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Importance of Farm Phosphorus Mass Balance and Management Options

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Phosphorus is a naturally occurring element that is one of 16 elements essential for plant growth and animal health. Research has documented that applying phosphorus in fertilizers or manure increases crop growth and yield on soils that are below critical agronomic levels, as measured during routine soil testing. Although the economic benefits of phosphorus fertilization on crop production are well-documented, too much of a good thing can be detrimental to the environment. Excessive soil phosphorus is a potential threat to water quality.

The management strategies for phosphorus are very different from the strategies used for nitrogen in crop production because they behave very differently in soils. It is critical that the nitrogen rate is determined by the crop needs and that the nitrogen is applied at the correct stage of growth when it is needed. If too much nitrogen is applied to a crop one year, most of the excess nitrogen will be lost, and, therefore, it will not be available to a crop planted the following year. This is because the predominant plant-available form of nitrogen (nitrate) is not held by soils and leaches with water movement.

Phosphorus, on the other hand, is held very strongly by soils through chemical reactions. Acidic soils, those with a pH of less than 7, are predominant in Virginia. The iron and aluminum hydroxides in these soils strongly hold phosphorus and prevent it from being leached. In the few calcareous soils — those with a pH greater than 7 — phosphorus can be retained by reacting with calcium. Soil testing is the only way to evaluate how much phosphorus is in your soils. Soil testing does not measure total phosphorus in your soil, but it is very effective at measuring the phosphorus that will be plant-available. For more information on soil testing, visit www.soiltest.vt.edu.

Native soils in Virginia are phosphorus-deficient and need phosphorus additions for productive agriculture. Relatively high rates of phosphorus are needed initially on soils very low in phosphorus (e.g., soil with only 4 parts per million [ppm] may require 100 pounds of phosphate (P_2O_5) per acre to grow corn grain). Increasing soil phosphorus concentrations can be accomplished by using any type of phosphorus-containing materials, such as fertilizers, manures, biosolids, or composted materials. However, with successive applications of phosphorus in excess of crop removal, phosphorus not taken up by the crop is mostly held by the soil (as described above) and will build up in the soil. The rate at which plant-available phosphorus builds up in soil depends on several factors, such as soil type, phosphorus application rates, and phosphorus removal (combination of crop and yield). Eventually, phosphorus can build up to the extent that little or no phosphorus fertilizer is needed to grow a crop. Again, the only way to know the concentration of plant-available phosphorus in your soil is through soil testing.

So if Phosphorus is Held Strongly by Soils, Why are There Environmental Concerns and Regulations?

There are two reasons for this.

First, when soil is eroded, the eroded soil particles carry phosphorus with them. Freshly tilled soils in particular are vulnerable to erosion during heavy rain events, and the sediment generated can release phosphorus when it enters rivers and streams. As soil phosphorus concentrations increase above the agronomic optimum range, more phosphorus can be released by eroded soils and sediments when they are deposited in rivers, lakes, and estuaries.

Second, although soils hold phosphorus strongly in the agronomic optimum range of soil test phosphorus, soils do have a finite capacity to hold phosphorus. Many years of phosphorus overapplication above crop needs will

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result in soils becoming saturated with phosphorus, just as a sponge can be saturated with water. As soil test phosphorus rises well above what crops need, soils will release soluble phosphorus in leachate and runoff water.

The good news is that soils can hold phosphorus strongly while still supplying adequate plant-available phosphorus in the agronomic optimum soil test range. Therefore, farmers can attain maximum crop yields without worrying about excessive phosphorus loss and environmental problems by applying phosphorus at rates recommended by a soil test. Phosphorus problems are mainly associated with soil erosion and/or excessively high soil test phosphorus. This excessively high soil test phosphorus is only seen where overapplication of phosphorus, beyond crop removal rates, has created an undesirable positive mass balance problem at the field or farm scale.

Phosphorus Mass Balance: Imports Versus Exports

Farms import phosphorus in feed, manures, biosolids, and fertilizer and export it in products such as animal products, milk, grains, and forages. The import minus the export is referred to as "mass balance," which can be expressed on a farm, field, or regional scale. A positive mass balance (surplus) means a farm is importing more phosphorus than it is exporting. If a farm has a positive mass balance, then soil test phosphorus will increase over time because the soil is where most imported phosphorus ends up. This is either through the direct application of fertilizer or through the feed phosphorus passing through an animal and being land-applied in manure. Unlike nitrogen, there is no gaseous form of phosphorus, so applied phosphorus will build up in soils.

The average value for crop removal of phosphate in the harvested portion of the crop is provided in table 1. Average values for nutrient concentrations in manures can be found in table 2, and average values for nutrient concentrations in animals and animal products are available in table 3. These numbers are helpful in calculating farm and field mass balances.

What Type of Farm Needs to Consider Mass Balance?

All farms should be aware of phosphorus mass balance, but a positive mass balance or surplus is generally only a concern on some types of farms. Cash grain farms using only chemical fertilizer can easily balance their

Table 1. Estimated removal of phosphate (P_2O_5) in harvested grain (and dried distillers grain [DDG]) and forage crops grown in Virginia.

Crop*	Yield Unit	Pounds of Phosphate (P_2O_5)/Yield Unit
Grains		
Barley	Bushels	0.40
Barley straw (per bushel grain)	Bushels	0.11
Buckwheat	Bushels	0.36
Canola	Bushels	1.30
Corn	Bushels	0.38
Dried distillers grain (DDG)	Tons	17.80
Oats	Bushels	0.33
Oat straw (per bushel)	Bushels	0.09
Proso millet	Bushels	0.39
Sorghum	Bushels	0.40
Soybean	Bushels	0.89
Triticale	Bushels	0.39
Wheat	Bushels	0.51
Wheat straw	Bushels	0.11
Silage		
Barley silage	Tons	5.10
Corn silage	Tons	4.20
Grass silage	Tons	5.70
Oat silage	Tons	5.00
Rye silage	Tons	5.60
Sorghum silage	Tons	5.40
Triticale silage	Tons	5.60
Wheat silage	Tons	4.20
Forages (hay)		
Alfalfa	Tons	14.50
Alfalfa grass	Tons	14.50
Bermudagrass	Tons	10.40
Clover and grass	Tons	14.00
Fescue grass	Tons	16.00
Hairyvetch	Tons	14.00
Indiangrass	Tons	10.00
Lespedeza	Tons	10.00

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Table 1. Estimated removal of phosphate (P_2O_5) in harvested grain (and dried distillers grain [DDG]) and forage crops grown in Virginia.

Crop*	Yield Unit	Pounds of Phosphate (P_2O_5)/Yield Unit
Forages (hay) (cont.)		
Millet	Tons	8.40
Orchardgrass	Tons	16.00
Perennial ryegrass	Tons	17.00
Red clover	Tons	10.00
Red clover grass	Tons	14.00
Small grain	Tons	10.00
Sorghum	Tons	8.40
Soybean	Tons	10.00
Switchgrass	Tons	10.00
Sudangrass	Tons	10.00
Tall fescue	Tons	16.00
Timothy	Tons	14.00

* For less-common crops, see table 4-7 in the Virginia Department of Conservation and Recreation's (2014) "Virginia Nutrient Management Standards and Criteria."

Table 3. Phosphorus concentration in animals and products.

Animal Type	Phosphate Concentration (pounds P_2O_5/pound of animal)
Cattle, beef (<1,000 lb.)	0.0167
Cattle, beef (>1,000 lb.)	0.0149
Cattle, dairy	0.0190
Cattle, dairy (milking herd)	0.0165
Chicken, layer	0.0133
Swine (<100 lb.)	0.0128
Swine (100 to 300 lb.)	0.0108
Swine (>300 lb.)	0.0108
Animal Product	**Phosphate Concentration (pounds P_2O_5/pound of product)**
Eggs	0.004
Milk	0.002

Table 2. Average analysis for manure tested in Virginia.

Manure Type	Total Nitrogen (TKN)	Ammonium Nitrogen (NH_4)	Phosphate (P_2O_5)	Potassium (K_2O)	% Moisture
Liquid dairy slurry*	19.22	8.88	9.08	17.35	94.60
Semisolid dairy	15.34	3.47	7.58	14.33	67.35
Semisolid beef	18.00	2.36	9.88	19.02	63.13
Dry chicken broiler litter	64.86	11.48	52.18	53.36	27.83
Dry chicken layer/ breeder	47.87	8.51	60.79	43.68	29.49
Dry turkey litter	62.03	13.05	50.23	38.31	28.64
Dry turkey breeder	58.82	12.64	61.23	36.18	25.48
Liquid swine lagoon*	7.20	5.66	2.81	12.23	99.35
Liquid swine pit*	23.56	15.29	16.71	15.74	97.48

* Values in pounds per 1,000 gallons; all other values in pounds per ton.

phosphorus by matching fertilizer phosphorus purchases with soil testing recommendations. The same principle applies to turf and home gardens. If phosphorus is not required, it is not purchased, and vice versa. Cash grain farmers can still purchase and apply fertilizers containing nitrogen and other nutrients if their soils do not require phosphorus.

Positive phosphorus mass balance (or surplus) problems are generally associated with intensive animal production, including dairy, poultry, swine, and horse farms. This is due to the importation of phosphorus in feed, which mostly ends up in manure, rather than animal products. While phosphorus in manure makes a good fertilizer, the intensification of modern animal farming means that many intensive animal farms do not have sufficient crop production acres to efficiently use it. On a national scale, phosphorus is mined and then applied as fertilizer to corn and soybeans in the Midwest. This phosphorus in corn and soybeans is then imported as feed to dairy and poultry farms in Virginia before ending up being land-applied as manure.

The situation is further complicated by the imbalance of nitrogen versus phosphorus in manure, as the N:P ratio in manure is lower than most crops need. Therefore, a farmer who applies enough manure to meet crop nitrogen needs will overapply phosphorus relative to crop uptake. The N:P ratio imbalance can be overcome where sufficient crop production acres are available by using manure to supply the phosphorus needs of the crop and by supplementing any additional nitrogen needed by applying chemical fertilizer and/or growing legumes in the rotation. When a soil test recommends that no phosphorus is needed, applying manure can supply valuable nitrogen, but the phosphorus it contains continues to raise the soil phosphorus concentration and will not increase crop production.

Long-Term Impacts of Phosphorus Surpluses

Because phosphorus is strongly held by soils, once a soil test recommends no phosphorus, applying phosphorus in excess of crop removal rates will lead to increased soil test phosphorus. Raising soil test phosphorus above agronomic recommendations does not help or harm crop production, but it does increase phosphorus losses when soils are eroded. Also raising soil test phosphorus above agronomic recommendations is a concern on permitted animal operations. Where farms are regulated, increasing soil test phosphorus brings soils closer to the point where manure applications are no longer permitted. Nutrient management regulations limit or ban manure applications to some soils with excessive soil test phosphorus because the risk of phosphorus loss to rivers and streams becomes unacceptable.

Building up or reducing soil test phosphorus is a long-term process. For example, research conducted over seven years on soils in the Shenandoah Valley of Virginia showed that it took 14 to 23 pounds of P_2O_5 added to or removed from soil to change soil test phosphorus by 1 ppm. A 25-year study at a very high soil test phosphorus site showed that a soil could be continuously cropped with corn for 15 years before any phosphorus additions were recommended by a soil test. Many animal farms in Virginia now have soils that have more phosphorus than crops need, which often limits additional manure applications.

Long-term planning and practices are needed to prevent more soils from becoming excessively high in soil test phosphorus and to lower the concentration in those that are already excessive. Best management practices, such as stream buffers, no-till, etc., will not solve phosphorus issues as long as farms have positive phosphorus mass balances.

What Options Are Available to Manage Farm Phosphorus Imbalances?

The concept of mass balance is fairly simple: A farmer with a positive mass balance can either import less phosphorus or export more. However, it becomes much more complicated when economics is included because changes in phosphorus mass balance may also have economic impacts. It also depends on the type of farm and the land base available. Where phosphorus mass balance is a concern, approaches to dealing with surplus phosphorus include:

1. Export manure. Many poultry farms produce much more poultry litter than they can efficiently use as a fertilizer on their farms. It was recently estimated that 85 percent of poultry litter is exported from poultry farms, and exporting poultry litter is a good option. Litter is a saleable commodity because it contains valuable nutrients and has relatively low moisture, which allows it to be economically transported by truck. Transporting dairy manure for long distances is not feasible because it is, on average, 95 percent water,

making transportation costs high relative to nutrient content. Many farms can benefit from manure nutrients, especially if they can purchase and apply those nutrients at a lower cost than chemical fertilizer. However, on farms where mass balance of phosphorus is a concern, purchasing manure will only exacerbate phosphorus problems. For example, a dairy farm with a positive mass balance of phosphorus should not import poultry litter as a cheap source of nitrogen.

2. Avoid dry distillers grain (DDG). Some dairy farmers can purchase DDG as a fairly cheap feed ingredient for protein. However, DDG has a relatively high phosphorus concentration that is of no benefit to the cows, so purchasing it will increase the phosphorus coming onto the farm as well as the mass balance.

3. Where possible, increase land base. If a farm does not have sufficient land to efficiently utilize all the phosphorus in the manure generated, try to increase the land area where manure is spread. Purchasing land is very expensive, but renting more land or spreading on a neighbor's land where the soil test recommends phosphorus may be an option. A rule of thumb is that a manure application to meet crop nitrogen needs uses sufficient phosphorus for about three years of crop removal. Therefore, a reasonable goal is to do a nitrogen-based manure application one year in three, use legumes or chemical nitrogen fertilizer in between, and keep track of soil phosphorus using a soil test.

4. Grow more feed and import less. This applies mainly to dairy farms because poultry farms import feed from the feed mill. For example, grow a winter crop such as ryegrass or wheat that can be harvested before corn is planted in the spring. As with No. 3 above, other approaches to increasing feed grown may require changing the land base accessible to the farm.

5. Import less fertilizer phosphorus. Farms with agronomically excessive soil test phosphorus should not import fertilizer phosphorus. This includes avoiding the import of organic fertilizers to use for a nitrogen source, such as manure or biosolids, because these will also import phosphorus. Applying starter phosphorus at planting is a common practice for crops such as corn, but there is some research showing that starter phosphorus is not necessary for very high phosphorus soils (starter nitrogen is still a benefit). Although relatively small, starter application of phosphorus will affect your soil test and mass balance over the longer term. If you are unsure if removing starter phosphorus is possible with your soils and soil test level, leave some test strips without phosphorus at planting and see if yields are affected.

Conclusion

Managing phosphorus to reduce unproductive overapplication to crop land and minimize loss to the environment can first be addressed by following soil test recommendations. On farms with animal operations, the initial approach is to apply manures to fields where phosphorus application is still acceptable according to a nutrient management plan. On operations where there is considerable importation of nutrients containing phosphorus, determining the mass balance of phosphorus is another important component to consider. However, there are limits to the options available in nutrient management plans.

As excess phosphorus continues to be imported onto farms and soil test phosphorus continues to increase, soil test concentrations will approach the regulated upper soil test threshold limits where no more phosphorus can be applied. No more phosphorus applications means no further manure applications. Therefore, addressing the farm mass balance of phosphorus is essential to the long-term sustainability of animal farming operations.

Reference

Virginia Department of Conservation and Recreation. 2014. *Virginia Nutrient Management Standards and Criteria*. www.dcr.virginia.gov/documents/StandardsandCriteria.pdf.