Land Application of Sewage Sludge in Pennsylvania

Use of Biosolids in Crop Production

INTRODUCTION

Approximately 300,000 tons (on a dry-weight basis) of municipal sewage sludge are produced each year in Pennsylvania. Three viable options now exist for disposal or use of this sludge: landfill placement; incineration; and recycling through application to farm, forest, or mine land. Although each of these options has its place, recycling efforts have increased in recent years because of growing recognition that our society cannot afford to throw away the valuable resources in sewage sludge. Before sewage sludges can be applied to farmland, however, they must be treated further to stabilize organic material and significantly reduce pathogens. Sewage sludges that have undergone such treatment and that are of sufficiently high quality to be used as an agricultural soil amendment ("land applied") under the current regulations are known as *biosolids.*

Biosolids contain significant amounts of nitrogen (N), phosphorus (P), and organic matter that can benefit crop production. Because biosolids are usually supplied and applied at no cost to the farmer, they also provide an economic benefit. To obtain maximum benefits, ensure long-term soil productivity, and minimize possible environmental risks, farmers must properly manage biosolids applications. Using biosolids also entails following several regulatory requirements. This fact sheet describes the characteristics of various types of biosolids and discusses management, regulatory, and other practical issues regarding their use on cropland.

BIOSOLIDS QUALITY CRITERIA

Under Pennsylvania's regulations, sewage sludges that qualify as biosolids and that can be applied to farmland must meet or exceed quality requirements in three areas:

- concentrations of eight trace elements and one organic chemical
- pathogen (disease-causing organism) reduction
- vector (animal that can carry or transfer pathogens) attraction reduction

The regulations specify two biosolids quality classes: exceptional quality (EQ) and non-exceptional quality (non-EQ). To qualify as EQ biosolids, treated sewage sludge must meet very stringent pathogen and vector attraction reduction requirements, and the concentrations of all trace elements and PCBs listed in Table 1 must be below the "pollutant concentration" values given in the left column. To qualify as non-EQ biosolids, sewage sludge must meet less stringent pathogen and vector attraction reduction requirements, and trace element and PCB concentrations must be below the "ceiling concentration" values given in the right column of Table 1. Sewage sludges that do not meet these requirements are not considered biosolids and consequently may not be land applied.

Table 1. **Trace element and PCB concentration limits for land-applied biosolids in Pennsylvania.**

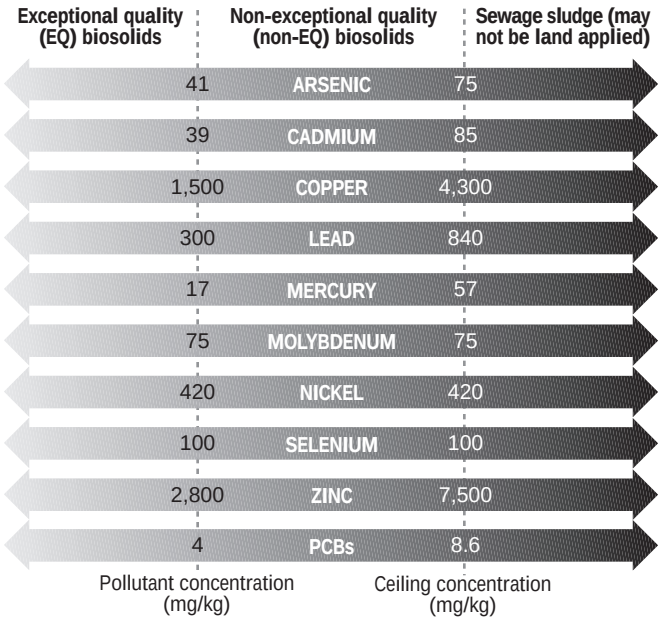

Table 2. **Characteristics of land-applied biosolids in Pennsylvania.**

	Biosolids treatment method					
	Aerobic digestion		Anaerobic digestion		Alkaline addition	
Biosolids property	Median[2] (%)	90th percentile[3] (%)	Median[2] (%)	90th percentile[3] (%)	Median[2] (%)	90th percentile[3] (%)
Solids content[1]	2.3	23.0	6.7	27.0	9.1	32.0
Organic matter	63.0	76.0	60.0	71.0	62.0	78.0
Total nitrogen	4.9	7.0	4.6	7.8	3.7	7.3
Organic nitrogen	4.7	6.3	3.6	5.2	3.6	6.5
Ammonium nitrogen	0.2	0.9	0.9	2.7	0.1	0.7
Phosphorus	2.4	3.8	2.1	3.8	1.3	2.5
Potassium	0.4	0.7	0.5	0.8	0.2	0.8

1. The wide range in solids content results from varying amounts of dewatering.
2. The median is the concentration below and above which equal numbers of the sampled biosolids tested.
3. The 90th percentile is the concentration below which 90% of the sampled biosolids tested.

Most biosolids that are applied to farmland in Pennsylvania are non-EQ biosolids. Although the vast majority of them have trace element concentrations that are well below the requirements for EQ biosolids, they have been classified as non-EQ because of the pathogen and vector attraction reduction requirements. Very few regulatory requirements are placed on land application of EQ biosolids, whereas land applying non-EQ biosolids is extensively regulated. The regulatory and record-keeping requirements described in this fact sheet pertain only to non-EQ biosolids. A complete description of Pennsylvania's biosolids regulations can be found in the Cooperative Extension fact sheet *Land Application of Sewage Sludge in Pennsylvania: A Plain English Tour of the Regulations.*

BIOSOLIDS CHARACTERISTICS

Biosolids vary widely depending on factors such as the source of the wastewater, the wastewater treatment processes, and the sewage sludge treatment processes that produced the biosolids. Their physical form and appearance can range from a black liquid suspension with less than 4% solids to a moist earthlike material with 20 to 50% solids to a dried material with greater than 90% solids. The treatment processes used to produce these varied biosolids can influence their alkalinity and the amount of organic matter, plant nutrients (especially nitrogen and phosphorus), and pathogens they contain; their trace element levels are largely determined by the original wastewater. Table 2 shows the range of characteristics in land-applied biosolids. These values are based on approximately 1,100 analyses of biosolids produced in Pennsylvania in 1996 and 1997.

BENEFITS OF BIOSOLIDS FOR AGRICULTURAL SOILS

The benefits of biosolids as soil amendments are similar to those provided by animal manures—they provide important plant nutrients and organic matter. Some biosolids have been treated or "stabilized" with lime or some other alkaline material to achieve pathogen reduction and to stabilize organic material. This type of biosolids will neutralize soil acidity and thus provide the same benefits as agricultural limestone.

Biosolids contain significant amounts of nitrogen (N) and phosphorus (P) but very small amounts (relative to crop needs) of potassium (K). The quantities of these nutrients depend on the treatment process used to produce the biosolids (Table 2). In general, biosolids contain more P than most animal manures and about the same amount of N. As with manures, most of the N in biosolids is organic and becomes available to crops as it is mineralized.

Biosolids also contain numerous micronutrients that are essential for crop growth. These include boron, chlorine, copper, iron, manganese, molybdenum, and zinc, among others. Only rarely, however, do Pennsylvania soils show a crop response to the addition of any of these micronutrients. This means that most agricultural soils in Pennsylvania are able to supply enough of these trace nutrients to meet crop needs. Certain coarse-textured, sandy soils may benefit from the addition of some trace elements.

Biosolids typically contain from 50 to 70% organic matter, and their continued application over several years will

gradually increase soil organic matter. The benefits of increased organic matter in agricultural soils are well documented and include:

- improved nutrient retention and slow release of nutrients
- improved soil tilth and friability
- increased water infiltration, retention, and availability
- improved soil structure and aggregate stability
- increased cation exchange capacity
- increased microbial activity and diversity

In addition to benefiting soil fertility and organic matter, biosolids also provide an economic benefit to farmers. Their short-term economic value is equivalent to the cost of the nutrients (N, P, and K) and limestone that they have replaced and that therefore do not need to be purchased during a production year. Furthermore, biosolids are usually hauled, applied, and incorporated at no cost to the farmer, providing additional cost savings in terms of labor and equipment operation. Fields receiving biosolids will still require inputs from the farmer: secondary tillage may be needed after biosolids application; supplemental K fertilizer may be necessary; and setback areas where biosolids are not applied will require all normal tillage and fertility management. Thus, the exact dollar value of biosolids will vary from one production system to another. The direct economic benefit of the organic matter provided by biosolids is more difficult to quantify. Increases in organic matter clearly improve soil health, quality, and long-term productivity, but the extent to which these factors contribute to crop yield will vary from year to year.

BIOSOLIDS APPLICATION RATES

Annual applications of biosolids are determined by the N requirements of the crop being grown, whereas total lifetime applications of biosolids to a field are limited by the cumulative loading of eight regulated trace elements.

Annual application rates

Annual biosolids applications may not exceed the nitrogen needs of the crop being grown. Annual biosolids application rates are determined in the same way as are those for animal manures, and should take into account the following factors:

- yield goals
- nitrogen credits from legumes in previous crop rotations

Table 3. **Percent availability of remaining organic nitrogen from biosolids during three years following application.**

	Year after application		
Type of biosolid	**First**	**Second**	**Third**
Aerobic digestion and alkaline addition	30	15	8
Anaerobic digestion	20	10	5
Composted	10	5	3

- residual N from previous applications of animal manure or biosolids
- method of spreading and time until incorporation into the soil
- any starter N fertilizer used
- inorganic and organic N content of the biosolids
- N mineralization rate of the biosolids being applied

Procedures for using this information to determine manure application rates are described in detail in two Penn State Cooperative Extension publications, *Estimating Manure Application Rates (Agronomy Facts 55)* and *The Agronomy Guide*, and in the DEP publication *Manure Management for Environmental Protection (Manure Manual).* Follow the instructions in these publications when determining annual biosolids application rates. Use the factors in Table 3 to calculate nitrogen availability in the first year after biosolids application and residual nitrogen from previous applications. In most instances, the treatment plant that produces the biosolids or the company that does the biosolids application will do these rate determinations. Nevertheless, farmers who use biosolids should carefully check all application rate calculations to ensure that the correct amount of nitrogen is being applied for crop production.

When using alkaline- (lime-)stabilized biosolids, farmers must take care to avoid excess alkalinity. These biosolids may have a liming value ranging from 20 to 50% calcium carbonate equivalency, and continued application on the basis of crop N needs may provide alkalinity in excess of soil liming requirements. This could increase the soil pH above 8, which is not desirable for most agronomic crops. High soil pH can reduce the availability of some micronutrients and can alter the effectiveness of some soil-applied herbicides. Therefore, if the soil pH is above 7.5, farmers should consider using biosolids that are not alkaline stabilized.

Lifetime application rates

Lifetime biosolids application rates are determined by the cumulative loading of the eight trace elements listed in Table 4. Cumulative loading refers to the total amount, in pounds per acre, of each of the eight elements from all applications of biosolids to a field. Before any biosolids are applied, a background soil sample must be collected and analyzed to determine the amount of each of these elements already present in the soil. This background level serves as the starting point for determining the cumulative load. Each time a biosolids application is made to a field, the number of pounds per acre of each of the eight trace elements that are applied must be added to the initial background level and to all previous biosolids applications. When the total amount added for any one of the eight regulated trace elements reaches the limit given in Table 4, no more biosolids may be applied to that field. An example calculation and more information on determining cumulative loading of trace elements can be found in the Cooperative Extension fact sheet *Land Application of Sewage Sludge in Pennsylvania: A Plain English Tour of the Regulations.*

As with annual application rates, determination of cumulative loading is the responsibility of the treatment plant that produces the biosolids or the company that applies them. Nevertheless, the farmer also should maintain records of cumulative loading.

Table 4. **Cumulative trace element loading limits for land application of biosolids.**

Trace element	Cumulative loading limit (pounds per acre)
Arsenic	36
Cadmium	34
Copper	1,320
Lead	264
Mercury	15
Nickel	370
Selenium	88
Zinc	2,464

Risks from land application of biosolids

Hundreds of scientific studies have been conducted to investigate possible environmental and human health risks from the use of biosolids as soil amendments. The E.P.A. used the results of these studies to develop regulations for land-applied biosolids. The regulations stipulate quality standards and management practices that enable beneficial use of biosolids resources while minimizing risks to soils, water, and crop quality, and to human and animal health. These risks can be separated into short-term and long-term risks. Short-term risks are those that could result from a single biosolids application, would occur within a relatively short period after biosolids application (days to months), but generally would diminish within a short period of time (less than a year). Such risks include excessively high soil pH, nutrient leaching or runoff, and transfer of pathogens to farm animals or humans. Long-term risks are those that result from repeated biosolids applications over many years and are associated primarily with the buildup of trace elements in soils.

Short-term risks

Soil application of any fertilizer material increases the risk of nutrient leaching or runoff. Of primary concern with biosolids application, as with manure application, is runoff and leaching of nitrate, as well as the loss of soluble and sediment-bound phosphate in runoff and erosion. Nutrient risks from biosolids can be managed effectively by carefully following the best management practices that have been developed for manures (see the D.E.P. publication *Manure Management for Environmental Protection).*

Just as with manure, applying biosolids on the basis of crop N needs will supply approximately four to five times more P than is needed by the crop. Continued annual application of biosolids on the basis of crop N needs, therefore, will inevitably cause a buildup of soil P levels. This also increases the risk that P could be moved from the farm field into streams or rivers either by erosion of sediment-bound P or by P dissolved in runoff water (see the Cooperative Extension fact sheet *Managing Phosphorus for Agriculture and the Environment).* The requirement that biosolids not be applied within 300 feet of a water source or within 100 feet of an intermittent stream greatly minimizes the possibility of P (and N) reaching streams or rivers. The long-term solution to this problem, however, is to balance P inputs with crop removal. For example, in a corn-forage rotation, biosolids could be used for corn production but not for forage production. This would allow for some P drawdown by the forage crop.

Treatment methods eliminate more than 95% of the pathogens in sewage sludge; the risk of disease from those that remain in biosolids is short-term because most of them do not survive beyond 30 days in the soil environment. In addition to requiring pathogen reduction treatment, Pennsylvania's biosolids regulations contain several risk

reduction and management requirements that reduce the likelihood of disease to very low levels. These requirements include:

- treatment and management practices to reduce the attraction of disease vectors and thus the probability that pathogens would be transferred from biosolids to humans or animals
- application setback requirements from occupied dwellings and from water sources
- minimum time requirements from biosolids application to harvest, ranging from 30 days for forage and feed crops to 38 months for some food crops
- no grazing allowed within 30 days of biosolids application to pastures

If carefully followed, these requirements make the risk of disease from land-applied biosolids similar to or lower than that of land-applied manures. In fact, there are no documented cases of human or animal diseases being contracted from land-applied biosolids.

Long-term risks

Repeated biosolids applications can cause a gradual buildup of certain trace elements in soil. If soil concentrations of these elements were to reach high enough levels, they could be toxic to crops or enter the food chain at unacceptably high levels. The purpose of the regulatory cumulative loading limits is to prevent this from happening. Concentrations of most trace elements in biosolids have decreased substantially during the past 20 years (see the Cooperative Extension fact sheet *Land Application of Sewage Sludge in Pennsylvania: Biosolids Quality).* The vast majority of biosolids currently produced and land applied in Pennsylvania have trace element concentrations that are below the regulatory limits (Table 5). Because of this, human health and environmental risks from trace elements in biosolids are very low. As a point of comparison, it should be noted that these trace metals are also present in manures and chemical fertilizers, sometimes at concentrations similar to those in biosolids.

To put long-term risk from biosolids application into context, it is helpful to consider some numbers. In almost all biosolids, copper is the trace element that will first approach its cumulative loading limit. Given typical Pennsylvania biosolids and application rates, it would take nearly 300 annual applications to reach the cumulative loading limit for copper (a total application of 1,270 tons/acre).

Table 5. **Median and 95th percentile concentrations of regulated trace elements in Pennsylvania biosolids compared to the regulatory standard for exceptional quality (EQ) biosolids. Median and 95th percentile values are based on over 1,000 analyses of biosolids produced in Pennsylvania in 1996 and 1997.**

Trace element	Median[1] (mg/kg)	95th percentile[2] (mg/kg)	EQ biosolids (mg/kg)
Arsenic	3.4	20.0	41.0
Cadmium	2.2	7.3	39.0
Copper	505.0	1,382.0	1,500.0
Lead	62.0	202.0	300.0
Mercury	1.5	6.0	17.0
Molybdenum	8.7	44.0	75.0
Nickel	22.0	85.0	420.0
Selenium	4.4	8.5	100.0
Zinc	694.0	1,989.0	2,800.0

1. The medians for each trace element are the concentrations below and above which equal numbers of the sampled biosolids tested.

2. The 95th percentiles for each trace element are the concentrations below which 95% of the sampled biosolids tested.

At that point, all other regulated trace elements would have reached about one-half, or less, of their respective cumulative loading limits.

At present, there is no cumulative loading limit for molybdenum. Because of concern about possible effects of molybdenum on cattle nutrition, however, the E.P.A. is assessing the need to establish a limit. Soil buildup of this element from biosolids applications will be a gradual, long-term process because of the generally low concentrations of molybdenum in most biosolids. Molybdenum also is held less strongly by the soil than some other trace metals. Because of this, leaching removes some of the added molybdenum from surface soils, further prolonging the buildup process.

Molybdenum occurs naturally in soils and is an essential element for both plants and animals. Its gradual buildup in soil, however, may eventually increase forage molybdenum concentrations to levels that could cause *molybdenosis*, a nutritional disorder, in animals that eat the forage. Molybdenosis is actually a dietary copper deficiency caused by excess molybdenum in the diet. Interestingly, because biosolids also contain significant amounts of copper, they may also alleviate molybdenosis problems. Crop species take up varying amounts of molybdenum from the soil (forage legumes tend to take up more than do grain crops), and uptake also tends to increase with soil pH. Animal nutritionists recommend that the ratio of copper to molybdenum in forage be at least 2:1.

BIOSOLIDS APPLICATION CONSIDERATIONS AND REGULATIONS

Every agronomic input comes with its own set of management challenges, and biosolids are no exception. Farmers who use or are considering using them must address these issues and possibly make some changes in farm operations and management practices. Some of the issues are discussed below.

Soil conservation. The requirement that all farms have soil conservation plans will be enforced for any farm that uses biosolids. The soil conservation plan also must be fully implemented. Because good soil conservation practices help to maintain long-term soil productivity and reduce erosion and farming-related environmental problems, this requirement actually should be viewed as another benefit of using biosolids.

Harvest restrictions. (applicable only to non-exceptional quality biosolids) Feed and forage crops may not be harvested for 30 days following biosolids application. The harvest restriction extends up to 38 months for certain food crops; therefore, farmers need to consider carefully how using biosolids will affect crop rotations and forage and hay production. Farmers also should check to be certain that the marketability of forage, feed, or food crops they produce will not be affected by the use of biosolids.

Livestock. Farmers with animal production operations should carefully consider if additional off-farm nutrients are needed. The regulations specify that biosolids may not be used on any farm where manure can supply all of the required nitrogen, unless a nutrient management plan demonstrating off-farm use of the excess nitrogen is implemented. Farmers also should consider the effect that biosolids would have on the overall phosphorus balance in the farm operation. In most cases, farms with significant manure production will not need additional phosphorus. Finally, animal producers should consider what effect harvest and grazing restrictions will have on their feeding program.

Setback areas. The regulations contain several restrictions on areas where biosolids may be applied. Biosolids may not be applied on areas with slopes greater than 25%, or to land that is within:

- 100 feet of a perennial stream, the edge of a sinkhole, or an exceptional-value wetland
- 300 feet of an occupied dwelling or a water source, unless the current owner provides a written waiver
- 11 inches of the seasonal high water table, or within 3.3 feet of the regional groundwater table

Farmers must determine the size of these restricted areas and how they will be managed.

Soil fertility management. The nutrient balance in biosolids does not match the balance required by crops. When applied to meet all crop N needs, biosolids will supply excess P and, typically, insufficient K. Farmers need to determine how they can manage their overall fertility program to balance nutrient inputs with crop needs.

Time of application. Most biosolids are applied to fields in the fall and early spring when standing crops are not present (application is prohibited on snow-covered or frozen ground). Ammonia volatilization, nitrate leaching, and denitrification can cause significant amounts of N loss from fall-applied biosolids. Farmers should consider management practices that minimize these losses, such as injection or immediate incorporation of biosolids, or planting a cover crop to take up available N.

Soil compaction. Biosolids are normally applied with tank trucks or manure spreaders. Frequent trips with heavily loaded equipment can cause soil compaction, particularly if soils are too wet. Farmers must take steps to minimize compaction (e.g., floatation tires, load limits) and ensure that spreading will not occur when soil conditions are unsuitable.

Nuisance issues. Nuisance issues and concerns from neighbors may arise when biosolids are applied. Farmers may have to deal with complaints about odors and increased truck traffic, as well as concerns about pollutants and pathogens in the biosolids. Farmers must be sure that biosolids applicators are sensitive to these issues and carefully manage the operation to minimize problems.

RECOMMENDATIONS

- Obtain as much information as possible about the biosolids to be used and the company that will do the application. Biosolids benefits can be maximized and risks minimized by using consistently high-quality biosolids produced by a well-operated treatment plant and applied by a reputable company. Contact other farmers who have used the biosolids or the supplier and ask about their experiences. Inquire at your regional Department of Environmental Protection office about the track record of the treatment plant producing the biosolids and the company doing the application. Request to see several analyses of

the biosolids to be used, spanning a one- to two-year period. Look for consistent nutrient levels, consistently low trace element concentrations (Table 5),[1] and consistent attainment of pathogen reduction.

- Determine annual biosolids application rates on the basis of the nitrogen needs of the crop to be produced. Monitor soil phosphorus levels in fields receiving biosolids. Recommendations for managing P in manures also should be followed when using biosolids. See the Cooperative Extension fact sheet *Managing Phosphorus for Agriculture and the Environment*.
- Farmers using biosolids should be actively involved in all decisions regarding biosolids management on their farm. Specifically, farmers need to confirm application rate calculations and specify to which fields and at what time of year biosolids will be applied. To safeguard against soil compaction, the farmer should make the final decision about when soil conditions are suitable for applying biosolids.

1. See the cooperative extension fact sheet *Land Application of Sewage Sludge Quality in Pennsylvania: Biosolids Quality* for additional information on trace element concentrations in Pennsylvania biosolids.

Prepared by Richard Stehouwer, assistant professor of agronomy.

Penn State College of Agricultural Sciences research, extension, and resident education programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

This publication is available from the Publications Distribution Center, The Pennsylvania State University, 112 Agricultural Administration Building, University Park, PA 16802. For information, telephone (814) 865-6713.

Issued in furtherance of Cooperative Extension Work, Acts of Congress May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture and the Pennsylvania Legislature. T. R. Alter, Director of Cooperative Extension, The Pennsylvania State University.

This publication is available in alternative media on request.

5M599ps27211