factsheet

Pork Information Gateway

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Phosphorus management in pork production

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Introduction

Phosphorus (P) is an essential element for normal growth, development, and reproduction of both plants and animals. In swine diets, P is especially important in bone and cell membrane structure, energy metabolism and other important metabolic pathways. Traditionally, P has been over-formulated in swine diets since it was a relatively inexpensive input. Combined with the fact that not all P in the diet is absorbed by the pig, over-formulation has led to high amounts of P in manure. Though P is used by plants following manure application, excess amounts of P can runoff and trigger such environmental problems as eutrophication. Producers must understand the problems associated with excess P in diets and work to make sure diets are correctly formulated to reduce P excretion.

Objectives

- Become familiar with the environmental hazards associate with excess P
- Identify P as a manure component in lagoon systems and use as a fertilizer
- Understand the sources and availability of P in swine diets
- Describe methods to reduce P excretion

Phosphorus and the environment

Excessive P levels can impair surface water quality. It is well established that P is the limiting nutrient for phytoplankton production in lakes. Phosphorus also is a key element controlling the productivity of streams and rivers. High P levels in surface waters accelerate the eutrophication process and often result in the excessive production of phytoplankton such as algae and cyanobacteria. The respiration and decomposition of these organisms leads to decreased oxygen levels in bottom waters, and under certain circumstances (at night under calm, warm conditions), in surface waters. These decreased oxygen levels can lead to fish kills and significantly reduce aquatic organism diversity. Excessive P levels in animal diets increase animal manure P excretion, and land application of this manure to soil can increase potential P losses from fields to surface and groundwater resources.

Much of the P that reaches surface and ground water occurs as runoff, often with sediment, from cropland receiving high rates of manure or inorganic fertilizers. Phosphorus loss to surface and ground water by P leaching through the soil profile is generally much smaller than runoff P losses. However, excessive P applications will eventually move P to lower depths of the soil profile, and this P can discharge into tile drains, ditches and eventually streams. Sandy soils with rapid drainage generally have greater P leaching potential than heavier textured soils. Manure and commercial fertilizer P also can move rapidly through soils to tile drains and groundwater via root channels, animal burrows and other macropores after land application, especially during the dry season when surface cracks form in the topsoil. Avoiding manure applications (especially when irrigating) during periods when surface cracks in the soil are evident can significantly reduce this preferential, bypass, or macropore flow.

The potential risk of P loss to the waters of the United States as it relates to pork production is site specific and related to the vulnerability of fields for P loss and the rate, timing and method of manure and commercial fertilizer P applications. In certain regions of the US, more P is produced in manure than can be utilized by productive cropland; however, most manure P loading challenges occur at the farm or community level. In the past 15-20 years, livestock producers have increased the number of livestock at individual farms more rapidly than they have increased the land area available for manure applications. As a result, manure applications have been made more frequently to individual fields. Frequent applications of manure to cropland, especially at nitrogen (N) based rates, rapidly increase soil test P levels and increase potential P loss from agricultural fields. Increased soil P accumulation at the farm, community and regional levels has prompted efforts to regulate or encourage the long-term management of manure applications on a P basis through the recent revision the USEPA CAFO NPDES permit rule and the promotion of NRCS sponsored comprehensive nutrient management plans (CNMPs) to improve nutrient balance and management at the farm level.

A simplified version of the soil-water P cycle is illustrated in Figure 1. Both organic and inorganic P compounds are present in soil; however, plants take up only inorganic P. Soil P dynamics are largely influenced by soil pH, clay content and mineralogy, amorphous iron, aluminum and manganese, organic matter, and soil moisture. Inorganic P is the predominant P form in both manures and commercial fertilizers. Depending on soil pH and mineralogy, inorganic P can be sorbed to the surface of clays and amorphous iron and aluminum compounds, or be precipitated as mineral salts until utilized by plants. Organic forms of P from crop residues, soil organic matter and manures can be mineralized to inorganic P by soil microorganisms and become available for plant uptake. Conversely, inorganic P can be immobilized to organic P forms, which are not available for plant uptake. In addition, some organic P forms excreted in manure may displace previously sorbed inorganic P from soils and increase inorganic P runoff and/or leaching in the soil. Other organic P forms may not be readily sorbed by the soil and move more rapidly via runoff or leaching.

The extent of P runoff from soils depends on rainfall intensity, soil type, topography, soil moisture content, crop cover, and the form, rate, placement, time and method of P application. Surface P applications will result in far greater P runoff losses from soil than incorporated P applications. Manure should be injected or incorporated as soon as possible after application to minimize short-term P runoff losses from recently manured fields in tilled systems. Conservation best management practices like reduced tillage, buffer strips, grassed waterways, etc. that reduce surface runoff and erosion can greatly reduce the risk of P loss from soils.

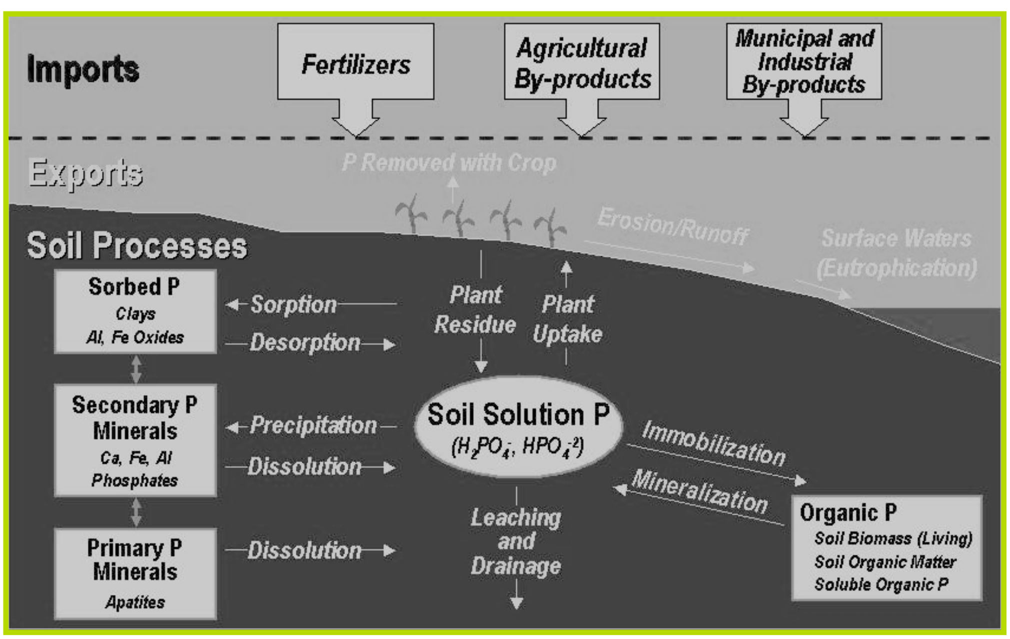

Figure 1. Simplified soil-water phosphorus cycle (adapted from Pierzynski et al., 1994).

Swine manure generation and composition

Approximately 60 million hogs are present on US farms at any one time and generate more than 90 million tons of manure each year. Hogs in the US excrete approximately 750 thousand tons of N, 220 thousand tons of P (500 thousand tons P_2O_5) and 330 thousand tons of potassium (K) (400 thousand tons of K_2O). Unfortunately swine manure N, P and K composition is not properly balanced for plant uptake by typical crops grown in production agriculture. The relative ratio of potentially available N, P_2O_5 and K_2O in manure from pigs fed commercial diets after storage in liquid pits is roughly 1:1:1. Additional N losses resulting from alternative manure storage systems, as well as manure application method and timing can result in relative N, P_2O_5 and K_2O ratios closer to 1:2:2. Corn grain production requires roughly a 3:1:1 ratio of N, P_2O_5 and K_2O, and if corn is grown for silage, then a 2:1:2 ratio of N, P_2O_5 and K_2O is desirable. Therefore, when manure is applied to meet the N requirements of crops, the P applied nearly always exceeds crop removal. For example, if manure is applied to meet the N requirement for corn grain, manure P applications may be 3-6 times greater than crop P removal.

Non-agitated lagoons are an important exception to the general discussion above. In these systems, much of the manure N is volatilized or denitrified to the atmosphere, while manure P tends to accumulate in the sludge layer at the bottom of the lagoon. While manure N to P_2O_5 ratios may actually be closer to crop nutrient requirements than with other systems, excessive K loading to soils is common as much of the K remains in the irrigated effluent. While K loading to soils does not pose a threat to water quality, forage crops grown on the irrigated fields can contain excessive K levels and potentially lead to nutritional imbalances in animals, especially when fed to cattle. In addition, a plan to manage the accumulating P-rich sludge layer must be developed for these systems.

Current regulations require pork producers to apply manure at agronomic rates based upon the most limiting nutrient. Producers can apply manure on a N basis and “bank” P in the soil for short periods of time if sufficient land is available to rotate fields for manure applications in subsequent years. A common practice may be to apply the manure to meet the N requirement of the crop, but only apply the manure to the field every 3 years. However, many producers do not have the ability to implement long-term manure application rotations due to limited land availability. Due to manure nutrient imbalance relative to crop needs, most manure applications for these producers will eventually become P based, regardless of other soil and crop management practices used. Regulations that more directly emphasize net nutrient balance at the farm level will significantly impact not only pork producers, but also the entire US livestock industry. Producers without adequate land needed to properly utilize manure without raising soil test P to excessive levels should strongly consider developing land use agreements with neighbors to ensure the long-term sustainability of their operation.

Phosphorus in swine diets

Phosphorus is an essential nutrient in swine diets, serving important functions as part of structural compounds in bone and in cell membranes, energy metabolism and other important metabolic pathways. Approximately 85% of total body P is found in bone, with 14% in soft tissue and muscle, and 1% in blood.

Although considerable research has addressed the P requirement of pigs, nutritionists still struggle to determine optimum dietary P levels. In the past, over-formulation of dietary P was not considered a major problem because P is relatively inexpensive to add to the diet. In addition performance of pigs is not hindered by small over-formulations in P, provided that Ca levels are kept at an appropriate ratio with P. However, with growing concerns about the environmental impacts of applying high P swine manure to soils, improved dietary P formulations have gained renewed interest with nutritionists. Minimizing over-formulation is the easiest and cheapest way to reduce P excretion. Reducing excess dietary P also increases the flexibility for adding other needed or desired supplements to the ration. Adjusting the P requirements for specific genetic lines at different phases of the life cycle of the pig allows for more precise formulation of feeds in phase feeding programs and complements the efforts of maximum N utilization that has been an emphasis in the past decade. The most recent swine National Research Council (NRC, 1998) report on the nutrient requirements of swine can be used to estimate the P requirement of pigs. Example diet formulations for swine are shown in other PIH fact sheets [1,2].

Availability of phosphorus in feeds

Historically, P requirements were reported on a total P basis. In recent years, it has been realized that the bioavailability of P differs among feedstuffs, so P requirements are now defined on an available P basis. The P requirement is listed in the most recent swine NRC as the amount of available P required per kilogram of diet and as the amount of available P required per day. Obviously, feed intake will affect the amount of available P consumed per day. Therefore, in diets with higher energy content resulting in lower feed consumption, it may be necessary to raise the concentration of available P in the feed to ensure that enough P is consumed. Ultimately, P requirements for market animals should be based on the quantity of available P required per pound of lean tissue growth. Due to different feed intakes and lean growth potentials for gilts compared to barrows, specific diet formulations for these groups also are needed. In addition, diets should be formulated on an available P:available Ca basis, but there is not enough data available to allow for this at the present time.

The bioavailability of P from inorganic P sources such as dicalcium phosphate, monocalcium phosphate and defluorinated phosphateused in swine diets is generally considered to be quite high; however, a substantial amount of variation has been reported. Inositol hexaphosphate, or phytate, serves as the primary storage form of P in plants, accounting for 50 to 80% of the total P in most grains. Because pigs do not secrete phytase (an enzyme that cleaves inorganic P from phytate) in sufficient quantities to release inorganic P from phytate in feed grains, most phytate P is considered unavailable for absorption. Ranges reported in the literature for total-, phytate- and bioavailable-P contents of various feed ingredients are presented in Table 1. Due to the relatively low bioavailable P content of plant-derived feedstuffs, relatively large quantities of highly available inorganic P sources have historically been be added to diets to meet the P requirement of pigs. While most phytate P is not available for absorption, much of the phytate P is mineralized in the large intestine and excreted in manure as inorganic P.

Byproduct feeds

Byproduct feeds can serve as a source of nutrients in pig diets. Often, byproduct feeds, such as distiller's grains, corn gluten meal, wheat middlings, etc. are included in the diet if they are readily available and favorably priced relative to conventional feed grains. Also, due to the processing methods employed, nutrients in the byproducts become more biologically available and can potentially reduce nutrient excretion if the byproduct nutrients can be balanced in the diet.

Feedstuff	Total P, %	Phytate P, % of total	Bioavailable P*, %
Corn	0.26 - 0.28	66	12 - 29
Soybean Meal	0.61 - 0.69	51 - 61	23 - 36
Barley	0.34 - 0.37	51 - 66	28 - 30
Wheat	0.30 - 0.39	60 - 77	46 - 51
Wheat middlings	0.80 - 0.93	66	41
Canola meal	1.01 - 1.12	36	21
Sorghum	0.27 - 0.31	68 - 70	20
Meat & bone meal	4.98	---	67 - 90

Table 1. Ranges in total P, phytate P and bioavailable P for various feedstuffs. *Bioavailability is expressed as a percentage relative to a monosodium phosphate standard which is assumed to have a bioavailability of 100%. If no standard was listed then bioavailability is expressed as a percentage of apparent absorption.

Distiller's dried grains with solubles (DDGS), which contains from approximately 0.6 to 0.9% P, has a higher concentration of available P than cereal grains and cereal co-products. Average P availability is about 75% for DDGS compared to a range of 15 to 50% for cereal grains and cereal co-products. Recent research suggests that adding up to 20% DDGS to grower and finisher diets may reduce or even eliminate supplemental inorganic P needs in the diet and reduce manure P excretion.

The relative availability of P in corn gluten feed and wheat middlings are 59% and 41%, respectively, compared to monosodium- or monocalcium-phosphate. Byproducts from dairy processing and high protein meals from animal origin also are high in available P (approximately 90 to 95% available). However, variation in the total P contents of these byproduct feedstuffs must be considered for determining optimum inclusion rates in a balanced diet. Feed processing can significantly influence the bioavailability of P. For example, fermentation of high moisture corn may have available P levels greater than 50% of total P, while P availability in dry corn is generally considered to be roughly 15% of total P. The presence of bacterial derived phytase during the fermentation process is thought to release more phytate P in fermented high moisture corn. Conversely, pelleting feeds by extrusion through a pellet mill may cause heat damage to natural phytases present in some feeds and reduce the availability of P.

Milling processes that degerm and dehull corn have created new interest in these materials as feed ingredients. Initial research has shown increased digestibility of dry matter, energy and N with degermed, dehulled corn compared to normal corn. In addition, these diets may reduce fecal dry matter, N and P excretion. Future processing techniques may result in feed byproducts that will allow more precise feeding with highly digestible nutrients; however, economic conditions may limit the implementation of these technologies.

Reducing phosphorus excretion

There has been a great deal of interest in altering swine diets to reduce P excretion. Two basic strategies have been employed to accomplish this important task: (1) adding phytase to the diet to increase phytate P availability, or (2) developing plants with lower amounts of phytate P in the grain. Both methods have been shown to work as both increase P utilization by pigs and decrease manure P excretion. Adding phytase to the diet while reducing inorganic P supplementation can reduce P excretion from 20-30%. Using low phytic acid grains in the diet, although not readily available for commercial use, also can improve P uptake and reduce P excretion from pigs another 20-25%. Combining low phytic acid grains and phytase in diets, with subsequent reductions in, or elimination of, supplemental inorganic P may ultimately provide producers the greatest ability to lower dietary P levels and minimize manure P excretion.

While the use of phytase in swine diets can significantly reduce manure P excretion, there has been some concern about the form of P excreted in manure and eventually applied to cropland. Some studies have shown that phytase can increase manure water soluble P (WSP) in swine manure; however, other studies have shown reduced WSP excretion from pigs fed phytase. Water soluble P from manure has been associated with greater P runoff losses, when the manure is surface applied. Incorporating manure will minimize WSP runoff.

Phase feeding pigs and adjusting dietary P levels to more closely meet the P requirement of the pig at each stage of growth can reduce P excretion 5-10% and improve profitability. In addition, split-sex feeding to meet the specific requirements of gilts and barrows also can help reduce P excretion. Minimizing feed wastage and milling feeds to the correct particle size (generally 600 to 700 microns) can significantly enhance nutrient availability and uptake by pigs.

Implications

To maximize manure nutrient use efficiency and economic returns, every producer should develop and implement a nutrient management plan that considers regulatory constraints, manure storage limitations, field availability, site vulnerability, labor and time constraints, and the judicious use of commercial fertilizers as a supplement to all planned applications of manure. Most states have developed risk assessment tools like the phosphorus index to help identify critical site or management factors that significantly impact P loss potential. These tools can be quite useful for developing nutrient management plans, and in many cases are required for the development of comprehensive nutrient management plans.

In addition, keep accurate records of all commercial fertilizer and manure application activities and use this information to improve the next nutrient management plan. To reduce potential P losses to the environment, inject or incorporate manure as soon as possible after application to minimize short-term P runoff losses from manured fields in tilled systems. Also integrate conservation best management practices like reduced tillage, buffer strips, grassed waterways, etc. to further reduce surface runoff and erosion.

Summary

Many pork production facilities generate more P in manure than can be effectively utilized by the cropland owned or managed by the operation. Therefore, source reduction is perhaps the single most important concept to ensure the long-term sustainability of these operations. The following list of management options, though not complete, should prove useful to producers seeking to improve P balance on their farm.

- Improve dietary formulations to more closely meet the P requirements of each animal group based upon available P in feed ingredients with split sex and phase feeding
- Use phytase in conjunction with reduced supplemental inorganic P
- Minimize feed wastage
- Grind feed to the appropriate particle size to maximize nutrient availability
- Purchase or rent the additional acres needed to properly utilize manure

- Develop a manure export plan, or arrange for neighbors to use manure as a nutrient resource on their farm
- Change the cropping system to include more crops with high P removal rates that can be marketed off the farm.

Literature Cited

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