# MANAGEMENT OF PHOSPHORUS IN ORGANIC AMENDMENTS FOR SUSTAINABLE PRODUCTION AND ENVIRONMENTAL PROTECTION

**Nanthi S. Bolan[1,2], Ravi Naidu[1,2] and Chris Anderson[3]**

*[1] Centre for Environmental Risk Assessment and Remediation, University of South Australia, Australia; [2] CRC for Contamination Assessment and Remediation in the Environment, University of South Australia; [3] Department of Soil Science, Massey University, Palmerton North, New Zealand.*

## Introduction

The use of organic amendments such as biosolids, poultry and animal manures and farmyard compost in agriculture holds dual benefits for the waste-producing industry and primary producers. For waste-producing industries, land application provides a primary avenue for safe and beneficial recycling of these resource materials. For agricultural producers, these organic amendments are an alternative source of nutrients, and thus the traditional routes of disposal for these valuable resources such as land-filling, incineration and ocean dumping are avoided. These organic amendments can also be used to enhance the rehabilitation of fragile disturbed lands such as mine sites.

Optimum use of these byproducts requires knowledge of their composition in relation to beneficial uses and environmental implications. Most of the environmental problems associated with land application of organic amendments have centered on potential contamination of ground and/or surface water with major nutrients, nitrogen (N) and phosphorus (P). The application of organic amendments as a nutrient source is generally based on N input which is likely to provide more of other nutrients (especially P) than is required by crops.

Cost-effective and innovative solutions are needed to expand the range of acceptable options in the management of nutrients, especially P in organic amendments. This will involve refining feed rations to animals, using feed additives to increase P absorption in animals, managing and recovering P in organic amendments, moving organic amendments from surplus to deficit areas, finding alternative uses for organic amendments, and targeting conservation practices to critical areas of P export during land application. This paper gives an overview of various strategies used in managing P in organic amendments including in relation to its disposal through land application with particular emphasis on potential for surface and ground water contamination. Since poultry manure is produced in large quantities and extensively used in agricultural production we focused on this organic amendment.

## Phosphorus input in poultry feed

Phosphorus is one of the essential minerals for all animals. It plays a critical role in cellular metabolism, as a part of the energy reservoir of the cell, in cellular regulatory mechanisms, and in bone development and mineralization. Through its involvement in these metabolic and structural processes, P is essential for animals to attain their optimum genetic potential in growth and feed efficiency as well as skeletal development. Of all the poultry species, the laying hen industry feeds typically much more P relative to the requirement, largely because of concerns of inadequate mineralization of egg shells and skeletal abnormalities resulting in poor egg production, morbidity, and mortality.

One third of the P is present in the forage as inorganic P which is easily digestible. The other two thirds is present as organic P especially in the form of phytic acid and phytate (Table 1). The phosphate stored in this way is not available for poultry and pigs but has to be hydrolyzed first. The most P-rich components in the feed include mono-calcium phosphate, di-calcium phosphate and mono-sodium phosphate. Typically, less than one-third of feed P is utilized by poultry, with the remainder excreted in manure and applied to land for crop use (Patterson *et al.*, 2005). Phytic acid P is variably available to poultry (0 to 50%), and in order to meet the P needs of the bird, inorganic P must be added to the diet. The enzyme, phytase, can liberate much of this P, thereby enhancing the utilization of P by poultry.

Table 1. Phytate-P content of various cereal grains and oil seed meals used as a source of poultry feed.

| **Cereal** | **Phytate P (% of TP)** | **Oilseed Meal** | **Phytate P (% of TP)** |
|---|---|---|---|
| Maize | 72 | Soybean meal | 60 |
| Barley | 64 | Cottonseed meal | 70 |
| Wheat | 69 | Peanut meal | 80 |
| Oats | 67 | Rapeseed meal | 59 |
| Rye | 61 | Sunflower meal | 77 |
| Sorghum | 66 | Coconut meal | 49 |
| Rice | 77 | | |

## Phosphorus in poultry litter

Among the various nutrients in poultry litter, N and P cause some environmental concerns. Phosphorus in poultry litter is present mainly in solid-phase as organic and inorganic P. The amount of total P in poultry litter varies with the diet and bedding material, and ranges from 0.3 to 2.4 % of dry matter. Fractionation studies have shown that a large proportion of P in poultry litter is in acid soluble fraction, indicating low bioavailability. Mineral species, such as struvite ($MgNH_4PO_4.2H_2O$), octo-calcium phosphate ($Ca_4H(PO_4)_3.3H_2O$) and di-calcium phosphate ($CaHPO_4.2H_2O$) have been identified in the solid fraction of poultry manure.

## Phosphorus management

### *Feed management*

Phosphorus in manure can be reduced by feeding the birds less P or treating feed to improve phosphorus utilization efficiency. Various feed and management strategies that reduce P in poultry litter have been investigated. The first of these strategies formulates feeds closer to the birds' actual P requirements. A second feeding strategy being tested is to use phytase, an enzyme which enhances the efficiency of P recovery from phytin in grains fed to poultry (Table 2). Phytase breaks down the P-phytate bonds making the P available for absorption by the bird. Another approach is to increase the quantity of P in corn that is available to poultry by reducing the amount of phytate produced by corn. The use of low-phytate corn in poultry feed can increase the availability of P and other minerals and proteins that are typically phytate-bound. A combination of these strategies is expected to result in a reduction in excreta P.

Table 2. Performance of commercial broilers (3-30 days) fed low P diets supplemented with microbial Phytase.

| Treatment | Weight gain (g) | Tibia ash % | P retention % |
|---|---|---|---|
| Basal diet A (1% Ca & 0.3% P) | 914 | 42.2 | 22.1 |
| Basal diet A+phytase (500 FYT/kg) | 1003 | 43 | 53.7 |
| Basal diet B (0.75%Ca & 0.3% P) | 1030 | 42.4 | 41 |
| Basal diet B + phytase (500 FYT / kg) | 1081 | 43.1 | 65.2 |

***Manure management***

Poultry manure is rich in plant nutrients including N, P, K, S, Ca and Mg (Table 3) Manure management practices include the recovery and immobilization of P in the litter. Commercially available manure amendments, such as alum, can reduce $NH_3$ volatilization, leading to improved animal health and weight gains; but they can also reduce the solubility of P in poultry litter (Table 4; Moore and Miller, 1994; Nichols *et al.*, 1997; Bolan *et al.*, 2010). For example, the dissolved P concentration (11 mg/L) of surface runoff from fescue treated with alum-amended litter was much lower than from fescue (83 mg/L) treated with unamended litter (Shreve *et al.*, 1995).

Table 3. Nutrient contents of organic amendments (g/kg)

| Nutrient | Poultry manure | Biosolids | Pig manure | Mushroom compost |
|---|---|---|---|---|
| Nitrogen | 32.8 | 21.7 | 18.2 | 17.5 |
| Phosphorus | 17.8 | 8.5 | 7.5 | 5.3 |
| Potassium | 15.2 | 2.5 | 8.2 | 9.2 |
| Calcium | 18.5 | 2.3 | 4.2 | 21.5 |
| Magnesium | 6.2 | 1.4 | 3.7 | 5.2 |
| Sulphur | 8.5 | 5.7 | 3.4 | 3.5 |

Table 4. Effect of various amendments on soluble P content of poultry manure

| Amendments | Total P | Soluble P | % soluble P |
|---|---|---|---|
| Control | 20.82 | 9.59 | 46.1 |
| Gypsum | 18.72 | 7.15 | 38.2 |
| Lime | 18.21 | 3.29 | 18.1 |
| Flyash | 18.51 | 2.12 | 11.5 |
| FBA | 18.75 | 1.79 | 9.54 |
| Redmud | 18.62 | 0.77 | 4.12 |
| Alum | 18.34 | 0.52 | 2.82 |

Undoubtedly, the most direct way to resolve P surpluses at a regional or watershed level is to simply transport poultry litter to geographic areas where P is needed for crop production (Sims *et al.*, 2005). However, increasing hauling cost remains a major limitation for economic and environmentally safe P reutilization (Keplinger and Hauck, 2006). For manure P relocation to be sustainable, some form of processing is necessary to decrease the manure volume, increase P concentration, and produce a more valuable product with alternative use options (Greaves *et al.*, 1999).

Poultry litter management through treatment technologies that would reduce volume and increase nutrient content can be grouped into screening, densification, biological, thermochemical and chemical processes. Thermochemical processes use high temperatures to break the bonds of organic matter and reform intermediate compounds into synthesis gas, hydrocarbons fuels, and/or a charcoal residual (Cantrell *et al.*, 2008). Solid residues from these processes are P-dense materials amenable to be reused as fertilizer. Combustion technology of poultry litter has received major attention world-wide as a method to produce heat and electricity at large centralized facilities (Kelleher *et al.*, 2002; Turnell *et al.*, 2007). The byproduct of combusted poultry litter is ash with high P content that can be used as fertilizer or P supplement in poultry feed. However, a major environmental concern with large centralized combustion facilities is the emission of nitrogen oxides, carbon monoxide and sulfur dioxide from the combustion of poultry litter that will necessitate effective gas cleanup (Turnell *et al.*, 2007).

A chemical treatment process, called "quick wash", was recently developed for extraction and recovery of P from poultry litter and animal manure solids (Szogi *et al.*, 2008) (Figure 1). The quick wash process consists of three consecutive steps: 1) P extraction, 2) P recovery, and 3) P recovery enhancement. In step 1, organically-bound P is converted to soluble-P by rapid hydrolysis reactions using selected mineral or organic acids. This step also releases P from insoluble inorganic phosphate complexes. The washed litter residue is subsequently separated from the liquid extract and dewatered. In step 2, P is precipitated by addition of lime to the liquid extract to form a calcium-containing P product. In step 3, an organic poly-electrolyte is added to enhance the P grade of the product. The remaining solid residue (washed litter) has a more balanced N:P ratio that is more environmentally safe for land application and use by crops.

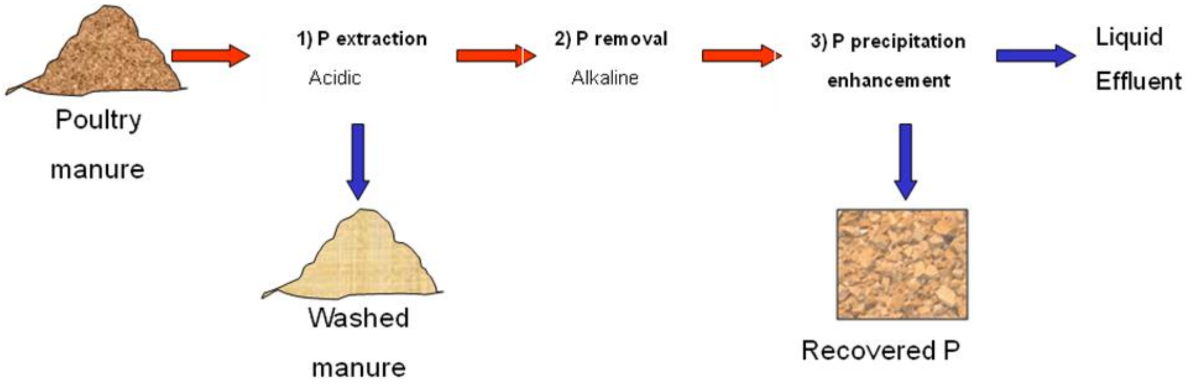


Figure 1. Extraction of P from poultry maure

***Soil management***

Soil remediation involves either chemically fixing P so it is biologically inactive or using some process to remove the compound from the soil. Aluminum- (drinking water treatment residuals (WTR) treated with alum), iron- (red mud) and Ca-based (coal combustion products) by-products have been shown to effectively reduce P solubility and transport to surface and ground water (Table 5). Several types of best management practices (BMPs) have been proposed to utilize these by-products in efforts to reduce off-site P transport. Examples include surface applying in vegetative filter strips to reduce runoff P losses and incorporation into high P soils allowing for reductions in extractable P concentrations. For example, Basta *et al.* (2000) have shown that WTRs incorporated into soil with high P concentration caused a reduction in runoff P losses between 19 to 67% compared to controls. A significant reduction in extractable P between 10 and 91% occurred after WTRs were blended with the high P soil and poultry litter.

Table 5. Effect of various amendments on Olsen P and P leaching in soil treated with poultry manure

| **Amendments** | **Olsen P (mg P/kg soil)** | **% P leached** |
|---|---|---|
| No PM | 18.2 | |
| PM alone | 37.5 | 35.6 |
| Lime | 28.1 | 28.2 |
| Flyash | 24.6 | 22.6 |
| Redmud | 14.1 | 3.2 |
| Alum | 11.2 | 2.8 |

***Nutrient management***

The application of poultry manure based on crop N requirements is likely to provide more of other nutrients (especially P) than is required by crops. For example, the application of 9 tons/ha of broiler litter, a rate commonly used to meet the N requirements of agronomic crops, will provide approximately 270 kg/ha of N, 100 kg/ha of P, 165 kg/ha of K and Ca/ha, 45 kg/ha of S and Mg, and 2-5 kg of Mn, Cu and Zn. Depending on the crop species grown this may result in the accumulation of some of these nutrients, especially P, in soils and the subsequent contamination of surface and ground water sources.

Several best management practices (BMPs) have the potential to reduce nutrients in runoff water and loading to surface waters (Sharpley *et al.*, 2007). They can be grouped into two broad categories: (1) technologies to reduce excessive nutrient levels in the soil, and (2) technologies to reduce discharges of nutrients via runoff or sediment loss from over-application of manure. For example, growing high biomass yielding plants can remove large amounts of nutrients and may be a promising remedial strategy to export and reduce excess soil nutrients. Bermuda grass and certain warm-season annual grasses produce large dry matter yields, and therfore take up large quantities of applied nutrients.

**References**

Basta, N.T., Zupancic, R.J., and Dayton, E.A. (2000). *J. Environ. Qual.* 29, 2007-2012.

Bolan, N. S., A. A. Szogi, T. Chuasavathi, B. Seshadri, M. J. Rothrock Jr. and P. Panneerselvam (2010). *World Poultry Science Journal 66, 673-698.*

Cantrell, K.B., Ducey, T., Ro, K.S., and Hunt, P.G. (2008). *Bioresour. Technol.* 99(17):7941-53.

Greaves, J., Hobbs, P., Chadwick, D. and Haygarth, P. (1999). *Env. Technol.* 20, 697-708.

Kelleher, B.P., Leahy, J.J., Henihan, A.M., O'Dwyer, T.F., Sutton, D. and Leahy, M.J. (2002). *Bioresour. Technol.* 83, 27-36.

Keplinger, K.O. and Hauck, L.M. (2006). *J. Agric. Resour. Econ.* 31, 424-440.

Moore, P.A., Jr., and Miller, D.M. (1994). *J. Environ. Qual.* 23, 325-330.

Nichols, D.J., Daniel, T.C., Moore, P.A., Jr., Edwards, D.R. and Pote, D.H. (1997). *J. Environ. Qual.* 26, 1002–1006.

Patterson, P.H., Moore, P.A., Jr., and Angel, R. (2005). In: *Phosphorus: Agriculture and the Environment.* J. T. Sims and A. N. Sharpley, Eds. American Society of Agronomy, Madison, WI. Pp. 635-682.

Sharpley, A.N., Herron, S. and Daniel, T. (2007). *J. Soil Water Conserv.* 58, 30-38.

Shreve, B.R., Moore, P.A., Jr., Daniel, T.C. and Edwards, D.R. (1995). *J. Environ. Qual.* 24, 106–111.

Sims, J.T., Bergström, L., Bowman, B.T. and Oenema, O. (2005). *Soil Use Manage.* 21, 141-151.

Szogi, A.A., Vanotti, M.B. and Hunt, P.G. (2008). Process for removing and recovering phosphorus from animal waste. Patent Application Serial No. 12/026,346, USTPO.

Turnell, J.R., Faulkner, R.D. and Hinch, G.N. (2007). *World's Poultry Sci. J.* 63, 223-231.