressive and acidifying gas, which is a product from urea degradation in manure (and urine). It causes respiratory problems in humans and animals and acidification of soils when deposited
Nitrate (NO_3^-)	It is formed in the soil by nitrification of NH_4^+/NH_3 after manure application. It is a water-soluble ion which is prone to leaching. Concentration in high quantity in potable water may lead to nitrite poisoning (NO_2^-) causing an oxygen deficit in the blood of humans and animals
Phosphate (P_2O_5)	It is from superficial run-off of manure and/or from leaching of the water-soluble form. It causes eutrophication of open waters (dense growth of algae and death of fish from subsequent lack of oxygen)

Source: [5].

Table 1. Some important gaseous emissions in chicken supply chain.

those of ruminants. The Global Life Cycle Assessment of emissions from chicken supply chain revealed some important information that could contribute to the effective mitigation of emissions and reduction of emissions intensities (**Table 2**). The chicken supply chain is responsible for about 606 million tonnes CO_2-eq of GHG emissions, representing about 8% of the total emissions from livestock sector [10]. Thus, chicken supply chains account for a quantity of GHGs emissions that warrant giving attention to its mitigation. Therefore, to be effective, mitigation strategies should target major emission sources along the chicken meat and eggs value chains. By emission category in the chicken supply chains, major sources of proportion are CO_2 (meat, 59.4%; eggs, 48.9%) and N_2O (meat, 36.5%; eggs, 40.1%) (**Table 3**).

Emission of N_2O from chicken manure management depends on the composition of the feces, microbes, and enzymes involved and the conditions of the feces after excretion. Mostly, N_2O are emitted as an intermediate product during nitrification and denitrification reactions, leading to nitrate reduction in some litter system. However, it is possible to store manure in a way that minimizes nitrogenous emissions. There is a trade-off between methane and nitrous oxide emissions because while handling of chicken manure under anaerobic conditions leads to the production of methane, management under aerobic conditions with pockets of anaerobic conditions encourages N_2O volatilization.

The composition of diets and the efficiency of its conversions to meat and/or egg affect the quantity, physical, and chemical properties of chicken manure and in turn the potential

System	Production (million tonnes)		Emissions (million tonnes CO_2-eq)		Emission intensity (kg CO_2-eq/kg product)	
	Eggs	Meat	Eggs	Meat	Eggs	Meat
Backyard	8.3 (14.3%)	2.7 (3.7%)	35.0 (16.1%)	17.5 (4.5%)	4.2	6.6
Layers	49.7 (85.7%)	4.1 (3.8%)	182.1 (83.9%)	28.2 (7.2%)	3.7	6.9
Broilers		64.8 (90.5%)		343.3 (88.3%)		5.3
Total	58.0 (100%)	71.6 (100%)	217.0 (100%)	389.0 (100%)	3.7	5.4

Source: [10].

Table 2. Global production, GHG emissions, and emission intensity for chickens.

Class of emission	Meat	Eggs	Sources
CO_2 emissions	59.4	48.9	Feeds, LUC soy bean, direct energy, postfarm
CH_4 emissions	1.6	9.0	Manure management
N_2O emissions	36.5	41.0	Applied and deposited manure, fertilizer and crops residue, manure management
Others	1.4	1.1	Feeds, rice CH_4 and indirect energy CO_2

Source: Based on [10].

Table 3. Global emissions from chicken meat and egg supply chain by category of emissions (%).

emissions [1]. Similarly, manure handling and environmental conditions would affect chemical and physical properties of the manure, that is, its chemical composition, biodegradability, microbial populations, oxygen content, moisture content, and pH [11].

3. Nitrogen excretions in chicken production

Annual manure excretions by species show that chicken production ranks in terms of manure turnout. It is evident that when compared with other categories of livestock, either on an individual basis or as a group, each chicken type animal unit is a major contributor to manure excretions (**Table 4**). The quantity of manure excreted by the animal also has far-reaching implications for the overall nutrients excreted into the environment. Depending on the efficiency of nutrient utilization, 50–80% of the nitrogen supplied in animal diets may be excreted [12] and more than 70% of the total nitrogen excreted in poultry is uric acid, which is rapidly converted to ammonia through the process of hydrolysis [13]. Therefore, chicken feces with higher proportion of total ammoniacal nitrogen will tend to emit ammonia more quickly and in higher quantities.

Nitrogen excretion in chicken production is largely influenced by over supply of protein and/or amino acids in the diets, although there may be other factors, and it is a major contributor to other nitrogenous emissions emanating from manure handling and production. Oversupply of dietary protein and some amino acids is a common practice which stems from the attempts to meet the requirements of the birds at various stages of growth, that is, starter, grower, and finisher phase [15]. A typical 23% crude protein diet contains significant quantity of amino acids in excess of requirement [8]. The requirement for protein in chicken is essentially the requirements for amino acids. Protein fed to chickens is absorbed for various metabolic functions in

Species of animal	Number of animals per animal unit (AU) (an AU 1000 lbs)	Annual manure production in tons per animal unit	Rank in terms of manure production per animal unit
Beef cattle	1.00	11.50	4th
Dairy cattle	0.74	15.24	1st
Swine (breeders)	2.67	6.11	9th
Swine (others)	9.09	14.69	3rd
Hen (laying)	250.00	11.45	5th
Pullets (over 3 months)	250.00	8.32	6th
Pullets (under 3 months)	455.00	8.32	6th
Broilers	455.00	14.97	2nd
Turkey (slaughter)	67.00	8.18	8th

Based on [14].

Table 4. Annual manure production estimates from livestock species per animal unit.

the body in the form of amino acids. Excess protein consumed is stored in the form of glucose or fat. In the event that amino acid is converted to glucose or fat, nitrogen is first removed in the liver and converted to urea. The urea is transported to kidney for elimination from the body in the form uric acid in the case of chickens. Such oversupply of nutrients is not necessary as it amounts to increased production costs, constitutes a drain on profitability, wastage of scarce and expensive resources, and reduced production efficiency, and contributes to environmental challenges associated with chicken production. A significant amount of protein fed to chicken is excreted in diverse forms of nitrogen, and this could be volatilized into the atmosphere through some biological processes (**Table 5**). It is possible to exceed the threshold concentration of both oxidized and reduced forms of nitrogen and these have consequences for the planet, the people and the chickens (which translates to negative effect on the profitability of the chicken enterprise). Some of such consequences include respiratory diseases caused by exposure to high concentrations of fine particulate matters, contamination of drinking water by nitrates, eutrophication of surface water bodies leading to harmful algal blooms and decreased water quality, changes in vegetation or ecosystems as a result of higher concentration of nitrogen, climatic change associated with increases in nitrous oxide in the atmosphere, nitrogen saturation in forest soils, and soil acidification through nitrification and leaching.

On fresh basis, chicken raised under the extensive system excretes an estimated 4.5% of its body weight and 0.02–0.15 kg/bird/day [5]. Diets, housing system, manure handling method, and season of the year are among the factors affecting nitrogenous emissions in animal production [17]. In addition, available fecal nitrogen can determine the extent of ammonification, nitrification, and denitrification. Thus, the proportion of nitrogen volatilized into the atmosphere differs with manure type, manure management practices, and increases with the length of storage (**Tables 5** and **6**).

Manure type	DM content (%)	Typical loss % total N	Range % total N	N form lost*
Type of poultry housing				
Poultry, high rise	—	50	40–70	NH_3
Poultry, deep litter	—	40	20–70	NH_3, N_2O, N_2
Poultry, cage and belt	—	10	4–25	NH_3
Poultry, aviary	—	30	15–35	NH_3, N_2O
Long term storage system				
Solid heap, poultry	50	10	5–15	NH_3, NO_3, N_2O
Solid compost	40	40	20–50	NH_3, NO_3, N_2O
Slurry tank, top loaded	10	30	20–35	NH_3
Slurry tank, bottom loaded	10	8	5–10	NH_3
Slurry tank, enclosed	10	4	2–8	NH_3
Anaerobic lagoon	5	70	50–99	NH_3, N_2, N_2O

Source: [16]*N forms are listed in order of the expected quantity lost, with most of the loss being in the form of NH_3.

Table 5. Typical losses of long-term manure storage used in animal production expressed as a percentage of total nitrogen entering storage.

Application method	Semisolid manure	Liquid slurry	Lagoon liquid	Dry litter
Injection		5	5	
Broadcast with immediate incorporation	25	25	10	10
Incorporated after 2 days	35	35	20	20
Incorporated after 4 days	60	60	40	35
Incorporated after 7 days or never incorporated	75	75	55	50
Irrigation without incorporation		80	50	

Source: [5, 18].

Table 6. Relative NH_4^+-N losses of some field practices as percentage of the total NH_4^+-N.

4. Challenges associated with nitrogen emissions in chicken production

Several challenges are associated with nitrogen excretions and/or emissions in chicken production. Air emissions and fecal minerals emanating from intensive chicken operations could have serious environmental consequences when poorly managed. Frequent complaints against animal-based industries are mainly associated with dust, odors, and bio-aerosols. For example, microbes, endotoxins, and mycotoxins are suspended in air, which are generated in production and manure storage facilities, as well as during land spreading of poultry litter [19]. An efficient handling of nutrients at all the stages of production is critical to reducing the release of nitrogenous and other emissions into the environment.

4.1. Some potential hazards associated with nitrogen excretions

Several hazards to personal safety are known to be associated with liquid manure storage facilities. Depending on the gas concentration and length of exposure, symptoms ranging from headaches and eye irritation to death can be caused by gases such as hydrogen sulfide and ammonia in such facilities. It is therefore advisable to wear appropriate protective respiratory equipment when entering an enclosed area that contains manure. However, nitrogenous emissions are also of considerable concerns outside the manure management and storage facilities.

Nitrogen excretions could also lead to degradation of ground and surface waters through contributions to nitrate runoff and nutrient loading. This is particularly important because chicken manure is also a rich source of several other elemental minerals/nutrients, which could find their ways into the ecosystem. Some of these nutrients rich in chicken manure include sodium (Na), potassium (K) phosphorous (P), magnesium (Mg), calcium (Ca), and sulfur (S). Therefore, the nutrient profile of chicken manure makes it valuable for use in crop and livestock production and at the same time a potential source of hazards (**Table 7**). About 30–50% of total N in chicken manure is readily available as a nutrient to plant [20]. However, due to limited availability of land and lack of nutrient test to determine requirements before applications, soils applied with chicken manure could have excess N and P [21]. Consequently, mineral nutrients from chicken manure are potential environmental risk factor, especially in soil and water pollution. Risks of nutrients, organic material, and pathogens contaminating water bodies are common with increased manure spread.

4.2. Some potential hazards associated with ammonia emissions

Ammonia is a major harmful gas associated with chicken production. Poultry production has the potential to be a large contributor of ammonia, which plays critical role in the formation of particulate matter emissions to the atmospheric environment [23]. Elevated concentrations of ammonia in chicken houses have negative effects on the health of the workers exposed to them and also on the chicken through reduced feed intake and impeded growth rate. Ammonia plays critical roles in the environment, and its control could be of immense benefits, particularly through the reduction of excessive loading of nutrients and acidification. In view of the nutrient profile of chicken manure, ammonia volatilization from the resource can be considered a loss of its fertilizer value. Ammonia is also a nutrient source to microbiological and plant communities; however, its excessive deposition in the ecosystem could have detrimental effects causing eutrophication and degradation of water bodies.

Component	Broiler litter		Chicken manure	
	Mean	Range	Mean	Range
	g kg^{-1} material		g kg^{-1} material	
Moisture	245	20–291	657	369–770
Total C	376	277–414	289	224–328
Total N	41	17–68	46	18–72
NH_4-N	2.6	0.1–20	14	0.2–30
NO_3-N	0.2	0–0.7	0.4	0.03–1.5
P	14	8–26	21	14–34
K	21	13–46	21	12–32
Ca	14	0.8–17	39	36–60
Mg	3.1	1.4–4.2	5	1.8–6.6
Na	3.3	0.7–5.3	4.2	2–7.4
	mg kg^{-1} material		mg kg^{-1} material	
Mn	268	175–321	304	259–600
Fe	842	526–1000	320	80–560
Cu	56	25–127	53	36–68
Zn	188	105–272	354	298–388

Source: [22].

Table 7. Chemical properties of broiler litter and chicken manure.

5. Strategies for reducing emissions

This section discusses some nutritional and manure management strategies for mitigating nitrogen emissions in chicken production. Several evidences are available to demonstrate that feeding low-protein diets is an effective approach for mitigating nitrogen emissions in chicken production by contributing to a significant reduction in nitrogen excretions. However, feeding low-protein diets may present some undesirable challenges which must be addressed to ensure sustainability of chicken production. Some manure handling and management measures to reduce nitrogen emissions are also presented.

5.1. Nutrition approaches for mitigation of nitrogen excretions in chicken production

In view of its effects on costs, performance and profitability of chicken production, emphasis is placed on protein in feed formulation. Dietary protein level has major effects on growth and overall cost of the finished poultry product and affects the carcass composition of the birds [24], while recent advances and progress in animal breeding has resulted in highly efficient breeds in terms of feed conversion and growth, it is important to seriously consider the pros and cons that may be associated with the dietary protein levels to be adopted in chicken production in a bid to ensure sustainability. This is because of the need to take adequate measures to balance the effects of dietary protein levels for more beneficial chicken production outcomes. For example, excess dietary protein results in lean birds but reduces feed efficiency thereby resulting in elevated nitrogen excretions, whereas less than optimal protein content increases fat retention [25]. This therefore underscores the need to maintain a balance in both dietary protein and amino acid contents of the diets for optimal production performance in chicken. Several research findings have demonstrated a wide range of effects of feeding and nutrition strategies for mitigation nitrogen emissions in chicken production. Nutritional strategies include feeding low dietary protein, formulating diets based on amino acids requirements while supplementing limiting amino acids with synthetic source, and use of enzymes in chicken production.

5.1.1. Effects of feeding low-protein diets on nitrogen excretions in chicken production

Dietary protein manipulation could be an effective way of reducing nitrogen excretion in chicken production. Dietary amino acids in excess of the requirements cannot be stored in the body; instead, they are transaminated and/or deaminated, with the majority of the excess nitrogen excreted as uric acid in poultry. Accordingly, the excess dietary protein could be described as wasteful and represents an economic loss to the farmer. In addition, challenges involved with disposal of excreted nitrogen include offensive odors and environmental pollution. Therefore, to address the growing concern of increased nitrogen emissions from livestock, a combination of adjustment in dietary content of amino acids to animals' requirements at a given age and lowering the amount of dietary crude protein with the use of crystalline amino acids. It is possible to lower the CP content of the chicken diet and still meet established amino acid requirements by replacing part of the intact protein with crystalline amino acids

[26]. This helps to obtain a balance of dietary amino acids closer to the animal's requirements. Feeding low-protein diets may therefore enable a farmer to cut down on the cost of the diet depending on the constituents of the feed while at the same time reducing nitrogen loss and its attendant environmental challenges. Formulating complete diets for specific amino acids rather than crude protein content can reduce the oversupply of amino acids provided in most protein-rich feedstuffs, thereby reducing nitrogen excretion (**Table 8**). Reduced nitrogen excretion and anthropogenic propensity without compromising animal performance have been demonstrated for this approach [27].

In layers, a direct relationship between dietary protein level and nitrogen excretion, as well as better utilization of protein, has been reported, when hens were fed diets with lower protein concentrations than the requirements [31]. However, a reduction in the dietary concentration of protein may result in imbalance of amino acid concentrations and may also change the optimal requirements of the limiting amino acids (lysine and methionine) at lower dietary protein levels. Taking steps to correct factors that may have triggered poor performance measured in terms of some parameters in layers may yield encouraging results. There are indications that the resultant lowering effect of nitrogen output in broilers fed low-protein diets appeared to be less effective as the quantum of reduction in dietary protein increased [30]. Therefore, to minimize performance losses of broilers fed low-CP diets while at the same time maintaining a significant reduction in environmental risks resulting from nitrogen excretions, there is a limit to which dietary protein could be reduced [32, 33].

Type of chicken	Protein level	N-related parameter	Level of reduction in N-related parameters
Broiler	16–20%	Nitrogen output	49.2–65.6%
		Nitrogen output intensity	12.50–45.83%
Broiler	20–22% with met. + Lys.	Nitrogen output	16–38%
		Nitrogen output intensity	18.75–40.63%
Broiler	20% + enzymes supplementation	Nitrogen output	25.8–35.1%
		Nitrogen output intensity	37.5–43.8%
Laying hens	11.5–17.5%	Nitrogen output	26.6–36.3%
		Nitrogen output intensity	20.0–33.3%
Laying hens	13.5% + enzymes supplementation	Nitrogen output	Similar
		Nitrogen output intensity	12.5–43.7%

Sources: Based on [28–30].

Table 8. Effects of feeding low-CP diets on nitrogen output of chickens.

5.1.2. Undesirable effects of feeding low-protein diets to watch out for in chicken production

Feed intake is one of the areas in which some marked differences in the response of birds to low dietary protein has been observed when compared with those on higher dietary protein regime. Effects of low dietary protein levels on feed intake of birds have some degree of variation which could range from no effects on consumption to higher or depressed feed intake. Reduced or increased feed intake in chickens fed low-protein diets is desirable if accompanied with similar or improved performance per unit input when compared with birds fed high protein diets. However, it calls for concern if it leads to poor performance in the birds. Suspected factors contributing to cases of lower feed intake in birds fed low-protein diets have been identified. These include increased methionine level, ambient temperatures, extent of reduction of CP contents, change in dietary net energy concentration and protein ratio, the class and age of birds, and the extent to which the intact protein sources are kept at constant ratios to minimize amino acid imbalance [34–36].

Feeding low-protein diets could result in a wide range of response on different production and economic performance parameters. These could range from lowering, neutral, and/or raising effect on some critical parameters such as growth, feeding intake, carcass yield, egg production, egg weight, and feed efficiency. A similar performance between birds fed low-protein diets and those fed higher levels may be considered a desirable development particularly if it translates to lower cost of production and lower feed conversion ratio [28]. However, there is a limit to which dietary protein could be reduced without any adverse effects on the performance of the birds. This means that dietary protein should not be increased or lowered arbitrarily but care must be taken to ensure that the physiological and other requirements of the birds are met by the adopted feed regime to guide against negative impact on performance, profit, and the environment.

5.1.3. Some issues of and corrective measures for undesirable effects of feeding low-protein diets in chicken production

Some reasons alluded for poor performances of birds fed low-protein diets, which provides a level of insights for providing corrective measures for sustainability. This includes:

i. There are some potential toxic effects of supplying amino acids in excess of requirements, reduced level of potassium or altered ionic balance, and lack of sufficient nitrogen pool to provide nonessential or dispensable amino acids [24]. Therefore, when supplying amino acids in excess of recommended requirements, care must be taken to ensure that it is kept within permissible limits. For example, [29] observed that supplementing low-protein diet (20% CP) with methionine and lysine at 10% level higher than levels recommended by [37] corrected the performance of the birds to be at par with those fed 22% CP without any observed adverse effect.

ii. The dietary regime that does not match the age/stage of growth of broilers and layers may negatively affect some performance the characteristics of the birds [38]. This means that lowering dietary protein beyond reasonable levels in broilers and layers will negate production performances and even some environmental benefits. Therefore, the supplied diets must match the requirements for the stage of growth of the birds in order to optimize the performance. In other words, reduction in crude protein must not be excessive but kept within reasonable limits that do not negate the performance of the birds while retaining the environmental benefits. Ref. [34] indicated that egg weight increased when dietary protein level was increased from 15 to 16.5% during the early laying phase. They reported that on the basis of egg weight, body weight, and feed efficiency data, 15% CP is adequate for layers during the entire laying cycle of 21–72 weeks of age.

iii. Altered ionic imbalance owing to lower potassium levels in the diets particularly when soybean meal is reduced in the diet [39]. Ref. [40] reported that FCR and egg production were significantly improved in the low-protein diet group with high electrolyte balance. This suggests that correcting some of the factors responsible for inferior performance of low-protein diets in hens could lead to additional benefits in form of improvement in performance parameters.

iv. Deficiencies or Inadequate intake of some amino acids has been implicated for poor performance in terms of egg weight and/or egg mass and body weight gain in chickens fed low-protein diets [41]. There are cases of recovery or better performance of the birds with the supplementation of the diets with the limiting amino acids [42, 43].

v. Use of low-quality feedstuffs and/or inadequate utilization of some components of the supplied diets. A wide range of enzymes have been used to correct some of the performance deficiencies and/or even lead to some superior performance in chicken supplied with low-protein diets compared with those on higher levels (**Table 8**).

5.1.4. Cobenefits of feeding low-protein diets to chickens

Some co-benefits have been observed when reductions in dietary protein are kept within the limits that do not adversely affect the performance of the chicken. One of the cobenefits of feeding low-CP diets to chicken is perhaps better utilization of protein.

Another cobenefit of feeding low dietary protein is reduced cost of production per unit of product (egg or meat) especially when reduction in offered protein level is kept within limits that will not adversely affect performance. Economic returns of chickens during the starter phase could be improved by increasing the amino acid density of the diets.

Significant reduction in excretion of nutrients other than nitrogen in chickens fed low dietary proteins could be of immense benefits to the environment and the producers [43]. Low-protein diets are also a potential means of reducing mineral excretions, such as phosphorus, calcium, magnesium, potassium, sodium, manganese, zinc, and copper, and lead in poultry production [43, 44].

Lowered amount of excreted nitrogen (including NH_3) contributes to reductions in potentially offensive odor and pollution from broiler production facility [45]. Quantitative reduction in nitrogen output with lower dietary protein could imply reduction in risk for the environment due to significant reduction in the amount of fecal nitrogen available for conversion to ammonia and nitrous oxide and eventual release into the atmosphere.

5.2. Manure management strategies for reducing nitrogen emissions in chicken production

One of the most important aims of manure management is possibly ensuring the loss of nutrients is prevented or kept at the minimum in the manure chain. The manure chain is the period from collection to storage, treatment, and application for feed production. Handling chicken manure in an environmentally sustainable way would help realize its value as a nutrient resource for crops and as a feedstock for renewable energy. Emissions at the various stages of manure management could be tackled in animal house, during storage, processing, and application/discharge. Thus, instead of losing nutrients into the environment, efforts should be directed at keeping them in the food and/or feed chain where they could enhance crop growths and contribute to significant reduction in the use of inorganic fertilizers. Sustainable manure management will contribute to household food security and income, improvement in agricultural production, reduction in public health risks, reduction in environmental pollution and greenhouse gases emissions, and decelerate global warming. Although several approaches and technologies are available to achieve this goal, unsustainable manure management practices are still very prevalent in some countries. Some of these unsustainable manure management practices include direct application and indiscriminate disposal of manure such discharge into water bodies, burning or open dumping and indiscriminate land application. Lack of relevant policies and/or regulations, as well as nonenforcement of some of the relevant available policies or regulations, are among the major contributor to unsustainable manure management practices. Ref. [5] provided some valuable information or tips that would contribute to handling and managing manure in such a way that keeps the nutrients intact as much as practicable. Some of these are highlighted below:

Collection point: This could be in the barn or the house of the animal. The type of chicken management system affects the form in which the manure is handled. While manure is mostly in solid state in chickens raised on floor, it is in the wet form in layers raised in cages. It is critical to ensure that the animal housing allows for ease of manure collection and prevents losses. Consequently, the floor should be waterproof and covered against the rain to prevent losses through nutrient volatilization, run-off, and leaching.

Manure storage: Manure storage could be indoor or outdoor, and it is essential to ensure the nutrients are intact from the period of collection to application. Manure could also be stored either in dry or liquid form. Liquid storage could be in lagoons which can be covered or open. More nitrogen losses occur in open than in covered lagoon. It is important to store manure properly to ensure optimal application. It is therefore advisable to provide cover for the manure in outdoor storage. Storage roofing will prevent losses into the soil and water through leaching, run-off. Providing a storage facility that is air-tight will also prevent losses through volatilization. There are some marked differences in the major gaseous losses depending on the state in which the manure is stored. Nitrogen volatilization from chicken manure occurs mainly in the form of ammonia, nitrous oxide, and nitrogen gas in dry storage. However, nitrogen could be lost to the environment through leaching when there is contact with water. Apart from nitrogen, other nutrients in the manure could also find their way into the environment and cause some damages if excessive. In liquid storage, the main form of gaseous emission is methane, a greenhouse gas which is classified as a short-lived climate pollutant. To ensure proper capture of methane and prevent its losses to the atmosphere, anaerobic digesters could be used for storage. Anaerobic bio-digester technologies are relatively simple and adoptable at any level and scale, industrial, village, and farm level. The bio-digester must be recharged daily after biogas production commences. Manure used for biogas production is mixed with water in equal ratio (that is, 1 kg manure: 1 L of water) and fed into the bio-digester. The captured methane could be used as bio-energy, while the bio-slurry could be used as fertilizer as the nutrients are still intact. This could be a direct or an indirect source of additional income to farmers. Although chicken manure can yield considerable amount of biogas (310 m^3/ton DM), comparable to other feedstock materials, a major challenge with the use of chicken manure for biogas production is that it is high in ammonium, which could inhibit the process of methanogenesis or biomethanation. Therefore, it is advisable to use chicken manure in small quantity. Biogas is composed of 50–70% methane, 30–45% carbon dioxide, 0–3% nitrogen, hydrogen, oxygen and hydrogen sulfide and therefore could be purified and used to power generators. When used for household cooking, caution must be exercised because of the highly inflammable characteristic of methane which is the main component of biogas.

Manure treatment and processing: There are several reasons for treating manure, namely; to reduce the volume, to improve handling as well as increase its value, applicability, reduce health related risks, and to prevent nutrient losses to safeguard the environment. There are several available methods of manure treatments, ranging from simple to highly complex one. These include air drying, anaerobic digestion, separation, adding solid materials to liquid manure, refining, composting, and amendment with alum or use of acidifying agents, and so on.

Manure treatment could begin from the animal house. For example, treatment of poultry litter with alum is a practice that is known to reduce manure nitrogen losses and commonly carried out during chicken production operations. Several types of alum used for water treatments could also be used effectively for chicken manure amendment. Ref. [46] compared poultry litters treated with salt solution, alum, and air exclusion and reported that alum treated feces had significantly higher percentage nitrogen retention and lower nitrogen depletion rate than salt and air-tight treatments. Ref. [46] also observed that maize seeds planted on alum treated and air excluded litter soils had an average germination percentage (GP) range of 65–75% and 54–75%, respectively, which were comparable to the average GP of 75% recorded for soil treated with the control manure. Sorghum plots also recorded a mean value of 99% GP on alum treated soil within 2 weeks of planting, surpassing airtight treated soil with mean value of 89% GP; however, seeds planted on salt treated litter soil recorded 0% germination. Ref. [30] suggested that ammonium alum was the least effective in preventing nitrogen losses in stored chicken manure compared with other forms of alum. Some of the benefits of using alum in chicken manure amendment include decreases in chicken house ammonia level, reduction in energy usage, improvement in birds' performance, precipitation of soluble phosphorus, reduction of phosphorus and heavy metals runoff, and imposition of drying effect that reduces litter moisture.

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Composting could be carried out using heap or pit method. Composting could be done in small and in large scale, and solid or liquid manure could be used. A major disadvantage of composting is that it could be labor intensive. Air drying could practically lead to the loss of manure nitrogen into the atmosphere. Air drying manure should only be done on waterproof floor. Air dried manure are easy to handle as they be bulked.

Manure application as organic fertilizer: Manure could be used as a valuable fertilizer resource. It is however critical to carry out both soil and manure tests to establish the nutrient levels and needs to avoid nutrient overload. Manure applications as fertilizer must be strictly need-based. It is advised that manure be incorporated into the soil during application.

6. Conclusions

Environmental approach to chicken production is an increasingly important consideration all over the world. Major emissions in chicken production include ammonia, nitrous oxide, and other oxides of nitrogen and methane produced through the poultry supply chain. Uncontrolled emissions of deleterious gases into the environment could pose serious challenges and negatively impact the future use of resources. Sustainability approaches to chicken production hold immense benefits for the planet and the people while at the same time guaranteeing profitability. Several technologies are available for use in reducing the environmental footprint of chicken. To minimize the loss of nutrients, appropriate knowledge of various emissions/losses is required, and appropriate measures are taken across the entire chicken and manure management chain. Enactment and enforcement of relevant policies, laws, regulations, and creating enabling environments will considerably promote sustainable practices in chicken production.

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