SoilFacts

Phosphorus Management for Land Application of Biosolids and Animal Wastes

Land application is a viable and environmentally sustainable way to handle and reuse many products. Animal wastes, municipal biosolids, industrial residuals, and agricultural by-products all contain valuable nutrients and organic matter that can be beneficially reused for crop production in a land application system. This publication addresses nutrient management concerns as they relate to land application, with a focus on phosphorus application and its impact on the environment. Methods for reducing P loss from land application sites are presented as general guidance for managers of land application systems, who must be knowledgeable of regulatory issues and permit restrictions as they relate to phosphorus and nutrient management.

Table 1. Definition of Key Terms

Term	Definition
Sludge	Separated materials collected during a treatment process
Residuals	The term typically used for sludge from an industrial process. Unless otherwise noted, used here to describe collectively animal waste, residuals, biosolids, and agricultural by-products
Biosolids	The term used for sludge from a municipal (domestic) wastewater source that has undergone digestion and treatment to meet land application regulations
Eutrophication	The natural aging process of water bodies as they accumulate sediment and nutrients, and plant and algae growth increases in the water. Eutrophication can be exaggerated with inputs from human activities (point and nonpoint source pollution)
Point source pollution	Pollution from a defined source or outlet, such as a pipe
Nonpoint source pollution	Pollution from a diffuse source, not easily identified, such as stormwater runoff or agricultural runoff
Phytase	An enzyme that can increase the digestibility of phosphorus in hog and poultry feed

Introduction

In North Carolina and the southeastern U.S., a considerable amount of organic waste is generated as residuals (sludge from industrial processes), biosolids (sludge from municipal wastewater treatments systems), and animal waste. Land application of such organic waste is a common practice. Regulations for these applications are typically developed and managed through a state's pollution control agency, and possibly

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with oversight by the U.S Environmental Protection Agency (EPA) and local ordinances. In most of the land application programs prior to 2007, nitrogen (N) has been regulated as the priority or limiting nutrient. In other words, application amounts and techniques have been devised based on the N in the material to be land-applied and the N need of the crop grown on the site. As with any organic nutrient source, when one component is targeted as the priority nutrient, other nutrients are either over- or under-applied.

Most crops and forages require more N than phosphorus (P). The ratio of N to P (N:P) varies with the crop, soils, and regions, but it is generally in the range of 3:1 to 8:1. Some soils, due to long-term application of P fertilizers or organic products, have adequate or very high levels of plant-available P such that no additional P is recommended. When animal and municipal wastes that have N:P ratios ranging from 1:1 to 1:2 are applied based on N rates on soils, over time P will accumulate (NC Division of Water Quality; Barker, Zublena and Waltz). A review of soil test data where animal manures and municipal residuals have been applied over a period of years shows this rise in soil-test P over time (Johnson). Very high soil-test P in the soil does not pose risks to the soil nor the crops. It is the potential loss of P in runoff from the field that has environmental implications as it may result in eutrophication of receiving waters. Table 2 shows the plant-available N and P concentrations in residuals that are commonly land-applied. These data are from the above-referenced sources as well as the USDA-NRCS Waste Utilization (633) Standard animal waste database.

Table 2. Average Plant Available N and P_2O_5 in NC Residuals*

Source	N	P_2O_5
Swine anaerobic lagoon liquid	2.5 lb/1000 gal	1.4 lb/1000 gal
Swine anaerobic lagoon sludge	8.8 lb/1000 gal	34.3 lb/1000 gal
Dairy manure slurry	8.8 lb/1000 gal	9.8 lb/1000 gal
Stockpiled poultry litter	18 lb/ton	56 lb/ton
Municipal biosolids (dry wt basis)	1.66%	4.58%

*Actual plant available N and P_2O_5 can vary substantially from average values. Average values are used for planning purposes, and residuals must be sampled for nutrient content at the time of application.

Phosphorus and the Environment

Streams and rivers experience excessive algal growth when their waters are enriched with dissolved nutrients (N and P). Excess aquatic plant growth has several detrimental effects: the plants deplete dissolved oxygen levels both when alive and dead, and this can kill fish; swimming and boating are more difficult; some aquatic plants produce toxins; and finally, excess aquatic plants increase the cost of cleaning the water for drinking.

Generally, P (as orthophosphate) is the limiting nutrient in freshwater aquatic systems. That is, if all P is consumed, plant growth will cease, no matter how much N is available. The natural background levels of total P are generally less than 0.03 ppm (mg/l). Recent national survey data from the EPA indicate that increased eutrophication of fresh waters is related to increased P delivered from nonpoint sources.

Phosphorus, applied on land, can be delivered to water bodies in four possible ways:

1. Attached to soil particles that are lost via soil erosion. A large fraction of P in fertilizers, biosolids, and animal manures usually attaches to soil particles. If these soil particles erode, the attached P will move with the soil. Soils with higher soil-test P levels will have higher P in eroded particles.
2. Dissolved in runoff water. Water moving over the soil surface will dissolve P that is present on the soil particles and in any applied P materials. This P then can readily be moved into surface waters.
3. Leached through the soil profile. In coarse-textured soils (high proportion of sand), P can leach through the soil into the shallow groundwater, and then transfer to surface water through natural stream recharge.
4. Transported by runoff of the residual from the site (source P loss). Animal waste, biosolids, and fertilizer can be washed directly into water resources by runoff.

Site Assessment

High P levels in soils do not necessarily indicate an imminent problem. It is the combination of P levels and loss factors that determine the potential for P entering surface waters. In North Carolina, a P management tool – the Phosphorus Loss Assessment Tool or PLAT – has been developed to help agricultural managers assess the risk of P loss from fields to receiving waters and develop management strategies to reduce it. (For a detailed discussion of PLAT, go to http://www.soil.ncsu.edu/publications/plat/plat_producers.pdf.) The tool is field scale, and a P-loss risk rating is determined for each agricultural field. Field data, such as soil texture, slope, P application rate, soil-test P, source of P being applied, type of crop, proximity to surface waters, and use of conservation practices, are used in the rating. From this information, each of the four loss pathways (soil-attached P erosion loss, soluble-P runoff loss, soluble-P leaching loss, and source-P loss) are calculated and added together to estimate the total P loss for a field. The final calculation is:

Total P Loss = Soil-attached P Erosion Loss + Soluble-P Runoff Loss + Soluble-P Leaching Loss + Source-P Loss

The data from this evaluation are summarized into categories called Index Values. The categories of low, medium, high, or very high classify the relative potential for P loss from the field. Table 3 describes the effect of PLAT rating on application of animal manure.

Note that a PLAT index value is not the same as a soil-test P index value. This is a source of confusion for site managers. Soil-test P index is a component of the PLAT rating, but the two values are not the same. It is possible to have a soil test with a high or very high P index and yet have a low or medium PLAT rating.

Because PLAT assesses each field based on several factors, it also can be used to determine if there are ways to lower the PLAT rating. For example, switching to a crop that reduces soil loss may affect the PLAT rating.

A PLAT assessment is not required for all agricultural fields that receive organic nutrient sources. Regulatory requirements vary by type of product (manure versus municipal biosolids versus industrial sludge) and by watershed. Regardless, a PLAT assessment can help a residuals application manager plan for more efficient application with less environmental risk from the potential loss of P.

Managing Phosphorus in Land Application

There are four main management techniques for dealing with P in land application programs:

1. Reduce the amount of P in the residuals.
2. Render the P in residuals less mobile by various treatment methods or chemical amendments.
3. Limit the amount of P applied to crop needs based on soil tests.
4. Crop and soil management

1. Reducing P in residuals

Studies and trials over the past few years with phytase have shown that increased P use efficiency can occur when phytase is added to hog and poultry feeds. For example, Pierce et al. (1997) reported that compared with pigs receiving a non-phytase diet, finishing pigs fed a diet supplemented with phytase had 30 to 40 percent lower P in the excreta. Use of low-phytate grain in feed can also increase P use efficiency, thereby decreasing P excretion (Klopfenstein et al., 2002). This study reports that feeding low-phytate corn reduced P excretion by up to 40 percent. Vadas (2004) has shown that adding phytase and decreasing P in diets reduced total P but increased soluble-P content in poultry manure compared to the normal diet. Managers should carefully review different research studies and results, and use the results in conjunction with a PLAT assessment, before modifying animal diets.

For biosolids, removal of source P is not practical as usually there are many input sources to a common collection facility. Also, as wastewater discharge limits for municipal and industrial sources become stricter for P, and wastewater treatment nutrient removal mechanisms become more efficient, more P is present in the residuals and biosolids.

Another method of reducing P from animal operations and municipal and industrial facilities is to prompt the formation of a crystalline product containing P commonly known as struvite (ammonium magnesium phosphate). Formation and collection of struvite allows for transport of the P material off site to be used as a fertilizer or animal feed ingredient. At present, this approach is not widespread, but is gaining in interest.

2. Rendering P less mobile from residuals

Some research supports that adding chemicals (such as alum) or making pH adjustments to residuals may

Table 3. PLAT Rating When Applying Animal Manure *

Rating	Index Value	Consequence of Rating
Low	0–25	Nitrogen-based manure application rate
Medium	26–50	Nitrogen-based manure application rate
High	51–100	Manure application rate is limited to P removal from the site in the harvested crop
Very High	>101	No additional P application is allowed

*These ratings apply in select situations for animal manure management in NC. These ratings are not directly relevant for other nutrient sources as of May 31, 2008.

convert some of the P to forms that are less mobile once land applied. Compared with nonamended litter, dissolved P loss in runoff from plots treated with alum-amended litter was 69 percent lower (Smith et al., 2004). Biosolids treatment with chemicals (such as iron and aluminum salts) has been shown to reduce the availability of P as compared to biological P removal in wastewater treatment plants in some studies. However, data from studies support inconsistent results in the ability to predict P loss as a function of manure and biosolids treatment. Results of chemical treatment can also vary by climate, soil type, and soil moisture levels. While some benefit may occur, more research is needed in this area. Even though P may be rendered less available by chemical treatment, over years it can become mobilized for plant uptake or field loss. For this reason, some researchers focus on total P applied rather than segregating out potentially unavailable P.

3. Limiting P application rate

Reduced P application rates should be considered if either the soil test shows a high or very high P level, or a PLAT rating is high or very high.

If soil tests recommend no or limited P application, then standard agronomic advice is to apply only enough P to match the P removal rate of the crop. For manure and biosolids, this usually means that a very low application rate should occur. Sometimes the application rate is so low that use of that field for residuals application is not feasible or economical, or the manager simply cannot physically apply the material at that low rate. Regardless, applying residuals at a P rate typically results in the need for additional N (such as commercial fertilizer) to meet the N needs of the crop.

If a PLAT determination results in a low or medium rating, a manager may consider applying residuals at a rate to meet N needs. If the PLAT rating is very high (Table 3), then no P can be applied. When the PLAT rating is high, residuals may be used to apply the amount of P removed by the crop. Because this amount is relatively small, however, supplemental N may have to be applied as synthetic fertilizer.

4. Crop and soil management

This refers to the discussion on PLAT above. A PLAT field assessment allows the manager to evaluate a number of management strategies that can reduce the PLAT rating (which means reduce the potential for P loss). Many options for management strategies exist, and they can be organized into the following categories:

a. Tillage systems. Compared to conventional tillage, conservation tillage reduces runoff and soil loss due to erosion. Although conservation tillage reduces loss of P bound to eroded soil, P will be concentrated near the surface (due to lack of incorporation), increasing soluble-P loss in runoff. Hence, conservation tillage may result in only modest reductions in P losses in runoff, though greater reductions may be observed in sandy soils. Overall, the tillage system may have less impact than residual injection and incorporation discussed below.

b. Soil injection and incorporation. Where possible, injecting the waste into the soil can reduce both total and soluble P loss (Daverede et al., 2004). However, incorporation through disking may increase total P loss due to increased erosion even though soluble-P loss may be reduced (Eghball and Gilley, 1999). Deep injection of waste into sandy soil with a high or fluctuating water table increases the risk of P contamination of the groundwater. However, injection and incorporation options are limited by tillage, cropping systems, or both.

c. Cropping patterns to reduce soil loss. Changing to crops with more soil cover, strip cropping, and winter cover crops help reduce erosion and subsequent P loss

d. Conservation measures to reduce soil loss. Practices such as changing slope length, using field borders, and grassed waterways help reduce erosion or reduce sediment reaching surface waters.

e. Timing of application relative to predicted rainfall. The greatest potential for runoff transport is immediately after application. This reduces with time. The land application manager should delay application of residuals if rainfall is in the short-term weather forecast. During marginal weather conditions, the manager should prioritize application of residuals to those fields with the lowest potential for runoff and the lowest PLAT index rating.

Summary

Land application of residuals leads to P buildup in the soil and can lead to losses of P to surface waters. Excessive P loadings of surface waters (along with N) can result in eutrophication, which reduces the economic and recreational value of the water bodies. PLAT is an assessment tool that can be used to estimate the potential of P loss from a site. PLAT can also be used to help develop a site management plan that minimizes the potential for P loss. Managers of land application programs should monitor P on land application sites and take steps to reduce P loss where practical. Several options are available to reduce the phosphorus excretion by animals and the potential loss of P from agricultural fields. For example, P can be reduced using phytase in animal diets, treating waste with amendments, limiting biosolids application rate based on PLAT, and injecting the waste instead of leaving it on the soil surface.

Managers should review their permit requirements to determine if they have land application limitations based on P. The rules concerning P assessment and application vary between animal manure application and biosolids application, and even vary within confined animal operations based on the number of animals and the type of permit. The manager must be aware of these regulations and follow appropriate guidance.

References

Barker, J. C., J. P. Zublena, and F. R. Waltz. Animal and Poultry Manure Production and Characterization. Biological and Agricultural Engineering, N.C. State University. Online: http://www.bae.ncsu.edu/programs/extension/manure/awm/program/barker/a&pmp&c/content.htm

Daverede, I. C., A. N. Kravchenko, R. G. Hoeft, E. D. Nafziger, D. G. Bullock, J. J. Warren, and L. C. Gonzini. 2004. Phosphorus runoff from incorporated and surface-applied liquid swine manure and phosphorus fertilizer. Journal of Environmental Quality 33:1535-1544.

Eghball, B. and J. E. Gilley. 1999. Phosphorus and nitrogen in runoff following beef cattle manure or compost application. Journal of Environmental Quality 28:1201-1210.

Johnson, N. C. Department of Agriculture and Consumer Services, Soil Testing Section database. Online: http://www.agr.state.nc.us/agronomi

Klopfenstein, T., R. Angel, G. L. Cromwell, G. E. Erickson, D. G. Fox, C. Parsons, L. D. Satter, and A. L. Sutton. 2002. Animal diet modification to decrease the potential for nitrogen and phosphorus pollution. CAST Issue Paper No. 21. Ames, Iowa: Council for Agricultural Science and Technology.

Laridi, R, Auclair, J-C, Benmoussa, H., “Laboratory and Pilot-scale Phosphate and Ammonium Removal by Controlled Struvite Precipitation Following Coagulation and Flocculation of Swine Wastewater”, EnvironmentalTechnology, 26(5):525-536, May 2005.

N. C. Division of Water Quality, Aquifer Protection Section. N. C. Depatment of Environment and Natural Resources, Raleigh. Online: http://h2o.enr.state.nc.us/aps/

Pierce, J. L., W. A. Dozier, III, G. L. Cromwell, and M. D. Lindeman. 1997. Effects of phytase on P balance in finishing pigs fed low Ca, low P diets. Journal of Animal Science 75 (Suppl. 2):66 (abstract).

Sibel Uludag-Demirer. Environmental Engineering Science. January 1, 2008, 25(1): 1-10. doi:10.1089/ees.2006.0168.

Smith, D. R., P. A. Moore, Jr., D. M. Miles, B. E. Haggard, and T. C. Daniel. 2004. Decreasing phosphorus runoff losses from land-applied poultry litter with dietary modifications and alum addition. Journal of Environmental Quality 33:2210-2216.

Vadas, P. A., J. J. Meisinger, L. J. Sikora, J. P. McMurtry, and A. E. Sefton. 2004. Effect of poultry diet on phosphorus in runoff from soils amended with poultry manure and compost. Journal of Environmental Quality 33:1845-1854.

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