Ohio Phosphorus Research and the Role of Cover Crops and No-till (ECO Farming)

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Background Information on Phosphorus

Phosphorus (P) is a major macronutrient and essential for plant and animal growth. Most plants are only about 0.2% P by weight but that small amount is critically important and most soil P is available between pH 6 and 7 (Hyland et al, 2005). Phosphorus is in our DNA and RNA, is used for cell energy transfer and energy storage (ATP) (Hyland et al, 2005), and gives strength to our bones and teeth (calcium phosphate). Current estimates are that USA supplies of phosphate rock used to make P fertilizer will be consumed by 2040 and worldwide we may run out of P fertilizer in 50-100 years (Cordell et al, 2009). The supply of P is limited, so the price is expected to increase greatly in the future as supplies are exhausted.

While P is limited, an estimated 8-15 million tons are lost annually in surface water runoff (Sharpley et al, 1994). Phosphorus is a limiting nutrient to aquatic life, so excess P is quickly absorbed by cyanobacteria, causing harmful algae blooms (HAB). When these bacteria die, they create dead zones because they consume so much oxygen during decomposition that aquatic life dies out due to a lack of oxygen. This process is called Eutrophication in fresh water bodies (Chesapeake Bay, Lake Erie, Grand Lake St. Marys) and excess nitrogen (N) and P in seawater is called hypoxia (Gulf of Mexico).

Increased phosphorus (P) fertilization from either manure or fertilizer may cause P movement to surface water causing eutrophication and harmful algae blooms (Sharpley, 1994). Agricultural cropland is a significant source of phosphorus (P) runoff and harmful algae blooms in Grand Lake St. Marys, Ohio (Hoorman et al. 2008) and Lake Erie, Ohio (Reutter, 2014). In August 2014, toxins from a HAB in western Lake Erie led to a two-day drinking water ban in Toledo for a half million people. Agriculture accounts for over 90% of the P runoff in Grand Lake St. Marys (Hoorman et al. 2008) and 60% of the P runoff in Lake Erie comes from the Maumee River, dominated by agricultural production (Reutter, 2014).

Management practices like tillage, soil depth, and soil type influence how P cycles and transforms in the soil (Hedley et al. 1982). Carpenter et al, 1998 in says "In the U.S. and Europe, only about 30% of the P input in fertilizers ends up being incorporated into crop plants, resulting in an average accumulation rate of 20 pounds of surplus P per acre each year" (Carpenter, 1998). Excess P accumulates in the soil in various inorganic (P_i) or mineral fractions and organic fractions (P_o) or P fixed by carbon and soil organic matter. The various P fractions react differently to various chemical, biological, physical, and environmental soil factors.

Understanding P transformations and availability will facilitate an understanding of how P transportation occurs in the soil (Kolahchi and Jalali, 2011).

Inorganic (Mineral) Forms of P

In Lake Erie, soluble reactive phosphorus (SRP) or inorganic P represents about 0.5% of the total soil phosphorus, and has become a major issue with HAB. Ohio State University researchers (Islam, Sundermeier, Hoorman) are looking at how P is tied up chemically by the soil using P speciation. Phosphorus in the soil is tied in an inorganic form (mineral tieup) by calcium/magnesium ($Ca^{2}+/Mg^{2+}$) ions, iron (Fe^{3+} or Fe^{2+}) oxides, and aluminum (Al^{3+}) oxides. Aluminum and iron comprise about 20-30% of the soil composition, so they are significant ions that tie up P. Al oxides are a large molecular compound that ties up the P very tightly. Calcium and Magnesium (Ca^{2+}/Mg^{2+}) also tie up P but not as tightly as the Al (Al^{3+}). Calcium phosphate (Ca-P) is also part of our teeth (apatite) so lime (calcium carbonate) and gypsum (calcium sulfate) are soil additives that can be used by farmers to actively tie up P. In Grand Lake St. Marys, alum (aluminum sulfate) has been used to tie up P in the lake. The calcium in lime and gypsum and the aluminum in alum chemically tie up the P in the soil or water.

Iron (Fe^{3+} or Fe^{2+}) is unstable and under certain environmental conditions (saturated soils, lack of oxygen or anaerobic condition), SRP is released (Brady and Weil, 1999). When the soil is saturated with water, soil microbes are searching for oxygen and they strip the oxygen from the iron oxide reducing the Fe^{3+} to Fe^{2+} releasing SRP. There are two similar reactions (depending on pH), but the result is the same, Fe^{3+} converts to Fe^{2+} releasing SRP. A similar process occurs with nitrates through denitrification; the soil microbes strip off the oxygen and convert N to nitrogen gas (N_2). In heavy clay soils, 40 to 60% of our N (Dick, 2008) can be lost when soils are saturated in the spring. We now know that SRP is now being released from the iron in the clay when the soil is saturated under anaerobic (lack of oxygen) conditions. These conditions commonly occur on fields that are excessively tilled, have poor soil structure, or are compacted.

A phosphorus study was conducted in Mercer County Ohio by Hoorman, Sundermeier, Renner, Islam) on two contrasting Ohio soils: Pewamo and Blount. Soil samples were collected from seven sites (low to extremely high Bray $P_{1,}$ grass, and forest). Soil samples were separated by <50PPM, 50-100, 100-150, 150-250, and >250PPM Bray P_1 for low to extremely high cropland P. Samples were collected in the Grand Lake St. Marys Watershed where phosphorus runoff is a major problem. Samples were split by depth (0-1, 1-3, 3-6, 6-9, and 9-12 inch depth).

Forested and grassed sites had low to medium levels of soi Bray P_1 test values but much higher percentage of soil organic matter (SOM) and Residual Phosphorus (Res-P) or P tied up by humus and the lowest FeP fraction. With higher SOM components, P was tied up mostly by ResP in both soils which is the most stable form of P tie up. In wooded sites, ResP represented 81% (Blount and Pewamo) of total phosphorus (TP) and on grass sites, ResP represented 84-85% of TP. In wooded areas, FeP represented 11% (Pewamo) and 6.8% (Blount) of TP, while in grass sites, FeP represented 8.9% (Blount) and 9.9%(Pewamo) of TP. FeP plays a much smaller role in typing up P in grass (9-10%) and wooded (7-11%) areas in disturbed soil. However, on disturbed soils like cropland, FeP represented almost 42% of TP on the extremely high P Blount soil sites, which is an unstable form of inorganic P.

FeP is relatively unstable under saturated and anaerobic (lack of oxygen) soil conditions and releases SRP (Brady & Weil, 1999). The FeP mean values were the highest on the cropland sites and lowest on the grass and forested sites. The ratio of ResP/FeP varied from 9.49 on grass to 7.22 on wooded areas down to 5.28 on LowP sites and 1.49-1.89 on Pewamo soils that were very high to extremely high in Bray P1 soil tests. On Blount soils, the ratio of ResP/FeP varied from 8.57 on grass to 12.66 on wooded areas down to 3.20 on LowP sites and 1.27 on extremely high Bray P1 soil tests. The ratio of ResP to FeP reflects the P soil concentration status and a higher number indicates that P is tied up by the more stable ResP or humus. As the ResP or SOM levels decline or become saturated with P, the FeP sites bind a higher percentage of P, which is more unstable and likely to be lost from the soil profile under saturated soil conditions.

The Mercer County study was similar to results by Kou et al. 2005 and which found that the FeP for the soil reflected the changes in soil P resulting from past P fertilizer inputs and P removal by the crops. Winter cover cropping may be needed to increase the return of organic matter to the soil (Kou, et al. 2005) and to increase the absorption of P in a stable form. Zhang and Mackenzie (1997) found that more than half (54% to 68%) of added P in excess fertilizer is tied up as FeP. Large carbon returns to soils in crop residues could be expected to increase soil organic P in a more stable form.

Farmer Tillage Management

When farmers till their soils, they change the soil structure so that the soil can absorb less water. We form bricks from clay by burning it in a furnace (burning off the SOM) and letting it dry. When farmers till the soil, they turn over soft wet clay, dry it out, and burn off the SOM. The clay particles have a negative charge and positive ions like calcium, magnesium, or potassium cause the soil to set up like a brick wall. We call a brick laying on top of the soil a clod, which is a man-made occurrence.

Farmers who excessively till their soil, getting their soil too fine (like cement mix), find that when it rains, their soils get hard and crust. Tillage decreases the SOM levels, increases soil compaction, and decrease water infiltration resulting in ponding water and saturated soils high in SRP that runs off.

Vertical tillage (shallow tillage, 2-4 inches deep) to incorporate organic residues (corn stalks, wheat straw, or soybean residue) into the soil is a common practice. If farmers do this when the soil is wet, tillage pans form and this also limits water infiltration. OSU researchers are researching whether vertical tillage may be contributing to surface runoff enriched with SRP.

Plant Available P and Organic Forms of P

Soluble Reactive Phosphorus (SRP) is plant available and an inorganic (tied to minerals) form of P but also runs off with surface water. Organic forms of P are tied to carbon and soil organic matter (SOM) and are less likely to be lost from the soil. There are two forms of plant available P, SRP which is inorganic and a small molecule and the exchangeable P (ExP) which is tied up by active carbon or sugars in the soil. ExP is a larger organic molecule that is less likely to be lost in surface water and tends to stay in the soil profile.

A recent study done by Ohio State University researchers Islam, Sundermeier, and Hoorman showed that a conventional tilled field (1.42 parts per million P) had 4.4x more SRP in the soil profile than a no-till field with red clover (0.34 PPM P) as a cover crop. The red clover (1.23 PPM-P) had 9.8 times more ExP than the conventional field (0.14 PPM-P). So the red clover cover crop was keeping the P in a form that was less likely to be lost from the soil profile. The red clover had a 4:1 ratio of ExP/SRP while the conventional tilled soil had a 0.1/1 ratio of ExP/SRP. Keeping the soil cover with live crops and roots results in more stable organic P in the soil profile that is less likely to be lost in surface runoff.

Dr. Andrew Sharpley, a leading P expert, showed that 90% of the P moves off the land during only 10% of the most intense rainfall events such as 2-3 inch pounding rains versus 0.5-1.0 inch slow rains. As the water runs off the fields, it picks up speed and energy and can carry more SRP to surface water. Keeping the soil covered with live crops increases water infiltration and decreases soil erosion, so more P stays in the soil.

Sharpley also found that 80% of the P lost from soil comes from only 20% of the land. He found that the fields closed to the streams lost the most SRP to surface water through runoff. P lost from a field is a function of the P concentration (high P soil test) and a transport factor. Sharpley tested fields by a stream that had low P concentration (next to the stream), medium P (500 feet away), and were high in P (farthest from the stream, 1000 feet away). After a rainfall event, the field closest to the stream with the lowest P concentration was found to contribute the majority of the P to the surface water. A worst case scenario though would be a high P soil test and close proximity (high transport factor) to a stream.

How can we keep iron (Fe^{2+}) oxides from releasing SRP? Most of the P in the soil (50-75%) is tied up in the long-term residual soil organic matter called humus (Stevensen, 1986). Residual P (Res P) is tied up in long complex carbon chains (humus) and is plant unavailable but slowly becomes plant available P as the humus breaks down. Residual P (organic P) ties up P tighter than calcium, iron, or aluminum inorganic ions in the soil profile but also slowly releases P back into the soil profile for plant use.

So how can farmers use this information to improve both their nitrogen (N) and P management? By using a combination of cover crops and no-till; farmers can utilize practices that closely mimic our natural cycles to reduce N and P being lost from the soil profile. The cover crop roots increase the SOM content and they increase water infiltration and water storage. Cover crops increase pore space so that more water and oxygen can be stored in the soil. Cover crop roots absorb soluble nutrients (N&P) and less N & P is lost through surface runoff and subsurface runoff through our tile lines. Cover crops and no-till are part of an ecological (ECO Farming) solution to improving N & P crop use efficiency by keeping both N and P in the soil profile while reducing N & P runoff to our surface water.

Summary

In phosphorus (P) speciation studies in Northwest Ohio, inorganic P (mineral P) ions like calcium, magnesium, iron (Fe^{2+}, Fe^{3+}), and aluminum all tie up P in an inorganic form but iron under saturated soil conditions and a lack of oxygen converts from Fe^{3+} to Fe^{2+}, releasing soluble reactive phosphorus (SRP). This is causing eutrophication or excess cyanobacteria growth in Grand Lake St Marys and Lake Erie. Cover crops and long term no-till (Ecological or ECO Farming) improve water infiltration and water storage (Hoorman, 2013; Hoorman et al, 2012), and allows SRP to be absorbed to inorganic minerals that are coated with soil organic matter to stabilize the phosphorus in a form that is less likely to be lost from the soil profile. In addition, cover crops increased active organic matter which can be used to tie up phosphorus as exchangeable P that is still plant available. Cover crops also actively absorb soluble nutrients like SRP and nitrogen for plant growth. Using an ecological system of practices (ECO Farming) improves nutrient recycling, nutrient efficiency, and results in less water and nutrient runoff to Ohio surface waters.

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