Phosphorus Issues

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Intended Outcomes

The participants will
- Understand how P affects water quality
- Understand why manures present a special problem with P
- Understand how to use the P-index

Regulatory Background

The current Georgia regulations require for all wet manure operations (swine, dairy, and layer operations for the most part) above 1,000 animal units that Comprehensive Nutrient Management Plans (CNMPs) be developed that meet NRCS standards. These standards require that CMNPs consider the risk of P losses from a field reaching a sensitive stream, river, or lake (NRCS, 1999). New EPA regulations will require that states develop regulations that will include dry manure operations (broiler operations) above 1,000 animal units.

How P Affects Water Quality

According to a recent survey by the U.S. EPA, accelerated *eutrophication* is the main cause of water quality "impairment" in the U.S. (U.S. EPA, 1996). Eutrophication is the natural aging of lakes or streams brought on by nutrient enrichment. This process is accelerated by human activities which increase nutrient loading rates to water. While both P and N contribute to eutrophication, P is the primary agent in freshwater eutrophication. In salt water estuaries, N is the primary nutrient controlling eutrophication.

Eutrophication restricts water use for fisheries, recreation, industry, and drinking, due to the increased growth of undesirable algae and aquatic weeds and oxygen shortages caused by their death and decomposition. Also, an increasing number of lakes are experiencing periodic algal blooms. These blooms contribute to a wide range of water-related problems including summer fish kills. One of the problems occurs when lake water that has high organic matter levels due to algal blooms is used for drinking water by cities (U.S. EPA, 2003). Water treatment plants commonly add chloride (Cl) to drinking water to kill pathogens but the Cl can combine with the organic matter to produce tetrahalomethanes (THM) and haloacetic acid (HAA), both of which are carcinogens. EPA has put a limit on the annual average concentration of these compounds that are allowed for drinking water plants.

Lakes are more sensitive to P than streams and rivers. According to a survey by the Georgia Department of Natural Resources (DNR), several of the large lakes in Georgia show signs of eutrophication. Due to accelerated eutrophication, the DNR has set limitations for five lakes in

Georgia on the amount of P that can enter from tributaries (Table 1). In 2001, the Cobb County Water Authority, which draws most of it's drinking from Lake Allatoona, came very close to exceeding the limit for HAAs in their drinking water. If the problem continues, finding an alternative treatment to Cl could cost the authority millions of dollars according to an article in the Atlanta Journal Constitution (2002).

Table 1. Large lakes in Georgia with the ten highest levels of trophic index (DNR, 1995).

Lakes	P limit (lb per acre-ft per year)
Lake Allatoona	1.3
Lake Jackson	5.5
Lake Lanier	0.25
Lake Walter F. George	2.4
West Point Lake	2.4

The sources of P entering streams, rivers, and lakes in Georgia include sewage treatment plants and factories that discharge into streams, runoff from lawns with failing septic systems or fertilizer, runoff from agricultural land with manure or fertilizer, and natural background sources such as rock minerals and wildlife.

Ground water is not affected by P because of the absence of algae. Only when ground water returns quickly to a stream, river, or lake, do we need to worry about P leaching to ground water.

What Happens When P is Added to Soils

Phosphorus is added to agricultural land as fertilizer or manure because it supplies an important element needed for plant growth. Phosphorus in soils exists in a number of mineral and organic forms, but most of it is adsorbed to iron and aluminum oxides in Georgia soils. These oxides have a large, but not unlimited, number of adsorption sites for P and when the adsorption sites start to fill up, there is more and more P dissolved in the soil water. It is mainly this dissolved P that is available to plants, and susceptible to runoff.

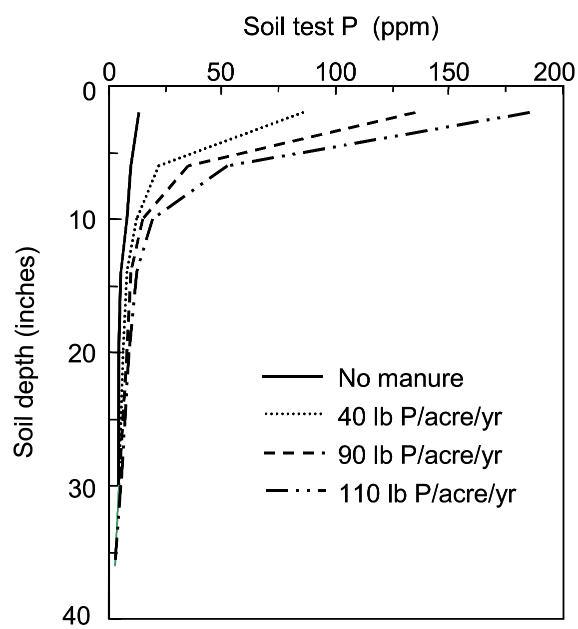

Figure 1. Soil test P as a function of depth for different rates of manure application.

P in soils can be expressed as P or P_2O_5. To convert P to P_2O_5, multiply by 2.29. When discussing plant available forms of soil P as determined by soil testing laboratories, we refer to them as *soil test P* (usually in parts per million or ppm) and identify in each case the specific method of analysis used (Mehlich-1, Mehlich-3, Bray-1, etc). Soil test P can also be expressed in lbs/acre. Based on a six inch soil depth containing 2 million pounds of soil, to convert ppm to lbs/acre, multiply by 2.0.

In most soils, the P content of the topsoil is much greater than the subsoil (Fig. 1). As manure and fertilizers are added to soil, the levels at the surface increase sharply, but there is little effect in the subsoil in most cases. This is because most of the P is tightly adsorbed and doesn't move very far. In addition, P is cycled from roots to aboveground parts of the plant and redeposited in crop residues on the soil surface. In very sandy soils which are low in iron and aluminum oxides, P can move into the subsoil.

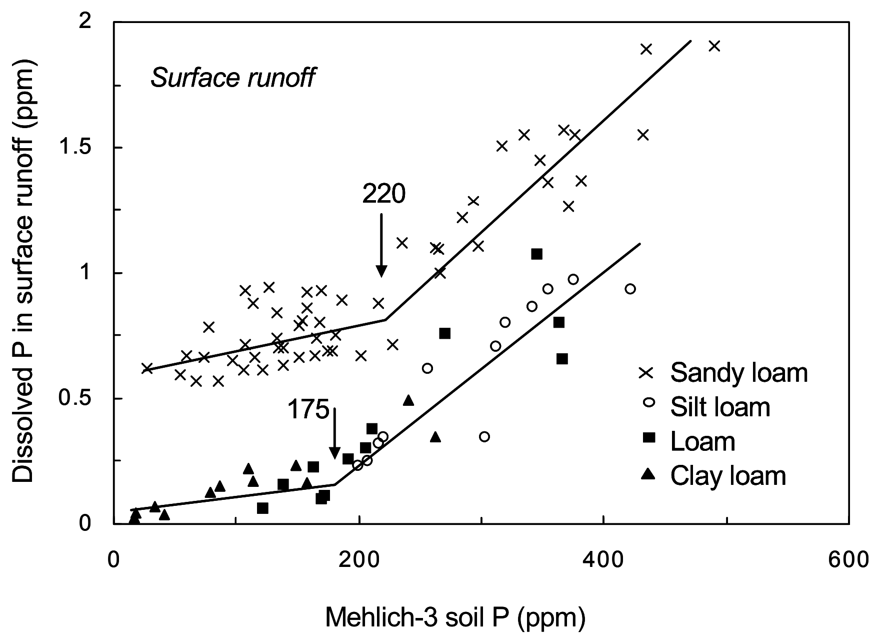

Figure 2. Dissolved P as a function of soil test P in four soils.

In recent years, we have learned that the concentration of P in runoff from agricultural fields increases as the soil test P level goes up. Part of the reason for this can be soil erosion where soil particles with high concentrations of adsorbed P are being washed off the field. But even in grass fields, where there is almost no erosion, research has shown that dissolved P concentrations in runoff increase with soil test P (Fig. 2). The reason why P concentrations in runoff increase with soil test P levels is that when rain occurs there is a thin layer of water near the surface that mixes with the soil water and can run off. If the concentration of P in the soil water is high (because most of the adsorption sites near the surface are filled with P), then the concentration in the runoff water will also be high. In Fig. 2, all soils show that P concentrations in runoff increase more sharply beyond a certain level of soil test P. This probably represents the level where most of the adsorption sites near the soil surface are filled.

There is no clear answer to what is an unacceptable concentration for P in runoff. The concentration of total P (adsorbed and dissolved) that is thought to trigger eutrophication in lakes is only 0.05 ppm. In Fig. 2, even the lowest levels of soil test P produce concentrations in this range. Most researchers agree that a realistic target is to try and keep agricultural runoff P concentrations below 1.0 ppm. The level of soil test P above which runoff concentrations exceed 1.0 ppm is sometimes referred to as the *environmental threshold* soil test P. In Fig. 2, the environmental threshold level would be approximately 300 ppm soil test P for the sandy loam and 400 ppm soil test P for the silt loam. By comparison, the *agronomic threshold* level (soil P level above which there is no increase in yield) for most crops using a Mehlich-3 extractant is around 50 ppm. In general, the environmental threshold is 2-4 times higher than the agronomic threshold.

Why Manures Present a Special Problem for Phosphorus

For the most part, soil test P levels at the surface in excess of the environmental threshold are unlikely to occur unless manures are being used. Even though farmers have been encouraged to "build soil test P" levels in the past, the cost of fertilizers discourages over-application of P in most cases. Manures present a special problem because the N-to-P ratio in manure is not the same as what most crops need. Most crops use about 8 lbs of N for every lb of P, or a ratio of 8-to-1. But manures usually have a much lower ratio.

Table 2. N-to-P ratios for different manures, ratios adjusted for available N, and the resulting over-application of P.

Type of Manure	N Content[1]	P Content[1]	N-to-P Ratio	Adjusted N-to-P Ratio[2]	Over-application of P
Anerobic swine lagoon	128 lbs/acre-in	22 lbs/acre-in	5.8	2.9	2.8 times crop needs
Anerobic dairy lagoon	132 lbs/acre-in	33 lbs/acre-in	4.0	2.0	4.0 times crop needs
Anerobic layer lagoon	179 lbs/acre-in	20 lbs/acre-in	9.0	4.5	1.7 times crop needs
Broiler litter	71 lbs/ton	30 lbs/ton	2.4	1.2	6.7 times crop needs

[1] from Barker et al. (1994).
[2]adjusted for available N (assumed to be half of the total N).

For example, a typical sample of broiler litter would have 71 lbs of total N and 30 lbs of total P per ton of litter, a ratio of 2.4-to-1 (Table 2). Since only about half of the manure N is usually available to plants (due to losses and limited organic N decomposition), the effective ratio is 1.2-to-1. This means for every 8 lbs of broiler litter N applied, one applies 6.7 lbs of P (8 divided by 1.2), or 6.7 times as much as the crop needs. As a result, excess P builds up at the soil surface in fields that receive repeated manure applications. Average N-to-P ratios vary for different manures and storage methods (Table 3). Values for a given operation need to be determined from periodic manure sample analysis.

As a result of the low N-to-P ratio in manure, excess P builds up at the soil surface in fields that receive repeated applications. This appears to have happened in many grass fields in the Piedmont region of Georgia where broiler litter applications are common. In 1995, 42% of the bermuda grass and 33% of the summer grass soil samples submitted to the University of Georgia Soil Analysis Laboratory tested High or Very High in soil test P.

Dry manures present a special additional problem when they are applied to grass fields and not incorporated. Under these circumstances, there is very little contact between the manure P and the oxides in soils. Rain water mixes directly with the manure causing a high concentration of dissolved P in the runoff. Some of adsorbed organic P also enters runoff as the manure is eroded from the site. Research has shown that runoff P concentrations are unrelated to soil test P in these situations. Runoff P concentrations can be quite high (> 25 ppm) when runoff occurs within a few weeks of manure application.

Best Management Practices to Reduce P Runoff Losses

There are a number of best management practices (BMPs) that can be adopted to reduce the risk of P contamination of surface waters. Some of these reduce the source of P in a field and others reduce the transport of P from the field to a stream.

The most obvious BMP for reducing the P source is to base nutrient management plans (NMP) on the crop's need for P rather than N (a P-based vs. a N-based NMP). This means that additional land must be found for manure application or livestock numbers must be reduced. Another way to reduce the P source is to make P in the feed more digestible so that lower levels can fed. This can be done by adding phytase enzyme to feed or through the use of new hybrids of corn that have a highly digestible form of P (Ertl et al., 1998). The P source can also be reduced by adding a compound called *alum* to the manure. The aluminum in alum combines with P in the manure and forms an insoluble compound. As a result, the dissolved P levels in runoff are lower when alum-treated manure is applied to fields (Moore and Miller, 1994). A simple way to reduce the source is not to apply manure during periods when runoff-producing rains are expected, for example in the winter months. If it's possible to incorporate dry manure or inject lagoon slurries, this will also reduce the source.

One of the most important BMPs that affect transport is the use of grass filter strips and stream-side buffers. Grass filter strips are very effective in filtering out P adsorbed to sediment because they slow down the flow of water and cause the sediment to settle out. They have less of an effect on the P dissolved in runoff. Artificially drained fields (tile drains or ditches) present a special danger in that transport from the field to the stream is enhanced. High concentration P water may move to the drains in sandy soils where there is little adsorption. Avoiding manure application to artificially drained fields is the best practice. Transport of P can also be reduced by any BMP that reduces runoff and erosion. Examples would be conservation tillage, terracing, contour plowing, and impoundments.

Georgia P Index

If the risk for P loss to a sensitive water body is sufficiently high, then a P-based plan should be adopted. But how do we determine the risk and what is *sufficiently high*? In Georgia, we have developed a *P index* that estimates the risk for P losses at the edge of a field. This might be compared to the heat index which gives us a temperature that has been adjusted to take into account both temperature and humidity and more accurately represents how hot it will seem to us.

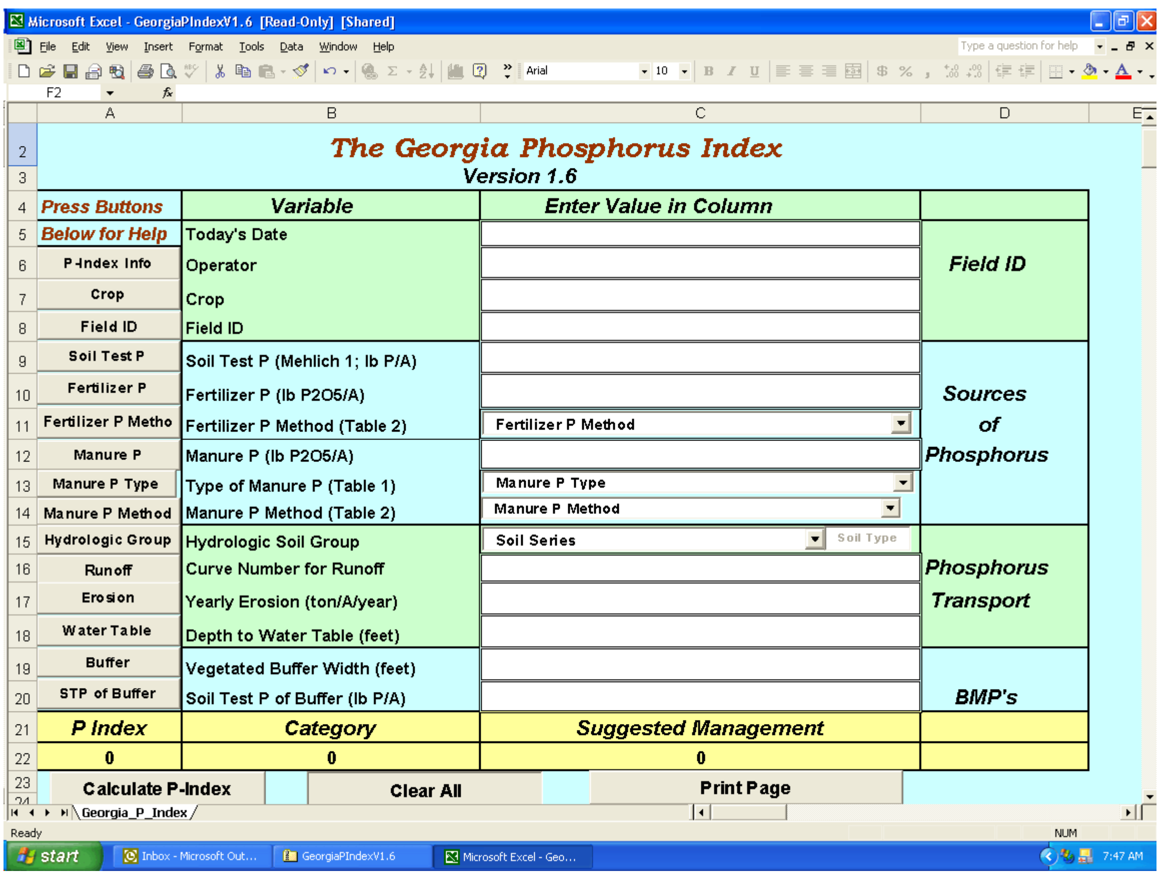

Figure 3. Georgia P index source, transport, and BMP factors.

The index is calculated using a spreadsheet and considers source, transport, and BMP factors (Fig. 3). The sources of P include soil test P, fertilizer P, and manure P. The methods of applying fertilizers and manures are also considered. The transport mechanisms include runoff, erosion, and drainage (a function of the soil hydrologic group and the depth to the water table). The only BMP considered (aside from methods of applying fertilizers and manures) is vegetated buffers. To be effective in filtering P, the soil test P in the buffer must not be too high so that too is a factor.

Table 3. Interpretation of the Georgia P index.

P Index Range	Category	Generalized Interpretation
0 to < 40	Low	Low potential for P movement from this site. Nitrogen-based nutrient management planning is usually satisfactory.
40 to < 75	Medium	Medium potential for P movement from this site. Use conservation practices and P applications that maintain a P Index < 75.
75 to < 100	High	High potential for P movement from this site. Add conservation practices or reduce P applications to achieve a P Index < 75 in the short term. If this cannot be achieved with realistic conservation practices and reduced P rates in the short term, then a management plan needs to be developed with the goal of achieving a P Index < 75 within 5 years.
$ to 100	Very High	Very high potential for P movement from this site. Add conservation practices or reduce P applications to achieve a P Index < 100 in the short term. Develop a management plan with the goal of achieving a P Index < 75 within 5 years.

The source, transport, and BMP factors are combined to get an overall P index:

P Index = *Risk of Soluble P in Runoff + Risk of Particulate P in Runoff + Risk of Soluble P in Leachate*

Depending on the value of the P index, the site is considered to have a Low, Medium, High, or Very High potential for P loss (Table 3). If the P index is low, then N-based NMPs can be used. If the P index is too high, then a management plan to reduce the P index needs to be implemented and could include a P-based NMP.

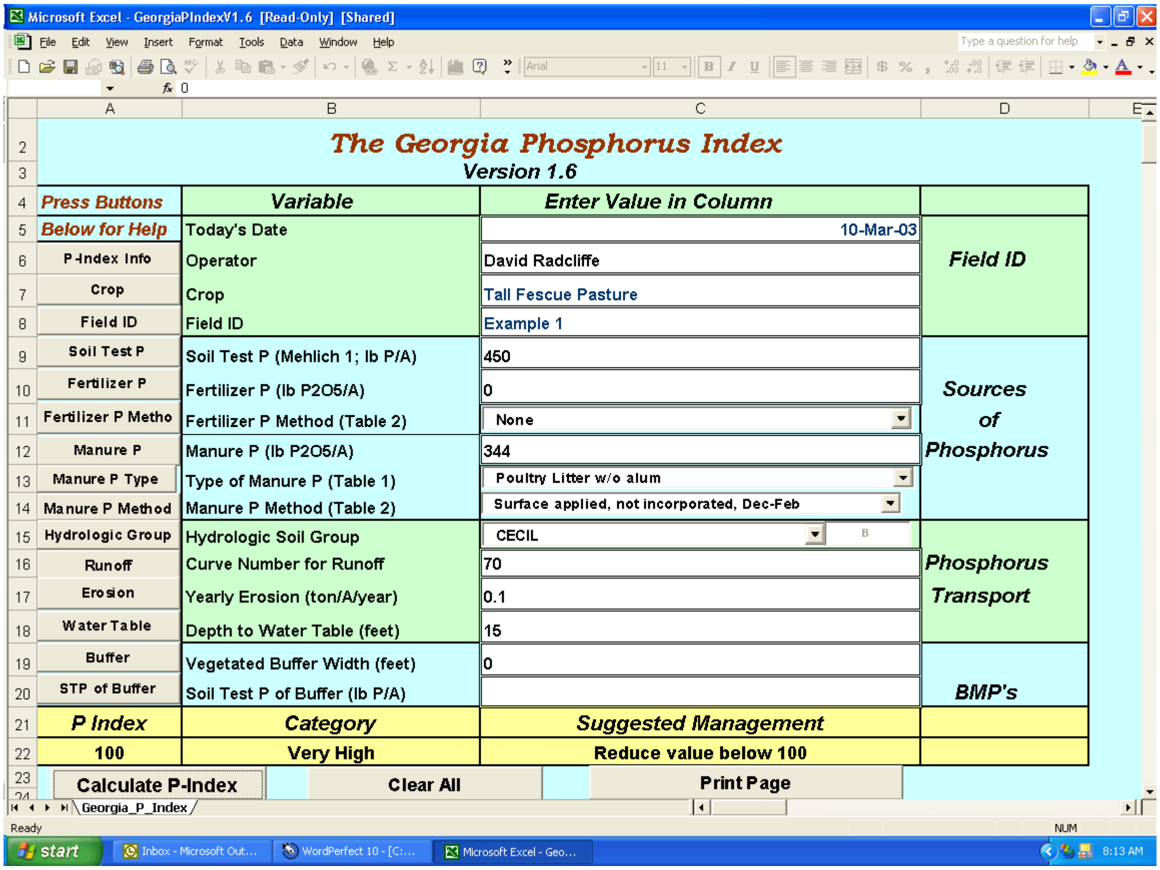

Figure 4. Georgia P index calculation for Example 1.

Suppose we have a hay field (Example 1) with the following source characteristics: the soil test P level is 450 lb/acre; poultry litter without any alum added is surface applied annually sometime during the period from December to February at a rate of 5 tons/acre; no fertilizer is applied. The amount of P added in the manure must be expressed as lbs of P_2O_5 per acre. To do this, multiply the manure rate (5 tons/acre) by the P content per ton from Table 2 (30 lbs P/ton) and then multiply by the conversion factor (2.29) to get 344 lbs P_2O_5 /acre. The site has the following transport characteristics: the runoff curve number is 70 (calculated using TR-55 or obtained from NRCS); the soil is a Cecil with hydrologic group B (obtained from Soil Survey database); the estimated annual erosion is 0.1 ton/acre (calculated using USLE or obtained from NRCS farm plan); the depth to the water table is 15 feet; there are no buffers around the field.

The calculated P index is 100, which is in the Very High category and we are advised to change our management plant in order to reduce the P index below 100 in the short-term and below 75 in the long-term (Fig. 4). If we try adding a vegetated buffer at the edge of the field and the soil test P is in this area is the same as in the field (likely to be the case), we don't get any reduction in the P index because the soil test P level is not less than 450 lb/acre (the upper limit for buffers to have a beneficial effect). We can change the time of application of the manure from December and February to November and March when the risk of runoff is lower. This will reduce the P index to 83 and we would satisfy the short-term goal of reducing the P index from the Very High to High category, but we would still have the long-term goal of getting the P index below 75 (to the Medium category). Changing the time of application to the period May to October reduces the P index to 65 and achieves the long-term goal.

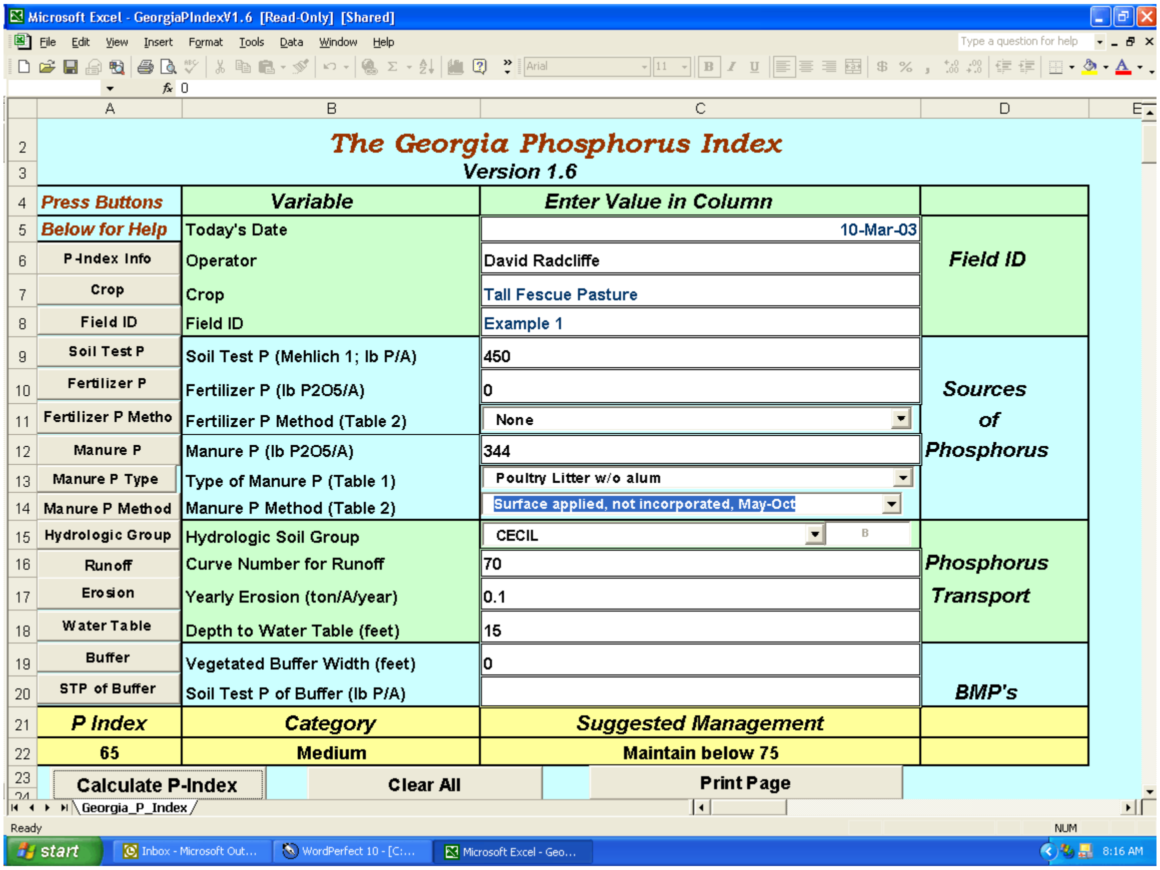

Figure 5. Georgia P index calculation for Example 1 after changing the time of application to May-Oct.

Other examples are provided in Table 4. Example 2 is the same as Example 1, except that the curve number for the soil is raised. This causes more runoff and raises the P index. Example 3 is a broiler litter example (4 ton/acre) where the crop is corn and litter is surface applied and incorporated within 30 days in a soil with a low soil test P. The erosion rate is higher in this example compared to the earlier examples due to tillage, but the P index is in the Medium category. This is due primarily to the effect of incorporation which reduces the risk of P loss in runoff and the low soil test P. Example 4 is the same as Example 3, except the soil test P is quite high and this produces a P index above 75. In Example 5, dairy slurry (3 in/ acre) is applied by a sprinkler system to a pasture with a high soil test P. In all of the examples except Example 3, BMPs or a reduction in the application rate is required to reduce the P index to a satisfactory level.

Table 4. Georgia P index Example calculations.

Example #	1	2	3	4	5
Manure	Broiler litter	Broiler litter	Broiler litter	Broiler litter	Dairy slurry
Crop	Pasture	Pasture	Corn	Corn	Pasture
Soil test P (lb/acre)	450	450	20	**400**	400
Manure P applied (lb P_2O_5/acre)	344	344	275	275	227
Manure P Method	surface Dec-Feb	surface Dec-Feb	surface incorporated <30 days	surface incorporated <30 days	sprinkler applied
Soil series (hydrologic group)	Cecil (B)	Cecil (B)	Cecil (B)	Cecil (B)	Cecil (B)
Curve #	70	**75**	80	80	80
Erosion (T/acre)	0.1	0.1	2.0	2.0	2.0
Water table (ft)	15	15	3	3	15
BMPs	none	none	none	none	none
P index	**100**	**148**	**63**	**93**	**84**
Alternatives	Change time of application, reduce application rate		OK	Add buffer, change time of application, reduce application rate	

The Georgia P index spreadsheet (an Excel file) can be downloaded from the Georgia NRCS web site www.ga.nrcs.usda.gov/gatechnical/afo.htm. There is also a Word file that explains the Georgia P index.

Summary of Essential Information

The most essential points in this lesson are listed below.

- The primary water quality concern with P is that it can cause eutrophication of lakes.
- Several large lakes in Georgia already show signs of eutrophication.

- Most of the P in soils is tightly adsorbed in the topsoil; but soil can be eroded with runoff, and a small amount of P is dissolved and also available to runoff.
- As the soil test P level at the soil surface goes up, so does the concentration of P in runoff.
- Manures present a special problem because the N-to-P ratio in manure is not the same as what most crops need – as a result P is over-applied when a N-based NMP is used.
- P-based plans will require substantially lower manure application rates.
- For P contamination to occur, there must be a source of high concentration P and a mechanism for transporting the P to a sensitive water body.
- There are a number of best management practices that limit the source or transport of P.
- The P index will be used to determine which fields in Georgia need to incorporate BMPs or reduce P application rates.
- Fields must have a P index less than 75.

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