Environmental Impacts of Land Applying Biosolids

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Benefits of Land Applying Biosolids

Applying biosolids can improve the soil by applying plant-essential nutrients, including nitrogen, phosphorus, sulfur, and micronutrients. The nutrients in biosolids usually are also released more slowly than those from traditional fertilizer sources, so nutrients are plant available over a longer time span and less of the nutrients are susceptible to leaching losses during heavy rains.

Biosolids also can have a favorable impact on the soil by increasing water-holding capacity and helping to reduce erosion. In Florida, biosolids can be especially beneficial because the sandy soils have low nutrient and water-holding capacities. Additionally, biosolids may contain micronutrients not present in typical chemical fertilizer mixes of nitrogen, phosphorus, and potassium.

Land applying biosolids represents a key management process for municipalities to deal with the 7 million tons of biosolids produced in the U.S. each year. Land filling or incinerating the biosolids wastes valuable landfill space and is expensive.

Phosphorus Fertilization

Phosphorus (P) is an essential element for plant growth and is often applied to the land with other elements to promote plant growth. Soils deficient in P require P fertilization, but many soils are no longer P-deficient. Indeed, many soils in developed nations now contain adequate to excessive P due to years of application of P-fertilizers or organic materials containing P.

Phosphorus build-up in the soil is not detrimental to crops, but it can negatively affect the environment. The problem arises when the excess P migrates off-site (off or out of the soil) and into water bodies to create environmental problems.

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Environmental Concerns

Eutrophication is defined by the Environmental Protection Agency as "a condition in an aquatic ecosystem where high nutrient concentrations stimulate blooms of algae." Eutrophication is a normal process in the development of a water body, but excessive levels of nutrients in a water body promote "accelerated eutrophication" and exaggerated environmental impacts.

A limiting nutrient in a water body is a nutrient that, if supplied, allows microorganisms and vegetation to grow in more prolific amounts than if the limiting nutrient is kept at optimal levels. Nitrogen, carbon, and P are common limiting nutrients, but P is usually the limiting nutrient in freshwater bodies. As the salinity content of the water increases, as in estuaries, the limiting nutrient is usually nitrogen.

It is difficult to control the exchange from the atmosphere of nitrogen and carbon, and the fixation of atmospheric nitrogen by blue-green algae. Thus, efforts to prevent eutrophication of freshwater bodies focus on reducing P levels. Soluble P concentrations as low as 0.02 mg L^{-1} can cause accelerated eutrophication.

Eutrophication can harm a water body in two ways. First, excessive vegetative growth can block sunlight from reaching the bottom of the water body and prevent underwater grasses from conducting photosynthesis (the way plants manufacture food for themselves). These grasses serve as food sources and hiding places for aquatic life; removing them leads to the death of aquatic animals and organisms.

Second, when the algal blooms die, their decay by microbes depletes the dissolved oxygen in the water. Aquatic life suffocates, resulting in fish kills.

Eutrophication can also affect humans. Eutrophication can limit water use for fisheries, recreation, industry, and drinking because of the accelerated algae growth and the oxygen deficiency that follows.

Algal blooms of certain species can produce harmful toxins. For example, a dinoflagellate species (*Pfiesteria piscidia*) caused neurological damage to humans in the eastern U.S. and Chesapeake Bay tributaries. The toxins can cause lesions on human skin, as well as on fish scales.

Eutrophication is more than unsightly pond scum; it is a serious environmental problem. The acceleration of eutrophication is why the continued land application, and loss, of P has been so closely scrutinized.

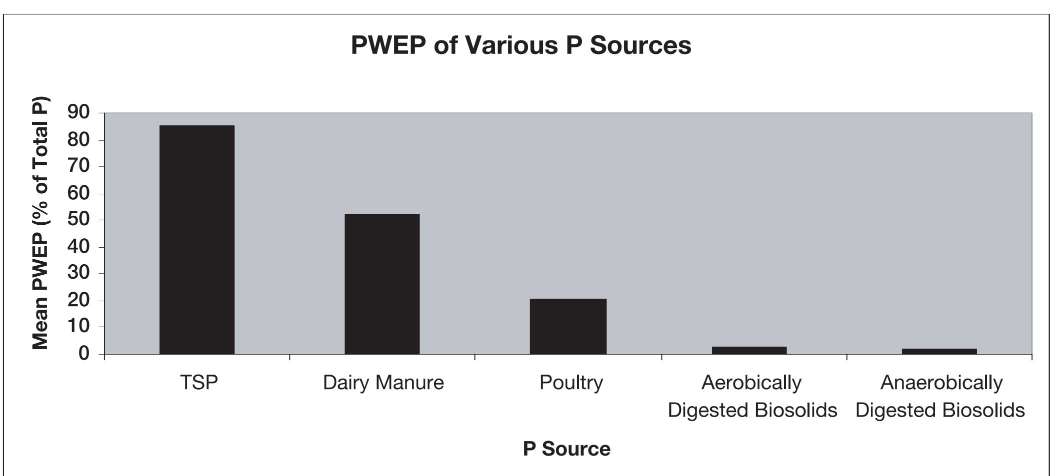

Figure 1. Comparison of percent water extractable P from fertilizer (TSP), dairy and poultry manures, and 10 aerobically and anaerobically digested biosolids (Brandt, et al., 2004).

Mechanisms of P Loss

P can be lost from the soils by leaching, runoff, and soil erosion.

- Leaching losses occur when the applied P dissolves in soil water and, with successive rainfall events, migrates down through the soil profile. The migrating water can move laterally and vertically and will eventually reach surface waters or groundwaters.

- Runoff losses occur when soluble P is washed off the soil surface into water bodies.
- Soil erosion losses occur when soil particles (with P attached) are transported in water (eroded) during heavy rain events.

In Florida, P is primarily lost via leaching or surface runoff because our sandy soils and flat topography minimize soil erosion.

The nature of the P source applied can affect P loss by influencing the runoff volume, influencing the solubility of P, and influencing the transport of particulate material. For example, some P sources promote infiltration of rainfall and reduce runoff and erosion; some supply much less soluble P than others.

Phosphorus losses are also affected by P-source application rate; timing; method, frequency, and timing of water application; and the speed with which water moves through the soil to underground or surface waters.

Controlling P Loss

Best Management Practices

A few simple steps can help reduce the amount of P lost from the soil, the first being good management of the soil and land to minimize rapid runoff after P application. Management practices include avoiding high application rates of P, timing applications to occur during drier weather, and incorporating the P into the soil.

Animal producers can reduce the amount of P that is added to the animals' diet, which in turn reduces the amount of P in manure that is land applied (Withers et al., 2003). Buffer zones between arable land and water bodies and fences to keep livestock from entering the water bodies can also reduce the P input to surface waters.

Phosphorus Source Solubility

Some P-sources contain less soluble P than others and represent less environmental hazard because less P is available at any one time to leaching and runoff events. For example, the data in Figure 1 show that fertilizers typically contain the greatest percentage of total P that is soluble in a water extract (PWEP). Animal manures contain intermediate amounts of PWEP, and most biosolids the least.

Not all biosolids are the same, however, as demonstrated in Figure 2. Biosolids processing treatment (heat-drying, composting, or biological P removal) can dramatically alter P solubility. Those biosolids with high total Fe and Al concentrations are particularly low in soluble P.

As a group, biosolids have less soluble P than manures and fertilizers, and less environmental lability. Thus, P losses tend to be greatest with fertilizer, less with manure,

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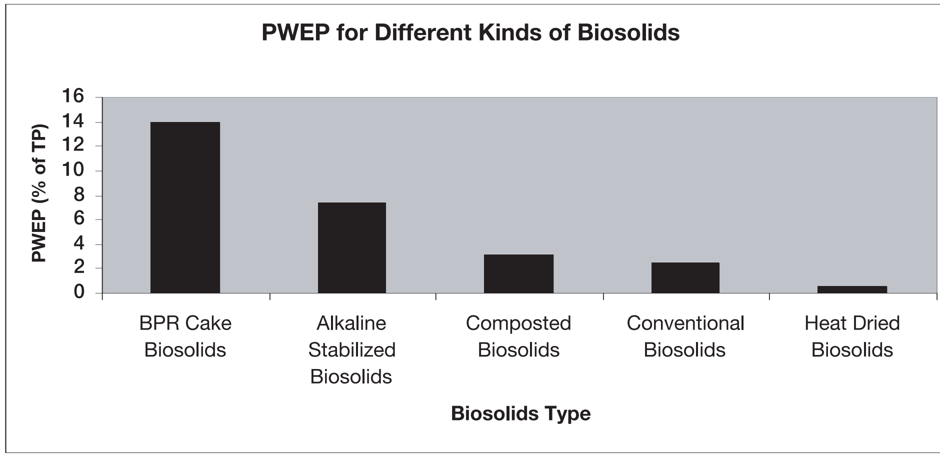

Figure 2. PWEP (% of Total P) of different biosolids types, including BPR, alkaline stabilized, composted, conventional and heat dried biosolids (Brandt, et al., 2004).

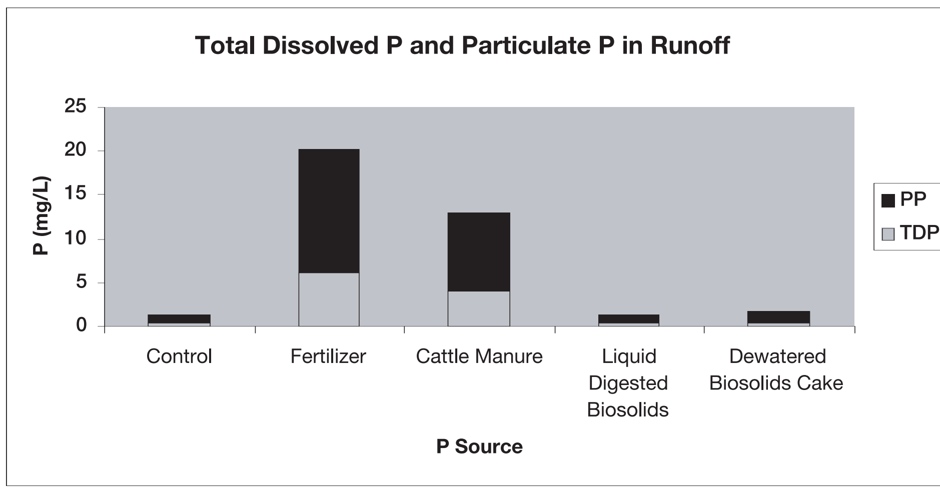

Figure 3. Particulate P (PP) and total dissolved P concentrations in runoff collected after a storm event. (Withers, et al., 2001).

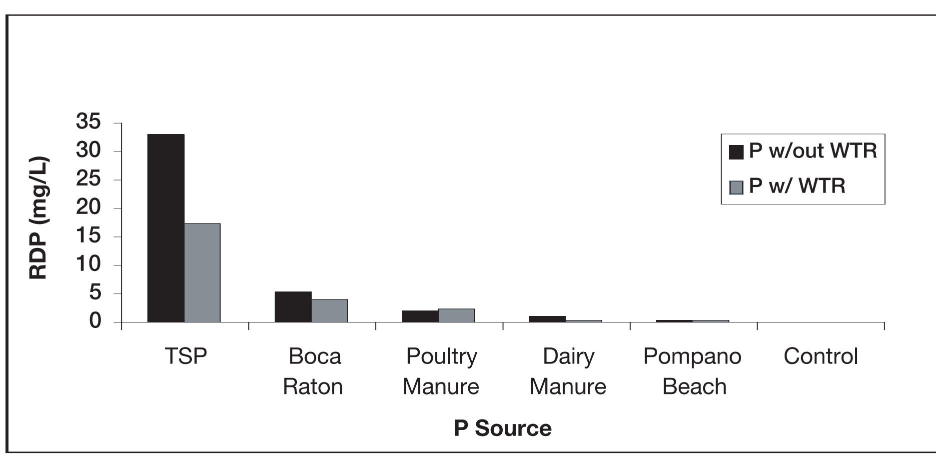

Figure 4. Runoff dissolved P for several P sources when surface applied at high P application rate with and without water treatment residuals (O'Connor and Elliott, 2002).

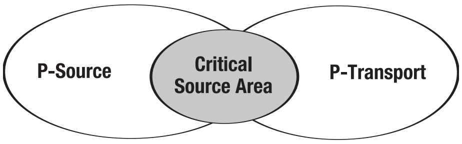

Figure 5. Venn diagram illustrating P-index tool (Elliott, et al., 2005).

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and least with biosolids P sources (Figures 3 and 4).

P Index Tool

The amount of P that may be an environmental hazard is a function of the amount of P in the soil and the potential for offsite transport of the P. A soil may have high P levels and yet have a low chance of P transport—or vice versa. In either case, the soil would not be at high risk for P loss. The problem is when a soil has both a high level of P and a high possibility for transport; this sets the stage for loss of P.

The P-index was created by the U.S. Department of Agriculture's Natural Resource Conservation Service to identify areas that are at risk for P loss. The P-index is both risk- and field-based, and is an annual rating that assesses the probability of P migration from an agricultural source (Figure 5).

Currently, 47 states use some form of the P-index to rank the possibility of P loss from fields. The original P-index had five source and four transport factors. Transport factors considered soil erosion, runoff, and site application distance from water bodies. Source factors focused on P-source solubility and soil P status for assorted crop and soil management practices.

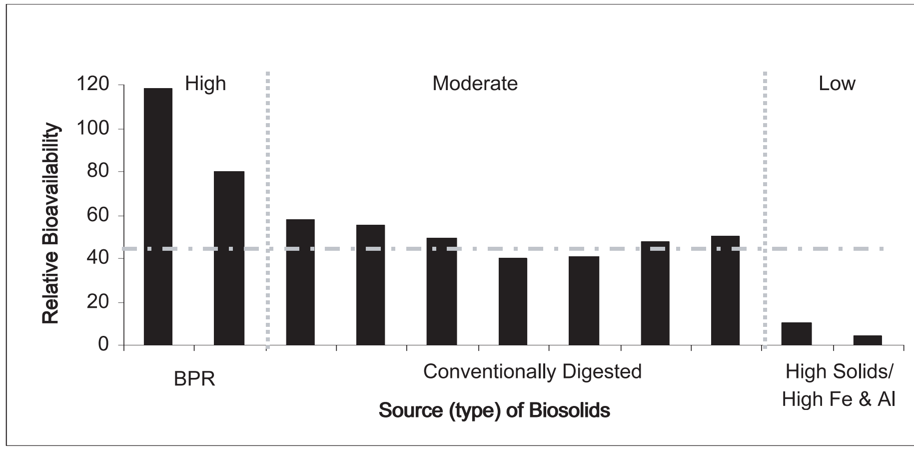

Figure 6: Phytoavailability of various biosolids sources (O'Connor, et al., 2004).

Each state can modify the original index factors to address the needs particular to the state and take into account local hydrology, climate, and geomorphology. Some states include consideration of P-source solubility (P Source Coefficients, PSC values) to distinguish between fertilizer, manure, and biosolids and to acknowledge the smaller P losses expected from low-solubility P-sources.

Plant Availability of P

Another way P-sources (fertilizer, manure, and biosolids) differ is in the fraction of total P that is plant available. Nutrient availability is a complex function of many factors, but nutrient source solubility and release rate are critical. Thus, P-sources of lower solubility or slower release rates have lower P availabilities.

P-fertilizers are designed to have high solubility and quick P release. Research has shown that most biosolids contain P that is only about 40-50 percent as available as fertilizer-P (Figure 6). Some biosolids-P sources (BPR materials) are more available, and some less available (heat-dried materials high in total Fe and Al), than the average.

Biosolids-P solubility appears to be the main factor for the differences, but P-release rates may also be important. Further research is necessary to fully explain the differences. Current data suggest that lower availability can be countered by applying more biosolids without increasing environmental hazard.

Research in the United Kingdom showed that the risk of P migration to water bodies was less from lands amended with biosolids than from lands amended with manures or traditional fertilizers, and that the bioavailability of P in manure is three times as great as it is for biosolids. Researchers concluded that biosolids are useful sources of crop nutrients that do not pose a greater risk of eutrophication than manure or TSP.

Application Rates

Biosolids and manures are usually applied at rates calculated to supply enough nitrogen (N) to meet a crop's needs. Such so-called N-based rates also supply P and typically at rates that exceed the crop's P needs. The excess P builds up in the soil and can represent an environmental concern if the P is lost from the soil.

An alternative approach is to add biosolids at rates that just meet the crop's P needs and so avoid excess P application. P-based rates, however, fail to supply sufficient N to meet the crop's needs, so supplemental N

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WEP (gkg^{-1})	PSC	Typical P Source
>9.0	1.0	Swine/Fertilizer
8.0	0.94	
7.0	0.85	Poultry/BPR biosolids
6.0	0.75	
5.0	0.66	Dairy Manure
4.0	0.56	
3.0	0.46	
2.0	0.35	Al/Fe treated manures and non-BPR biosolids
1.0	0.24	
0.5	0.18	
<0.1	0.12	Heat dried, high Fe plus N-Viro® biosolids

Table 1. Making PSC (P Source Coefficient) a continuous variable in the P index

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must be applied.

The necessity of supplying additional N translates into extra trips across the field to apply the N and additional farmer costs spent purchasing the additional N source. Also, applying biosolids at a P-based rate means that much less material is applied on a tons/acre basis (typically 1-2 tons/acre) than when biosolids are applied at N-based rates (typically 5-10 tons/acre). The smaller application rate means more land (about 5-fold more) is required to accommodate a municipality's land-based recycling program, increasing the program's cost.

The P-based rates of application can be so low as to be impractical and land application may suffer or cease. Given the benefits of land-applying biosolids, ceasing biosolids land-application is a misuse of resources.

Certain biosolids (those with small amounts of water soluble P) may allow application at greater (N-based) rates without unduly endangering environmental quality. If research proves such practices to be environmentally safe, farmers, municipalities, and environmentalists may all be accommodated.

Biological Phosphorus Removal Biosolids

Wastewater treatment plants seek to reduce the P concentration in the effluent they produce. Lower P concentrations reduce effluent impacts on receiving water quality and assist a region in meeting legislatively mandated Total Maximum Daily Loads (TMDLs), which have been derived to protect water quality and desired uses.

Treatment plants typically employ one of two techniques to reduce effluent P concentrations. The first is to add chemicals in the wastewater treatment process that remove P from solution. Phosphorus in the effluent is reduced to acceptable levels, but the removed P is simply transferred to the solids (biosolids) produced, and increases the mass of biosolids that must be recycled.

The second option, which is becoming increasingly popular, is to convert to a Biological Nutrient Removal (BNR) process. In a non-BNR process, the microbes that assist in the water treatment process contain about 12 percent N and 2 percent P by weight. The BNR process is engineered so that the microbes remove more nutrients than normal (i.e., more nutrients than their metabolism demands).

Part of this process is Enhanced Biological Phosphorus Removal; the biosolids that result are called Biological Phosphorus Removal (BPR) biosolids. They tend to have greater total P concentrations and a greater percentage of water soluble P (Figure 2) compared to biosolids from non-BNR processes.

Both the fertilizer value (bioavailability – Figure 6) and the potential for loss of P to the environment tend to be greater for at least some BPR materials than non-BPR materials. Thus, attempts by wastewater treatment facilities to address effluent quality issues (meet TMDLs) can create other problems.

Although BPR biosolids have more labile P than other types of biosolids, many BPR products still have less WEP than most manures and fertilizers. In particular, BPR materials that are heat-dried and/or that contain high concentrations of Fe and Al appear to have low P solubility and environmental lability. Such materials are expected to have P characteristics similar to non-BPR materials, but little research has been conducted.

Current Research

Research sponsored by the Florida Water Environment Association's Utilities Council is under way at the University of Florida to characterize biosolids materials produced and marketed in Florida. The biosolids studied will represent all major types of biosolids (heat dried, BPR, aerobically/anaerobically digested, and metal-conditioned). Studies will determine the amount of environmentally labile P (subject to leaching and runoff) and the plant availability of the different P sources.

Pertinent Literature

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