



# Land Application of Sewage Sludge in Pennsylvania

## Effects of Biosolids on Soil and Crop Quality

The use of biosolids on Pennsylvania cropland has been a common practice since the mid-1970s. Biosolids contain essential plant nutrients and organic matter that can benefit crop production. Therefore land application of biosolids represents a beneficial reuse alternative to landfill disposal or incineration. Like any other soil amendment, biosolids application to agricultural land must be properly managed to obtain maximum benefits and minimize potential environmental risks. This fact sheet, which is part of a series on land application of biosolids, presents the results of a three-year research project that investigated how agronomic biosolids utilization has affected soil and crop quality.

### INTRODUCTION

Long-term implementation of crop production and soil management practices such as tillage, crop rotations, and fertilizer or manure application can profoundly change various soil properties, which in turn can affect the crops grown on those soils. The goal of modern production agriculture is to manage production practices so that soil and crop quality are maintained or improved, crop yields are maximized, and adverse environmental effects are minimized. Biosolids (treated municipal sewage sludge) are used in agronomic crop production primarily as a nitrogen (N) fertilizer source, and biosolids applications are normally managed to meet crop N needs. However, biosolids also contain significant amounts of phosphorus (P) and organic matter, some contain lime, and all contain small amounts of various trace elements. Thus, in addition to their effects on soil and crop N, biosolids could also affect soil and crop P levels, soil pH, soil organic matter content, and soil trace element concentrations. Objectives of biosolids management then include supplying sufficient nutrients for crop production while

minimizing the potential for nutrient loss from the soil, and maintaining soil pH and organic matter levels in desired ranges. Because many trace elements tend to accumulate in soil, biosolids management also requires tracking trace element additions to soil. A three-year research project was recently completed by Penn State in which the effects of biosolids utilization on soil and crop quality were assessed. The assessment focused on the quality parameters mentioned above and did not address other issues related to biosolids utilization such as human pathogens or nonregulated pollutants. This fact sheet reports the results of that assessment.

The assessment was carried out on 20 farms located in 18 Pennsylvania counties (Fig. 1, see p. 2). Each of these farms had a history of using biosolids as an agronomic input. At each farm, two production fields were selected for soil and crop sampling and analysis. One field was termed the *biosolids* field and had a history of biosolids applications. The total amount of biosolids applied to these fields and the years in which applications occurred varied between farms (see Table 1 on page 2). The other field was termed the *control* field and had never had biosolids applied to it. The control field was selected to be highly similar to the biosolids field with respect to soil type (it was usually adjacent to the biosolids field), crops grown, and management practices other than biosolids application. Soils and crops from every field were sampled each fall for three consecutive years. Soils were sampled at 3 depths: 0–4, 4–8, and 8–16 inches. Crop samples were collected from the same locations as the soil samples. The crop tissues sampled were always the portion of the plant that would be harvested from that field. The samples were analyzed for the chemical parameters listed in Table 2 on page 2. Soil nutrients were extracted using standard soil testing procedures. These tests are designed to measure plant available nutrients. Soil trace elements were extracted using strong acid digests to extract essentially all trace elements in the soil. Crop samples were

completely digested to extract all nutrients and trace elements in the crop tissue. To determine the overall effects of biosolids on soil and crop quality, the difference between biosolids and control fields was determined for each farm and the average difference for all farms was calculated. Statistical analysis was used to determine if the differences were large enough and consistent enough to conclude that they resulted from using biosolids.

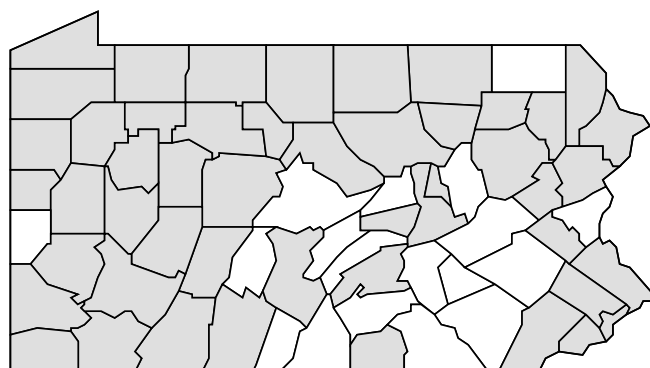


Figure 1. Farms used in the biosolids assessment were located in counties shown in white.

Table 1. Total amounts (cumulative) of biosolids applied to farm fields in the assessment study, and the years in which biosolids were applied.

Site	Total amount of biosolids applied tons per acre (dry weight basis)	Years in which biosolids were applied
Beaver	45.3	1984–2001
Berks	5.3	1994–1998
Blair	9.3	1991–1996, 1997–2000
Centre	7.0	1991, 1993, 1999
Columbia	16.9	1995–1998
Cumberland	18.0	1986, 1989, 1997, 2000
Dauphin	21.0	1980, 1981, 1984, 1990, 1991, 1996–1998
Franklin	18.8	1988, 1991–1995, 1997
Fulton	70.9	1986–1999
Juniata	2.3	1997, 1998
Lancaster 1	48.3	1986–1995, 2000
Lancaster 2	52.7	1990–1994, 1996, 1999, 2000
Lebanon	5.4	1996, 1998
Northampton	4.6	1997–1999
Schuylkill	22.4	1992, 1994–1997, 2000
Susquehanna	44.5	1982–1995, 1995, 1997–2000
Union	7.2	1994–1997, 1999
York	28.7	1988–1993, 1995–1997

Table 2. Parameters analyzed in the soil and crop tissue samples.

Soils	Crops
pH Total carbon Organic carbon Total nitrogen	Yield
Exchangeable or extractable nutrients	Total macro-nutrients
Ammonium Nitrate Phosphorus Potassium Calcium Magnesium Sodium	Nitrogen Phosphorus Potassium Calcium
Total extractable trace elements	Total micro-nutrients and trace elements
Arsenic Cadmium Chromium Copper Lead Mercury Molybdenum Nickel Selenium Zinc	Cadmium Chromium Copper Lead Molybdenum Nickel Zinc

## BIOSOLIDS EFFECTS ON SOILS

### Soil organic matter

Biosolids contain from 60 to 65 percent organic material. Therefore, one might expect that repeated application of biosolids over several years would increase soil organic matter levels. However, soil organic matter levels were similar in biosolids and control fields averaging 4.0, 3.1, and 1.6 percent at depths of 0–4, 4–8, and 8–16 inches, respectively. The reason for the lack of increase in organic matter is likely two-fold. First, biosolids application stimulates soil microbial activity and much of the added organic material will be decomposed. Second, at most farms in this study, the control fields received manure applications. Manure would also add organic matter to soil thus erasing differences from the biosolids.

### Soil pH and calcium (Ca)

The pH of most soils in this study was in the range of 6 to 7.5. Biosolids utilization increased soil pH in the 0–4 inch depth by an average of 0.2 pH units, but did not affect pH at greater depths in the soil. Higher pH of soils that received biosolids can be attributed to two factors. One is

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that some farms included in this study received alkaline-stabilized biosolids, which is sewage sludge that has been mixed with lime at the treatment plant as a means of stabilizing organic matter and reducing pathogens. These biosolids have very high pH, are strongly alkaline, and are effective soil liming materials. The other reason is that regulations require soil pH to be at least 6.0 when biosolids are applied. Consequently, fields that receive biosolids may be limed more frequently than fields that are not, leading to higher soil pH.

Biosolids fields had higher exchangeable Ca than control fields at all three soil depths (Table 3, see p. 4). Liming and use of alkaline-stabilized biosolids would also add a lot of Ca to the soil, thus these increases are expected and are consistent with the increase in pH. Soil pH and exchangeable Ca increases in this range represent improvements in soil quality for agronomic crop production. Normal production practices tend to decrease soil pH and exchangeable Ca, and the desired outcome of recommended agricultural limestone applications is to increase pH and exchangeable Ca. Increased soil pH would only be a problem if it reached excessively high levels ( $\geq 8$ ). Soil pH in this range could affect the activity and breakdown of pesticides and decrease plant uptake of some micronutrients.

#### **Ammonium (NH<sub>4</sub>), nitrate (NO<sub>3</sub>), phosphorus (P), and potassium (K)**

The goal of good nutrient management is to match soil nutrient supply with what the crop needs for optimum growth and production. Insufficient nutrients result in decreased yield; excess nutrients could increase nutrient loss from farm fields to streams, rivers, lakes, or groundwater. Two forms of soil N were measured in this study: ammonium and nitrate. These are both inorganic forms of nitrogen that can be taken up by plant roots. Nitrate is also very mobile in soil and can be moved in runoff water and in water that percolates down through the soil. Ammonium levels were similar in biosolids and control fields at all three soil depths. Soil nitrate concentrations, however, were higher in biosolids fields than in control fields (Table 3). While the differences varied somewhat from year to year, on average the biosolids fields had nearly two times more soil NO<sub>3</sub> than the control fields at all three depths.

Biosolids application rates are most often calculated on the basis of how much nitrogen will be needed by the subsequent crop, and by regulation may not exceed that amount. Managing nitrogen fertility with organic materials such as biosolids and manures is complicated because most of their

nitrogen is organic and must be converted to inorganic nitrogen (mineralized) for plants to use it. Thus determining an application rate requires predicting or estimating how much mineralization will occur during the growing season. Mineralization factors have been established for various types of biosolids and are used to calculate biosolids application rates. If these factors are lower than actual mineralization during the growing season, more nitrogen will become available than can be used by the crop, and would accumulate in the soil. Higher nitrate in the soil could also result from ongoing nitrogen mineralization after crop growth has ceased. The higher soil nitrate levels observed in this assessment do not necessarily indicate an environmental risk from increased nitrate leaching. However they do indicate a need to carefully manage nitrogen when biosolids are used. Measures could include planting a non-legume cover crop in the fall to take up any excess soil nitrate and using pre-sidedress nitrate tests in the spring to better determine nitrogen needed by corn crops. Finally, mineralization factors currently used to calculate biosolids application rates should be reassessed to determine if they are appropriate.

Soil test phosphorus was higher in the surface soil layer of biosolids fields than in the control fields (Table 3). Most biosolids have lower nitrogen to phosphorus ratios than do dairy or beef manures and are similar to poultry manure. Thus, just as occurs with manure application, when biosolids are applied to provide nitrogen for crop production, the amount of phosphorus added exceeds what the crop needs. When such applications are repeated several times over several years, the excess phosphorus will accumulate in the soil and increase soil test levels. The environmental significance of such phosphorus buildup was not addressed as part of this assessment. Phosphorus normally binds strongly to soil, and there is some evidence that biosolids phosphorus is held more strongly in soil than is manure phosphorus. However, as Pennsylvania moves to phosphorus-based nutrient management, this issue will need to be addressed.

Soil test potassium levels were lower in biosolids fields than they were in control fields (Table 3). The amount of potassium in biosolids is low relative to nitrogen, so when biosolids are applied to provide nitrogen, the amount of potassium added will be less than what is needed by the crop. Over several years the soil reserve of plant available potassium will decrease as crops remove more potassium than is added. Therefore when biosolids are used, soil potassium levels should be monitored and alternative sources of potassium added (chemical fertilizer or manure) to maintain optimum potassium soil test levels.

**Table 3. Average soil concentrations of macronutrients in control fields and biosolids fields. Dashed lines indicate there was not a significant difference between the control and biosolids fields.**

Soil Macronutrient	Soil Depth Increment	Control Field Concentration	Biosolids Field Concentration	Difference in Concentration
	inches	mg per kilogram or parts per million (ppm)		
Calcium	0-4	1722	7472	750
	4-8	1678	2145	467
	8-16	1438	1772	334
Nitrate	0-4	11.5	20	8.5
	4-8	10.3	17.8	7.5
	8-16	5.7	14.1	8.4
Phosphorus	0-4	164	209	45*
	4-8	133	152	—
	8-16	62	53	—
Potassium	0-4	174	149	-25*
	4-8	114	99	-15*
	8-16	90	81	—

\*Change was significant in the second and third years of the study, but was not significant in the first year of the study.

**Table 4. Average soil concentrations of trace elements in control fields and biosolids fields. Dashed lines indicate there was not a significant difference between control and biosolids fields.**

Soil Trace Element	Soil Depth Increment	Control Field Concentration	Biosolids Field Concentration	Difference in Concentration
	inches	mg per kilogram or parts per million (ppm)		
Copper	0-4	24.0	34.0	9.9
	4-8	24.5	34.4	5.8
	8-16	24.2	28.3	4.0
Chromium	0-4	25.3	28.8	3.5
	4-8	26.6	29.3	2.8
	8-16	28.8	30.7	1.9
Lead	0-4	16.8	19.9	3.1
	4-8	16.9	19.2	—
	8-16	13.1	17.0	3.9
Mercury	0-4	0.06	0.10	0.04
	4-8	0.05	0.08	0.03
	8-16	0.05	0.05	—
Molybdenum	0-4	3.40	3.77	0.37
	4-8	3.43	3.77	0.34
	8-16	3.44	3.78	0.34
Zinc	0-4	90.1	106.1	16.0
	4-8	88.9	94.9	—
	8-16	82.1	95.1	—

**Trace elements**

The nine trace elements listed in Table 2 are regulated in biosolids because EPA has determined that these elements could potentially affect human or environmental health when biosolids are land applied. Extensive scientific research with these trace elements has shown that most of them are held quite strongly by soil. Thus these elements tend to remain where they are placed, although some movement in leaching water is possible. Since most of them are present at higher concentrations in biosolids than in soils, it is reasonable to expect that repeated biosolids applications would increase soil concentrations of these trace elements. In fact, concentrations of several trace elements were found to be higher in biosolids fields than control fields at one or more soil depths. Those elements and soil depths are listed in Table 4 on page 4.

Biosolids are typically injected or incorporated into soils by tillage to depths of about 6 inches. Rarely would the depth of incorporation exceed 8 inches. Increases in soil trace element concentrations would be expected within the depth of incorporation, but not at greater depths. However, as is shown in Table 4, soil concentrations of copper, chromium, lead, and molybdenum were greater in biosolids fields than control fields at the 8–16 inch depth, clearly below the normal maximum mixing depth. The actual biosolids mixing depths for the fields in this assessment were not known, and it is possible some biosolids in some fields could have been mixed below 8 inches. Occasional deep tillage operations could also have mixed biosolids deeper into the profile. However, these results could also indicate movement of trace elements deeper into the profile due to the leaching action of percolating water. Further research is warranted to determine if, and to what extent, such movement is occurring.

This assessment was not designed to determine the environmental significance of these increases in soil trace element concentrations. However, comparing these increases to the amount of increase that is permitted under the biosolids regulations provides some indication of environmental risk. The biosolids regulations establish limits on the total amounts of eight trace elements that may be added to soil with biosolids applications. The risk assessments used by EPA to develop these limits indicated that this level of addition would be protective of human health and the environment. To make this comparison the soil concentration increase for each trace element (given in Table 4) was converted to the quantity of the trace element added per acre of soil to give that amount of increase. That gave the amount of trace element added to each depth increment over one acre. The amount of trace metal addition for each depth increment was added together to give the total amount of trace element added per acre. The results of these calculations and the comparisons to regulatory limits are given in Table 5. Chromium and molybdenum are not included in Table 5 because there is not an application limit for these metals in the current regulations. The trace element that increased the most relative to its regulatory limit was lead (6.1 percent), while increases in other trace elements were less. Thus the measured increases in soil trace elements are far smaller than amounts determined to be protective, and likely too small to cause any increase in environmental risk. Furthermore, these increases are in line with what would be expected given the amounts of biosolids added to the fields. No fields were sampled that had higher than expected concentrations of any measured trace element. Thus there was no evidence that biosolids with extremely high concentrations of these trace elements had been applied.

Table 5. Measured trace element increases in the 0–16 inch depth of the soil profile as a percentage of regulatory limits.

Trace Element	Regulatory limit	Soil profile increase	
		Measured increase	Percent of regulatory limit
----- pounds per acre -----			
Copper	1,320	28	2.1
Lead	264	16	6.1
Mercury	15	0.11	0.7
Zinc	2,464	55.1	2.3

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## BIOSOLIDS EFFECTS ON CROPS

There were no differences in crop yields between biosolids and control fields, nor were there differences in crop tissue contents of macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium). Biosolids were used as a nitrogen fertilizer on these fields, while control fields used conventional chemical fertilizers and manures. The similar crop yields and nitrogen contents on biosolids and control fields indicate that biosolids can be as effective as other sources of nitrogen.

There were also no differences in the trace element concentrations of crops grown on biosolids and control fields. Thus the higher soil concentrations of trace elements in biosolids fields did not result in increased crop uptake, and consequently no increase in the amounts of these trace elements entering the food chain. The lack of any differences in crop tissue concentrations of trace elements further suggests that the soil concentration increases were too small to cause an increase in environmental risk.

## CONCLUSIONS

Repeated application of biosolids to farm fields has altered some soil quality parameters, but has had no measurable effect on crop quality parameters.

- Biosolids are clearly providing nitrogen for crop production. Similar crop yields and nitrogen content indicate crops fertilized with biosolids are receiving sufficient nitrogen. However, higher soil nitrate concentrations in biosolids fields at the end of the growing season indicate that nitrogen management with biosolids could be improved. Nitrogen mineralization constants used to calculate biosolids application rates should be reassessed to determine if they are appropriate. Biosolids fields should be planted with winter cover crops to take up any excess soil nitrogen and reduce the potential for nitrate leaching or runoff. When biosolids are used for corn production, application rates could be reduced and pre-side dress soil nitrate testing utilized to determine the need for additional nitrogen fertilizer.
- There is evidence that, similar to animal manures, continued biosolids use will lead to increased soil phosphorus levels. The environmental significance of such increases needs to be examined, particularly as Pennsylvania moves to phosphorus-based nutrient management.
- Because biosolids are low in potassium, soil test potassium levels should be monitored when biosolids are used.

Other sources of potassium fertilizer should be added as needed to maintain optimum soil potassium levels.

- Repeated biosolids applications have increased soil concentrations of several trace elements. Such increases are expected since concentrations of these trace elements in biosolids are greater than background soil concentrations. The very small magnitude of these increases relative to allowable trace element additions under current biosolids regulations suggests that these increases are too small to have increased risk to the environment or to human health. Increased trace element concentrations in soil below the depth of normal biosolids mixing indicate deeper than expected movement of these trace elements. Such movement could have occurred by deep incorporation, deep tillage operations, or by downward leaching.
- Yields, nutrient contents, and trace element contents of crops grown on biosolids and control fields were similar, indicating the use of biosolids has not affected crop quality and has not increased trace elements entering the food chain.

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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.

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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.

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Produced by Information and Communication Technologies in the College of Agricultural Sciences

CAT UC181

5M3/03ps4247