Extension
University of Missouri

Benefits and Risks of Biosolids

Ken Arnold and Robert Magai
Water Pollution Control Program, Missouri Department of Natural Resources

Richard Hoormann
University Agricultural Extension

Randall Miles
School of Natural Resources

Biosolids are domestic wastewater sludge that meet standards for beneficial use as fertilizer or soil conditioner. The U.S. Environmental Protection Agency (EPA) and the Missouri Department of Natural Resources (Missouri DNR) developed standards to regulate safe use or disposal of biosolids. The standards were specifically developed to protect human health and the environment, including the health of animals, crops, soils, wildlife and aquatic life.

Background

Land application of domestic wastewater and biosolids is not a new management concept. For centuries cultures around the world have applied wastewater biosolids as fertilizer. In some European countries such as Germany and the Netherlands, almost all biosolids are applied on agricultural land. In fact, the widespread popularity of biosolids in most industrialized nations stems from the nutritional benefits and soil-conditioning that biosolids provide. However, in addition to the numerous benefits that can be derived from land application of biosolids, there are certain risks. Municipal wastewater may contain low levels of industrial and commercial wastes. Nonetheless, with the strict controls on the use of biosolids, these compounds should offer little or no threat to human health.

Industrial pretreatment

Recent technological advances in industrial pretreatment systems have drastically reduced the likelihood of introducing pollutants into biosolids. Operational and monitoring controls in most wastewater treatment facilities regulate the concentration of toxic pollutants coming from industries. These controls reduce the concentration of heavy metals and other pollutants in the resulting municipal wastewater biosolids.

Biosolids disposal options

Biosolids are removed from wastewater treatment systems in order to provide an acceptable quality of the treated wastewater. The wastewater treatment operator is then faced with four optional methods for the use or disposal of biosolids. These include landfilling, incineration, surface disposal and land application. Land application of biosolids is the method of choice by both the EPA and Missouri DNR; it is the only option that promotes beneficial reuse or recycling of biosolids and will, under good management, cause the least harm to the environment.

History of biosolids research

In 1973 leading researchers from the U.S. Department of Agriculture, the EPA and the National Association of Land Grant Colleges met at a national workshop to discuss land application of municipal biosolids. Their goal was to form a comprehensive framework for assessing the potential long-term hazards from land application. To do this, the researchers knew they would have to study the effect of leaching on water quality, plant uptake and food chain transfer of toxic chemicals, plant toxicity, pathogens and public health concerns. Twenty years later, studies provided data and understanding of these basic research areas. Regulatory agencies and leading researchers have used this information to reach a scientific consensus on acceptable risk factors and to write sound guidelines for land application. The research findings have been used as the scientific basis for the current state and federal sludge regulations.

Interpreting test results

Confusion can result from the many different types of laboratory testing methods and the way data are reported. For many of us the confusion is compounded when we try to understand the metric system units such as milligrams per kilogram (mg/kg), which are commonly used in scientific publications. It may be easier to visualize this by using the general term of parts per million (ppm); 1 milligram per kilogram = 1 ppm. Table 1 gives some examples of how much one part per million is.

Table 1
Common examples of one part per million

One part per million is equal to the following:

- 1 drop in 132 gallons of water
- 1 gallon of paint in 1 million gallons of water
- 1 pound of salt spread over 500 acres
- 1 gallon of sand in 495 dump trucks of soil

Data can also be reported as wet weight (as-is basis), which is commonly used for wastewater or drinking water test results, or as dry weight. Test results for biosolids are reported as milligrams per kilogram or ppm on a dry weight basis. This allows comparison of test data from biosolids that contain different amounts of liquid. Since most biosolids contain 80 percent to 99 percent water, this dry weight data may seem like a large number when compared to wastewater or drinking water test data. However, remember these numbers are expressed in parts per million. For example, a biosolids sample that is 99 percent liquid and has a dry weight concentration of 10 ppm arsenic would be only 0.01 ppm arsenic on a wet weight or liquid basis.

The Missouri experience

Missouri's firsthand experience with land application began in the 1960s when a handful of communities began to land apply biosolids. In the 1970s the land application method of biosolids became widespread as new treatment plants were constructed in rural communities. In 1982 the Missouri DNR, in cooperation with MU and other interested groups, published WQ429. The biosolids series of Water Quality guides addresses state and federal regulations under 40 CFR 503 for use and disposal of municipal biosolids. The EPA sludge standards under Part 503 regulations (issued in February 1993) are similar to the 1982 Missouri land application guidelines. Missouri guidelines are more stringent in certain cases, giving an additional margin of safety for its citizens.

Study of pollutants in Missouri biosolids

Questions on the types and levels of pollutants in Missouri sewage sludges were addressed in a 1982 study by MU Environmental Trace Substances Laboratory[5]. This study analyzed the biosolids from 74 domestic wastewater treatment facilities for toxic levels of organic compounds, nutrients and heavy metal contaminants. Twelve land application facilities were chosen for further research. Soil samples were analyzed for potential accumulation of pollutants. The following conclusions were drawn from the study:

- High levels of crop nutrients were found in all biosolids tested
- All biosolids were found safe for agricultural use
- None of the soils analyzed had accumulated pollutants at levels of environmental concern.

Soil and groundwater study

Between 1982 and 1985, sludge from the city of Columbia was studied to determine the reactions of biosolids with the soil and the potential for toxic chemicals to migrate into groundwater. This study was conducted using biosolids research plots located at the City of Columbia Wastewater Treatment Plant and was published by MU[5] in 1985. Nitrogen was determined to be the pollutant creating the most concern due to its potential to leach into groundwater. Excess nitrate leaches into the groundwater if nitrogen is applied in excess of normal crop fertilization levels. Proper annual application rates are essential. Metals in the applied biosolids were retained within the top 1 or 2 inches of soil in relatively insoluble forms. Maximum cumulative loading rates for metals, as recommended in previous research, were believed adequate for long-term safety of the soil-plant-water environment. The study recommended continuing the Missouri DNR guidelines on land application of biosolids.

Benefits of biosolids applied to agricultural land

Supply nutrients

One of the foremost benefits of land application of biosolids is the addition of plant essential nutrients, such as nitrogen (N), phosphorus (P) and potassium (K). Applying biosolids to cropland gives producers an opportunity to gain plant available nutrients, particularly nitrogen and phosphorus, at a relatively low cost.

Increase yields

The most significant result of applying biosolids to soils is yield increase. Yield increase is attributed to the availability of a wide array of trace minerals in biosolids. The presence of trace minerals affects the overall health of the soil environment. Most soils are deficient in the essential trace elements (heavy metals) that are required by plants for healthy growth. The deficiency in trace minerals can be amended by applying biosolids to the soils. Biosolids are like vitamin pills for soils because they contain nearly all the essential trace elements, such as zinc (which is chronically deficient in soils but essential for crop growth), vanadium, chromium, iron, copper, cobalt, and molybdenum. There are no fertilizers available on the market today that can supply a more complex array of essential trace nutrients. A fertilizer blend composed of all the required plant nutrients would be costly — beyond the financial means of an average farmer.

Add organic matter

Increased organic matter is an indirect benefit of biosolids. The amount of biosolids applied at agronomic rates is too small to make a direct impact on organic matter increases. The increase in organic matter from biosolids is attributed to a corresponding increase in plant residues after harvest, such as leaves, stems, and more significantly the proliferation of plant roots in the soil. The microbial degradation and transformation of plant residues into organic matter enhance the availability of trace elements for plant uptake. Plant residues left above and below the soil surface after harvest also control erosion by providing a soil cover against wind and rain.

Improve soil structure

One of the long-term benefits of biosolids application to land is the improvement of soil structure. When biosolids decompose, they form a substance that glues and binds the soil particles together to form blocks. The end product is a stable soil with good physical properties. Soils with an improved structure have increased porosity, which enhances water root penetration and decreases bulk density. All these factors combine to give favorable soil tilth.

Benefit the community

Communities benefit from the land application of biosolids because it frees up much needed room in sanitary landfills. In rural Missouri, landfill space is already inadequate for solid waste needs, and suitable new landfill sites are not easily available. The costs to the community are considerably less with land application of biosolids than with disposal methods, such as landfilling or incineration. Land application also provides an opportunity for the farmers and city to work together in a cooperative venture that benefits both groups.

Potential risks of biosolids applications

Misconceptions over high levels of heavy metals, other pollutants and potentially harmful pathogens create concerns about the potential adverse impact of land application. Most people lack the technical knowledge needed to understand how nutrients move through soil, the technical issues surrounding potential risks, and the general practice of applying biosolids. It is true that potential exists for toxic materials in biosolids, which are highly variable in quality. Consequently, the EPA developed risk-based standards for controlling the use and disposal of biosolids.

Disease causing organisms

One health risk with the land application of biosolids is the potential exposure to pathogens (disease causing organisms). Organisms in this category include, but are not limited to, bacteria, protozoa, viruses and viable helminth ova. Pathogens can be eliminated by treating biosolids prior to land application using one or more of the many available treatment technologies for control of pathogens and vectors.

Toxic chemicals

A perceived risk is that the biosolids may contain chemicals that are directly toxic in small concentrations or doses. Most pollutants can be considered toxic or harmful at certain concentrations or doses, such high concentrations have rarely been found in biosolids. Common foods or products, such as salt or aspirin, are safe at normal levels but are also toxic at certain high doses. The same concept is true for biosolids (Tables 2 and 3).

Table 2
Guide for interpretation of toxicity data

Ratings	Relative toxicity	Probable lethal oral dose of the pure chemical for a 150 pound human adult
supertoxic	6	a taste to 7 drops
extremely toxic	5	7 drops to a 1 teaspoon
very toxic	4	1 teaspoon to 1 ounce
moderately toxic	3	1 ounce to 1 pint (1 pound)
slightly toxic	2	1 pint to 1 quart (2 pounds)
practically nontoxic	1	more than one quart

Reference
Naylor et al. 1982[12]

Table 3
Toxicity of some common chemicals

Chemical	Toxicity[1] rating
Strychnine	6
Caffeine	4
Antifreeze	3
Aspirin	3
Cayenne pepper	3
Table Salt	3

Sugar	1
Biosolids[2]	1

Reference
Naylor et al. 1982[12]
[1]See Table 2.
[2]Based on the highest concentration of most toxic chemicals in municipal sewage sludge.

Natural background levels in the environment

Most of the metals found in biosolids occur naturally in soil, water and air media
Quantities of metals found in soils, water and air are called background levels. These background levels vary from place to place in various media. The amount of metals added by the annual land application of biosolids is small compared to the background levels in some soils One acre of land contains about 1,000 dry tons of soil 6 to 8 inches deep. If 2 dry tons of biosolids are incorporated into 1 acre of soil, the annual addition of zinc would increase the soil level of zinc by only 1 or 2 percent for a low metals biosolid (Table 4).

Table 4
Quantity of metals in Missouri soils and biosolids

Element	**Soils pounds per acre foot**	**Biosolids pounds per dry ton**
Arsenic	18	0.01 to 0.08
Chromium	108	0.02 to 24
Copper	26	0.09 to 10.4
Lead	40	0.08 to 1.9
Nickel	28	0.02 to 0.07
Zinc	98	0.34 to 26

Biosolids use in crop production

Numerous research studies, in both the laboratory and field, have shown that there are no short-term risks to agricultural field crops when biosolids are applied at recommended rates based on nitrogen content. However, in the long term, metals will accumulate in the soil to the point that crop uptake of them will increase. With the approval of research scientists, cumulative loading rates (in pounds per acre) of metals have been established in order to protect the long-term productivity of the soil and assure that crops will be suitable for food-chain use. These loading rates are based on the soil's ability to retain metals in an immobile form and on maintaining proper soil pH. The same reactions in the soil that protect crops will also protect groundwater supplies.

Biosolids fed to cattle

Researchers have fed biosolids directly to beef and dairy cattle at 10 percent to 20 percent of their diet with no negative health results. Other research studies also show that there is not a significant health risk to beef or dairy cattle from consuming feed grown on biosolids amended soils. The use of best management practices will reduce the potential for direct ingestion of biosolids while grazing cattle on biosolids-amended pastures.

See MU publication WQ426[13], *Best Management Practices for Biosolids Land Application.*

Storm water runoff

Research has been conducted on pollutant levels in storm water runoff from land application sites. Since most biosolids are adsorbed onto soil particles, it is important to minimize soil erosion and sediment transport. Biosolids that are surface-applied must be able to infiltrate into the soil surface. Biosolids that are applied during frozen or saturated soil conditions risk being transported off-site if storm water runoff occurs before the soil dries. Intense storm water runoff occurs several times each year at random intervals in Missouri. Runoff can be controlled when recommended best management practices are followed.

EPA risk assessment

In 1988 the EPA conducted the National Sewage Sludge Survey, which sampled municipal sludges from 200 cities across the nation and tested for about 400 different pollutants. Most of these pollutants were found at very low levels. The EPA used this survey information and national research data to select pollutants for the risk assessment under the 40 CFR 503 rules. The EPA risk assessment looked at 14 possible pathways that land application of biosolids could impact the environment (Table 5).

Table 5
Exposure pathways for biosolids land application

Exposure pathway	Description
1. Sludge-soil-plant-human	Consumers in regions heavily affected by land application.
2. Sludge-soil-plant-gardener	Farmland converted to home garden use.
3. Sludge-soil-child	Farmland converted to future residential use, and child-ingested soil.
4. Sludge-soil-plant-human	Farm households eating a major portion of meat products from animals fed crops grown on sludge-amended soils.
5. Sludge-soil-animal-human	Farm households eating a major portion of meat from animals grazing on sludge-amended soil.
6. Sludge-soil-plant-animal toxicity	Livestock eating food or feed grown on sludge-amended soil.

7. Sludge-soil-animal toxicity	Livestock ingesting soil while grazing.
8. Sludge-soil-plant toxicity	Crops grown on sludge-amended soils.
9. Sludge-soil-soil biota toxicity	Soil biota living in sludge-amended soils.
10. Sludge-soil-soil biota-predator	Animals eating soil biota.
11. Sludge-soil-airborne dust-human	Tractor operator exposed to dust.
12. Sludge-soil-surface water-fish-humans	Water quality criteria for all beneficial uses of surface water.
13. Sludge-soil-air-human	Farm households breathing fumes from any volatile pollutants in sludge.
14. Sludge-soil-ground water-human	Farm households drinking water from wells.

Reference
EPA Risk Assessment for 40 CFR 503 Rules[8]. 1993.

The EPA risk assessment evaluated the health risk to the general population as well as to a highly exposed individual, such as a person who would have direct contact with biosolids land application sites for a lifetime. The aggregate health risks to the U.S. population from all biosolids land application is much lower than many other common activities in our everyday lives. The aggregate health risks per one million (1,000,000) persons is less than one person for biosolids land application compared to 42 persons for motor vehicle accidents (Table 6).

Table 6
The relative risks of activities

Annual risk of death per one million population	
Smoking 1 pack per day	277
Motor vehicles accident	42
Alcohol consumption (light drinkers)	5
Eating peanut butter (4 tbsp. per day)	<1
Biosolids land application (all exposure pathways)	<1

References
EPA Risk Assessment for 40 CFR 503 Rules[8]. 1993. Wilson et al.[14] 1987.

References

- Missouri Department of Natural Resources. 1982. *Agricultural Use of Municipal Wastewater Sludge: A Planning Guide.* Division of Environmental Quality.
- Missouri Department of Natural Resources. 1985. *Agricultural Use of Municipal Wastewater Sludge: A Planning Guide.* Division of Environmental Quality. Second edition.
- Baxter, J.C., D. Johnson, W.D. Burge, E. Kienholz, and W.N. Cramer, 1983. *Effects on Cattle from Exposure to Sewage Sludge.* EPA Research and Development Project Summary, EPA-600/S2-83-012, April 1983.
- Blancher, R.W., P. Koening, C.L. Scrivner, and W.R. Teaque, 1985. *Distribution of Sludge Components From the Hinkson-Perche Waste Water Treatment Facility In Soil-Plant-Climate System.* MU.
- Clevenger, T., D. Hemphill, and K. Roberts, 1982. *Study of Chemical Compositions of Municipal Sewage Sludges in Missouri.* Environmental Trace Substances Laboratory. MU.
- Dowdy, R.H., R.D. Goodrich, W.E. Larson, B.J. Bray, and D.E. Pamp, 1984. *Effects of Sewage Sludge on Corn Silage and Animal Products.* EPA Research and Development Project Summary, EPA-600/S2-84-075, May 1984.
- Duncomb, D.R., W.E. Larson, C.E. Clapp, R.H. Dowdy, D.R. Linden, W.K. Johnson, 1982. *Effect of Liquid Waste Water Sludge Application on Crop Yield and Water Quality.* Journal of Water Pollution Control Federation, volume 54, Number 8.
- EPA Risk Assessment for 40 CFR 503 rules, Federal Register, volume 58, number 32, Feb. 19, 1993.
- Fricke, C., C. Clarkson, E. Lomnitz, and T. O'Farrell, 1985. *Comparing Priority Pollutants in Municipal Sludges.* Biocycle Magazine, January/February 1985.
- Larson, W.E., and R.H. Dowdy, 1976. *Heavy Metals Contained in Runoff from Land Receiving Wastes.* Proceeding of the National Conference on Disposal of Residues on Land, September 13-15, 1976.
- *National Sewage Sludge Survey,* U.S. EPA, Office of Water Regulations and Standards, October 1989.
- Naylor, L.M., and R.C. Leohr, 1982. *Priority Pollutants in Municipal Sewage Sludge.* Biocycle Magazine, July/August 1982.
- Wilson, R., and E. Crouch, 1987. *Risk Assessment and Comparisons: An Introduction.* Science, volume 236: 267-270.

To learn more about water quality and other natural resource issues, contact the Missouri Department of Natural Resources, P.O. Box 176, Jefferson City, Mo. 65102, 800-334-6946.
