Phosphorus and Compost White Paper

1. Introduction

Minnesota has long been concerned about the impact of phosphorus (and nitrogen) migration into its lakes and streams. The impact can be severe, with eutrophication increasing algae growth, which degrades water quality to the detriment of native game fish. There are a variety of sources for these excess nutrients; including commonly used agricultural and horticultural products that are applied to the soil (e.g., excess manure application, chemical fertilizers) to enhance crop production.

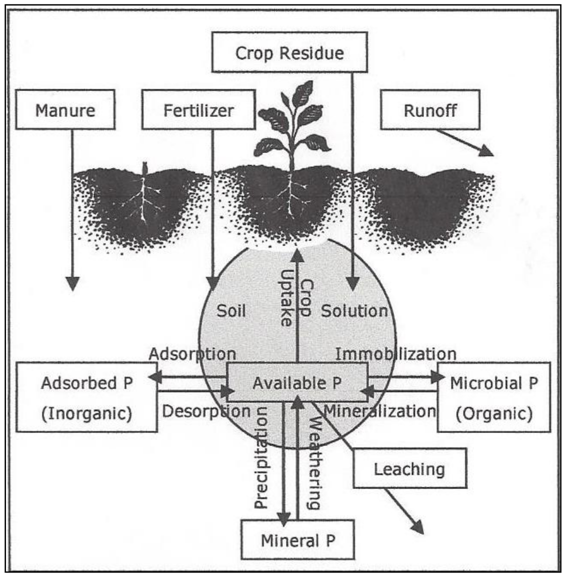
With these issues in mind, in 2002 the State of Minnesota was the first state in the country to enact regulations that limited the use of phosphorus in turf fertilizers. Since then, many other states have followed suit. Also since then, the state also created the Minnesota Phosphorus Index, which is a tool for farmers to use to reduce the potential over application of phosphorus. The tool also acknowledges the fact that a large percentage of phosphorus is lost through soil erosion, rainfall runoff and snowmelt runoff.

Minnesota has a large and thriving composting industry which uses compost in a variety of applications. Being an environmental industry, it has interest in better understanding the relationship between phosphorus in compost (and in related and competing products) and the environment. To assist identifying ‘what we know’, ‘what we think we know’ and ‘what we don’t know’, the following ‘white paper’ on the topic was completed. The purpose of this review is to provide composters and regulators with the information needed to for composters and end users to continue to use compost, but do so minimizing any potential negative environmental impacts.

2. Important Nutrient

Phosphorus is one of the 3 major plant nutrients; along with nitrogen and potassium. It helps in the formation of important plant compounds (e.g., nucleic acids, RNA, DNA) and helps to store and transfer energy. Phosphorus is also important in root, flower and seed development, and helps to hasten maturity in food crops. Furthermore, Phosphorus is an essential component of adenosine triphosphate (ATP), which is involved in most biochemical processes in plants and enables them to extract nutrients from the soil. Phosphorus also plays a critical role in cell development and DNA formation.[1]

Phosphorus fertilizers are sold in the marketplace based on their content (‘as is’) of *available phosphate*. Available phosphate is identified on fertilizer labels within the guaranteed analysis and is calculated as phosphorus pentoxide or "P_2O_5". Available phosphate is defined by the Association of American Plant Food Control Officials as *the sum of the water-soluble and citrate-soluble phosphate*. Available phosphate is considered by many as the amount of ‘plant available’ phosphorus in a fertilizer product. However, this is really not the case, as plants can only take up phosphorus that is dissolved in the soil solution. That is not what the available phosphate test measures. It is also important to note that the dissolved phosphorus available to plants is also phosphorus that can leach and cause potential environmental concern. That stated, most soil phosphorus exists in stable chemical compounds, with only a small amount being available to plants at any given time. Maintaining soil organic matter levels is important in phosphorus management. Mineralization of organic matter results in the slow release of phosphorus to the soil solution during the growing season, making it available for plant uptake.[2] Of course, phosphorus is also provided through the weathering of phosphorus rich minerals naturally found in the soil, as well as the addition of chemical or inorganic forms of phosphorus fertilizer. Mineralization is the microbial conversion of organic phosphorus to $H_2PO_4^-$ or HPO_4^+, forms of plant available phosphorus known as orthophosphates.[3] Phosphorus is primarily adsorbed by plants in their ionic forms, as orthophosphates. The graphic below illustrates a simplified version of the phosphorus cycle[4].



Simplified phosphorus cycle[4]

Phosphorus can be chemically bound to soil particles through adsorption and can be released into the soil solution through desorption. The amounts of these ions (orthophosphate) in the soil solution are determined by soil pH.[5] However, pH does not directly affect the availability of phosphorus. Instead, soil pH levels indicate how certain minerals – iron, aluminum, and calcium – interact with phosphorus in the soil, and it is this interaction that affects phosphorus availability.[6] Phosphorus is in its most plant available form when the (soil) pH is between 6 and 7.[7] At a lower pH, phosphorus is bound to iron and aluminum compounds in the soil, and at a higher pH, it is bound to calcium.

3. How We Got Here

Phosphorus is readily bound in fine textured soils, therefore making it difficult for plants to access. For that reason, we have tended to over apply phosphorus in order to try to get plants the amount that they require for optimal growth. Inorganic phosphorus fertilizers have been over applied by some in agricultural production and turf management for many years. While some farms have applied manure and biosolids to satisfy the nitrogen requirements of crops, which in turn has resulted in excess phosphorus being applied. For this reason, many agricultural sites with a history of manure application already have soil phosphorus amounts beyond the levels needed to maximize crop yields. The over application of phosphorus has been further exacerbated because applying luxury amounts of phosphorus typically don't damage crops.

Aside from these issues, there are many nutrient compromised regions of the county where the production of animals, often in confined animal feeding operations (CAFO), has led to over manuring to such a degree that phosphorus (and nitrogen) actually leaches out of the soil and into ground water.[8] Perhaps the most wide spread threat to surface water quality in the US has been soil erosion. In these circumstances, water erodes the soil and carries it (sediment) and the nutrients (and other contaminants) attached to it to surface waters.[9] Although sediment movement is supposed to be regulated by communities, through NPDES (National Pollutant Discharge Elimination System) permits, related regulation often goes unenforced.

4. Testing For Phosphorus

Without going into great detail regarding the specifics of individual test methods, it must be noted that the test methods used to determine the phosphorus content in chemical phosphorus (inorganic) fertilizers is not the most appropriate test for determining the phosphorus content in carbon-based products (e.g., compost, biosolids, manure). Typically, testing labs will automatically use the test methods which will provide the most accurate (and reproducible) test results based on the material being tested. The individual submitting the product sample for testing, will not even typically know that different testing methods are being used. Further, the test methods used to test native soils, are different from the methods used to test input products, such as fertilizer and compost. The recommended methods used for soil fertility testing vary depending on region and, in some cases, soil type (e.g., mineralogy, texture) within a region. It's important to recognize that routine soil fertility tests (extractable P, K, Ca, Mg, and micronutrients) only provide an index of available soil nutrients, not a direct measure. The interpretation of soil test results is based on their correlation with the probability of a profitable response to fertilizer[10.]

While soil erosion is a major problem, when it comes to phosphorus migration into surface waters, soil chemistry (and texture) also greatly impacts the movement (leaching) of the phosphorus. For example, under acidic or alkaline soil conditions, phosphorus fertilizer is rapidly converted into less soluble compounds that may be nearly unavailable for plant nutrition. Even available forms of phosphorus are bound to clay, and organic soil compounds and are relatively immobile in the soil profile; except as a passenger during soil erosion.[11] Therefore, when considering the risk of phosphorus movement, it is important to keep in mind that phosphorus is more susceptible to leach(ing) in sandy soils and more susceptible to run-off (through erosion) in clay/heavier soils (finely textured).[12]

More recently, research is being completed to reduce the risk of phosphorus application in agricultural, specifically through the use of manure and biosolids, through the concept of phosphorus indexing. Indexing considers the transport factors related to phosphorus (e.g., soil erosion, leaching potential, runoff potential, distance to water body), as well as source factors (e.g., soil test phosphorus, fertilizer application rate, method and timing). These efforts have also started to create a rating system which assigns a 'phosphorus (P) source co-efficient' to products based on their phytoavailability relative to inorganic phosphorus (triple super phosphate). So basically, how easily could phosphorus leach compared to a synthetic fertilizer. Much of the initial research in this area has been funded by the biosolids industry, but their research has also evaluated manures, composts and other recycled organic products. A key aspect of creating P source co-efficients, is the utilization of a test method for water-extractible phosphorus (WEP), agreed upon by SERA-17. SERA-17 is the Southern Extension and Research Activity; an Information Exchange Group (IEG) formed to develop an interdisciplinary approach to identifying phosphorus sensitive watersheds and water bodies; expanding and improving upon the Phosphorus Index site assessment tool, develop best management practices (BMPs) to reduce agricultural P losses to surface waters by erosion and runoff (surface and subsurface), and much more.[13]

Using the WEP test method, and during 2006 research completed for the Milwaukee Metropolitan Sewerage District (producers of Milorganite, a biosolids fertilizer), the University of Florida researchers were able to illustrate the water extractible phosphorus content of Milorganite, compared to a series of carbon-based inputs, as well as a popular inorganic phosphorus product (Table 1). The data illustrates that different products containing phosphorus, release it into the soil solution differently. Specifically, phosphorus found in carbon-based products appears to be less extractable (available to the plant and the environment). Therefore, testing carbon-based product for total phosphorus alone is not a good indicator of environmental risk (leaching), the WEP test method should also be utilized.

Table 1 - Water Extractable Phosphate in Various Products

Phosphorus Source	Water Extractable Phosphate (% of total P)
Heat dried biosolids (such as Milorganite® 6-2-0)	<2 %
Biological Phosphate Removal – type biosolids	5 – 25 %
Poultry manure	20 %
Dairy manure	50 %
Triple Super Phosphate (0-44-0 synthetic)	85 %

Source: O'Connor & Chinault, University of Florida (14)

Research suggests that the composting process alone will not reduce P availability[15], unlike with the N in compost. Further, the majority of phosphorus in compost is in inorganic form[16], therefore it has the potential of leaching. That stated, the WEP content of composts that have been tested (Table 2) are quite low, so the majority of the P in compost is not very leachable. *Note: WEP is a percentage of Total P; it is not related to the content of* P_2O_5*. The tests are totally independent.*

Table 2 - Water Extractable Phosphate in Various Composts

Feedstocks	Biosolids Treatment	Total Solids %	Total P % dw	P_2O_5 % dw	WEP[a] % of Total P
Leaf / yard wastes	NA	39.4	0.15	0.34	8.4%
Leaf / yard wastes / food	NA	47.5	0.18	0.42	7.4%
Leaf / yard wastes / food	NA	53.9	0.19	0.43	6.8%
Biosolids / wood chips	No P removal	39.8	0.34	0.78	20.5%
Biosolids / wood chips / yard wastes	No P removal	72.1	0.35	0.81	12.2%
Biosolids / wood chips	No P removal	48.1	0.70	1.60	22.3%
Biosolids / yard wastes / WTR[b]	No P removal	53.5	0.73	1.67	4.6%
Biosolids / yard wastes / WTR[b]	No P removal	47.8	0.73	1.68	4.1%
Biosolids / wood chips	An. digest /No P removal	59.2	0.82	1.87	7.7%
Leaf / yard wastes / gelatin residuals	N/A	51.1	0.96	2.19	2.0%
Biosolids / wood shavings	Biological P removal	42.8	1.05	2.41	13.3%
Biosolids / wood chips	Chemical P removal	38.8	1.59	3.65	1.8%

[a]WEP = Water extractable phosphorus, [b]WTR = water treatment residuals
Source: Modified from Phosphorus and Compost Use Dynamics, Alexander, 2016. (17)

Data generated through product testing by Agresource, Inc. (Rowley, MA), and distilled by Dr. John Spargo at Penn State University, illustrates the following[(18)]:

1. The amount of phosphorus, whether P_2O_5 or WEP, in the compost varies.

2. The amount of phosphorus that is WEP is low in comparison to the total P. The WEP ranges from about 2% to 22% of the total P.

3. The amount of WEP is only loosely correlated with total P. As expected, the leaf and yard waste composts have lower total P and generally lower WEP than the biosolids composts. However, among the various biosolids composts there is a wide range of both total P and WEP, and some of the biosolids composts with the highest levels of total P have among the lowest levels of WEP.

4. The percentage of P that is WEP is very closely correlated with the amount of iron (Fe) and aluminum (Al) in the compost. The greater the Fe and Al content, the less WEP. Further, the data set supports other studies that indicate that for biosolids products, WEP is dependent upon how the biosolids are treated at the wastewater treatment plant.

5. If we assume that WEP is a predictor of P losses, the data indicates that some biosolids composts, despite the relatively high total P, could be used to build soil organic matter levels with no more risk than the leaf compost that have lower total P.

5. Compost Phosphorus in Use

A substantial body of research exists that pertains to the use of compost in varying applications, and how the usage (and other factors) relates to potential phosphorus P and environmental risk. This data is outlined below, in several categories.

Soil Incorporation

Compost is a popular soil amendment used throughout the US as means to improve the physical, chemical and biological properties of soil. Although compost is primarily used as a means to improve soil structure, it also contains plant required nutrients; including P and nitrogen (N) which can impact the environment. With the climate changing, one of the greatest benefits of compost is the product's ability to increase the water holding capacity of the soil. Along with this, compost has the ability to reduce the bulk density of finer soils, while improving aggregate stability. This allows the water to be more easily accepted into the soil, infiltrating instead of running off, while reducing its ability to erode.[19] In urban settings, where soil compaction is common because of construction practices or land usage patterns (e.g., athletic fields), reducing soil compaction not only benefits plant growth, but also improves the soil's ability to accept and treat storm water. This was the concept behind the Soils for Salmon program in western Washington State, which uses the soil's ability to act as a biofilter, to both bind and degrade certain pollutants. Keys to the program are capturing storm water within the soil profile (through soil decompaction by organic matter incorporation) and reducing soil erosion.

Few studies have been completed which focus on nutrient migration from compost amended soils (soil incorporated with compost) in landscape scenarios. In these situations, compost is not being reapplied with great frequency and its application is not typically done in order to meet the nutrient requirements of the plant.

Larger volumes of research exist where nutrient rich composts (e.g., biosolids and manure) were used in repeated applications to meet the nitrogen requirement of agricultural crops. In a Virginia field research study on a clay loam soil where biennial applications of biosolids and poultry manure composts were completed, compost treatments significantly increased soil carbon, decreased bulk density, and increased phosphorus levels in the soil. The concentration of phosphorus in runoff was highest in compost treatments, but the mass of dissolved phosphorus was not different among treatments because infiltration was higher and runoff lower in compost amended soil (compared to the control and fertilizer only treatment). Improved soil physical properties associated with poultry litter-yard waste compost application decreased loss of total phosphorus and total suspended solids.[20]

Field research completed on yard trimmings compost amended soil in Washington State (1997) illustrated that the amended soils increased soil water holding capacity and porosity, thereby reducing runoff volumes. This delayed peak flow of water off the slope reducing total phosphorus migrating from the slope. Overall, the runoff from the compost-amended soils showed the following: 70% less total phosphorus, 58% less soluble-reactive phosphorus and 7% less nitrate in the runoff compared to the runoff from the till-only soil.[21] Turf was planted on the plots and chemical fertility was applied to assure turf establishment.

A lab and field research project sponsored by the Texas Department of Transportation evaluated the water holding capacity and water quality impacts of biosolids and manure-based composts used as a component to compost manufactured topsoil (3 soil to 1 compost, by volume), as well as erosion control compost (1 compost to 1 woodchip v/v). The research found that the concentrations of constituents in the leachate produced in the laboratory from the compost manufactured topsoil are more concentrated than the leachate produced in field conditions. Under field conditions, water passing through the compost manufactured topsoil (or erosion control compost) would continue to percolate into the supporting soil, be taken up by plants and/or undergo chemical and biological transformations by microbial activities in the supporting soil resulting in lower concentrations, if the leachate reached surface and ground water sources.[22] The study further noted that the results of the first-flush and extended column studies indicated that the concentrations of phosphorus in the leachate from the sand compost manufactured topsoil and erosion control compost mixtures were higher than in the leachate from the clay compost manufactured topsoil when deionized water was applied. The leachate from the sand compost manufactured topsoil contained more total phosphorus than the leachate from the clay compost manufactured topsoil or erosion control compost when highway runoff was applied. The results of the extended column study indicated phosphorus concentrations in the leachate decreased over time for all compost manufactured topsoils and erosion control composts. The total phosphorus concentration after 12 months of equivalent rainfall were less than 2 mg/L for clay compost manufactured topsoil blends and less than 10 mg/L for sand compost manufactured topsoils and erosion control composts.[23]

Although there is little doubt that WEP is a good predictor of runoff P loss from surface applied biosolids; however, for incorporated compost it may not be so simple. Once the compost equilibrates with the soil, the reactivity of P, Fe, Al, and Ca are going to change, driven by soil mineralogy, soil moisture, acidity, enhanced microbial activity, etc. There is no question that Fe, Al, and Ca content are going to have an impact, but it is also going to be significantly influenced by soil properties. Further, runoff P loss is a function of both source (i.e., P concentration and solubility) and transport factors (e.g., soil structure, water permeability, slope, slope length). Therefore, the amount of organic matter applied with compost is also going to play a big role in mitigating risk of P runoff losses.[24]

BMP's to Reduce P Migration in Soil Incorporation Applications

- Consider the use of compost that contains a lower volume of WEP and total P.
- Once applied, incorporate compost before significant rains commence.
- Apply compost in finer textured soil, and those containing significant amounts of Ca, Fe, and/of Al.
- Use recommended erosion and sediment control devices (e.g., compost sock, erosion control blanket) to avoid compost or compost amended soil from eroding to surface waters.
- Do not over apply fertilizer P after compost has been applied.
- Vegetate the site as soon as possible

Soil Surface

The use of compost as an erosion control blanket, a composted surface mulch which is derived from a combination of coarser and finer compost particles, has become a popular tool for managing both soil erosion and storm water on sloped surfaces. Not only has the use of compost in this application been heavily researched, but field experience has been extensive and project successes have been impressive. Compost blankets should only be used in applications where water moves as a sheet (not concentrated) flow. Research has even shown that these compost-based systems often out perform these conventional slope stabilization and sediment control methods. Probably the greatest advantages to using compost-based systems are that they:

1) provide immediate and effective control,
2) bind and degrade specific chemical contaminants, and
3) improve the establishment of a vegetative cover. [25]

Compost blankets have been widely utilized for erosion control and prevention on construction sites, and more recently as a storm water reduction practice in low impact development (LID) applications. The US EPA specifically recognizes LID and runoff source reduction practices as key methods to reduce all types of storm water pollutants, including turbidity, originating from both disturbed and stabilized sites. Arguably the best way to decrease or prevent highly turbid discharges is through prevention – whether through runoff or soil erosion. By preventing or reducing runoff, pollutant loads are automatically lowered as well, including sediment and turbidity.[26] Research has illustrated that a compost blanket's ability to absorb water is the primary method in which its usage can reduce nutrient (including phosphorus) migration. Further, the compost blanket's ability to improve extensive vegetation establishment (and rooting) and provide a total cover to the soil are also keys to the techniques efficacy.

Iowa State University compost blanket research found that runoff from compost and soil treatments resulted in one or more of the composts containing significantly higher concentrations of N, P, K (potassium), and nine heavy metals than the control soil or the topsoil. Similarly, soluble and adsorbed concentrations of nutrients and metals contained in runoff and erosion products exported from the compost-treated test plots were generally much higher than those from the topsoil and control plots. Due to significantly lower runoff and erosion rates on the compost-treated test plots, however, the masses of all nutrients and metals exported from the compost-treated plots were significantly lower than the pollutant masses leaving the topsoil and control soil.[27]

L.B. Faucette (University of Georgia) found similar results in a series of research trials, as well as the fact that *treatments* (compost) *with lower respiration rates (greater stability) and nitrate-nitrogen concentrations tended to have less erosion and transport of solids*[28]. In another experiment, he found that:

- Compost systems produced significantly less runoff than hydroseed during storms after vegetation establishment and once vegetation was mature, with significantly greater infiltration for all storm events.
- Compost systems reduced total solids by 97 to 99 percent relative to a bare soil, and had 3.5 times less solids loss during the first storm after application and 16 times less solids loss during a second storm, relative to hydroseed and silt fence.
- Materials high in total N and total P are likely to lose more of each nutrient to storm runoff; however, N and P loading is greatly diminished after the first runoff event. Because hydroseed is applied with inorganic N and soluble P it is more likely that these nutrients will be lost to storm runoff and consequently are in forms more available to aquatic plants. Mass loading of total P from hydroseed was five times greater than compost, and dissolved reactive P was six times greater than compost; even though the total amount of P applied was two to nine times less from hydroseed relative to compost.
- Composts high in inorganic N generated higher N loads in runoff, therefore compost with a high percentage of organic N of the total N is recommended. Additionally, high concentrations of C, organic

matter and Ca (as added gypsum) in compost may reduce P loss in runoff. The high C content (and by relation organic matter content) of composts is likely very important in minimizing P loss.[29]

BMP's to Reduce P Migration in Soil Surface Applications

- Consider the use of compost that contains a lower volume of WEP and total P.
- Use properly sized compost for an erosion control blanket application; as it will resist eroding.
- Vegetate the compost blanket as soon as possible.
- Use erosion and sediment control devices to avoid compost eroding to surface waters.
- Consider whether the application of inorganic P fertilizers can be avoided.

Berms and Socks

Coarse compost based filter berms and socks have established themselves as excellent alternatives to recognized sediment control techniques (e.g., silt fences, hay bales, etc.). Filter berms are most effective in managing sediment from sheet flows of water, while filter socks can be used to remove sediment from both sheet and concentrated flows of water. In concentrated flow conditions, filter socks are typically staked to the ground. One of the greatest benefits of using these compost-based technologies is the fact that they are 3-dimentional structures (larger surface area), and therefore possess a large capacity to capture sediment. Further, these structures can be vegetated, improving their long-term efficacy and improving their appearance.

In 2006, the Texas Transportation Institute completed research on seeded and unseeded compost filter berms derived out of yard trimmings, biosolids and dairy manure composts. Results showed that the yard waste compost outperformed the dairy manure compost and biosolid compost in water quality characteristics and structural durability in performance (the yard waste compost introduced the least amount of dissolved solids including sulfates, nitrates, and phosphates).[30] The berms that were seeded and left in place long-term surpassed the unseeded berms in their ability to sustain overtopping and retain their structure. The seeded compost filter berms proved to be highly efficient as sediment trapping devices by bringing about an almost complete removal of suspended solids.[31]

Based on their research, the Texas Transportation Institute recommended a series of installation criteria to the Texas Department of Transportation; including the following (which are most related to nutrient movement):

- Compost filter berms should not be used as the most downstream BMP or the last BMP before runoff enters receiving water. Another sediment capturing device should be present in the event of berm failure.
- All compost filter berms should be seeded and placed as soon as possible to allow for vegetative growth and berm establishment prior to rainfall events.[32]

L.B. Faucette (University of Georgia) completed sediment and P removal research with straw bales, mulch filter berms, compost filter socks, and compost filter socks + polymer used as perimeter sediment control devices under high intensity/duration single storm event conditions. His research found that:

- All treatments discharged significantly lower total solids (concentration and load) than the bare soil, while all compost sock treatments were significantly lower (concentration and load) than the mulch filter berm and straw bale.

- All compost filter socks had significantly lower (water) turbidity relative to bare soil, and the addition of the polymer to the compost filter sock treatments had significantly lower turbidity relative to the compost filter socks without the polymer.[33]

A related study found that compost filter sock and silt fence removal efficiencies for total suspended solids (TSS) concentration (62% to 87% and 71% to 87%), TSS load (68% to 90% and 72% to 89%), and turbidity (53% to 78% and 54% to 76%) were nearly identical; however with the addition of polymers to the compost filter socks improved sediment removal efficiencies from 91% to 99%.[34] Further, when polymers were added to the filter socks and installed on P fertilized soils, P removal efficiencies increased to 92% to 99%.[35]

BMP's to Reduce P Migration in Compost Berm and Sock Applications
• Only use compost that contains a lower volume of WEP and total P. • Use properly sized compost for a berm or sock application; reduce the content of fine compost in the compost (as possible, while maintaining efficacy). • Consider vegetating the compost berm or sock. • Do not use compost filter berms as the most downstream BMP or the last BMP before runoff enters receiving water. • Consider the incorporation of additives into the compost that bind soluble P (e.g., Fe or Al rich materials, specific polymers, etc.). • Do not fertilize berm or sock that is vegetated.

Bioretention Media

The use of bioretention features (e.g., bioretention ponds, rain gardens, bioswales) to manage storm water has grown in popularity over the past 10 years. Many communities desire the use of bioretention features, as they are typically more attractive and less expensive than conventional 'grey' infrastructural methods. Bioretention systems are unique LID treatment practices due to the complex set of simultaneous physiochemical and biological processes. A conventional bioretention cell consists of a depression in the landscape that includes a vegetated layer underlain by a mulch layer; a layer of blended sand, soil, and organic matter (termed the filter media); and an underdrain or internal storage reservoir. Runoff pollutants are treated by media, plants, and microorganisms by a variety of physical (filtration), chemical (sorption, fixation), and biological (transpiration, denitrification, immobilization, assimilation, and decomposition) processes. Treatment of runoff occurs during transport through and storage within the bioretention media.[36]

The features are constructed to accumulate storm water, allowing for sediment and contaminant (e.g., nutrients, oils, etc.) removal, then allowing the treated water to dissipate into the surrounding soils. Some rain gardens and bioretention ponds treat the storm water and return it to the water or sewage treatment facility through an underdrain. In many jurisdictions, compost is a major component to the primarily sand-based bioretention media. Compost can act as a carbon filter for the media. Since it possesses a high cation exchange capacity, it can bind certain heavy metals, and through its biologic activity, it can degrade certain petroleum hydrocarbons. That stated, compost does contain both P and N, and since they are considered to be contaminants to potable and non-potable water resources, concern exists about their leaching from the bioretention media.

Inspections of operating bioretention features in Washington State identified that although the bioretention soil mix is effective at removing pollutants through sedimentation, filtration, and adsorption, the media itself can act as a pollutant source if not properly configured. Fine sands and associated bound pollutants will export during a flushing period of variable duration. In addition, labile nutrients and other bound pollutants will leach from the compost fraction for an undetermined amount of time.[37] That stated, lab studies which placed both pure compost products and compost/sand based bioretention media into columns, then flushed them with water, found that concentrations of N, P, and copper were high in the initial few storms, and then decreased.[38]

P (soluble or reactive P) losses through leaching must be kept in perspective, as the compost may only make up 10 to 30% of the media. Further, its presence in the media can be an effective method to capture heavy metals and is an asset in keeping the vegetation alive in the bioretention feature, which improves its overall functionality. It should further be noted that in research completed at both the University of Florida and Washington State University found that the addition of Fe or Al rich water treatment residuals to biotetention media containing compost and biosolids treated soils can substantially bind soluble phosphorus.

BMP's to Reduce P Migration in Bioretention Media Applications

- Only use compost that contains a lower volume of WEP and total P.
- Use a smaller percentage of compost in the media.
- Use compost with a reduced content of fine compost (as possible, while maintaining efficacy).
- Establish vegetation as soon as possible.
- Consider growing vegetation which can be harvested to remove excess nutrients.
- Mulch over the bioretention media with a non-floating (*minimally*-floating) organic mulch.
- Consider the incorporation of additives into the compost that bind soluble P (e.g., Fe or Al rich materials, specific polymers, etc.).
- Only fertilize with slowly releasing fertilizer products.

6. Conclusions / Take Aways

Moving forward, it will be challenging to find appropriate ways to limit the amount of P that impact our water resources. An immediate step would be to assertively enforce erosion and sediment control regulation required under the NPDES. Further, communities should implement methods to better manage the larger volumes of storm water generated by our changing climate. These efforts would limit the migration of P (N, and other contaminants) attached to sediment, which is incredibly important in protecting surface waters. However, reducing P applications in agriculture are more challenging, since we have to grow food to survive, and P from a variety of sources binds to the soil never reaching the crop. Therefore, we over apply P. Further, the elimination of P fertilizer applications necessary for growing healthy turf is not likely a sustainable solution. Research has shown that the lack of P over time will negatively affect grass cover, exposing more soil to erosive forces. With these facts in mind, there are steps than can be taken and facts that should be considered.

- Soil type matters - There is a much greater chance for P to leach from sandy soils, as they possess a lower cation exchange capacity. Therefore, limiting the amount of inorganic (or even compost derived) P being applied, depending on the project location (and distance to water), may be warranted. Further, using compost products which contain a lower amount of WEP (and total P) could be prudent. Also, remember, that compost's ability to increase in water holding capacity in sandy soils can reduce the overall volume of soluble P migration. The chemistry of finer clay and silt based soils makes leaching of P much less likely; especially in ornamental applications where compost would not be applied on an annual basis. In these soils, the P supplied by the compost over time becomes more tightly bound to soil Al and Fe oxides; thus P availability decreases unless additional P is added. This effect is more pronounced in finer- than in coarser-textured soils.[39] It should be understood that leaching of P is not common, except in deep, coarse-textured soils….The greatest P loss pathway from soils is P bound to eroded soil particles and soluble P in runoff, where large masses of P have been added (e.g., from manure, biosolids). [40]

- Inputs matter – We have the ability to test compost (and other carbon-based) products for their content of WEP, and we know that certain elements reduce the WEP in these products. We further understand that most commercial fertilizer products (especially those that are not 'organic') possess much higher levels of soluble P. Therefore there is data that already exists that can assist product specifiers and buyers to make informed purchasing decisions, based on the requirements (and environmental concerns) related to their specific project. Further, in the case of compost used in erosion control blankets, products containing the proper particle distribution is key to improve success (and minimize environmental risk), as they are less likely to migrate off of the slope. Also, when using compost in berms or sock applications, or as a component to bioretention soils, removing excess fines or using additives may allow us to more confidently use compost in environmentally sensitive applications. Much more research is required in this field.

- Reality matters – We have to be realistic and fair in the way we specify or regulate the use of P containing products. It is not currently possible to eliminate all risk of P migration when it comes to using compost, but that is not the most important point. The question we probably need to be asking ourselves is whether the use of compost in these applications are better than the other existing options? Does it's use provide an overall (or 'net') improvement to the environment. This requires us to take a longer term view of what we are doing *in the field*.

- Research matters – One size does not fit all when it comes to creating regulation regarding the use of P fertilizer or P containing soil amendments. Science should rule the day and not political expediency. This means that funding additional and focused research will be required in order create realistic and economically viable solutions. P related areas of continued research include:
    - Better understanding if compost stability affects P release,
    - Does improving soil structure reduce P migration risk, aside from reducing storm water volumes,
    - What are the most realistic P binding additives to use in different compost applications,
    - Create methods to free up soil P, as necessary, without increasing substantial environmental risk,
    - How relevant is microbial activity to P availability and environmental risk,
    - Does compost containing higher Al, Fe and/or Ca levels (reduced WEP levels), reduce WEP levels to the point that P is unavailable to plants or that soluble P contributed from storm water would be bound.

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