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Dietary protein and phosphorus in poultry manure: Implications for soil nutrient management and environmental safety: A review

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Abstract
Poultry manure contains valuable nutrients, but excessive or poorly managed application can contribute to nitrogen and phosphorus losses and environmental contamination. This review examines how dietary protein and phosphorus management influence nutrient excretion, manure composition, phosphorus solubility, runoff, manure treatment, and soil amendment value. The reviewed studies indicate that reducing dietary crude protein with adequate amino-acid supplementation can reduce nitrogen excretion, while reducing non-phytate phosphorus and using phytase can reduce selected phosphorus fractions in poultry litter. However, lower total manure phosphorus does not consistently translate into lower runoff phosphorus because solubility, sediment transport, soil phosphorus status, rainfall, treatment, and application practices also determine losses. Stabilization through composting or anaerobic digestion may improve the suitability of poultry manure as a soil amendment, but treatment performance is process- and hazard-specific. Overall, effective management requires coordination of feed formulation, manure treatment, soil testing, application rate, and environmental monitoring. The review also identifies the need for longer-term, integrated studies in poultry systems beyond the commercial broiler, layer, and turkey evidence most commonly represented in the literature.

Keywords: Poultry manure, dietary protein, phosphorus phytase, nitrogen excretion, soil amendment, nutrient management, environmental safety

Introduction
Poultry production generates substantial quantities of manure and litter. Most poultry litter is land-applied as a source of nutrients and soil amendment, but nutrient and contaminant leaching can occur when application conditions do not support agronomic utilization of manure-borne nutrients (Bolan *et al.*, 2010) [2]. Poultry manure is therefore both a recoverable nutrient resource and a potential source of environmental pollution.

Manure composition is not fixed. It reflects the diet supplied to birds, nutrient utilization, manure collection, storage, treatment, and the physical materials mixed with the excreta (Bolan *et al.*, 2010; Cappelaere *et al.*, 2021) [2, 3]. Dietary formulation is especially relevant because excess dietary protein increases nitrogen (N) excretion, whereas phosphorus (P) supplied above the animal's requirement can increase P excretion and manure P. This makes nutrition an upstream intervention: it can change the quantity and chemical form of nutrients entering manure before storage or land application (Figure 1) (Cappelaere *et al.*, 2021; Maguire *et al.*, 2004) [7].

The purpose of this review is to examine how dietary protein and phosphorus influence N and P excretion and manure characteristics, and to evaluate the consequences for soil nutrient management, phosphorus runoff, and environmental safety. The review focuses primarily on commercial poultry evidence and identifies gaps that limit transfer to other avian systems. This article is a focused narrative review based on peer-reviewed studies published between 1999 and 2023.

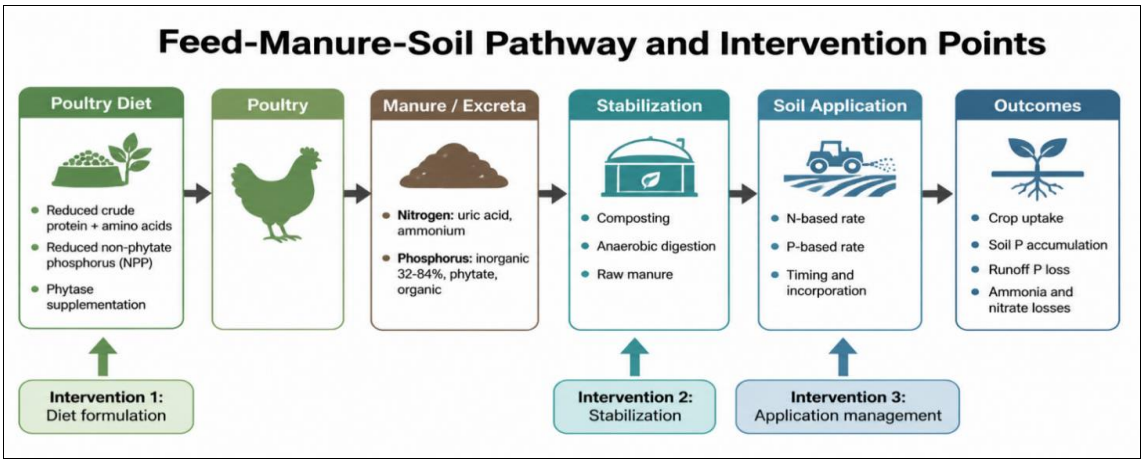


Fig 1: Feed-manure-soil pathway for poultry manure nutrient management and the three intervention points examined in this review.

Dietary Protein and Nitrogen Excretion

Dietary crude protein (CP) supplies amino acids required for growth, maintenance, and production. When crude protein is reduced while limiting amino acids are supplied accurately, nitrogen intake and excretion can fall without necessarily reducing productive performance. Blair *et al.* evaluated reduced-crude-protein diets under commercial conditions using broiler experiments containing 2,400 birds each and a layer experiment containing 1,350 birds (Blair *et al.,* 1999) [1]. The study reported similar broiler and layer performance on reduced-crude-protein diets, although broiler body fat increased (Blair *et al.,* 1999) [1].

The quantitative results are useful but should be kept tied to the actual outcomes measured. Blair *et al.* reported a 10–27% reduction in total N excreted during the six-week broiler rearing period and a 30–35% reduction in daily N output from layers (Blair *et al.,* 1999) [1]. The study also emphasized that accurate amino-acid composition data and supplementation of limiting amino acids are necessary for successful crude-protein reduction (Blair *et al.,* 1999) [1]. These findings support reduced-crude-protein diets as an N-management strategy, but they do not justify transferring the same percentage reduction to every poultry species, diet, or production system.

A later review similarly concluded that reducing dietary crude protein can lower N excretion and alter manure composition, while feed-grade amino-acid supplementation is important for maintaining performance (Cappelaere *et al.,* 2021) [3]. The same review cautioned that the environmental effect depends on the production context and that poultry evidence for some manure-emission endpoints remains less developed than evidence for pigs (Cappelaere *et al.,* 2021) [3].

Birds excrete nitrogen predominantly in the form of uric acid, and manure N is subsequently transformed by microbial processes. The environmental consequence depends not only on total N but also on the amount
present in readily degradable or ammoniacal forms, manure moisture, pH, temperature, storage duration, and application conditions. Reduced-crude-protein diets lower the supply of excess amino acids and can reduce manure N content; however, the magnitude of downstream emission reductions depends on manure management and soil conditions (Cappelaere *et al.,* 2021) [3].

The evidence supports distinguishing reduced dietary N input, reduced total N excretion, reduced manure N concentration, and reduced field emissions. These are related outcomes, but they are not interchangeable. A diet study that measures N excretion cannot automatically be cited as evidence of a specific reduction in ammonia volatilization or nitrate leaching.

Dietary Phosphorus, Phytase and Runoff

Phosphorus is required for skeletal development and physiological functions, but excessive or poorly available dietary P increases the amount entering manure. Phytase hydrolyzes phytate-bound P and can improve the availability of feed P, thereby reducing the need for supplemental inorganic P (Maguire *et al.,* 2004) [7]. The environmental effect must nevertheless be assessed using both total P and soluble P measurements (Maguire *et al.,* 2004; Vadas *et al.,* 2004) [7, 10].

Maguire *et al.* generated broiler and turkey litters using diets that varied in non-phytate phosphorus (NPP) and included phytase in some treatments. Reducing dietary NPP and using phytase decreased total P in litters by up to 38% (Maguire *et al.,* 2004) [7]. Feeding NPP closer to requirement decreased water-soluble P by 21–44%, whereas phytase did not affect water-soluble P under the reported extraction condition (Maguire *et al.,* 2004) [7]. Phytase did reduce phytate P by 25–38%, demonstrating increased phytate hydrolysis (Maguire *et al.,* 2004) [7].

These results show why total P, water-soluble P, phytate P, and runoff P should not be treated as synonyms. The form and solubility of manure P influence subsequent environmental behavior, and a reduction in total P does not necessarily produce the same proportional reduction in every soluble or runoff endpoint (Maguire *et al.,* 2004; Vadas *et al.,* 2004) [7, 10].

Maguire *et al* [7]. (2005) studied turkeys fed diets with two NPP levels, with and without phytase, and evaluated litter applied to soil under simulated rainfall. Combining reduced NPP with phytase decreased the total P application rate by up to 38% and P applied above crop removal by approximately 48% (Maguire *et al.,* 2005) [6]. Reducing NPP reduced dissolved reactive P in runoff in the Day 1 runoff event, whereas phytase did not significantly change dissolved reactive P concentrations (Maguire *et al.,* 2005) [6].

Vadas *et al.* reported a different but complementary pattern: phytase and reduced supplemental P decreased total P but increased water-extractable P in manure, while the dietary treatments did not significantly change total P or molybdate-reactive P loads in runoff (Vadas *et al.,* 2004) [10]. Composting reduced total P and molybdate-reactive P loads in runoff, and the authors concluded that the final environmental effect of dietary phytase depends on management of the diet, manure, and farm-scale P balance (Vadas *et al.,* 2004) [10].

Penn *et al.* found that alternative turkey diets decreased manure total P and water-soluble P compared with a standard diet, but dissolved reactive P concentrations were higher from soils amended with manure from the high-available-phosphorus (HAP) corn treatment. Runoff dissolved reactive P was not directly related to manure water-soluble P; sediment loss and the mass of manure applied also influenced the result (Penn *et al.,* 2004) [8]. Taken together, these studies support dietary P reduction as a source-control measure, but they do not support the claim that phytase alone reliably prevents runoff P.

Nutrient Composition and Characteristics of Poultry Manure

Poultry manure contains nutrients that can support crop production, but its composition varies with diet, bird type, bedding, manure collection, storage, treatment, and moisture. The poultry-litter review by Bolan *et al.* describes litter as a source of N, P, and trace elements and emphasizes that land application can create pollution when soil and climatic conditions do not favour agronomic nutrient utilization (Bolan *et al.,* 2010) [2].

Nutrient concentration also differs from nutrient availability. Organic N and P fractions may require microbial transformation before plant uptake, whereas soluble fractions can be immediately available but more vulnerable to loss. Storage and treatment can alter nutrient forms, moisture, stability, and mineralization (Cappelaere *et al.,* 2021; Rizzo *et al.,* 2022) [3, 9]. For this reason, application

decisions should use measured nutrient concentrations and, where possible, information on nutrient availability rather than relying only on a generic manure nutrient value.

Rizzo *et al.* compared raw poultry manure with compost and digestate and assessed physicochemical, microbiological, toxicological, and mineralization characteristics. Compost and digestate showed better general conditions for use as organic soil amendments than raw poultry manure, while the highest pathogen content was recorded in poultry manure (Rizzo *et al.,* 2022) [9]. The same study reported P accumulation in soil amended with a high dose of poultry manure and recommended stabilized, mature manure-derived amendments (Rizzo *et al.,* 2022) [9].

Poultry Manure as a Soil Nutrient Amendment

Properly managed poultry manure can supply N, P, potassium, and organic matter and can contribute to soil fertility (Bolan *et al.,* 2010). Its agronomic value depends on the nutrient requirement of the crop, the existing soil nutrient status, manure composition, and whether the material is raw, composted, or otherwise stabilized (Rizzo *et al.,* 2022) [9]. Land application is therefore best treated as nutrient management rather than simply waste disposal.

Manure nutrients are released over time through decomposition and mineralization. Raw poultry manure can release nutrients rapidly and may cause nutrient losses when application is poorly synchronized with crop uptake. In the Rizzo study, high-dose poultry manure produced N loss and P accumulation during mineralization, whereas compost and digestate had more favourable general amendment characteristics (Rizzo *et al.,* 2022) [9]. These findings support assessing both total nutrient content and the timing of nutrient release.

Poultry manure should be applied according to crop nutrient requirements and soil-test information. Applying manure at an N-based rate can oversupply P when the manure N:P ratio is lower than the crop requirement. Repeated application can therefore increase soil P and the potential for transfer to surface water (Vadas *et al.,* 2004; Maguire *et al.,* 2005) [6, 7, 10]. The rate, timing, incorporation method, slope, rainfall, and soil properties all influence the final environmental outcome (Penn *et al.,* 2004; Vadas *et al.,* 2004) [8, 10].

Environmental and Safety Concerns

N losses may occur through ammonia volatilization, nitrate leaching, and gaseous transformations during storage and after application. Reduced-crude-protein diets can reduce the amount of N entering manure, but downstream emissions remain dependent on manure form, moisture, storage, treatment, and field management (Cappelaere *et al.,* 2021) [3]. P losses are especially sensitive to soil P status, application rate, soluble P, runoff-generating rainfall, and sediment movement. The runoff studies above show that total manure P is an incomplete predictor of runoff P (Vadas *et al.,* 2004; Penn *et al.,* 2004) [8].

Kacprzak *et al.* describe poultry-manure management as a coupled carbon, nitrogen, and phosphorus cycle. Their review identifies ammonia and nitrous oxide emissions as major threats from unmanaged poultry manure and notes that composting can remove N through leachate and gaseous emissions (Kacprzak *et al.,* 2023) [4]. They report that phosphorus in poultry manure may be predominantly inorganic (approximately 32–84% of total phosphorus), depending on the manure and management context. They also discuss phosphorus accumulation and potential environmental losses when untreated manure is applied excessively (Kacprzak *et al.,* 2023) [4].

Raw poultry manure can contain pathogenic microorganisms. Rizzo *et al.* found higher pathogen content in poultry manure than in the compost and digestate materials evaluated (Rizzo *et al.,* 2022) [9]. Kyakuwaire *et al.* identified pathogens, including bacteria, fungi, helminths, protozoa, and viruses, as well as antibiotics, antibiotic-resistance genes, heavy metals, growth hormones, and pesticides as potential chicken-litter hazards (Kyakuwaire *et al.,* 2019) [5]. Their review reported that measured *Escherichia coli* and coliform counts exceeded cited permissible limits in the assembled evidence, while emphasizing that standards are inconsistent and often absent for chicken litter (Kyakuwaire *et al.,* 2019) [5]. These findings justify risk-based stabilization and monitoring, but should not be generalized to every poultry-litter sample. Consequently, untreated manure should not be assumed to be microbiologically equivalent to stabilized amendments. Treatment effectiveness depends on the process, temperature, duration, moisture, and the organism or hazard being evaluated.

Potential safety assessment should also consider contaminants associated with feed, medication, manure handling, and repeated soil application. These include trace elements, antimicrobial residues, and antimicrobial-resistance determinants (Bolan *et al.,* 2010; Kyakuwaire *et al.,* 2019) [2, 5]. Kyakuwaire *et al.* also noted that contaminant standards vary across jurisdictions and are lacking for many chicken-litter contaminants (Kyakuwaire *et al.,* 2019) [5]. Claims about persistence, removal, or human-health risk must be tied to the specific contaminant and treatment process; composting or digestion should not be described as a universal method for eliminating every chemical or biological hazard (Rizzo *et al.,* 2022) [9].

Composting and anaerobic digestion are stabilization options, but they do not have identical effects. Rizzo *et al.* reported that compost and digestate had better general amendment characteristics than raw poultry manure, while only compost met the stability and maturity conditions assessed in that study (Rizzo *et al.,* 2022) [9]. Treatment should therefore be combined with manure characterization, appropriate storage, and nutrient-based application rather than treated as a substitute for those controls.

Research Gaps and Future Directions

The available evidence in the studies assembled here is concentrated on commercial broilers, layers, and turkeys and is distributed across separate parts of the feed-manure-soil pathway. More integrated studies should measure dietary nutrient input, total and soluble manure fractions, storage and treatment conditions, soil nutrient change, crop uptake, runoff, and gaseous losses within the same experimental framework (Blair *et al.,* 1999; Cappelaere *et al.,* 2021; Vadas *et al.,* 2004) [1, 3, 10].

Long-term field validation is particularly important. Short-term runoff-box studies can identify mechanisms, but they do not fully represent repeated manure application, changing soil P status, weather

variability, crop uptake, or farm-scale nutrient balances. The available low-crude-protein literature also indicates that poultry evidence for some manure-emission endpoints is

less developed than evidence for N excretion itself (Cappelaere *et al.,* 2021) [3].

Future work should standardize manure characterization, report nutrient fractions and extraction methods clearly, and distinguish dietary N or P reduction from reductions in manure loss or field runoff (Maguire *et al.,* 2004; Vadas *et al.,* 2004) [7, 10]. Research is also needed in non-commercial, captive, ornamental, and other understudied avian systems.

Conclusion

Poultry manure is both a useful nutrient amendment and a potential source of environmental and safety risks. Reducing dietary crude protein with adequate amino-acid supplementation can lower poultry N excretion, while reducing dietary NPP and using phytase can lower total litter P. The phosphorus evidence is more nuanced: dietary interventions can change P concentration and form, but runoff depends on solubility, sediment movement, soil conditions, composting, application rate, and rainfall. Sustainable use therefore requires an integrated feed-manure-soil strategy in which dietary formulation, stabilization, nutrient-based application, and environmental monitoring are considered together.

Table 1: Dietary strategies and reported effects on poultry manure and phosphorus loss.

Dietary or management strategy	Poultry system	Reported manure or litter effect	Reported environmental endpoint	Main qualification
Reduced crude protein with limiting amino-acid supplementation	Broilers and layers	Lower total N excretion while maintaining performance in the reported experiments; broiler body fat increased	Nitrogen-input reduction	Results depend on amino-acid adequacy, diet formulation, species, and production context (Blair *et al.,* 1999; Cappelaere *et al.,* 2021) [1, 3]
Reduced dietary non-phytate phosphorus	Broilers and turkeys	Lower total litter P and, in some experiments, lower water-soluble P	Lower P application and early-event dissolved reactive P	The magnitude depends on the dietary comparison and manure application rate (Maguire *et al.,* 2004; Maguire *et al.,* 2005) [6, 7]
Phytase supplementation	Broilers and turkeys	Greater phytate hydrolysis and lower total litter P in some dietary contexts	Runoff response was not consistently reduced	Phytase should not be treated as a stand-alone runoff-control measure (Maguire *et al.,* 2004; Vadas *et al.,* 2004) [7, 10]
Composting or anaerobic digestion	Poultry manure	Changes in stability, mineralization, pathogen content, and nutrient release	Potentially improved amendment characteristics after treatment	Treatment performance is process- and hazard-specific; stabilization does not eliminate every contaminant (Rizzo *et al.,* 2022) [9]
Nutrient-based application and soil monitoring	Manure-amended soils	Avoids repeated nutrient oversupply	Lower risk of soil P accumulation and runoff	Rate, timing, incorporation, rainfall, slope, soil P, and sediment movement remain important (Penn *et al.,* 2004; Vadas *et al.,* 2004) [8, 10]

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