Balancing the Phosphorus Budget of a Swine Farm: A Case Study

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ABSTRACT

Trends in animal production have moved the industry toward large confined animal feeding operations (CAFOs). These CAFOs concentrate large amounts of manure-based nutrients in relatively small areas, which increases the risk of nutrient loss to the surrounding environment. In response to water quality concerns, P-based manure application regulations are becoming more common. Mr. Pritchard is the owner and operator of two 4500-head swine (*Sus scrofa*) farms located in an area of intensive animal production in North Carolina. He has noticed an increasing trend in the soil P concentrations in his manure application fields and realizes that he does not have enough land to apply his anaerobically treated liquid swine manure based on crop P uptake. Mr. Pritchard is now faced with the dilemma of what to do to slow down the P accumulation in his soil. This case constructs a P budget for Mr. Pritchard's farm to examine ways of balancing on-farm nutrients. Students are encouraged to explore solutions related to animal nutrition, crop production, water quality, soil chemistry, and manure management. Furthermore, students should evaluate the appropriate role of government and industry in assisting Mr. Pritchard to protect the environment while remaining a profitable swine producer.

During the past 20 years the trends in the swine production have been moving toward increasing size and number of large confined animal feeding operations (CAFOs). Although CAFOs may have potential economic advantages, there are rising concerns about their long-term environmental impacts; specifically regarding the management of large amounts of manure-based nutrients that accumulate on the farms. To reduce possible environmental impacts, land application of animal manure is regulated based on the nutrient content of the manure. The Natural Resource Conservation Service (NRCS) has updated its Nutrient Management Conservation Practice Standard (Code 590) to include nutrient management guidelines for P (NRCS, 1999). The updated standard recommendations are that annual P application should not exceed the amount of P removed by the growing crop when there is risk for P loss to surface water. Many states, including North Carolina, have adopted the NRCS Nutrient Management Conservation Practice Standard as the basis for issuing permits to CAFOs. During the next 5 to 10 years, producers will need to comply with these new regulations, a change requiring them to re-evaluate their nutrient management practices.

This case study highlights the decisions faced by a typical swine producer who is concerned about the accumulation of P on his farm in relation to new regulations for manure management. The data presented in this case are from personal interviews, soil and lagoon liquid analysis, and farm records of lagoon liquid application, crop production, and swine production.

THE CASE

Mr. Pritchard owns and operates two adjacent swine farms in Sampson County, North Carolina, each with 4500 swine. The *old farm* was established in the early 1970s and the *new farm* was established in 1996. The two farms are operated in much the same way, with the main difference being the age of the farm. Swine manure is treated in anaerobic lagoons and excess lagoon liquid is irrigated onto adjacent crop land to meet the N requirement of the growing crops. However, recent changes in the regulations have prompted Mr. Pritchard to evaluate the risk of P loss from fields receiving swine lagoon liquid. If there is a high risk of P loss, he will need to apply the lagoon liquid based on the P removal of the growing crop. A high P loss rating could easily affect the profitability of his farms as well as the overall value of the farm when he decides to sell it. Therefore, Mr. Pritchard has decided to immediately re-evaluate his current nutrient management plan to determine if he can reduce the rate of P accumulation in soils of fields receiving lagoon liquid.

General Farm Operation

Like most of the swine producers in the area, Mr. Pritchard contracts with a large swine integrator that supplies him with piglets (20 kg), animal feed, and veterinary services. Mr. Pritchard is responsible for the daily management of the farm, such as caring for the pigs, maintaining the physical facilities, and managing the manure. After 140 days, the integrator returns to Mr. Pritchard's farm and picks up the grown pigs (approximately 106 kg). Mr. Pritchard is paid by the integrator according to the hog weight gain during the time that he cared for the animals. This type of production system is commonly referred to as a *grower-finisher operation*. In the surrounding region, more than 20 million swine are produced each year.

Both farms have several swine houses, which each hold 700 to 1000 swine. Swine manure is removed once or twice a week from cement pits under the swine houses using recycled flush water (Exhibit 1). Manure from the houses is flushed to an open-pit anaerobic lagoon, where most of the organic components are removed through anaerobic digestion (conversion to CO_2 and CH_4) and settling. Stabilized organic components and other solids settle in the lagoon to form a sludge layer, which is removed from the lagoon every 10 to 15 years and applied to nearby cropland (Mikkelsen, 2000a). An average annual excess of 12,900 m^3 of lagoon liquid, or effluent (<10 g L^{-1} solids), containing 3970 kg plant-available N (PAN) and 1170 kg P, is irrigated from each lagoon onto adjacent fields to meet the N requirement of the crop, growing primarily on a Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults; Exhibit 2).

The nutrient flux for the waste application fields depends on the cropping system on the two farms (Exhibit 3). Mr. Pritchard grows

Abbreviations: BMPs, best management practices; CAFOs, confined animal feeding operations; HAP, high available phosphorus; M3-P, Mehlich-3 extractable P; NRCS, Natural Resource Conservation Service; PAN, plant-available nitrogen; PLAT, Phosphorus Loss Assessment Tool; RYE, realistic yield expectations; SERA-17, Southern Extension–Research Activity Information Exchange Group 17.

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Exhibit 1. Average chemical composition of lagoon liquid from Mr. Pritchard's swine manure treatment lagoons compared with statewide average chemical composition of lagoon liquid and lagoon sludge.

Source	N†	P	K	Ca	Mg	S	Mn	Zn	Cu
		mg L^{-1}							
Mr. Pritchard's lagoon liquid	625	92	888	110	25	31	0.4	1.2	0.4
Avg. lagoon liquid‡	563	98	484	122	40	34	0.9	3.1	1.2
Avg. sludge‡	2926	14437	942	2838	818	593	36	94	36

† Total N; the plant-available N (PAN) is determined by multiplying total N content by an availability coefficient of 0.5 when swine lagoon liquid is applied through sprinkler irrigation, or 0.6 for lagoon sludge injected or incorporated into the soil.
‡ Barker et al., 1994.

Exhibit 2. Soil profile description of Norfolk loamy sand (Typic Kandiudults), the dominant soil series in Mr. Pritchard's fields.

Horizon	Depth	Description
	cm	
Ap	0–23	grayish brown loamy sand; weak fine and medium granular structure; very friable; strongly acid
E	23–36	light yellowish brown loamy sand; weak medium granular structure; very friable; strongly acid
Bt	36–178	yellowish brown sandy clay loam; weak medium subangular blocky structure; friable; strongly acid
BC	178–208	mottled brownish yellow, strong brown, and yellowish red sandy clay loam; weak medium subangular blocky structure; friable; strongly acid
C	208–254	mottled red, strong brown, brownish yellow, and gray sandy clay loam; massive; friable; strongly acid

Exhibit 3. Average nutrient concentrations and realistic yield expectations (RYE) for selected field crops and forages grown on a Norfolk Sandy loam soil in North Carolina (adapted from Zublena, 1991).

Crop	Realistic yield expectation†	N requirement‡	Nutrient conc. in harvested biomass§		
			N	P	K
	kg ha^{-1}		g kg^{-1}		
Corn grain (*Zea mays* L.)	7,220	150	16.1	2.8	4.0
Oat grain (*Avena sativa* L.)	3,660	130	19.5	3.4	4.9
Wheat grain (*Triticum aestivum* L.)	4,040	140	20.8	4.5	5.2
Soybean [*Glycine max* (L.) Merr.]	2,820	180	62.7	6.0	20.5
Tobacco (*Nicotiana tabacum* L.)	3,700	110	28.3	2.2	42.9
Coastal bermuda hay¶ (*Cynodon dactylon* L.)	17,930	400	25.0	2.5	17.9
Coastal bermuda pasture¶ (*Cynodon dactylon* L.)	13,450	300			
Tall fescue (*Festuca arundinacea* Schreb.)	7,850	180	19.3	4.1	21.9
Perennial ryegrass (*Lolium perenne* L.)	11,210	250	21.5	3.7	19.9

† RYE are for crops at the following moisture contents: corn, 15.5%; oat, 14%; wheat, 13.5%; soybean, 13%; tobacco and forages, 0%.
‡ Recommended N application based on RYE.
§ Nutrient concentrations are for crops with above-mentioned moisture contents.
¶ Overseeded with a winter annual grass.

coastal bermudagrass (*Cynodon dactylon* L.) on the majority of his cropland (Exhibit 4), with some fields grazed and others cut for hay. In addition to the bermudagrass hay and pasture, Mr. Pritchard grows a forage rotation that includes oat (*Avena sativa* L.), rye (*Secale cereale* L.) and sudangrass [*Sorghum bicolor* (L.) Moench]. On the old farm, a few fields are planted in a 3-year rotation of corn (*Zea mays* L.), tobacco (*Nicotiana tabacum* L.), and soybean [*Glycine max* (L.) Merr.]. Each cropping system requires different amounts of N and therefore receives different amounts of P. Irrigated lagoon liquid is the only P import to the annual crops, while P imports to the bermudagrass pasture include lagoon liquid and stocked cattle. The only P export from the pasture is in the cattle. Bermudagrass hay, annual forage, and bermudagrass pasture cropping systems remove 42, 25, and 10% of the applied P, respectively (Exhibit 5).

Anaerobic swine lagoon liquid has a PAN/P ratio (3:1) that exceeds the typical crop biomass N/P ratio (8:1). As illustrated in Exhibit 5, whenever anaerobic swine lagoon liquid is applied to meet crop N requirements, P is simultaneously over-applied by two to three times. The continued application of P in excess of crop needs has increased the soil test P levels well beyond the requirement for crop growth (Exhibit 4).

Nutrient Management

The manure-derived nutrients from swine production help increase the profitability of Mr. Pritchard's crop and cattle production. The ready supply of nutrients for his pasture and hay fields helps to maintain maximum productivity, thereby eliminating the need to buy hay throughout the winter months and the need to buy fertilizer. Although excess P will not harm the crops, it could pose risks to aquatic environments if it moves to surface water by runoff, leaching, or erosion. Several research reports have documented that increased dissolved P losses in runoff water are directly related to high soil P concentrations in the fields even when erosion is not a primary loss pathway (Cox and Hendricks, 2000; Sharpley et al., 1994).

Soil P concentration is not the only factor affecting P loss from the effluent application fields. Erosion rate, runoff volume, soil type, manure application rate and method, and riparian buffer width are all factors that affect P transport from the field to surface water (Sharpley et al., 2003). The North Carolina Phosphorus Loss Assessment Tool (PLAT) incorporates all these factors into a simplified model that rates the risk of P loss from agricultural fields from 1 to 100, with 100 representing the greatest risk (Osmond et al., 2003). If the P-loss index exceeds 50, then future P additions cannot exceed P removal by the crop (known as P-based application). The PLAT rating for a field is the sum of P loss risk ratings for the following four loss pathways: erosion P, or P lost through erosion; runoff P, or P desorbed from soil to runoff; leachable P, or P lost below 75 cm through leaching; and source P, or P lost directly from a P source (fertilizer or manure) to the runoff water. Each rating combines the quantity of P available for transport with a transport factor, such as

Exhibit 4. Rotations, soil test P, and P loss ratings for lagoon liquid application fields on Mr. Pritchard's two swine farms (new and old).

Field ID	Area	Rotation	Erosion rate†	Surface M3-P‡	Runoff volume§	DRP¶ in runoff	PLAT rating of P loss risk#				
											Total
	ha		Mg ha^{-1} yr^{-1}	mg kg^{-1}	cm ha^{-1} yr^{-1}	mg L^{-1}			index		
					New farm						
C01	6.3	bermudagrass hay	0.1	160	0.4	0.8	0	1	0	1	2
C02	1.1	bermudagrass hay	0.0	123	0.4	0.6	0	1	0	1	2
C03	1.8	winter annual/summer annual grazing	1.9	68	2.1	0.3	0	2	0	3	5
C04	2.2	permanent pasture	0.0	176	2.1	0.9	0	4	0	3	7
C05	1.9	permanent pasture	0.0	112	2.1	0.6	0	3	0	3	6
					Old farm						
T05	5.5	permanent pasture	0.0	315	0.8	3.1	0	5	3	1	9
T06	3.6	winter annual/summer annual grazing	1.9	259	0.8	2.6	1	4	3	1	9
T07	6.2	tobacco, corn, soybeans (conv. tillage)	3.3	267	7.9	1.3	4	24	3	15	46
T08	7.7	tobacco, corn, soybeans (conv. tillage)	3.3	202	7.9	1.0	1	18	3	14	36
T09	4.4	permanent pasture	0.1	156	0.8	1.6	0	3	0	1	4
T10	3.6	winter annual/summer annual grazing	2.5	248	0.8	2.5	1	4	3	1	9

† Determined using the Revised Universal Soil Loss Equation (RUSLE).

‡ Sampled 0 to 20 cm. Crop response to P fertilizer is not expected for soil tests >60 mg Mehlich-3 extractable P (M3-P) kg^{-1} soil. Unfertilized soil on the farm contains <5 mg M3-P kg^{-1}.

§ Determined using the NRCS curve number method.

¶ DRP, dissolved reactive phosphorus, determined as a function of soil type and surface M3-P concentration.

Ratings are as follows: 0 to 25, low; 25 to 50, medium; 50 to 100, high; >100, very high.

Exhibit 5. Average annual P flux for Mr. Pritchard's lagoon liquid application fields on the new farm.

Phosphorus flux and storage	Bermudagrass hay	Oat	Bermudagrass pasture
Area, ha	7.4	2.2	3.5
Lagoon liquid application rate, m^3 ha^{-1}	1150	220	1050
Cattle stocking rate, head ha^{-1}	0	0	30
P imports from lagoon liquid, kg ha^{-1}	+106	+20	+97
P imports from cattle, kg ha^{-1}	+0	+0	+48
P exports, kg ha^{-1}	−45	−5	−58
Surplus P, kg ha^{-1}	61	15	87

runoff or erosion. Listing the four parts of a PLAT rating allows the producer to target conservation strategies toward pathways with the highest risk for P loss. For example, a high source P index could be lowered by changing P application method, P application rate, or reducing transport factors (runoff or erosion). The PLAT ratings for two of Mr. Pritchard's effluent application fields on the old farm are nearing the P-based application threshold of 50 (Exhibit 4).

Switching to a P-based effluent application plan could easily decrease the profitability of Mr. Pritchard's swine farms since it would require additional land and irrigation equipment to apply the lagoon liquid to new fields. Furthermore, he would need to purchase supplemental N fertilizer for crops that had previously been receiving the full N requirement from lagoon liquid. He may also have to switch to less profitable cropping patterns.

Phosphorus Budget

A P budget was constructed to quantify P imports and exports from the swine houses, lagoon, and effluent application fields for the new farm (Exhibit 6). The P flux for the swine barns consists of imports from piglets and feed while exports consist of live hogs, dead pigs (mortality), and manure. Because the swine houses are completely cleaned before receiving new piglets, all excess P moves to the lagoon. The budget shows that 40% of the P entering the barns leaves in the exported hogs and the remaining 60% goes to the lagoon (Exhibit 7).

Phosphorus in the lagoon occurs in two fractions, the lagoon liquid (mostly dissolved inorganic P) and the lagoon sludge (mostly organic and particulate-bound P). On average, only 14% of the P entering the lagoon is removed with the effluent, leaving 86% of the P to accumulate in the sludge (Exhibit 8). Although this sludge is not of immediate concern, it must be cleaned out and land-applied every 10 to 15 years. On average, 0.003 m^3 of sludge accumulates in the lagoon each year per kilogram live animal weight on the farm (Bicudo et al., 1999). Estimating average animal weight of 63 kg, Mr. Pritchard's farms would each accumulate approximately 850 m^3 of sludge per year.

In summary, swine feed is the main P input to the farm, and mature swine are the main P export. However, swine only export 40% of the P imported in the feed and crops export less than 3% of total P inputs. A closer look at the feed reveals that nearly two-thirds of the P in corn–soybean–based feed is in an organic P complex called phytate that passes largely undigested through the swine (Ertl et al., 1998; Jongbloed and Kemme, 1990). Because phytate-P is unavailable for swine, the feed is supplemented with approximately 2 g inorganic P kg^{-1} feed. This P supplementation to the swine feed accounts for nearly 4760 kg of P imported onto Mr. Pritchard's farm each year.

DECISION

Both the soil concentrations and the P budget indicate that P is rapidly accumulating on Mr. Pritchard's farms. Although only a few fields are currently approaching high risk for P loss, Mr. Pritchard is very concerned about the long-term sustainability of his present nutrient management practices. He worries that he might be degrad-

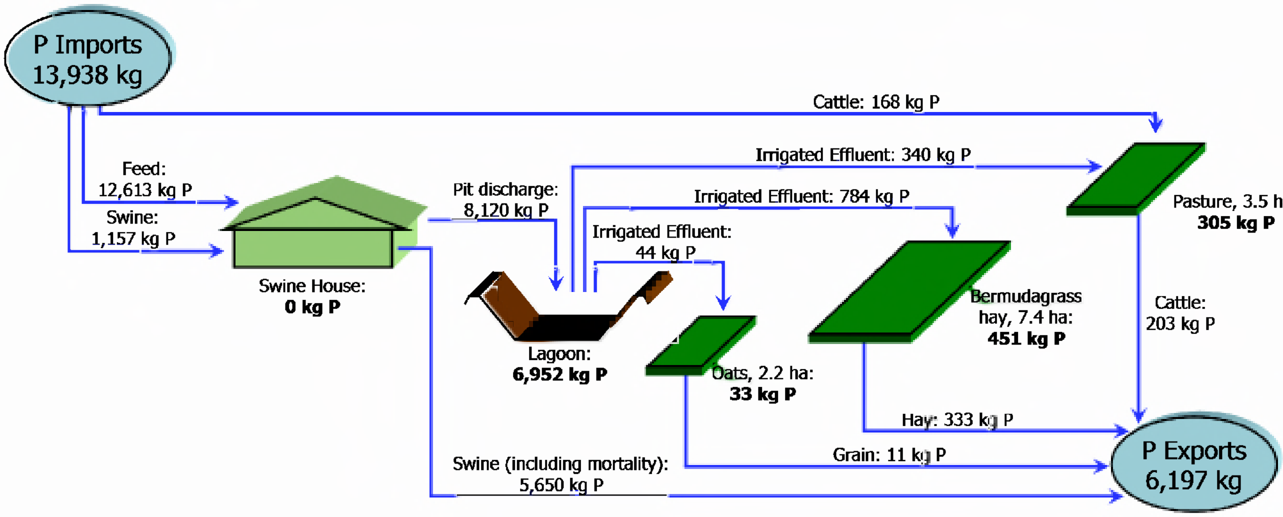

Exhibit 6. Average annual mass balance phosphorus budget for Mr. Pritchard's new swine farm (bold numbers represent net annual P accumulation for each P sink).

ing the future value of his farms by what he is currently doing. What actions would you recommend he take to decrease the risk of P loss and/or slow P accumulation in his effluent application fields? Can you balance the P budget of this swine farm?

TEACHING NOTE

Case Objectives

This case should be used to teach students about soil fertility, crop management, manure management, animal science, nonpoint-source pollution, nutrient cycling, and sustainable agricultural production on a farm scale. This case emphasizes multidisciplinary problem solving skills and the interconnections between local- and regional-scale agricultural production systems. Students should learn to identify the long-term impacts resulting from the changes in agricultural production systems and markets. Students can also extend their analysis to more complex issues such as regulatory control of local agricultural practices.

Use of the Case

Stimulant Questions

1. Is the P accumulation on Mr. Pritchard's land a significant agronomic or environmental concern?
2. What changes, if any, should Mr. Pritchard make in his nutrient management and cropping system to bring on-farm nutrient inputs and outputs closer together?
3. Is continual nutrient over-application and accumulation a sustainable agricultural practice? Does this depend on the nutrient characteristics and soil management practices?
4. What are the long-term environmental, economic, and social impacts of farm- and regional-scale P accumulation?
5. Should Mr. Pritchard be allowed to manage nutrients without regulatory interference?
6. What realistic practices can Mr. Pritchard implement (both short- and long-term) to reduce P input to his farms?
7. Currently the only P exports are in mature swine, grazing cattle, and harvested crops. Are there other ways Mr. Pritchard can increase P export from his farm?
8. What role should integrators and government regulatory agencies take in minimizing P accumulation on CAFOs? Who should pay for the expenses associated with possible changes in nutrient management?

Teaching Aids

An internet website containing additional information about this case (including maps, photos, and a video interview with Mr. Pritchard on his farm) has been set up at http://courses.soil.ncsu.edu/ssc342/CaseStudy/index.htm (verified 29 Aug. 2005). These materials may also be obtained by directly contacting the authors. The video is particularly useful for familiarizing students with the farm operation and a production viewpoint on nutrient management.

Because direct suggestions on methods of addressing issues discussed have been reserved for the Author's Analysis and Interpretation section, some students may benefit from additional information pertaining to best management practices (BMPs) to control P loss. A series of P loss BMP fact sheets have been developed by the Southern Extension–Research Activity Information Exchange Group 17 (SERA-17) and are available on the internet at www.sera17.ext.

Exhibit 7. Average annual P flux in Mr. Pritchard's swine houses.

Source	P content	P flux, kg
	Imports	
10,824 piglets	0.10692 kg P head^{-1}	+1,157
2,378,895 kg feed	0.005302 kg P kg^{-1}	+12,613
	Exports	
10,407 live pigs	0.52894 kg P head^{-1}	–5,505
417 dead pigs	0.34698 kg P head^{-1}	–145
Surplus (to lagoon)		+8,120

Exhibit 8. Average annual P flux in Mr. Pritchard's anaerobic swine manure treatment lagoon.

Source	P content	P flux, kg
	Imports	
Surplus P leaving swine houses	NA†	+8,120
	Exports	
12,700 m^3 irrigated lagoon liquid	92 mg L^{-1}	−1,168
Surplus (accumulation in sludge)		+6,952

† Not available.

vt.edu (verified 29 Aug. 2005). Fact sheets particularly pertinent to this case study include Smith and Joern (2005), discussing methods to reduce P solubility in lagoon liquid; and Smith (2005), discussing reduction of feed P concentrations.

Author's Analysis and Interpretation

Mr. Pritchard's new farm accumulates an average of 55% of the imported P, or a total of 7741 kg P yr^{-1}. The majority (86%) of the P accumulates in the sludge with the remainder largely accumulating in the soil of the irrigated fields. Looking at the P flux for each operation of the farm reveals some important points for balancing the nutrient budget. First, swine feed is the largest source of P entering the farm and only 40% of the feed P is exported in the mature swine. Second, soil P concentrations in the effluent application fields of Mr. Pritchard's old farm are double the already high soil test P in the newer farm, thus suggesting the long-term accumulation of P, which will result from continued lagoon liquid applications. The lagoons will soon require that sludge be removed, at which point he must address the disposition of a large amount of stored P. He will have to dispose of perhaps as much as 70 Mg of P (typically irrigated onto adjacent cropland or hauled in trucks to nearby fields and applied to meet the N needs of the growing crop).

Large nutrient accumulations are not uncommon in other CAFOs such as poultry, beef feed lots, and many dairies. This case study focuses on the farm-scale P imbalance; however, CAFO nutrient imbalances also exist on the regional scale. The CAFO operations frequently become locally concentrated for economic efficiency and the feed is often brought in from outside the region. For example, two neighboring North Carolina counties, Sampson and Duplin, contain 7.2 million broilers (*Gallus domesticus*), 3.9 million swine, and 5.8 million turkeys (*Melleagris gallopavo*). These same counties only have 107,160 ha of cropland on which to apply the manure-based nutrients (North Carolina State University, 2000). The majority of the feed-based nutrients are imported from other states where the crops are grown with mineral fertilizers, creating a continual influx of nutrients to this region. Students should be able to identify that nutrient imbalances are not sustainable in the long-term. Although Mr. Pritchard's options may appear to be limited, students should creatively explore industry-wide changes that may be useful.

Options for balancing the P budget on the farm consist of either decreasing the P imports (mainly in the feed) or increasing the quantity of P exported from the farm. Since the integrator supplies the feed formulated for maximum swine growth (supplemented with inorganic P), this is not a factor that Mr. Pritchard currently controls. Increasing the digestibility of phytate-P present in feed grain would reduce the need for inorganic P supplementation. The digestibility of phytate-P in grain-based feed can be increased by adding phytase, a microbially derived enzyme that hydrolyzes the phytate-bound P. Studies have shown that the addition of phytase to a corn–soybean meal diet can increase the digestible P by as much as 1 g kg^{-1} (Beers and Jongbloed, 1992). Another method of increasing the digestibility of P in swine feed is by the use of high available P (HAP) corn, also known as low-phytate corn. The HAP corn is a genetically mutated corn variety that has 65% less phytic acid than traditional corn with a corresponding molar increase in available P (Ertl et al., 1998). Low-phytate soybean plants are also being developed (Oltmans et al., 2004). Using such technology, it may be possible to greatly reduce or even eliminate the need for feed supplementation with inorganic P.

Phosphorus loading to cropland could be reduced by precipitating and recovering P from the lagoon liquid. A common method of P removal used by municipal waste treatment plants is the precipitation of Ca- or Al-phosphates. This method could work for swine lagoon liquid also, although the precipitation process relies on chemical amendments and produces a sludge that requires disposal. Another less common method of P removal from wastewater is precipitation of P-containing minerals such as magnesium ammonium phosphate ($MgNH_4PO_4{\cdot}6H_2O$; struvite). Struvite precipitation is advantageous compared with other forms of P removal from lagoon effluent because the precipitation requires fewer chemicals and the product can potentially be sold as a slow-release fertilizer (Wrigley et al., 1992; Bridger et al., 1962). Research has shown that struvite precipitation has the potential to reduce P concentration in anaerobic swine lagoon liquid to 2 mg L^{-1} (Nelson et al., 2003). Struvite precipitation has had only limited field-scale evaluation in the swine industry. Struvite could possibly be sold as a value-added waste product, thereby removing the P from the farm and possibly generating income to help offset the additional lagoon liquid treatment costs.

A less expensive but short-term solution to reduce the risk of P loss from fields is to stabilize the P in the soil. Land application of various materials high in Ca, Fe, or Al (such as drinking water treatment residuals, alum, or other industrial waste products) will decrease P solubility and thus reduce P concentrations in runoff (Gallimore et al., 1999; Haustein et al., 2000; Elliott et al., 2002). Because drinking water treatment residuals, which contain Al, Fe, and/or Ca, are currently disposed of in landfills, they may be available at minimal cost to farmers. This will not change the overall P budget, but it has potential to temporarily reduce the risk of P loss to surface waters. The long-term stability of the Al-, Fe-, or Ca-phosphate minerals in these acidic soils remains an important consideration when using this technique to remediate high P conditions. Calcium phosphates would not be stable at low pH (Lindsay, 1979). Initial research suggests that Al-phosphate complexes formed in alum-treated chicken litter would be stable for long periods (Peak et al., 2002). However, there is a lack of long-term data to support this. Students may discuss the benefits of short-term solutions compared with achieving a long-term balanced P budget.

The students will benefit from a discussion of this situation from a regulatory standpoint. The imposition of mandatory P-based manure application would be a major financial burden for Mr. Pritchard and other CAFO operators in the area, and could possibly put them out of business. The Norfolk loamy sand is a common soil used for agricultural production in the southeastern U.S. Coastal Plain with a high (>7.5 cm h^{-1}) infiltration capacity. This soil has minimal erosion and runoff when planted into permanent grass. The sandy clay loam subsoil will likely provide sufficient adsorption capacity to minimize P leaching. The PLAT model currently used to rate the risk of P environmental impacts is science based, but largely unproven and these model predictions vary considerably from state to state. Should the farmer be forced to change management practices before all the scientific studies have been completed?

This case study can be customized by discussing animal production practices in the student's local area. Students could develop a nutrient budget for local dairies, feedlots, or poultry farms (e.g., Tarkalson and Mikkelsen, 2003). Focus could be placed on other nutrients, such as Cu and Zn that also may accumulate in effluent application fields (Mikkelsen, 2000b). This case should be used with these and other questions to impress upon students the essential role of nutrient management planning in sustainable animal production.

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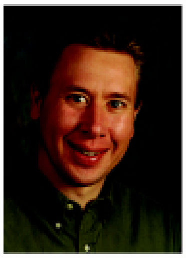
About the author…

Nathan O. Nelson



Nathan O. Nelson is currently a soil scientist at the USDA-ARS in Kimberly, ID; and as of 1 Nov. 2005 will be assistant professor, at the Kansas State University, Manhattan, KS. Dr. Nelson believes case studies bring real situations into the classroom, allowing students to think through complex problems and come up with a variety of solutions. Solutions to case studies are often multidisciplinary, thereby allowing students to draw on their own backgrounds and ideas. He adds, "I prefer offering minimal guidance in solving problems presented in the case, which gives students greater ownership in the solutions they develop. I have observed that students respond positively to case studies and ask questions that extend beyond the presented material, thus showing their expanded interest in the subject matter."