

# Mitigating High-Phosphorus Soils

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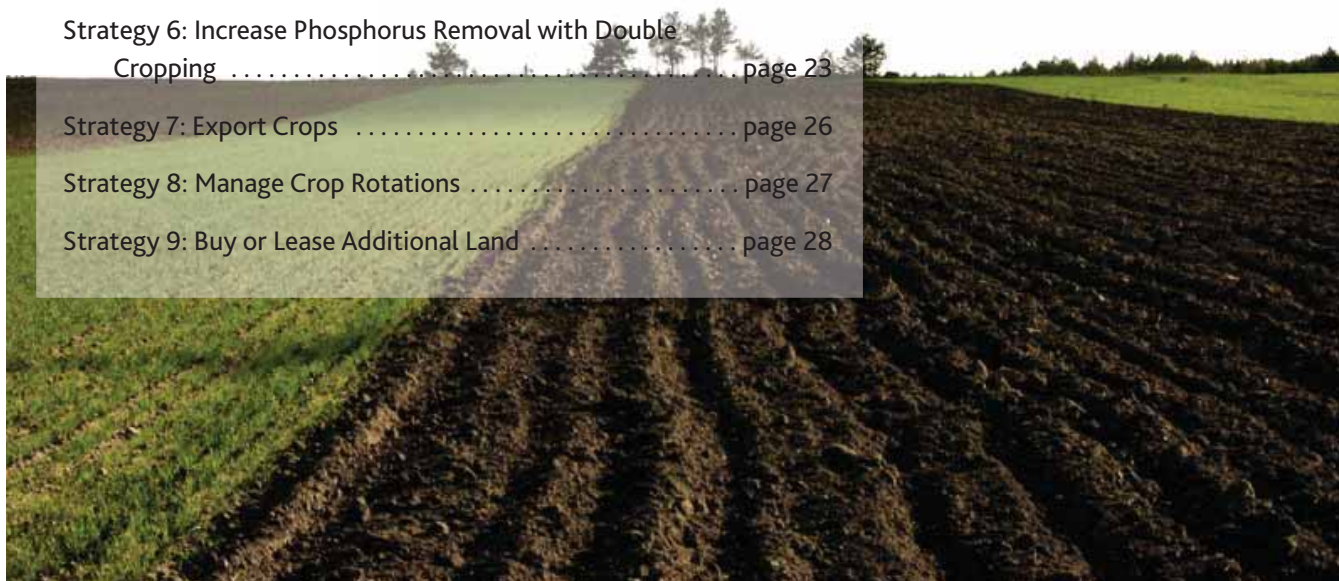
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## INTRODUCTION

This bulletin highlights the environmental and nutrient management issues related to phosphorus (P) on livestock operations in Idaho. The Nutrient Management Team at the University of Idaho also presents several strategies for avoiding or reducing high soil phosphorus levels in fields receiving manure.

The concentration of specialized farming systems has led to a phosphorus (P) transfer from grain to animal production areas. This transfer has created local and regional surpluses in P inputs as fertilizer and feed, soil P in excess of crop needs, and increased losses of P from land to water. Phosphorus, an essential nutrient for crop and animal production, can accelerate freshwater eutrophication—the nutrient enrichment of surface water leading to nuisance aquatic growth. Eutrophication is one of the most common surface water quality impairments in many developed countries. Algal blooms—harmful overgrowth of algae such as *cyanobacteria* and *Pfiesteria*—across the country have increased society's awareness of eutrophication and the need for solutions. Algal blooms lead to oxygen depletion in the water, which causes fish to die. *Pfiesteria* can produce toxins which harm fish, shellfish, and other animals. Some species of cyanobacteria, also known as blue-green algae, also produce toxins. Consequently most states, including Idaho, have developed legal and practical measures to mitigate these P concerns.

Recent research shows that most P loss to surface or subsurface flow originates from only a small area of a watershed during a few storms. These are areas where high soil P, from P application as fertilizer or manure, coincides with high runoff or erosion potential. The overall goal of efforts to reduce P loss through runoff and leaching should be to balance P inputs and managed outputs at both farm and watershed levels, while managing soil and P in ways that maintain productivity.

Nutrient management in large Idaho confined animal feeding operations (CAFO) such as dairies or feedlots is regulated by the USDA-NRCS Nutrient Management 590 Standard for Idaho (<http://efotg.nrcs.usda.gov/references/public/ID/590.pdf>). This Standard regulates rates of adding phosphorus to the soil based on the soil

test value and crop uptake (removal) of P. This bulletin will not only help livestock operators to be in compliance with the law, but will also help farmers to make sure the operation is in a long-term balance in terms of phosphorus added to and removed from the soil. While most livestock operators are aware that they must file a Nutrient Management Plan, they might not be aware of the range of strategies they can use to balance their P inputs and outputs.

Management strategies that minimize P loss to water may involve optimizing P use efficiency, refining animal feed rations, moving manure from surplus to deficit areas, sampling manure prior to application, and refining cropping systems. Some of these strategies are more easily implemented than others. The appropriate strategy will depend on the operation's size, the ration fed, availability of land resources for manuring, collaborative agreements with neighbors, and several other factors mentioned in this publication. This publication should be useful in helping to identify the best options for your animal operation.

## PHOSPHORUS CONCENTRATION AND DISTRIBUTION

This section was excerpted with minor changes from the Livestock and Poultry Environmental Stewardship curriculum, lesson authored by Rick Koelsch, University of Nebraska, courtesy of MidWest Plan Service, Iowa State University, Ames, Iowa 50011-3080, *Copyright* © 2001. <http://www.lpes.org>.

The fundamental question, "Is my dairy or feedlot concentrating nutrients?" must be the premise for any successful nutrient management plan. Most nutrient-related issues associated with animal production result from poor nutrient distribution. Distribution issues can be challenging at local or regional levels.

***Single-field nutrient concentration issues.*** An integrated crop and livestock farm commonly experiences this distribution problem within its own boundaries. Some fields, often those closest to the livestock facility, receive excessive manure applications, while commercial fertilizer is purchased to meet the needs of fields more distant from the livestock. Spreading manure

based upon convenience, and not on the crop's nutrient requirements, causes nutrient enrichment in manured fields, higher risks of water quality problems, and greater fertilization costs in non-manured fields.

**Individual farm nutrient concentration issues.** Farms focused primarily on livestock production import significant quantities of nutrients as animal feeds. Livestock utilize only 10% to 30% of these nutrients, excreting the remaining in manure. This results in a concentration of nutrients on the livestock farm and a shortage of nutrients (typically replaced by purchased commercial fertilizers) on neighboring crop farms supplying feed. Separated crop and livestock production typically drives this problem. Such problems are common in regions where sufficient crop land is available, but separately owned livestock and crop enterprises create legal, logistical, and other limitations to better nutrient distribution.

**Regional nutrient distribution issues.** Regional nutrient distribution imbalances have been exacerbated in the last 30 years as livestock/poultry production and feed grain production have concentrated in separate regions of the country. Examples include the concentration of pork production in the Carolinas, poultry in southern and Mid-Atlantic states, beef cattle production in the High Plains, and dairy in western, north central, and northeastern states. Many of these regions import significant quantities of nutrients, primarily as feed grains and byproducts, from the Corn Belt. The nutrients excreted by these animals can overwhelm the ability of locally grown crops to recycle these nutrients. These regional distribution problems represent the animal feeding industry's greatest nutrient challenges.

While manures in some areas of the country are concentrated such that the land resource cannot indefinitely accommodate their application, this is not the case in most areas of the country, nor in Idaho. Excessive manure concentrations in Idaho tend to be localized and associated with individual animal enterprises. But some counties in western and south central Idaho have animal operations with manures concentrated sufficiently to provide from 50 to 100% of the P required for growing the crops in those counties. For these counties, finding land resources to economically transport and apply manures can be challenging.

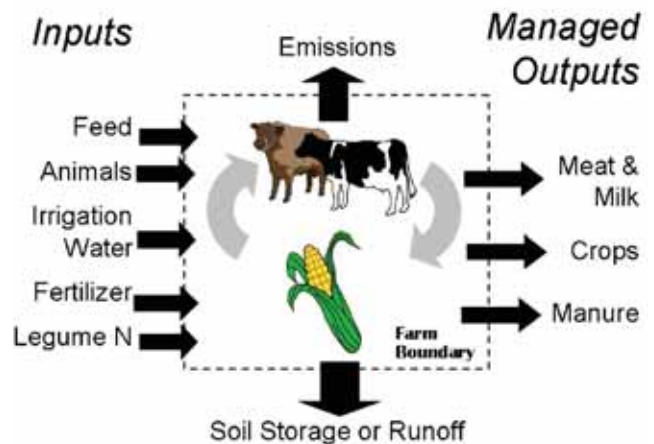
To determine if these nutrient concentration concerns are affecting your dairy, feedlot, or cropping system requires an appreciation of the total nutrient balance for your operation. A discussion of a "Whole Farm Nutrient Balance" follows.

### Whole Farm Nutrient Balance

Nutrients are transported along multiple pathways and in a variety of forms on a livestock operation. Our tendency is to focus on a small part of the total picture, such as the nutrients in manure and their losses into the environment. However, to identify the underlying cause of nutrient concentration concerns as well as their solutions, we need to understand the entire picture.

Figure 1 shows a general diagram of nutrient flow. Nutrients arrive on a livestock operation through purchased products (fertilizer, animal feed, and purchased animals), rain and irrigation water, and nitrogen (N) fixation by legume crops. These "Inputs" are the origin of all nutrients required for crop and livestock production that accumulate in soils, as well as those nutrients that escape into the environment.

**Figure 1. A whole farm nutrient balance considers all nutrient inputs and managed outputs. The difference or imbalance causes risks to air and water quality.**  
(Graphic courtesy of Livestock and Poultry Environmental Stewardship Curriculum. Used by permission.)



Within the farm boundaries, nutrients are “recycled” between the livestock and crops. Applied manures recycle nutrients to fields for crop production and crop nutrients are in turn recycled as animal feed for livestock or poultry production.

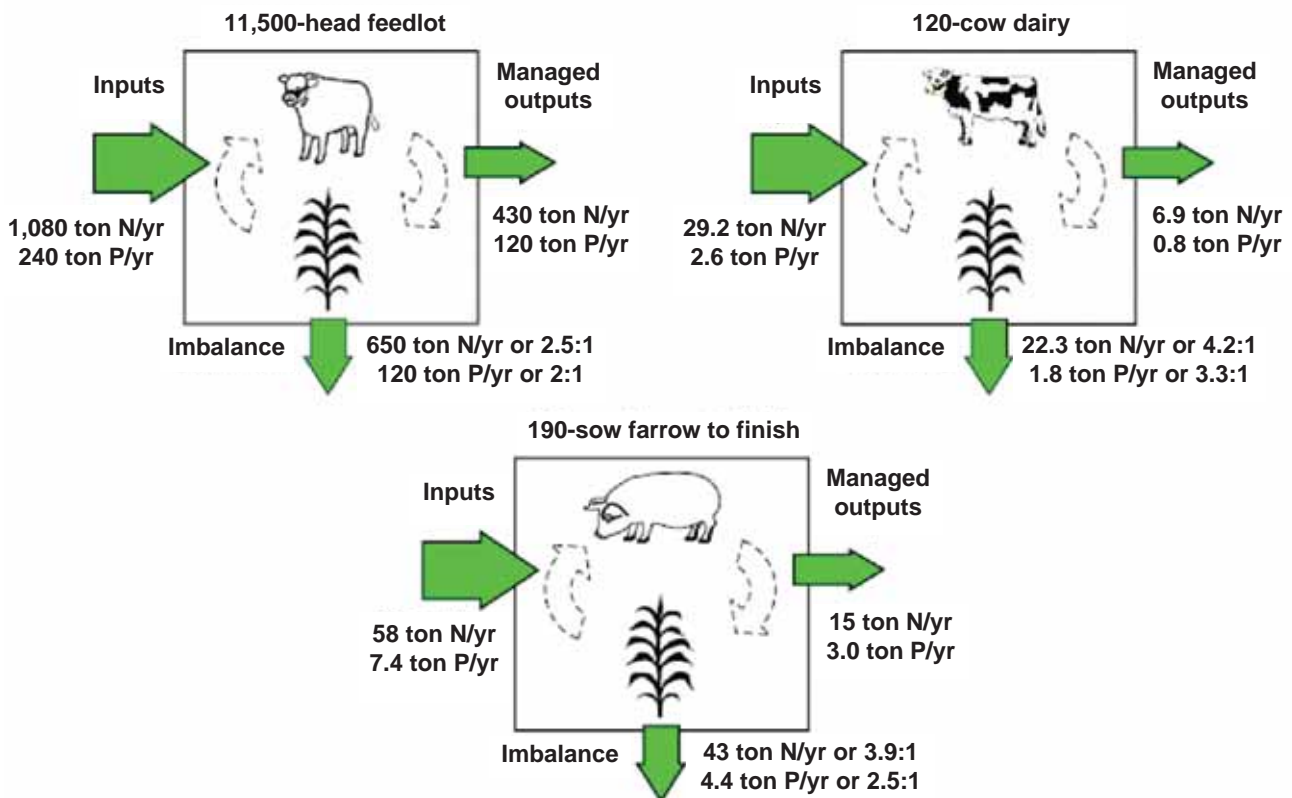
Nutrients primarily exit a livestock operation as “Managed Outputs” in the form of animals or animal products, crops, and animal manures moved off-farm (for example, manure sold or given to a neighboring crop producer). Nutrients may also leave the farm as losses to the environment, such as nitrates in groundwater, ammonia volatilized into the atmosphere, and N and P into surface water runoff. Nutrients, especially P and potassium (K), can also accumulate in large quantities in the soil. Although not a direct loss to the environment, a growing accumulation of nutrients in the soil adds to the risk of future environmental losses through storm or irrigation water runoff and groundwater contamination, or nutrient-related feed maladies (such as milk fever in cows, which can be caused by forages grown in soil with high potassium levels).

The “imbalance” is the difference between the nutrient Inputs and the nutrients in the Managed Outputs. This imbalance accounts for both the direct environmental loss and the accumulation of nutrients in the soil. A significant imbalance of concentrating nutrients results in increased risk to water quality. In contrast, livestock operations that have achieved a proper nutrient balance represent an economically and environmentally sustainable production system.

Many current best management practices (BMPs) for manure handling focus on short-term solutions without correcting the origin of the imbalance. BMPs such as grass filter strips, not applying manure on frozen soil, or soil erosion control, do not correct the imbalance.

Nutrient management planning must ensure a whole-farm nutrient balance. The nutrient inputs on a farm should roughly balance with those exiting. After a balance is achieved, then best management practices will provide additional long-term benefits.

**Figure 2. Typical nutrient imbalances observed for several different livestock systems.** (Graphic courtesy of Livestock and Poultry Environmental Stewardship Curriculum. Used by permission.)





## Typical Nutrient Balances

A nutrient imbalance is often expressed as a ratio of inputs to managed outputs. For example, a ratio of 3:1 suggests that for every three pounds of nutrient entering a farm, one pound leaves as a managed product and the remaining two pounds are lost to the environment or accumulate in the soil.

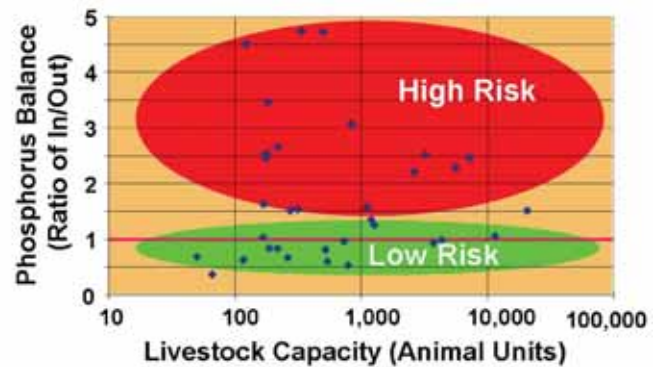
The nutrient balances for typical feedlot, dairy, and swine operations are illustrated in Figure 2. For the feedlot, the input to output ratio was 2.5:1 for N (imbalance of 650 tons/year) and 2:1 for P (imbalance of 120 tons/year). While the magnitude of the imbalance is smaller for the dairy and swine operations (they produce less overall excess N and P), still they are severely imbalanced: the ratio of inputs to outputs ranges from 2.5:1 to 4.2:1. Inputs to outputs ratios of 2:1 up to 4:1 are common for many livestock operations.

Livestock operation size is generally a poor indicator of the nutrient imbalance. Larger operations are not necessarily more out of balance than smaller ones. For example, a review of the whole-farm nutrient balance for 33 Nebraska swine confinements and beef feedlots showed no trend between nutrient input to output ratio and the number of animals per livestock operation. Many of the operations involved in this study had a P balance near the ideal 1:1 ratio, while others exceeded ratios of 4:1. The range in ratios was greatest for the operations with less than 1,000 animal units (AU), which had both the lowest (favorable) and highest (worst) P imbalances.

A P balance provides a preferred indicator of the risk to Idaho surface water quality. Eutrophication of most Idaho surface waters is normally exacerbated more by higher P than by higher potassium, nitrogen, or other nutrient concentrations. The soil test for P is a good indicator of soil P enrichment.

Farms with a P input to output ratio near 1:1 (“Low Risk” group in Figure 3) have the potential to be environmentally sustainable. Soil is the primary reservoir for P and average soil P should not increase for an input to output ratio near 1:1 and the nutrient-related water quality risk should not increase.

**Figure 3. P balance vs. size for 33 Nebraska livestock operations. (The term “risk” refers to nutrient-related water pollution)** (Graphic courtesy of Livestock and Poultry Environmental Stewardship Curriculum. Used by permission.)



Livestock operations with a large imbalance (1.5:1 and greater) can expect steadily increasing soil P levels. Runoff and erosion of soils from these operations will carry an increasing P load as soil P levels increase. Measures to reduce runoff and erosion will partially reduce this risk and provide temporary solutions. However, the P imbalance must be corrected to stabilize the risks to water quality. These “High Risk” operations are not environmentally sustainable.

## Determining if Your Operation is in Balance

There are two issues of concern: on individual fields, making sure you are moving toward a soil test P level at or below the threshold for the resource concern (surface water runoff or groundwater contamination), and also making sure that your entire operation is in balance in terms of the nutrient inputs to managed nutrient outputs.

By testing each field for phosphorus and implementing the strategies in this bulletin, you can make sure that you are not dumping excess phosphorus into the groundwater or surface water.

How can you tell whether your entire operation is in balance or not? If the soil test P values are not increasing on all your fields, then it is likely that your operation is in balance. Your test values may still be high (because of a previous imbalance), and you still may need to reduce them, but since they are not increasing, it is likely that your operation is in balance. It is important to take

into consideration the soil test P of all your fields when determining whether or not the operation is in balance.

If you would like to estimate your balance on an ongoing basis, without waiting for the soil test results, you can use the following forms for calculating whole farm nutrient balance: ([http://pubwiki.extension.org/mediawiki/files/f/f3/LES\\_02.pdf](http://pubwiki.extension.org/mediawiki/files/f/f3/LES_02.pdf)). The forms on this web page begin on page 20 of the lesson. Spreadsheets are also available online for entering the numbers for an operation and having the calculations done for you: (<http://nebraskawater.unl.edu/web/drinkingwater/134?doAsUserId=LJl9J64Gueg%253D>).

## PHOSPHORUS MANAGEMENT IN IDAHO

### Manuring Rate Regulation

Manuring rates for Idaho animal operations are regulated by the USDA – Natural Resources and Conservation Service Idaho Nutrient Management 590 Standard. Since eutrophication of Idaho waters are typically more affected by phosphorus enrichment than by other nutrients, any limitations to manuring are based on phosphorus rather than nitrogen.

The Idaho Nutrient Management 590 Standard focuses heavily on ISDA-sponsored regulatory soil testing for P levels. The purposes of the testing are several: (1) to ensure compliance with the nutrient management plan (NMP); (2) to monitor the effectiveness of NMP implementation or the need for changing; and (3) to gauge the long-term environmental risks of the NMP. Each field has a regulatory P soil sample taken at a depth dictated by the resource concern (Table 1) that was identified when the NMP was developed. The same field is then sampled at least every five years to determine whether the soil test P value is increasing or decreasing.

Manure or wastewater application rates are determined by comparing the soil test P values to the applicable threshold values listed in the Standard. These thresholds are split into two primary categories within the Standard: surface water runoff, and groundwater. The first is used when the land application field is gravity irrigated (using furrows, corrugates, or a border strip) without tail water return, or when the field has a significant precipitation runoff concern.

If the site falls under these conditions, the soil test P threshold is 40 parts per million (ppm) in the 0-30cm (0-12") sample, using the sodium bicarbonate (Olsen) test procedure (Table 2).

The second threshold category is used if no significant runoff occurs from the field. In this situation there are two subcategories with different thresholds based on depth to resource concern (groundwater, fractured bedrock, or extremely permeable layer). If the depth to resource concern is less than 1.5m (5'), the soil test P limit is 20 ppm in the 46-61cm (18-24") soil sample (Table 2). If the depth to resource concern is greater than 1.5m (5'), the soil test P limit is 30 ppm in the 46-61cm (18-24") soil sample. Phosphorus in the groundwater can eventually migrate from seepage or springs into surface water, causing eutrophication.

**Table 1. Soil sampling depth for P threshold.**

Primary Resource Concern	Threshold P Soil Sample Depth
Surface Water Runoff	0 – 30 cm (0 – 12")
Groundwater, Fractured Bedrock, Cobbles or Gravel	46 – 61 cm (18 – 24")

*Note: Surface water runoff concerns exist when runoff leaves the contiguous operation from average storm events, rain on snow or frozen ground, or irrigation.*

**Table 2. Idaho soil P threshold value for each resource concern.**

Primary Resource Concern		P Threshold concentration	
		Olsen	Bray 1
Surface Water Runoff		40 ppm	60 ppm
Groundwater, Fractured Bedrock, Cobbles or Gravel	less than 5 feet of soil	20 ppm	25 ppm
	more than 5 feet of soil	30 ppm	45 ppm

The P soil test and its relation to the threshold determine the rate for manure or commercial P application. Soil test values below the threshold allow the application of manure P or manure N at the University of Idaho Fertilizer Guide recommendation for the crops to be grown in the rotation. See <http://info.ag.uidaho.edu:591/catalog/fertilizers.html> for Fertilizer Guides for northern and southern Idaho.

If the soil test value is at or above the threshold (for either resource concern), this requires P application rates to be held at or below crop P uptake (Table 3). The application rate can be based on the entire crop rotation. Therefore, even if the soil test is above the threshold, high rates of manure or commercial P may be applied during two years of a six-year rotation, as long as the total P application during the rotation doesn't exceed the crop P uptake of the entire rotation.

**Table 3. Phosphorus application guidelines.**

Soil Test P	Maximum P Application Rate
< Threshold ppm	Recommended P Rate or N Rate or Crop P Uptake
> Threshold ppm	Crop P Uptake

### Understanding Soil Test P

Since measurement of available soil P is one of the determining factors regulating manure application rates in Idaho nutrient management plans, a better understanding of the test can be useful for interpreting the values reported and scheduling the sampling.

In southern Idaho, available P is measured by the Olsen method, which involves extracting P from soil using a sodium bicarbonate ( $\text{NaHCO}_3$ ) solution and is commonly termed "Olsen P". In northern Idaho, where soils are more acid, the Bray test is used. Both test results are primarily indexes of the readily available inorganic P and were developed originally to identify soils with low P where crop yield could be improved with applied P. They also effectively measure P enrichment from P added beyond that required for optimum plant growth. The P test value is directly related to the P concentra-

tions in runoff water, so it is well suited for measuring the potential environmental risk of contributing to surface water P enrichment and eutrophication.

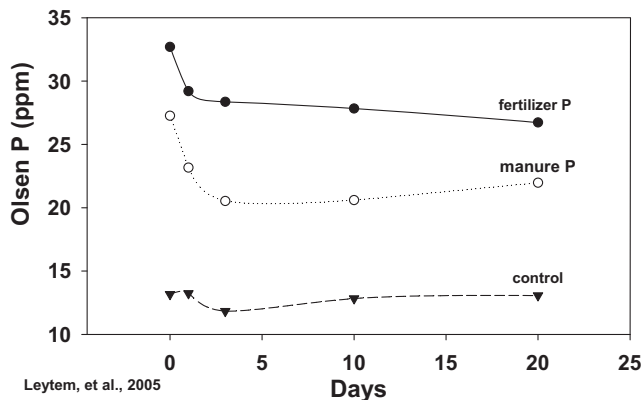
The Olsen test is particularly adapted for neutral to calcareous soils and has been used extensively in the West since first introduced in 1954. Since then, considerable practical and research experience has been gained with this test in southern Idaho and elsewhere. Although the Olsen test was developed for calcareous soils, it generally serves at least as well as other soil P tests when used for soils ranging widely in pH, as they do in Idaho.

Olsen P changes reflect the P added to or removed from soil. But the change in Olsen P depends on the soil's chemistry, the type and amount of reactive elements or minerals present, and the type and amount of P present or added. Soils differ appreciably in properties that influence the Olsen P change. So although you may be adding the same amount of manure to your soil as another livestock operator, your soil tests may show very different readings of P.

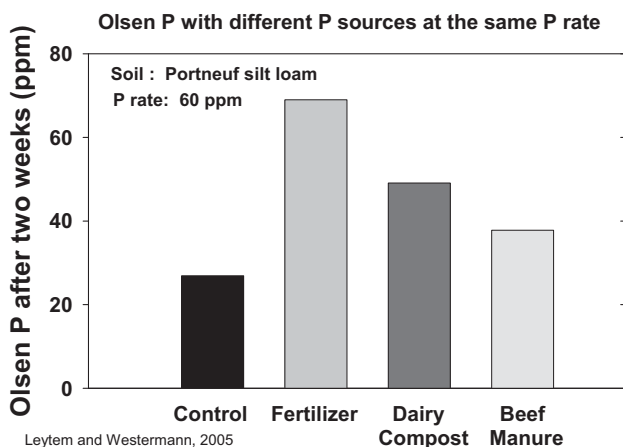
Furthermore, the timing of the soil test can also influence the P value. Olsen P typically increases initially with added P (Figure 4), but is reduced as P is incorporated into microbial tissue; reacts with minerals in the soil such as calcium, aluminum, iron, and manganese to form relatively stable complexes or precipitates; or as P is adsorbed to mineral surfaces. In Figure 4 the same amount of total P was added as fertilizer or manure P and both declined after the initial increase. Southern Idaho soils are predominately calcareous with ample calcium available to reduce P solubility, but aluminum, iron and manganese are also present and can be as important. Irrigation water can also contain the elements that react with P in soil, calcium in particular.

The form of P in the waste may also affect the rate of increase in soil test P. The greater the organic P (example, phytate or inositol P esters) content of the waste relative to the total P content, the lower the initial increase in soil test P. Other organic acids from manures can increase extractable P in calcareous soil by reacting with iron and manganese or by competing with inorganic P for sorptive surfaces.

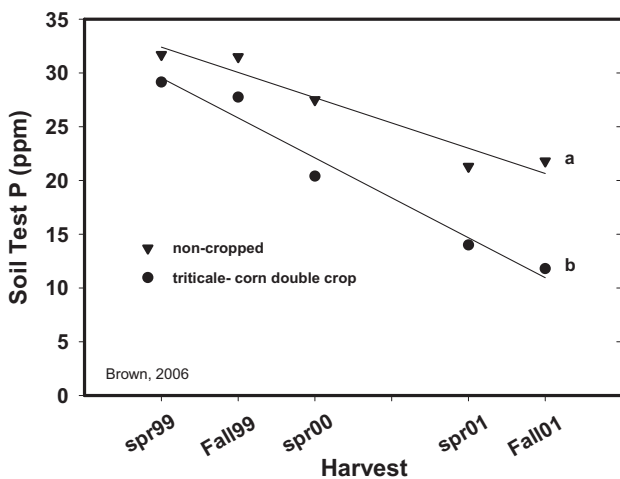
**Figure 4. The change in Olsen P as affected by time and type of P added.**



**Figure 5. Olsen P two weeks after various P sources were added at the same rate of total P to a Portneuf silt loam.**



**Figure 6. Soil test P in fallowed (non-cropped) and double cropped treatments over time in a Greenleaf silt loam.**



Also, the higher the carbon to phosphorus (C:P) ratio in manures, the more the applied P is incorporated into microbial tissue and the smaller the initial increase in soil test P. Figure 5 shows the Olsen P after adding different sources of P at the rate of 60 ppm. After two weeks, all P sources increased Olsen P in the Portneuf silt loam above that in the non-treated control. The largest increase occurred with fertilizer P. Note that the composted dairy manure resulted in higher Olsen P than the beef manure, likely because the C:P ratio was only 17 in the compost but 112 in the manure.

The point is that your particular soil test P value will be based not just on how much P was added, but also on the type of manure or fertilizer, the minerals in your soil, and how soon after adding P the soil sample was taken.

Barring any P additions, Olsen P tends to decline with time depending on crop P removal and a natural decline that occurs even without P removal with crop harvests. In a calcareous silt loam treated the previous fall with 300 pounds of  $P_2O_5$  per acre, soil test P was measured the following spring (1999), and periodically in the following three years in soil that was either double cropped for the duration or not cropped at all (Figure 6). On the non-cropped land, soil test P measured 31 ppm the first spring and declined to about 22 ppm two years later, despite no P removal through cropping. Note that about half of the soil test P decline with double cropping (winter triticale and corn silage) can be attributed to the background natural decline in soil test P.

The time of year of soil sampling for available P can also influence the soil test P value. Typically soil collected in spring is higher in P than soil collected in the fall. To avoid the effects of season on the soil test P value, soils collected for monitoring P should be sampled at the same time every year. It is also preferable to collect soil samples before animal waste applications rather than after, to help determine crop preplant nutrient requirements and because soil test P may not be stable the first few days or weeks after the applications, depending on the nature of the P added. To more accurately monitor the effects of waste P applied, soil should be sampled no sooner than six to eight weeks following the application.



For measuring compliance with the current Idaho 590 Standard, soil samples are collected by either the Idaho Department of Agriculture, the NRCS, or a certified soil sampler. Any measured soil test P value by itself needs to be compared to the initial or previous soil test P. The soil test P values may be high and indicate fields where excessive manure application has occurred in the past, but the relevance is whether the values are changing, and by how much, from those measured before the nutrient management plan was implemented or from the last sampling. If soil test P was initially high and still increasing, the nutrient management plan or its implementation is not working and needs adjustment. If the initial value was high but subsequent samples show the value declining, this suggests the nutrient management plan and implementation are working.

Samples collected for monitoring P and NMP implementation are required to be taken at intervals of every three to five years. If manure P is only applied once during a lengthy multi-year rotation, then testing once in five years might be enough to satisfy the letter of the law. However, sampling every three to five years does not provide adequate frequency to field-monitor a new or altered NMP and make timely adjustments. Therefore, we recommend testing the soil annually for phosphorus.

Analyses of the three to five year samples should be more extensive than those collected annually prior to cropping, and should include measurement of the total salts, pH, exchangeable sodium percentage, and DTPA extractable copper. The additional measurements are necessary in that they are related to the potential productivity of the soil. For example, 50% increases in the values for all but the pH are signs of potentially declining soil productivity. Samples collected annually prior to either cropping or manure application can be useful for providing interim monitoring and should routinely include available N, P, K, sulfate-sulfur (SO<sub>4</sub>-S) and the micronutrients zinc, manganese, copper and iron. Appreciable short-term changes in Olsen P—for example increases of 20 ppm—may warrant re-assessment of the NMP or its implementation.

Olsen P is a useful index of P available for plant growth, the soil P enrichment from P applied in excess of crop needs, as well as the potential risk of surface water enrichment. It is a critical measurement for monitoring the effectiveness of a NMP or its implementation.

## **STRATEGY 1: BALANCE PHOSPHORUS IN RATION**

Reduction in the dietary concentration of phosphorus is the most efficient way to correct or minimize a P imbalance in the operation. It will decrease the amount of P excreted in manure, and thus decrease the P load and risk on the environment. This reduction can be achieved by matching the amount of P consumed to the animal's requirements for maintenance, growth, pregnancy, and lactation. The amount of P consumed in excess of requirements leads to an increase in the amount of P excreted, a decrease in the efficiency of P utilization, and a greater accumulation of P in the soil.

Overfeeding of dietary P is common in the United States. Several management practices can minimize the amount of excess P consumed by the cow, and thus reduce the amount excreted in manure.

### **Formulate Rations to Meet the 2001 NRC Guidelines**

Dairy cow rations are typically formulated with a "safety margin" that exceeds the cow's nutritional requirement by more than 30%. Feeding higher than recommended levels of dietary P does not improve either milk production or reproduction. Rations should be formulated to meet and not exceed the National Research Council (NRC) recommendations. Phosphorus fed in excess of a cow's requirements will be excreted in feces. Reducing or eliminating the supplemental mineral P in the ration is the first step that should be taken to reduce dietary P. Free-choice P minerals should not be used on dairies, as there is no benefit associated with this management practice. The elimination of P supplementation improves profits because P is one of the most expensive mineral supplements. In addition, producers under mandatory phosphorus-based nutrient management will see additional reduced costs because of the decreased need to haul manure greater distances, or to purchase additional land for manure application.

## **Group and Feed Cows According to Their Stage of Lactation and Reproduction Status**

More and more dairies have been feeding one ration to all cows in the herd regardless of the production level. In those herds, the ration is formulated to meet the requirements of the highest producing cows, with lower producers being consistently overfed. This results in cows eating approximately 7% more P than requirements. Multiple feeding groups should be used whenever it is practical to mix different rations. Milking cows should be grouped and fed according to the amount of milk they produce, as well as according to their reproductive status. The benefits include decreased feeding costs and less excretion of P.

## **Routinely Analyze the Ingredients Used in the Ration**

The level of P in the feed ingredients used in dairy cow rations is variable, especially in forages purchased from different sources and in byproducts. This variability needs to be considered when formulating dairy rations. Frequent testing of forages, concentrates, and byproducts is recommended. Book values should not be used when formulating a ration. The test for P content of ingredients should be done by wet chemistry in a certified lab, not by Near Infrared (NIR) Spectroscopy. See Strategy 5 for additional forage analysis information.

## **Wisely Use Byproducts and Concentrates in Dairy Cow Rations**

Byproducts typically used in dairy cow rations provide the opportunity to reduce costs associated with feeding dairy cows. As more corn is used for ethanol production, expect to see an increase in corn prices and a greater availability of corn byproducts at lower prices. However, most of these byproducts are characterized by a very high concentration of P. Corn fermentation results in the removal of most of the carbohydrates from the kernel, which leads to a threefold increase of the other components that are left, including P. Nutritionists should be encouraged to utilize ingredients with lower P concentrations, especially if they can be purchased at a similar or lower cost. Regardless of cost, the amount of high P byproducts in the diet should be controlled. Corn distillers' grains and other corn byproducts are inexpensive sources of protein and energy, but since

their P content is approximately two to three times the amount of P present in grains, they should be used carefully. In general, byproduct ingredients (such as distillers' grains) and oilseed meals (such as soybean meal) are very high in P relative to cereal grains and forages.

## **Maximize the Use of Forages in the Ration**

Maximizing the amount and quality of forages in dairy cow rations improves cow health, reduces the need to use imported byproducts high in P, and reduces the need for imported feed, which increases the P imported to the farm. For example, soybean meal, which is typically added as a protein source for the ration, contains 0.7% P compared to 0.3% for alfalfa. The same concept applies to byproducts like distillers' grains (0.9% P), which could significantly increase the amount of P in manure. Using high quality forages such as alfalfa reduces the need to purchase supplemental feeds and optimizes the recycling of P on the farm.

In an age of environmental concerns and regulations, dairy farmers and their nutritionists can still feed for high performance while minimizing the operation's P imbalance and the negative impacts of P accumulation in the soil. The overfeeding of P to dairy cows is costly. Reduction of dietary P from 0.45% to 0.38% will reduce the P excreted in manure by approximately 25%, leading to less land required for manure application, and the potential for less P runoff from application fields. Overfeeding P pointlessly increases the cost of producing milk and increases the environmental risks associated with P runoff.

## **Increasing Animal P Utilization**

Non-ruminants, such as swine and poultry, do not utilize the P content of forages as well as ruminants such as cows. Most P in the grain fed to these animals is in an organic form as phytate P. This organic form is poorly used by swine and poultry, with some studies showing only 10 to 20% of total P in corn being utilized, the rest being excreted in the animal manure.

Two practices are used to lower the P content in non-ruminant manures. In some cases phytase, the enzyme which changes phytate P to the inorganic and better utilized form of P, is included in the ration. The greater

the conversion of phytate to inorganic P, the greater the animals' utilization of the P fed, and the less P excreted in manure that is applied to the land.

The other practice used is to feed low-phytate grain, grain that is lower in phytate P and higher in inorganic P. Increasing the amount of inorganic P rather than phytate P fed also increases the animals' P utilization of the P in the ration. Lower manure P concentration is again the result, with less P applied to land.

Low phytate corn and barley feed grains are currently available for planting and swine and poultry production. Low phytate grain is a relatively recent development and low phytate grain cultivars may not be as productive for the grain producer as normal feed grains are. With continued plant breeding, the difference between low phytate and normal feed grain yields will likely decrease.

## STRATEGY 2: APPLY MANURE BASED ON SAMPLING AND TESTING

Testing manure for its nutrient content is the only way livestock producers and crop farmers can determine what nutrients are applied to their fields. Manure application rate not only has an impact on the phosphorus concentration in the soil, it also impacts the concentration of nitrogen, potassium, salts, and the many micronutrients required for crop production. Not sampling, or ignoring the application of manure entirely in nutrient planning, may result in higher soil nutrient concentrations than desired, or enriched nutrients in surface runoff or shallow groundwater.

Many producers have asked, "Why sample? Manure is just too variable." It is true that manure varies depending on its age and moisture. But there is also variability in total mixed rations (TMRs) due to forage and grain qualities and mixing equipment calibration. Yet, routinely sampling a TMR is an accepted quality control practice. Manure sampling should also be implemented.

The second argument against manure sampling is, "This was taken into account in my NMP." This statement is not entirely correct. The amount of manure and its P

content are simply estimated when developing a NMP, in order to give a general sense of how to balance the nutrients in manures with the amount and productivity of the land that is available. The rates calculated in the plan are not precise enough to dictate field application rates.

The first problem with using table values is that they are national averages, and most likely do not reflect appropriate conditions on individual Idaho fields. Secondly, most NMPs in Idaho were developed using values published by the USDA-NRCS in 1993 (Table 4) based on animal studies that were conducted in the 1970's and 1980's. Over the past 10 years, as Confined Animal Feeding Operations (CAFOs) nationwide adopted NMPs, nutrient concentrations for waste materials were updated to consider modern animal genetics and feeding programs. The 1993 USDA values reported 0.21 pounds of P to be excreted per dairy cow per day, whereas because of modern feed recommendations, the rate has increased to 0.39 lbs/cow/day according to 2005 data from the American Society of Agricultural and Biological Engineers (ASABE). This is almost a two-fold increase. Without manure sampling to identify this higher level of P excretion compared to the values in the farm's NMP, a P imbalance may occur and soil P levels will continue to increase.

**Table 4. Dairy manure production table values from two sources.**

Standard	Volume ft <sup>3</sup> /hd/d	N lb/hd/d	P <sub>2</sub> O <sub>5</sub> lb/hd/d
USDA, 1993	1.82	0.63	0.21
ASABE, 2005	2.4	0.99	0.39

In addition to the fact that the average cow excretes more phosphorus than in previous years, nutrient concentrations also vary within most types of manure. A review of samples from 42 dairies in Idaho (Table 5) showed that N and P in wastewater lagoons also vary greatly between farms. For example, on small open lot dairies (< 1,000 head), P can range from 16 to 28 pounds per acre-inch, while on large open lot dairies (> 1,000 head), the range is 12 to 20 pounds per acre-inch.

**Table 5. Average lagoon wastewater concentrations from various types of Idaho dairies.**

Farm Type <sup>a</sup>	Ammonia (NH <sub>3</sub> ) lb/ac-in	Total Kjeldahl Nitrogen (TKN) lb/ac-in	Total Phosphorus (TP) lb/ac-in	Total Solids (TS) mg/l
OL < 1,000 hd	40 +/- 2 <sup>b</sup>	119 +/- 29	22 +/- 6	29,291 +/- 12,098
OL > 1,000 hd	61 +/- 22	92 +/- 36	16 +/- 4	5,087 +/- 1,386
FS Scrape	175 +/- 75	181 +/- 75	28 +/- 11	24,122 +/- 13,826
FS Flush	149 +/- 23	162 +/- 24	27 +/- 4	10,770 +/- 2,138

<sup>a</sup> Farm Type: OL = Open Lot Dairy; FS = Freestall Dairy; hd = head.

<sup>b</sup> Average values +/- standard error.

Concentrations of P in lagoons from scraped freestall dairies ranged from 17 to 39 pounds per acre-inch, while the P from freestall flush dairies ranged from 23 to 31 pounds per acre-inch. This broad range of nutrient levels shows the maximum and minimum values differing by more than a factor of two. These numbers send the clear message that average nutrient estimates may be suitable for the purposes of developing a NMP, but are not adequate for calculating proper application rates.

Application rates should be based on current laboratory test results rather than those from previous years because nutrient concentrations can change significantly over time. Changes occur with changing ration formulations or when manure is exposed to different environmental conditions. For example, nutrient levels in a lagoon or storage pond can be greatly diluted by more rainfall than normal, or concentrated due to excessive evaporation during the summer months.

Manure should be sampled and analyzed as close to the date of application as practical, or within 30 days of application. However, if there is an urgent need to pump down a full lagoon or storage pond, don't wait until you can sample and obtain the results. Instead, you should sample on the day of irrigation. The results can later be used to determine the nutrients applied to the fields

and identify the need for additional nutrients to complete crop production.

Producers who do not test each manure source before or just after land application are faced with a number of questions they may not be able to answer:

- Am I supplying plants with adequate nutrients?
- Am I building up excess nutrients that may ultimately move to surface water or groundwater?
- Am I applying heavy metals or salts via manure at levels that may be toxic to plants and permanently alter soil productivity?

Because environmental damage generally occurs at some distance from the livestock operation, and losses in plant yield and quality often happen before visible plant symptoms appear, always have manure analyzed by a competent lab to prevent future problems. Certified labs in Idaho can analyze manure samples, and may be able to make agronomic recommendations regarding the use of the manure as a fertilizer. For more information on how to sample manure, please see "*Manure and Wastewater Sampling*," University of Idaho Extension publication #CIS 1139 (<http://info.ag.uidaho.edu/pdf/CIS/CIS1139.pdf>).



### STRATEGY 3: ENHANCE SOLID SEPARATION & PHOSPHORUS REMOVAL FROM MANURE

Solid separation of manure prior to entering the lagoon can provide significant reductions in lagoon solids and liquid nutrient concentrations. Separated solids reduce the P entering storage lagoons and the solids may be recycled after composting as bedding. If composted, the phosphorus in solids is further concentrated and manure P may be more easily exported from the operation as fertilizer or soil amendment, facilitating more favorable P Input:Output ratios.

Gravity or mechanical separation can remove a small percentage of P, and is currently used on most dairy facilities for solids separation.

Biological removal of P through batch aeration treatments (sequencing batch reactors) showed wide ranges of P removal that could only be improved with chemical additions.

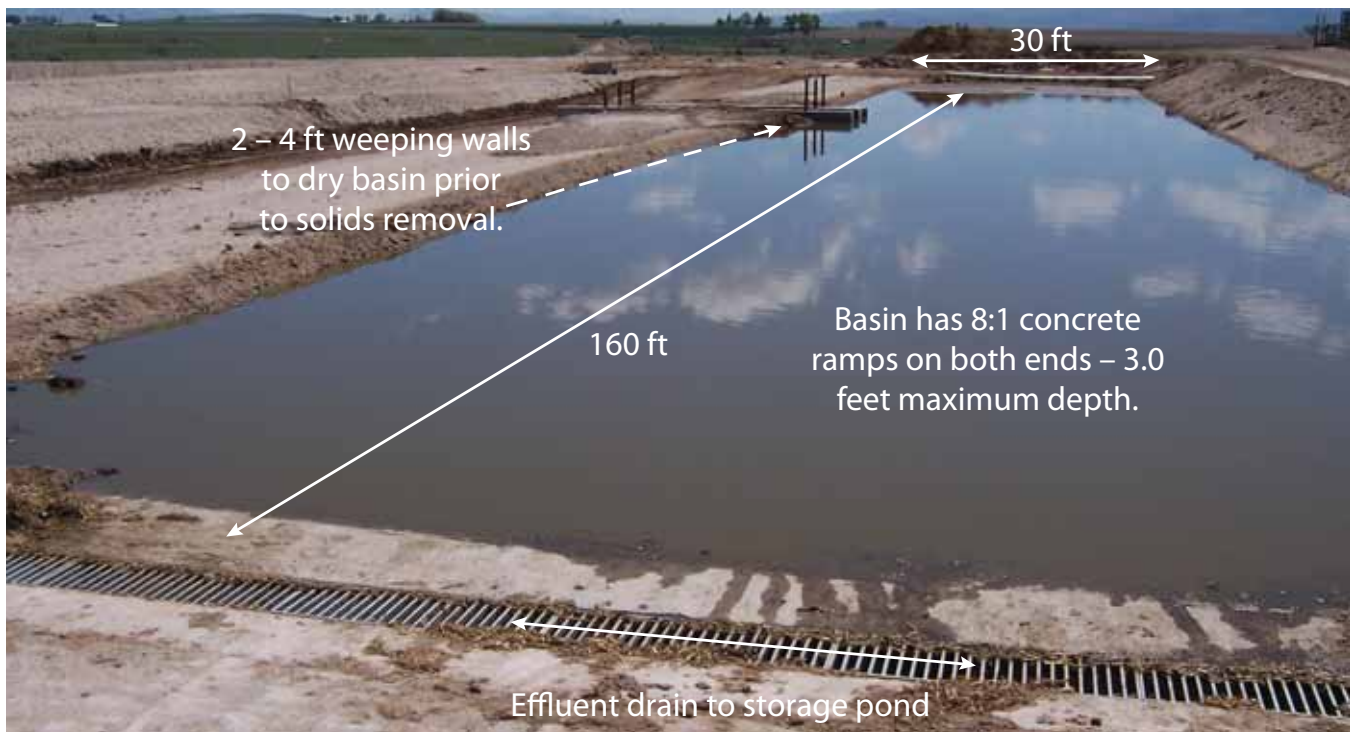
Chemical treatment, using alum, ferric chloride, and lime have shown excellent P removal efficiencies in lab-

oratory studies. However, these technologies can be expensive due to high chemical dosing rates and construction of additional separation systems. They result in a byproduct that has limited solubility and fertilizer value without further treatment, although it can be applied to the soil, so it is not a waste problem.

#### Mechanical Separation

Mechanical separators of animal waste include inclined screens, vibrating screens, and screw presses. Manure is collected in a sump that is sized to store the largest combination of flush tank capacities or pit storage accumulations. A submersible or stationary bottom-impeller lift pump mixes the manure and liquids into a slurry and pumps it across the separator where the liquid drains off. These devices effectively remove solids (Table 6), which have a moisture content between 60 and 70 percent, but the devices are typically less efficient than gravity systems. However, because they are less expensive and take up less space than gravity systems, mechanical separators are widely used. Separators with few moving parts, such as inclined screens and vibrating screens, are more effective when large amounts of water

Figure 7. Dual-stage gravity separator.



are moved through the devices, such as by flushing systems. Most mechanical separators require daily cleaning and flow adjustments. Screens need to be replaced periodically when the solids removal is decreased.

### Gravity Separation

Gravity separation will remove approximately 50% of all solids and a greater percentage of total P than all mechanical separation methods. A new style of settling basin has been developed and installed in Idaho (Figure 7). These Dual-Stage Gravity Separators maximize the surface area of the basin, while allowing wastewater re-

moval from the top and sides of the basin. This allows for the cleanest water to be removed and the greatest amount of solids to remain in the basin. Basins are designed to slow down the influent water to 0.01 – 0.05 ft/second and have a maximum depth of 4 feet. The shallow depth prohibits the long-term storage of solids, thus reducing noxious odors. Once the basin is observed to be half full of solids, wastewater is diverted to another basin and the first basin is allowed to be drawn down. Horizontal weep boards are removed slowly on the side of the basin, allowing water to be removed gradually from the basin.

**Table 6. Performance of mechanical separators.**

Separator	Animal	Screen Size (mm)	Total Solids in Raw Manure (%)	Separation Efficiency (%)		
				Total Solids	Total Kjeldahl N	Total P
Stationary Screen						
	Swine	1.5	0.2 – 0.7	9	-	-
		1.0	0.2 – 0.7	35	-	-
		1.0	1.0 – 4.5	6 – 31	3 – 6	2 – 12
	Dairy	1.68	4.6	49	-	-
Vibrating Screen						
	Swine	1.7	1.5	3	-	-
		0.841	1.5 – 2.9	10	-	-
		0.516	3.6	21 – 52	5 – 32	17 – 34
		0.44	1 – 4.5	15 – 25	2 – 5	1 – 15
		0.3	0.2 – 0.7	22	-	-
		0.104	3.6	50 – 67	33 – 51	34 – 59
	Dairy	1.7	0.9 – 1.9	8 – 12	-	-
		0.841	1 – 1.8	12 – 13	-	-
		0.6	1 – 1.7	10 – 16	-	-
Rotating Screen						
	Swine	0.75	2.5 – 4.12	4 – 8	-	-
		0.8	1 – 4.5	5 – 24	5 – 11	3 – 9
Belt Press						
	Swine	0.1	3 – 8	47 – 59	32 – 35	18 – 21
Centrifuge						
	Swine	-	1 – 7.5	15 – 61	3.4 – 32	58 – 68

Adapted from: Zhang, R.H. and P.W. Westerman. 1997. Solid Separation of Animal Manure for Odor Control and Nutrient Management. Transactions of ASAE. 13(5):657-664.

## Sequencing Batch Reactors

Sequencing Batch Reactor (SBR) refers to a system where the batch of effluent (liquid manure) goes into one tank (or lagoon) for aerated incubation to promote microbial growth. The sludge formed by the bacteria settles and the clearer liquid of the batch is transferred to the next container for continued aeration and additional microbial growth to settle out. The solids that settle and contain P are collected and dewatered for transport to fields within the operation or exported to neighbor fields. Efficiency of separation depends on the initial waste stream and may need additional treatment for maximum P removal. For more information about this kind of system, see:

[http://www.epa.gov/owmitnet/mtb/sbr\\_new.pdf](http://www.epa.gov/owmitnet/mtb/sbr_new.pdf).

## Using Coagulants to Increase Solid Separation

A number of chemicals can be used to coagulate the solids in wastewater, and thus remove a larger percentage of P. These chemicals include lime, alum, and flocculants. University of Idaho researchers are also experimenting with a new system using “struvite,” a mineral consisting of magnesium, phosphorus, and ammonium.

### *Chemical treatment using lime*

Chemical treatment of wastewater using lime, alum, and other chemicals has long been a method for removing P from industrial wastewaters. For the past 15 years, researchers have been investigating how to economically use these chemicals on-farm to reduce P in wastewater and reduce runoff losses from the farm fields. For example, researchers from the USDA-ARS Center at Florence, SC, showed that the addition of lime ( $\text{CaCO}_3$ ) removed over 90% of total P from raw swine wastewater.

The University of Idaho has been testing and designing a “Lime-Based Precipitation” method for P removal. This system builds upon work conducted by the USDA-ARS Center. Tests in Idaho, using wastewater from the project dairy, showed an 84% removal of total P and the production of a low-odor wastewater. The calcium-phosphate solids are concentrated and settled for removal from the farm. Figure 8 shows an example of the

coagulation occurring in a wastewater slurry consisting of 0, 1% or 5% lime solution.

Following manure solid separation, a lime “milk” solution is added to the separated wastewater (Figure 8). The “milk” solution is a 1:2 ratio (weight basis) of hydrated lime and water. The “milk” and wastewater are mixed together in a small mixing tank. The reacted liquid is then allowed to settle in a cone-shaped clarifier (Figures 9 and 10) where the low P wastewater is removed from the top of the tank, and the high P solids concentrate in the cone. The solids can be pumped from the cone and then separated using most mechanical separators. The high P solids themselves have limited P fertilizer value, but once separated they may be further reprocessed into marketable P fertilizer blends. The reprocessing entails an acidification treatment of the solids to resolubilize the P from the product.

### *Flocculants and polymers*

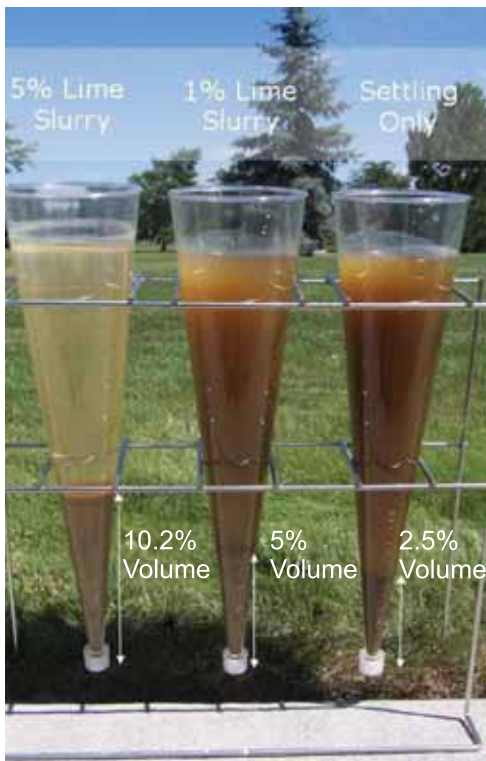
The use of polymers or other flocculants comes up frequently in discussions about solid separation of animal manure. This is especially true in frequent flush or pit recharge swine houses due to the liquid nature of swine manure and the dilution by flush water. Dairies with high volumes of wastewater (such as flush systems) may benefit from the use of flocculants and polymers. Solid separation of manure prior to entering the lagoon can provide significant reductions in lagoon solids and liquid nutrient concentrations. Chemical flocculants and polymers can be added after the solids have been coagulated with chemicals such as lime or alum. The flocculants and polymers help to alter the physical state of dissolved and suspended manure solids to increase the percent of manure solids removed by solid separation equipment.

First, chemicals are added to wastewater which react with P and other metals to coagulate dissolved particles into small visible floc. Then, polymers or flocculants are added which help the coagulated floc to form larger, more easily separated clumps. In some cases the chemicals that react with P and the flocculants are added simultaneously. Many natural polymers such as starches and chitosan, a product from shellfish, and synthetic polymers such as those derived from polyacrylamide

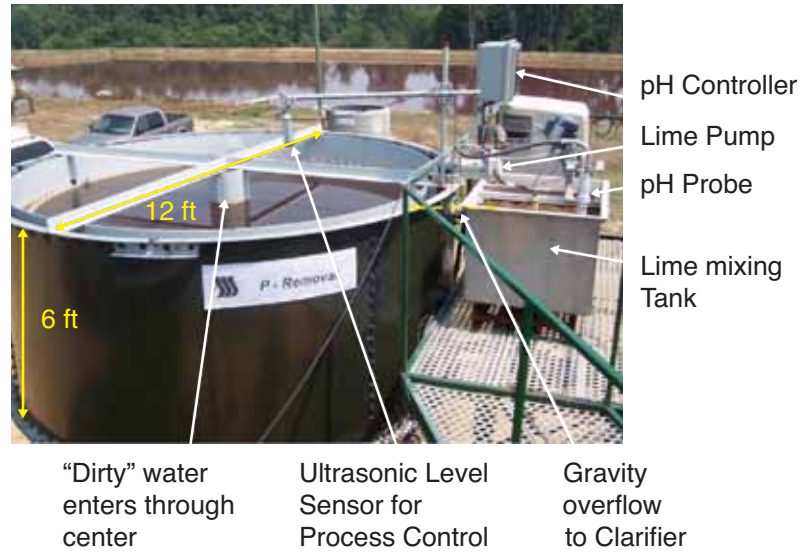
(PAM), are commercially available as flocculants. Some are used on Idaho dairies. Decisions about whether to use a polymer should consider the cost of the polymer and additional equipment requirements, such as polymer mixing devices and metering pumps.

Bench-scale separation evaluations of an inclined bed screen separator indicated that a 1/32" screen would be a more efficient choice than a 1/16" screen for situations either with or without polymer additions (Table 7). Some questions that producers may want to consider include: Why is polymer use being considered? Will solids separation alone suffice? Do the costs of the polymer and the additional equipment outweigh the anticipated benefit?

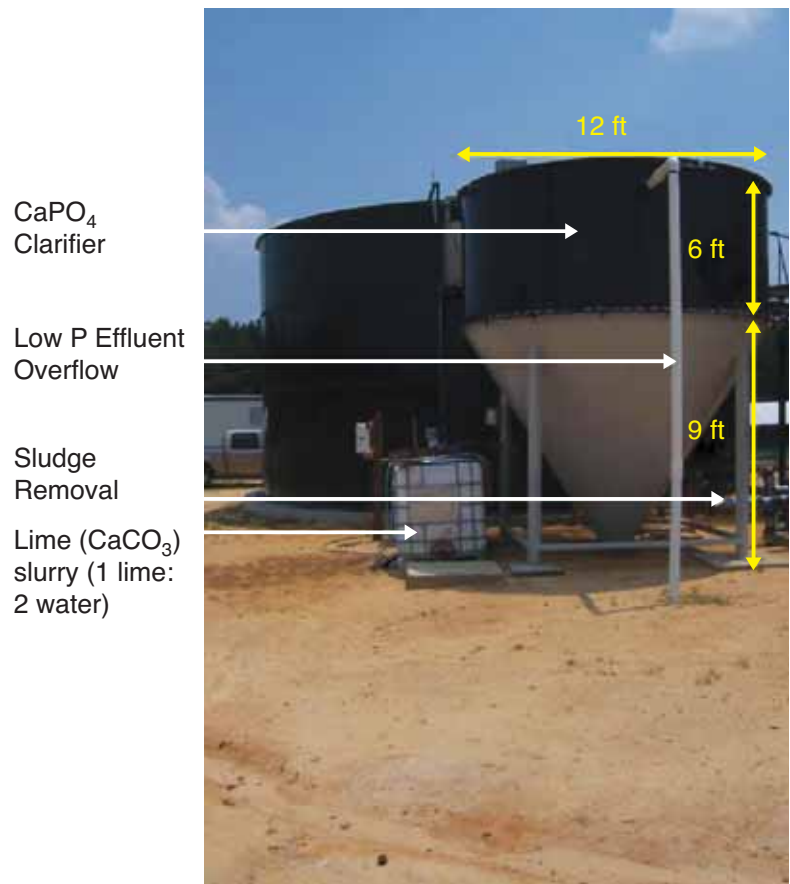
**Figure 8. Lime-precipitated dairy parlor wastewater.**



**Figure 9. Lime-based precipitation, top view.**



**Figure 10. Lime-based precipitation, side view.**





**Table 7: Solids removed by screen size and polymer concentration.**

Screen Size (inches)	Polymer Added (mg/L)	Solids Removal (%)
1/16	0	1.5
	40	9.3
	60	21.1
	100	25
1/32	0	12.7
	40	17.9
	60	47.2
	100	64.2

NOTE: Results are for an inclined bed screen separator utilizing flushed swine manure.

**Struvite crystallization**

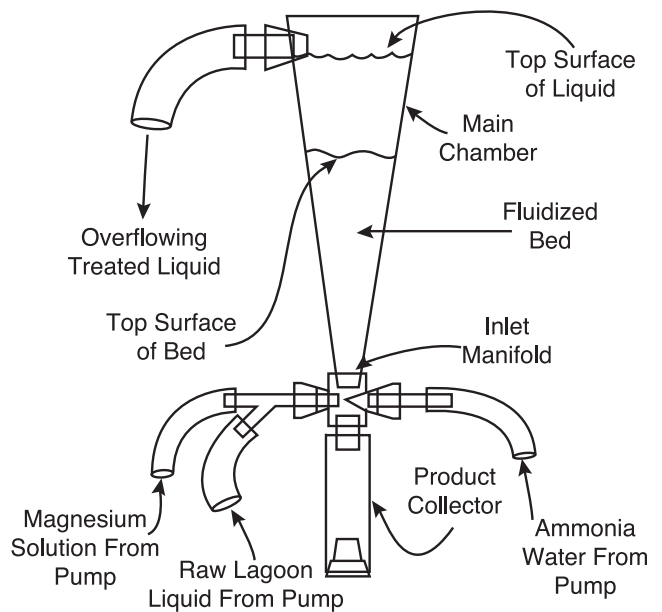
One problem with using lime or alum to remove P from wastewater is that the byproduct, without advanced treatment, is not marketable as a fertilizer, since the P is bound up with the chemical.

To address this issue, the University of Idaho, in partnership with North Carolina State University and Washington State University, is developing a new treatment system to remove P from wastewater. The technology uses a chemical process to form "struvite" ( $MgNH_4PO_4 \cdot 6[H_2O]$ ) as a granular and harvestable P source. This P is readily available when applied to crops. The product would greatly facilitate P export and P mitigation, because it produces a valuable product that can be sold on the market. Further, the struvite produced includes some N, which increases its marketability: it has an NPK fertilizer analysis of 4-24-0.

The reactor for removal of struvite is a fluidized bed crystallizer. The cone-shaped design of the crystallizer provides a wide range of up-flow velocity, which ensures that a wide range of crystal sizes is available in the bed. This reduces the amount of seeding needed and leads to greater efficiency and reduced construction costs.

To form struvite, the pH of the wastewater must be raised and ammonia and magnesium must be available to complete the reaction. Anhydrous ammonia is provided to the system to raise the pH. This additional ammonia has fertilizer value, which is needed in a P-based nutrient management system. Acidifying a small stream of wastewater with carbon dioxide and then passing it through a cone of magnesium oxide provides the magnesium needed for the system. The fluidized bed is formed with seeds of crystallized struvite, which is then perpetuated with the formation of struvite when the system is in operation (Figure 11).

**Figure 11. Fluidized bed crystallizer schematic.**



Field tests in Idaho and Washington have shown that the technology can remove 35% of the total P from dairy and industrial wastewater, at an approximate cost of \$0.05/cow/day. It is therefore not as effective as lime at reducing P in the wastewater. Research indicates that improving the removal efficiency of P is limited by the fact that P reacts with calcium to reduce soluble P in the wastewater. Acidifying the wastewater increases soluble P from the calcium compounds so that more P is available for struvite formation. Increasing acidity can increase the removal efficiency to 50%, but increases the cost to over \$0.12/cow/day, and produces a smaller radius granule (Figure 12). Further research is being conducted using the struvite crystallization with calcium inhibitors and following anaerobic digestion processes.

Figure 12. Conventional and acidified struvite crystals.



Non-acidified struvite



Acidified struvite

#### STRATEGY 4: REDUCE MANURING RATES, REDISTRIBUTE MANURE AND EXPORT

Often, manure is applied to the closest available land, increasing the P of this land, while more distant fields or a neighbor's fields have too little manure applied. In this case, the best way to adjust the soil test P is to reduce manuring rates on land that has high soil test P values, redistribute manure to lands that have low P values, and export manure to other farms.

Redistributing manure on one's own fields can be a very effective way to prevent a high concentration of soil P. Many argue that an integrated crop and livestock system is the best example of an economically and environmentally sustainable farming system. However, delivering manure to a field at the right time and in the right amount can be costly. If delivery and application costs are low enough, then substituting manure for fertilizer can increase profits from crop production. If the delivery costs are too high, then only a portion of the delivery cost can be recovered by reduced fertilizer cost, and farmers will not have a strong incentive to adopt technologies that match manure application rates to crop nutrient requirements.

Manure export is the most rapid means to adjust phosphorus outflow and gain a more favorable P Input:Output ratio. Animal manures can substitute for commercial fertilizers. An additional benefit of manure

is that long-term soil productivity can be enhanced because manure is a rich source of organic material. Manuring may be the most effective means of restoring the productivity of subsoils that have been exposed by erosion and land leveling.

To remain in compliance with CAFO regulations, producers must make decisions concerning the transport and application of wastes at their operation. It is essential that these systems be designed to operate in a cost-effective manner for dairy producers to remain economically viable.

#### Reduce Manuring Rates

- **Reduce the amount of wastewater generated:** Even though this practice does not directly reduce the phosphorous content in wastewater, it can tremendously impact the volumes of wastewater treated, reducing costs and increasing the effectiveness of different treatments. Reduce or stop the use of wash sprinklers. Develop a parlor water savings plan and train workers in these techniques. Most producers are amazed by the amount of water that is dumped daily due to careless operation. Update milk refrigeration systems to closed-circuit systems. If this is not practical, reuse this water for direct irrigation (landscaping, for example) instead of adding it to the wastewater stream. Depending on the wastewater collection design, consider storing parlor and other liquid waste-

water separately from collected slurry and flush water. Redirect non-contaminated runoff to a separate pond or area (such as the building's roof, parking lots, transit areas, or farm home areas).

- **Apply manure based on P demand for soils with low to moderate soil P:** A P based manuring standard such as the Idaho 590 limits manuring rates at most application sites. However, when manure is applied based on N demands, as when soil P is at low to moderate soil P levels and below the threshold, the amount of P applied will be much higher than the crops require, and P will quickly build up in the soil. Applying manure based on P requirements is more expensive than using N requirements, because supplemental N may need to be purchased or more land required for manure application. However, applying manure based on P requirements is more environmentally sustainable.
- **Apply manure below crop P requirement for soils with high soil P:** Applying manure below the recommended phosphorus crop removal rate allows the crop to naturally reduce high soil P levels built up over time due to over-application. This practice should be used with other strategies to allow producers to land-apply some manure to high P fields while working toward the overall goal of reducing high soil P concentrations.

## Redistribute and Export Manure

### Trucking

Exporting manure off the farm is not cheap, especially in areas of concentrated animal production. In these areas, livestock producers compete with each other for farms to accept their manure. In the best scenario, a livestock farm and crop producer form a symbiotic relationship, with the dairy supplying manure to the crop producer, and the farmer provides feedstuffs to the dairy. In several cases, after feedstuffs have been delivered, manure is "back-hauled" in the farm's empty commodity trucks. In the worst scenario, a crop producer receiving manure from several farms disregards the nutrient content of the manure, greatly increasing the nutrient content of the soil, and increasing the risk of pollutant runoff and leaching. Dairies and feedlots with

excess P in their soils need to consider exporting manure to P deficit areas and avoid the legal "dumping" of manure on fields of neighboring or distant operations.

The cost of exporting manure depends on the type of manure and how it will be applied to fields. As shown in Table 8, trucking manure off the farm is more expensive than pumping it onto one's own land or a neighbor's land. The cost of hauling increases as the solid content of the manure increases: solid manure is more expensive to haul than slurry (~ 5-15% solid), and slurry is more expensive than liquids. On average, incorporating manure into the soil will increase the handling cost by 20%.

As the number of livestock producers or the amount of manure within an area increases, the nearby land for manure export decreases, competition for the nearby land resources increases, and the CAFO may need to export manure further, or receive less for the manure applied. The same result occurs if the percentage of nearby farmers willing to accept manure decreases. Competition for limited manure receivers or limited available lands increases the cost of exporting the manure. Figure 13 illustrates the dramatic decrease in cost as more farmers wish to use manure on their fields.

**Table 8. Typical cost of hauling and handling manure.**

Unit Mile Charge	
Slurry Pumped	\$0.001025/gallon
Slurry Hauled (trucked)	\$0.00123/gallon-mile
Solid	\$0.13/ton-mile
Base Manure Handling Charge	
Slurry: Hauled	\$0.0079/gallon
Slurry: Hauled and incorporated into soil	\$0.0088/gallon
Liquid: Hauled	\$0.0057/gallon
Liquid: Hauled and incorporated into soil	\$0.0071/gallon
Solid: Hauled	\$6.00/ton

Figure 13. Change in net cost due to the percent of farmers willing to accept manure. (Adapted from USDA-Economic Research Service.)

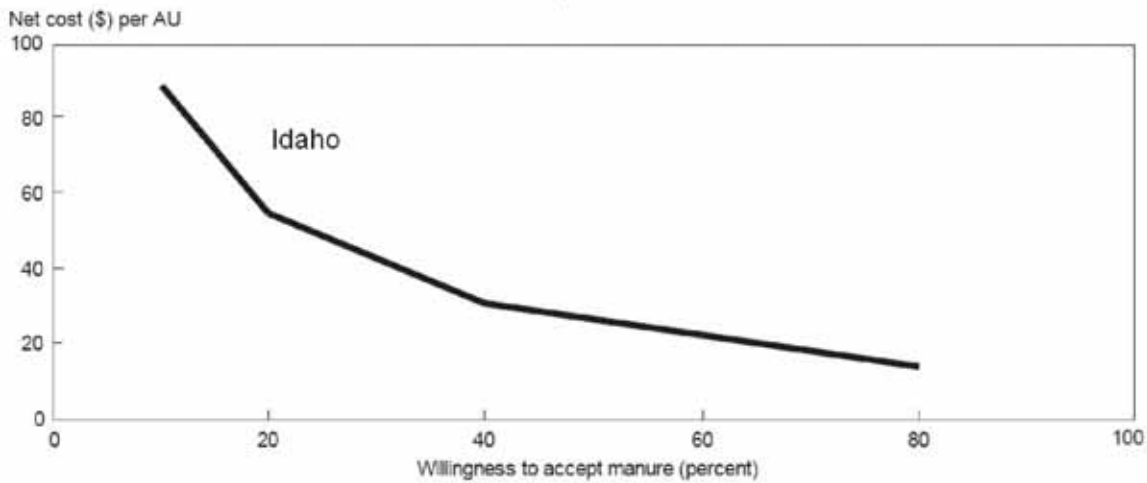


Figure 14. Percent change in production cost due to manure hauling as affected by the size of dairy herd. (Adapted from USDA-Economic Research Service.)

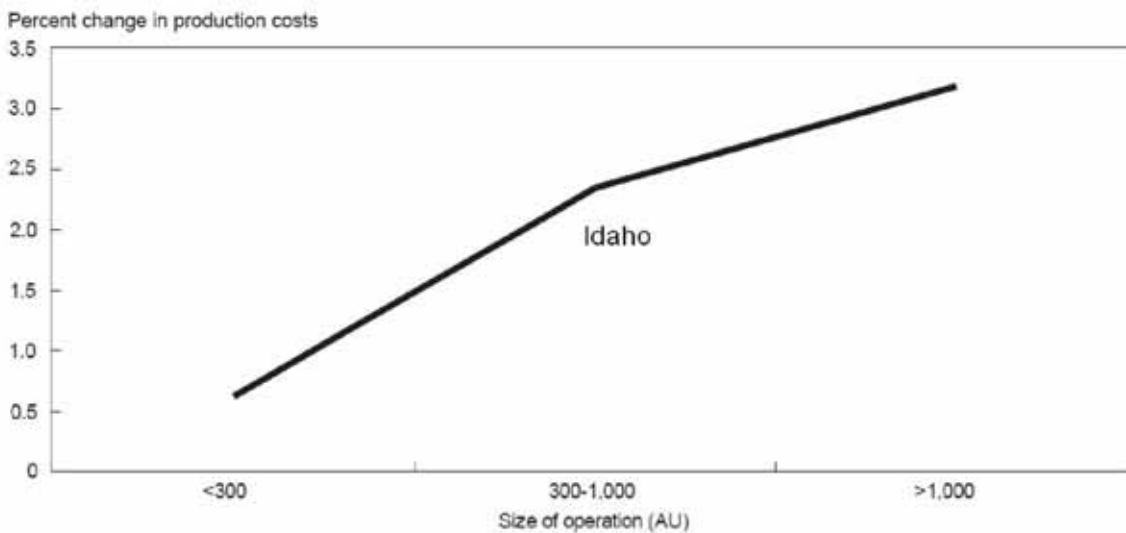


Table 9. Cost per cow to apply wastewater with center pivots.

		Distance to Apply Manure From the Storage Area					
		0.5 Mile		1.5 Miles		4.0 Miles	
		N <sup>a</sup>	P <sup>b</sup>	N	P	N	P
800 Cow Dairy	Broadcast	\$24.68	\$28.18	\$29.78	\$33.96	\$49.87	\$56.21
	Incorporated	\$27.71	\$32.36	\$32.95	\$38.13	\$53.29	\$60.39
2,000 Cow Dairy	Broadcast	\$22.47	\$26.55	\$27.06	\$32.06	\$43.07	\$52.05
	Incorporated	\$25.01	\$29.49	\$29.75	\$35.44	\$47.08	\$55.44

<sup>a</sup> Column values are based on manure applied at rates to satisfy N requirements.

<sup>b</sup> Column values are based on applying manure based on crop P uptake.



### ***Irrigation system expansion***

As farms get larger than 800 head, it becomes more cost effective per unit to pump rather than haul manure. This is likely not news to most people. The rate at which the cost increases to haul manure expands dramatically (Figure 14) as the herd size increases. The cost per cow of pumping manure is less than hauling but also increases with distance even though the cost per cow decreases (Table 9). Thus as dairies and feedlots get larger, producers should consider specialized pivots to handle wastewater or hose-drag irrigation systems (Figure 15) specifically designed to handle slurry and lagoon liquids. Irrigation system expansion allows for better redistribution of manure within the operation as well as export outside the operation.

### ***Reduce manure volume by composting and biogas generation***

There are several technologies used to treat wastes in order to reduce the volume of manure, and therefore make it easier to export or redistribute. When done properly, composting can achieve up to 50% reduction in volume, as well as significantly reducing odors, killing pathogens, and producing a valuable fertilizer byproduct. Since only the volume has been reduced, the final compost is more concentrated in phosphorus than the original separated solids or corral manure. Due to its low density, compost can be more economically shipped off the farm and become a valuable part of the operation's manure export plan. However, without the addition of carbon, a large proportion of N in the manure will be lost to the atmosphere. Adding straw to the manure can promote microbial activity, help the manure compost more quickly, and immobilize N so less is volatilized during composting. However, it does add to the P content of the manure.

Several dairies in Idaho and Washington have been using compost-based manure management systems. These systems utilize vacuum tanks equipped with manure scrapers to collect manure from freestall and open lot alleys. The collected manure is then applied to the top of windrows of carbonaceous material, separated manure solids, or dried and stockpiled open lot manure and straw (Figure 16). These compost-based systems allow producers to produce high-quality compost for

export or redistribution while minimizing the amount of manure that is collected and stored in liquid storages. For vacuumed freestall facilities an estimated 85% of the total manure and P can be exported from the farm.

Biogas generation using digesters is becoming a more practical option. This procedure slightly reduces the volume of manure, generates a useful renewable energy source (gas), kills pathogens, and stabilizes the waste, but it demands a relatively high initial investment. For more information about this option, see the Natural Resources Conservation Service publication, "*An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities*": <http://www.agmrc.org/NR/rdonlyres/7C726820-7D50-498A-90F0-FA3690392238/0/manuredigesters.pdf>.

**Figure 15. Hose-drag irrigation system.**



**Figure 16. Compost-based manure management system.**



## STRATEGY 5: MONITOR FORAGE P ANALYSIS

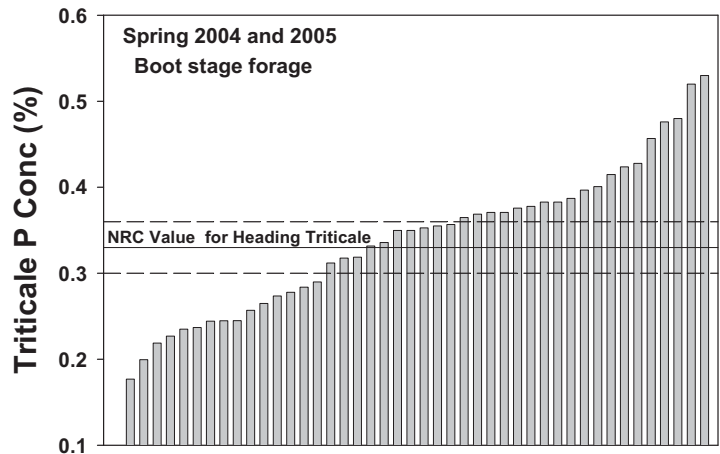
Strategy 2 emphasized the importance of testing your manure for phosphorus levels before applying it to the soil. Accurate estimates of the P uptake in crops is equally essential for balancing P added and removed from fields. In this section, we discuss the importance of testing the phosphorus in the crops used to remove P from the soil, and used in the rations you are feeding your animals.

For example, if you feed your animals based on the average values of P in triticale, you could in reality be feeding much more or much less P than is called for in your nutrient management plan. And if you plant triticale in order to remove P from your soil, you may be removing much more or less P than average. We use triticale as an example in this section because, as noted in Strategy 6, triticale is very successful at removing P from the soil and producing winter forage. However, you should test for the P concentration in any forage you grow and feed to your animals. Total P is a common analysis available at feed testing laboratories.

For nutrient management planning using the Idaho OnePlan software, computer estimates of manure P generated are balanced with estimates of crop P removal in the operation. Accurate estimates of P removal are required to avoid excessive enrichment of manured and cropped fields in the operations. Accurate forage P concentrations are also required for forages fed in the ration in order to avoid excessive P in the ration.

Software estimates of forage triticale P concentration are based on the National Research Council (NRC) values of 0.34% P for heading triticale. The NRC values for triticale P contents may differ from the actual P content of forages from heavily manured fields where soil has been highly enriched with manure or compost P. How much variability is there in actual P content of triticale? To determine the validity of the NRC value (0.34% P) used for planning in the Idaho

Figure 17. Winter triticale boot stage forage P concentrations for southern Idaho manured fields.



OnePlan, a survey of triticale boot stage forage was conducted in 44 manured fields in the Magic and Treasure Valleys of southern Idaho during spring 2004 and 2005. We found that there was a huge variation of P values in the triticale grown.

Triticale total P concentration ranged widely from 0.18 to 0.53% P, with a mean of 0.33% for boot stage samples (Figure 17). This mean value is practically the same as the NRC mean value of 0.34% for triticale at heading. In Figure 17 the mean is bracketed by lines representing P concentrations differing 10% from the mean. Over three quarters of the fields were either above (43%) or below (34%) the 10% bracket on each side of the mean.

Using an average value for triticale P concentration for calculating P removal could grossly underestimate P removal in some fields and overestimate P removal in others.

Tissue P concentrations can be diluted with greater forage dry matter production, and higher concentrations may occur when dry matter production is limited by factors other than available P. In other words, when growth is abundant, each individual plant can have lower P concentrations than when growth is more limited. Western Idaho triticale dry forage ranged from 1.58 to 5.95 tons per acre in 2004, and 2.95 to 3.81 tons per acre in 2005.

The P removed ranged from 7 to over 36 pounds per acre in 2004, and from 13.2 to 33.9 pounds per acre in 2005. Triticale

forage P removal exceeding 30 pounds per acre is considerably more than has been documented in research trials involving non-manured soils.

How can you figure out how much P was removed from your soil? This depends both on how much P is in the harvested forage tissues (the forage P concentration measured at your feed testing lab), and how much total forage was produced. You can't assume that overall P uptake increases just because the concentration of P in the forage increases, or because your forage production increases.

The P uptake is calculated by multiplying the forage dry biomass on a per acre basis by the forage P concentration as shown below:

$$\text{forage P uptake} = \text{forage dry biomass} \times (\% \text{ forage P concentration}/100)$$

In this formula, forage biomass is expressed as pounds per acre and the forage P concentration from the forage analysis is expressed as a percent P on a dry matter basis. Most feed testing labs will report total P as a dry matter percentage. It may also be reported as parts per million (ppm) or as mg per kg, which are equal. To convert ppm or mg per kg to percent P simply divide by 10,000. After plugging your numbers into the formula above, you will end up with a figure that will tell you how many pounds per acre of P your forage has removed.

It is interesting to note that triticale P concentrations were closely related to soil test P. In other words, if your soil has more phosphorus in it, then plant tissue grown in that soil will contain higher phosphorus concentrations. From this relation, using the current threshold of 40 ppm P from the NRCS 590 standard, the predicted value for triticale forage P is only about 0.28% P, well below the NRC default value of 0.34% P used in the Idaho OnePlan, or the mean for the surveyed fields. Using the same relation, the NRC triticale P value of 0.34% would be associated with 88 ppm soil test P. The soil test P for a field would provide a more accurate estimate of forage P concentration than using the NRC default value. Of course, the most accurate determination of forage P is to have the forage analyzed in a feed testing lab for total P.

If you under- or overestimate crop P removal, using NRC based estimates of average crop P concentrations instead of testing your forage, the results are predictable. Overestimating P removal can lead to higher manure application rates that steadily increase soil test P values. Conversely, underestimating P removal will cause soil test P to decline more rapidly, as more P is removed with harvest than is applied with manure. Underestimating P removal could cause you to overestimate the lands required to accommodate your CAFO. Higher estimated land requirements unnecessarily increase the costs for development or expansion of an operation, or the estimated amount of manure that should be exported, leading to unnecessary hauling and application costs.

Monitoring crop P concentrations is essential for balancing the feed ration and accurately estimating crop P removal, estimates that in turn are necessary for optimizing manure management, and avoiding or mitigating soil P enrichment for protection of water resources.

## **STRATEGY 6: INCREASE PHOSPHORUS REMOVAL WITH DOUBLE CROPPING**

With the current Idaho 590 Standard, in fields with soil test P above the threshold, additional manure and compost applications to the soil are limited to the amount of P removed by crops. Some CAFOs have limited land resources, and more waste P is generated than can possibly be removed with annual cropping.

Increasing the amount of P removed in harvested crops could be helpful in mitigating the effects of P applied in manures and composts. Greater crop P removal can slow the rate at which soil test P increases; help reduce soil test P over time; increase allowable manuring rates and thereby postpone the need for capital improvements required for extending delivery systems; reduce costs associated with exporting manure; or enable dairy herd expansion.

Double crop (winter cereal and corn) forage systems have potential for appreciably increasing the P removed by cropping over that removed with a single corn silage crop, as well as increasing forages otherwise used in the CAFO enterprise, and could provide an extended win-

dow for manure applications. Ideally, winter cereals harvested at the late vegetative or boot stage (rather than soft dough) provide additional forage and increase P removal without sacrificing silage corn production. Furthermore, harvesting winter cereals at the boot stage (to enable a timely corn planting) still removes most of the potential P uptake by that crop because winter cereal P accumulation, unlike total biomass, is largely completed by heading. Thus, a boot stage harvest does not sacrifice much P removal, and although you do not get as much total winter forage biomass as if you harvested at a later stage, the forage quality can be better.

### **Double Cropped Winter Forages and Corn Silage**

Several winter cereals were evaluated over three years at the Parma R & E Center for their capacity to accumulate P by the boot stage in a double crop forage system. Winter forages included fall plantings of three winter cereals (barley, wheat, and triticale) and two spring cereals (wheat and triticale). Planting dates for winter forages were October 21, 1998; September 27, 1999; and October 3, 2000. Corn for silage was grown after each winter forage. For comparison, two other treatments were used. One field was planted with a single crop of silage corn, and the other was a fallow treatment where no crop was planted for the duration of the study. Forage treatments were repeated every year in the same plot so that cumulative effects of treatments over three years could be determined.

Total winter forage production over three years ranged from 6.5 to 8.8 tons of dry matter per acre (Figure 18). Winter triticale averaged the highest in total forage production but did not differ significantly from spring triticale. Winter wheat was less productive than triticale over three years. Winterkill reduced winter barley and fall planted spring wheat stands in the first year, which reduced production in that year and the cumulative total production over the three years (Figure 18). Total P removal over three years ranged from 36 pounds per acre for fall planted spring wheat to 58 pounds per acre for winter triticale (Figure 19). In general, P removal mirrored forage production: the more forage produced, the more P that was removed. How-

ever, because some cereals had higher P concentrations, a small difference in forage production could translate into a larger difference in P removal. For example, spring wheat averaged 75% of the forage production of winter triticale but only 62% of the P removal. Consequently, forages differed more in P removal than they did in dry matter production.

These estimates of winter forage and P removal are probably conservative. In our trials, forage dry matter production, and especially P removal, appeared to decline with each season in winter forages unaffected by winter kill, as shown in Figures 18 and 19. This was likely due to declining available soil P that may have limited production in the final year. Winter forage average P concentrations declined from 0.39% in the first season to 0.25% in the third season. Soil test P also declined over the three years of double cropping. If more P had been available in the soil during the final year, dry matter production and P removal might have been greater.

Corn silage yield over the three years following winter forages ranged from about 5 to 16% less than corn alone. Total double crop forage yield over a three-year period ranged from 31 dry tons per acre with corn alone, to 36 dry tons per acre with spring wheat and corn (Figure 20), a 19% increase.

Corn silage P removal ranged from 105 to 119 pounds per acre over the three years, considerably more than removed by the winter forage alone (Figure 21). Silage corn P removal was not affected over the three years by previous winter forage. In other words, each year corn removed about the same amount of P, whether or not other crops were grown during the winter.

The combined P removal with winter forage/corn silage double cropping ranged from a high of 168 pounds of P per acre with winter triticale and corn to a low of 154 pounds of P per acre with spring wheat and corn (Figure 21). Note that the winter forage and silage corn combinations that resulted in the highest P removal (winter triticale and corn) did not always result in higher total double crop forage. Corn alone removed only 120 pounds of P per acre.

Figure 18. Annual and cumulative winter forage dry matter production when harvested at the boot stage, Parma 1999-2001.

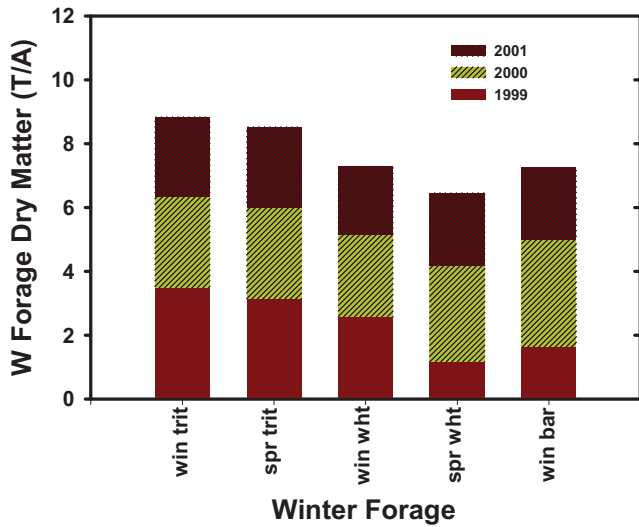


Figure 19. Annual and cumulative winter forage P removal when harvested at the boot stage, Parma 1999-2001.

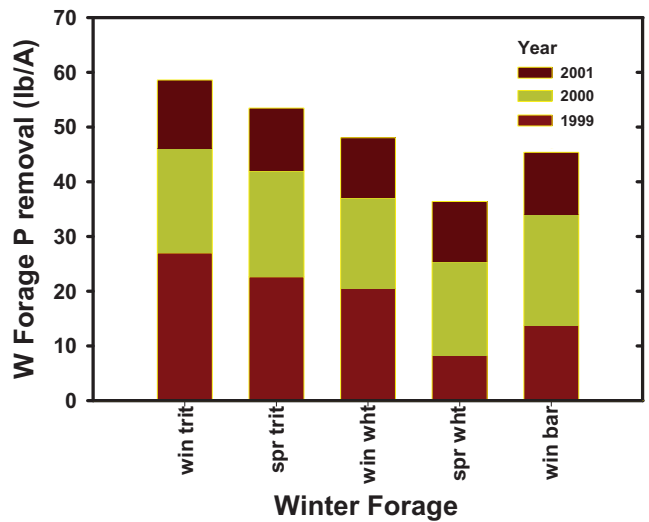


Figure 20. Annual and cumulative winter forage (WF DM) and silage corn dry matter (Si DM) yield over three years, Parma 1999-2001.

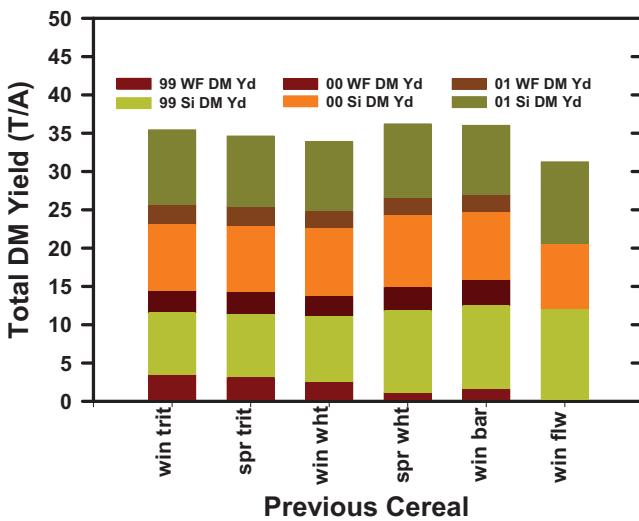
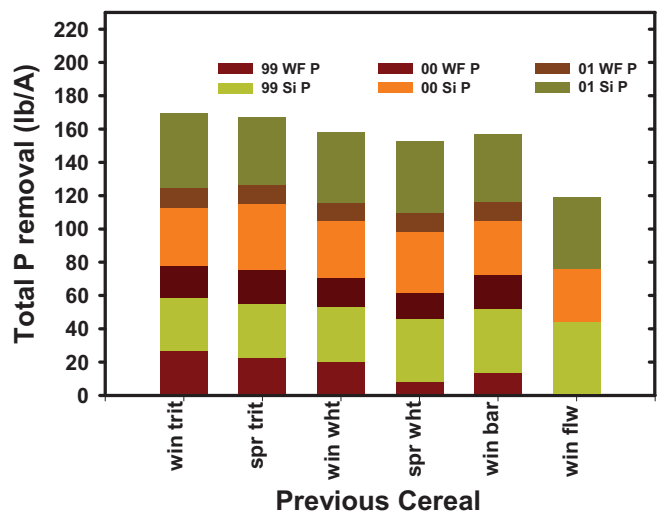


Figure 21. Annual and cumulative winter forage and silage corn P removal over three years, Parma 1999-2001.





Production practices that maximize boot stage winter forage production will also maximize P removal. Early fall plantings, adequate seeding rates, and sufficient available fall N promote higher boot stage forage yields.

Double cropping does not affect an operation's P Input:Output ratio, since the P is cycled within the operation. It does provide potential for redistribution of P among the operation's land resources as the forage P is recycled into the manures.

Another potential advantage of double-cropping is that it could reduce some diseases and pests which attack corn when it is grown continuously. Continuous corn can reduce corn yields by increasing insect and disease pressure. Long-term build-up of soil-borne pathogens or insects can reduce corn stands, vigor, and yield, and decrease P uptake necessary for P mitigation.

Double cropped corn and winter cereal offers some break in the continuous corn cycle, while increasing total forage production, and total P removal. The rotation advantage of double cropping to silage corn is largely speculative as little research has addressed the issue. While small grains may not be a host for the western corn rootworm, winter cereals can be hosts to some soil-borne pathogens affecting corn. Still, double cropping, when feasible, may help break the cycles of at least some pests which attack corn.

Including winter cereal forages may offer increased flexibility in areas or seasons where water is limited for full season corn productivity. If by the time the winter cereal forage is normally harvested it is clear that the winter snow pack and available irrigation water will not support full season corn, the winter cereal forage can be harvested later to produce considerably more winter cereal forage and result in somewhat more P uptake. Total forage productivity and P removal would be sacrificed without the corn silage in drought years, but having a cereal forage crop already established and harvested later for greater winter forage and P removal could compensate to some extent for the lost corn silage.

## STRATEGY 7: EXPORT CROPS

The quickest way to reduce excessive soil P in fields is to temporarily stop any manure or compost application while continuing to grow crops that can be exported from the operation. Exporting both manure and crops from the CAFO can help balance P Inputs and Outputs. Even this option could entail several years of cropping before soil test P is lowered to the threshold, depending on how high the soil has been P enriched.

Exporting the manure or compost to fields of nearby landowners is common. Often a dairy will trade manure for forage, or contract for forage production provided the dairy's manure is spread on the neighbor's field where the forage is grown. Sometimes the neighbor can accept much more manure than could be applied to the livestock operator's own land.

With this strategy, livestock operators or their neighbors can grow crops on the unmanured CAFO land, and make more rapid progress towards lowering the phosphorus in the CAFO field soil. The crops grown on the unmanured land can then be exported, contributing to P mitigation. If livestock operators are not limited to growing forages for their animals, they can choose to grow other crops that are easier to sell.

The P export with various crops depends on crop productivity. The amount of P removed in the harvested portion of crops grown in southern Idaho for specific yields, based on the table values for moisture and P content, is shown in Table 10. The values in the table are based on the assumption that P contents are going to be at the higher end of the range normally found in crop production, since the fields are typically enriched with P. For the yields shown, no single crop removes as much P as silage corn.

Finding alternative lands for disposal of the waste can be problematic depending on the distance the lands are from the CAFO and several other factors. The crop export option can also be problematic for CAFOs that depend on their land resource for forage production, and even more so if they depend on the lands for manure P disposal. However, if the crop production is sufficiently lucrative, the enterprise can afford to purchase necessary forages with crop proceeds.

**Table 10. P content and removal with harvest of crops commonly grown in southern Idaho.**

Crop	%P (dry wt basis)	%H <sub>2</sub> O	Yield per acre	lb P Removed per acre
Wheat grain	0.43	10	120 bu	28
Barley grain	0.39	10	120 bu	20
Oats grain	0.40	10	160 bu	18
Corn grain	0.30	15.5	180 bu	25
Corn silage	0.26	67	30 tons	51
Canola seed	0.44	10	2000 lb	8
Potatoes	0.20	80	500 cwt	20
Sugar beets	0.13	77	35 tons	21
Dry beans	0.60	40	28 cwt	10
Mint hay	0.38	--	4 tons (dry)	30
Peas	0.38	13	2000 lb	7
Soybeans	0.60	14	60 bu	17
Alfalfa hay	0.28	15	8 tons	44
Onion	0.26	8	700 cwt	15

**STRATEGY 8: MANAGE CROP ROTATIONS**

The mitigation of high P soils is a complex issue with several factors to consider. Corn silage or grain provides good feed for livestock and the highest P uptake of crops currently grown in southern Idaho. However, continuous corn and high corn acreages may have ramifications that should be considered for maintaining corn productivity, as well as the diversity and sustainability of the area's agricultural industries and our economy.

Maintaining high yield potential in corn is essential for maximizing forage production, P removal for P mitigation, and economic returns. Continuous corn can reduce corn yields by increasing insect and disease pressure. An examination of 26 different studies showed that corn yield decreased with continuous corn compared to a corn-soybean rotation in all but two of the trials.

Yield reductions typically range from 5 to 15% for corn following corn compared to the first year corn.

The cost for insect control increases with continuous corn, especially with western corn rootworm (*Diabrotica virgifera virgifera*). The eggs laid in the soil during the fall hatch the following spring. Larvae feeding on the corn roots can cause yield loss. Additional crop losses can be caused by the beetles feeding on the female flowers (silks) and soft kernels. Widespread continuous corn production in other areas has led to increased corn root worm damage, and repeated efforts to control the insects have led to resistance to the commonly applied insecticides methyl parathion and carbaryl. Therefore, crop rotation is an important option to prevent large rootworm infestations, damage to corn, and reduced P uptake and removal.

Costs for disease control can also increase with continuous corn. The long-term buildup of soil-borne pathogens can reduce corn stands, vigor and yield, and decrease P uptake necessary for P mitigation. Corn residues are hosts for pathogens. Corn root rot, seed rot and seedling blight, leaf spots and blights, stalk rots and smut are all diseases that are more prevalent in continuous corn, as the pathogens can survive on corn residues and/or in the soil. The possible financial losses from pathogens, and reduced corn P removal with continuous corn, should be considered in the strategy for maximizing P uptake and forage production. Crop rotation is an effective management tool for reducing pathogen hosts and minimizing diseases.

Increased corn acreage with more corn stubble, roots, and crowns has the potential for increasing *Fusarium graminearum*, a soil-borne pathogen that causes primarily scab (head blight) in wheat or barley, and stalk and ear rot of corn. *Fusarium graminearum* has increased head blight incidence and severity in wheat and barley in the upper Midwest growing areas where corn acreage has expanded. *Fusarium graminearum* produces a vomitoxin (deoxynivalenol), which causes vomiting in monogastrics (such as pigs and poultry). Many malt barley companies have a zero tolerance policy for vomitoxin. Head blight in other malting barley production areas may be one of the reasons why some malting barley production has moved from the upper Midwest to Idaho. Whether increased corn acreage and/or continuous corn will contribute to greater incidence of head blight in southern Idaho barley or wheat remains to be seen, but there is concern as head blight has been documented in southern Idaho.

Limited irrigation water due to drought or curtailment can significantly affect corn silage production and P removal. In these situations, small-grain forages harvested earlier than corn and requiring less water may be critical for production of high-quality livestock feed and maintaining good crop rotations to minimize disease, weed, and insect problems.

Annual small grain forages have been evaluated in southern Idaho. Small grain options may include mixed plantings of grain and legumes (such as peas, clover, and

alfalfa). Cereal-legume mixtures may be less productive, but protein concentrations of winter cereal and legume mixes can be double those of dough stage cereal silages and are higher than corn silage. Awnless cereals are available to facilitate feeding. Small grain forages planted in late summer may provide both late fall and early spring grazing, and still provide an option for grain or dough stage silage production. A preliminary study by the University of Idaho showed that grazing winter wheat is feasible in some areas of southern Idaho. Double cropped corn and winter triticale offers some break in the continuous corn cycle, increases total forage production, and total P removal as was indicated in Strategy 6. But it is not clear to what extent continuous double cropping can address the increased pest incidence with continuous corn. The impact of the winter forage is likely very pest specific.

The dairy industry and other CAFOs have a major impact on southern Idaho's economy and other agricultural industries. For many, a sustainable livestock industry and meaningful P mitigation will likely depend on effective collaboration between CAFOs and neighboring cropping enterprises. Collaborative cropping and manuring arrangements between the CAFO and their neighbors can provide increased opportunities for breaking continuous corn rotations that would maintain corn productivity and crop P uptake and removal potential. These collaborations can ensure adequate availability of high quality forages, and enable appreciable P export from P enriched fields, depending on the collaborating enterprises and their needs.

## **STRATEGY 9: BUY OR LEASE ADDITIONAL LAND**

CAFOs have increased significantly in size in the last few years, from hundreds of animals to several thousand animal units (AU) per farm. Farmers and livestock operators should limit the number of AU according to their capability to properly manage the nutrients generated. If the strategies presented in this bulletin cannot offer more capability for the proper control and application of manure, the only solution left before reducing the number of AU is to buy or rent more land in order to expand land application capabilities.

For some operators, buying more land is feasible when land is available. For some areas such as the Magic Valley in south central Idaho, with prices averaging \$4,000 or more per acre as of 2007, water shortages, and fewer productive acres left, this option is increasingly difficult.

CAFO operators can consider the following options:

- **Buy more land:** CAFO operators need to perform a thorough economic analysis to determine if the price paid for additional land balances the profit from the increased number of animals added to their operation, or the increased costs of more distant manure hauling and application. Any expansion in animal units or lands may be restricted by state regulations or local ordinances, so these should also be taken into consideration. Buying more land to facilitate balancing P applied and P removed could be economically feasible in order to maintain or increase AU in the CAFO.
- **Buy alternative lands:** In general, producers try to buy land around their existing operations, which is logical from a logistical and economic point of view. Producers can also explore buying more distant farmlands. Less productive or undeveloped farmlands can be an alternative. These lands might be unproductive because of lack of nutrients, poor management, or lack of water. CAFOs usually have access to the economic and technical resources to develop these lands. Manure hauling and irrigation costs should also be considered. Operators need to find an imaginative approach to this balance. For example, dry cows and/or calves can be relocated to the new land, moving some of the manure production to the new site.

- **Rent land:** Renting land from other landowners can be beneficial for both parties. CAFO operators will have more land to produce their feed and to apply their manure, especially when applying accumulated lagoon sludge. For the landowners, renting out their land provides income, the possibility of diversifying their crop rotation, and nutrients added to their soil.
- **Share land with neighbor farmers:** Land sharing arrangements between CAFOs and nearby cropping operations that can accommodate more manure and compost applications can be mutually beneficial. CAFO operations may be limited by equipment needs for crops other than what they usually produce for the enterprise. This may lead to cooperative agreements with neighbors to grow crops on nearby acreages in exchange for manure/compost disposal and/or forage production. It can enable sharing of limited labor, equipment, and expertise. It may help to diversify crop rotations in both enterprises and increase the productivity of the crops by reducing harmful pests (insects, diseases, or weeds). Manure may be especially useful in restoring the productivity of neighboring fields where erosion or land leveling has exposed less productive subsoils.

In all of these cases, an economic analysis and evaluation of available land, labor, and other resources needs to be conducted.

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