Fertilizing with Biosolids

A Pacific Northwest Extension Publication
Oregon State University, Washington State University, University of Idaho
Fertilizing with Biosolids

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What are biosolids?

Biosolids are a product of municipal wastewater treatment. Raw sewage solids must be processed to meet U.S. Environmental Protection Agency (USEPA) standards before they can be called biosolids. Biosolids contain organic matter and nutrients that are beneficial for soil, crop, and livestock productivity. This publication focuses on how biosolids can be used to supply nutrients for crop production.

Biosolids as a nutrient source

Table 1 shows the typical macronutrient content of biosolids produced by Pacific Northwest wastewater treatment facilities. These nutrients include both rapidly and slowly available forms. Biosolids also provide plant-essential micronutrients, including copper (Cu), boron (B), molybdenum (Mo), zinc (Zn), and iron (Fe).

Biosolids usually are applied at rates designed to supply crops with adequate nitrogen (N). The other nutrients they contain also reduce fertilizer requirements.

For all nutrients except N, soil testing can be used to monitor the change in soil fertility resulting from biosolids application. A long-term monitoring plan to track soil nutrient levels over the years should use consistent sampling and analysis methods. Extension publications listed in “For more information” (page 16) provide guidelines for designing a sampling and testing program.

See the sidebar “Fertilizer replacement value of biosolids” (page 3) for more information.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Usual range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Organic matter</td>
<td>45</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>3</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>1.5</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>0.6</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>1</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>0.4</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>0.1</td>
</tr>
</tbody>
</table>

*Nutrient concentrations are expressed on a total elemental basis. Not all elemental content is in a plant-available form.

Usual range for freshly digested biosolids. Lagooned biosolids, composted biosolids, and alkaline-stabilized biosolids typically have lower nutrient concentrations.

Phosphorus and potassium are expressed on an elemental basis. Use the following conversion factors to convert to units used for fertilizer marketing: To get P₂O₅ (phosphate), multiply P x 2.29. To get K₂O (potash), multiply K x 1.2.
Biosolids nitrogen (N)

Forms of N

Biosolids contain organic and ammonium-N; nitrate-N is absent in most biosolids. Ammonium-N is available to plants immediately after application. Organic N provides slow-release N (Figure 1, page 4).

The proportions of ammonium and organic N in biosolids are related to the stabilization process (e.g., digestion, composting) used at the wastewater treatment facility. Liquid, anaerobically digested biosolids often contain more ammonium-N than organic N. In biosolids produced by anaerobic digestion and dewatering (the most common product offered to farmers), about 80 percent of total N is in the organic form, with the remainder present as ammonium-N. Heat-dried biosolids contain more than 90 percent organic N and a trace of ammonium-N.

Plant-available N

Calculating biosolids application rates based on N

A companion publication, PNW 511-E, Worksheet for Calculating Biosolids Application Rates in Agriculture, provides a step-by-step process for calculating application rates that supply crops with adequate available N. The worksheet estimates ammonium-N retained and

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**Fertilizer replacement value of biosolids**

Table 2 estimates the fertilizer replacement value of anaerobically digested biosolids N, P, K, and S for the first year after application. This estimate is based on typical biosolids analyses and estimates of nutrient availability from university field trials.

With the exception of N, the fertilizer replacement value for nutrients depends on existing soil test values and the cropping system. Typically, a biosolids application to meet crop N requirements eliminates the need for annual P and S applications.

The fertilizer replacement values shown in Table 2 do not include the potential benefits to soil quality from biosolids. Soil quality benefits are difficult to express in simple economic terms and are unique to every location (see page 10).

To convert percentages given for P and K in Table 2 to units used in fertilizer marketing, use the following conversion factors:

- To get P₂O₅, multiply P by 2.29.
- To get K₂O, multiply K by 1.2.

For example, biosolids with 2.5 percent P and 0.3 percent K contain 5.7 percent P₂O₅ (phosphate) and 0.36 percent K₂O (potash).

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**Table 2. Approximate first-year fertilizer replacement value of anaerobically digested biosolids.**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Expressed as</th>
<th>Total nutrient (% dry wt)</th>
<th>Available nutrient (% of total nutrient)</th>
<th>Nutrient value ($/lb)</th>
<th>Fertilizer replacement value of biosolids nutrient ($/dry ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>5.0</td>
<td>35</td>
<td>0.57</td>
<td>19.95</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P</td>
<td>2.5</td>
<td>40</td>
<td>1.09</td>
<td>21.80</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>0.3</td>
<td>100</td>
<td>0.69</td>
<td>4.14</td>
</tr>
<tr>
<td>Sulfur</td>
<td>S</td>
<td>1.0</td>
<td>35</td>
<td>0.38</td>
<td>2.66</td>
</tr>
<tr>
<td>Total</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>48.55</td>
</tr>
</tbody>
</table>

**Table notes:**

- Estimated plant-available nutrient released in the first year after biosolids application, based on Pacific Northwest field research by Washington State University and Oregon State University.
- Based on 5-year average national inorganic fertilizer prices (2009–2013) compiled by USDA Economics Research Service: urea ($521/ton), diammonium phosphate ($643/ton), potassium chloride ($641/ton), and ammonium sulfate ($421/ton). The actual cost of a pound of nutrient from inorganic fertilizer varies, depending on nutrient form and analysis, transportation charges, market conditions, and the quantity purchased. Cost of fertilizer application is not included.
organic N mineralized from different types of biosolids. It uses the following general equation to forecast plant-available N release from biosolids:

\[
\begin{align*}
& a \ (\text{ammonium-N in biosolids}) + b \ (\text{organic N in biosolids}) \\
& + c \ (\text{organic N from previous biosolids applications})
\end{align*}
\]

where:

\[
\begin{align*}
& a = \text{fraction of ammonium-N retained after application} \\
& b = \text{fraction of organic N mineralized during the first growing season} \\
& c = \text{fraction of organic N mineralized from previous biosolids applications on the same field}
\end{align*}
\]

**Ammonium N retained after application**

When biosolids are surface applied (not tilled or injected into soil at application), a portion of the biosolids ammonium-N is lost as ammonia gas. Ammonia loss is very rapid during the first hours after application.

Tillage or sprinkler irrigation with clean water immediately following biosolids application increases ammonium-N retention in soil. However, tillage or immediate irrigation is not feasible or desirable in many cropping situations.

When biosolids are not incorporated, ammonium-N retention is greater for liquid biosolids than for dewatered cake biosolids. With liquid biosolids, some of the ammonium-N infiltrates below the soil surface, thereby reducing ammonia loss.

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**Figure 1. Nitrogen cycling: Forms and pathways following biosolids application.** Biosolids contain both organic-N and ammonium-N. If biosolids are not immediately incorporated by tillage, some of the applied ammonium-N is lost as ammonia to the atmosphere. In the soil, ammonium-N is rapidly converted to nitrate-N by soil microbial activity (indicated by dashed arrows). Both ammonium-N and nitrate-N can be used by crops. Nitrate-N can be lost to the atmosphere through denitrification or to groundwater via leaching. Nitrogen loss can be minimized by matching the biosolids application rate to crop N need. Organic N must be converted to ammonium-N by microbial activity before plants can use it. Figure by Dan Sullivan.
Organic N mineralized during the first growing season after application

Following field application, organic N in biosolids is converted to plant-available forms (ammonium and nitrate) by soil microorganisms through a process known as mineralization. The biosolids treatment process affects the organic N mineralization rate after land application. Freshly digested biosolids usually contain more mineralizable N than do biosolids produced with more intensive stabilization processes (composting or long-term lagoon storage).

The organic N mineralization rate also is affected by soil temperature and moisture conditions. Mineralization is most rapid when soil is moist and warm (above 60°F). When biosolids are applied to dry soil and not incorporated by tillage, N mineralization is delayed until moisture is present.

Mineralization proceeds most rapidly immediately after biosolids application, provided soil temperature and moisture are favorable. Usually, more than half of first-year N mineralization occurs within the first 3 to 6 weeks following biosolids application.

Organic N mineralized from previous biosolids applications

The organic N not mineralized during the first year after application is mineralized slowly in succeeding years. Thus, when biosolids are applied repeatedly to the same site, the annual application rate needed to meet crop needs is reduced (Figure 2).

Field trials have demonstrated that crop N fertilizer requirements are reduced for several years following biosolids application. For example:

- In dryland cropping systems in the 10- to 14-inch precipitation zone in central Washington, the amount of N fertilizer needed to attain maximum yield was reduced from approximately 60 lb N/a to 20 lb N/a for the second crop following an agronomic biosolids application (3 dry ton/a).
- In western Washington, N fertilizer needs for a cool-season grass forage (tall fescue) were reduced by about 60 lb N/a during the second year following a one-time application of biosolids at 4 dry ton/a.

The worksheet used for estimating agronomic application rates of biosolids (PNW 511-E) explains how to estimate credits for N mineralized from biosolids applied in previous years.

Building soil organic matter

Biosolids N is cycled through soil organisms and crops. This process allows some of the applied biosolids N to remain in the field for 5 or more years (Figure 2). An increase of 0.1 percent in soil organic matter (e.g., from 3.0 to 3.1 percent) represents an increase in soil N of about 100 lb N/a (0- to 6-inch depth).

Biosolids phosphorus (P)

Biosolids supply large quantities of P when applied to meet crop N needs. The P supplied by biosolids can provide a long-term benefit to soil fertility when applied to P-deficient soils. Where P is already high, however, increasing soil P can increase the potential for P loss from the field to surface water.
Controlling P loss to sensitive water bodies is an important environmental issue. Algae blooms in surface waters can be triggered by P inputs. Algae blooms can reduce water clarity, create unpleasant swimming conditions and odors, interfere with boating and fishing, and harm fish or other aquatic life. Phosphorus-induced algae blooms occasionally produce substances toxic to humans and livestock.

Agronomic soil tests for P were created to determine the probability of increased crop yield in response to P fertilizer application. These same test methods are now used to assess the risk of P movement from agricultural fields to nearby surface water bodies. Generally speaking, the risk of P loss to nearby water bodies is low to medium at soil test P levels considered near the optimum for crop production (Figure 3). High agronomic soil test P values correspond with higher risk of P loss to nearby surface water.

Two soil test methods are routinely used to determine soil test P in the Pacific Northwest, the Bray P1 test for acid soils west of the Cascades, and the Olsen (bicarbonate) test for neutral or alkaline soils east of the Cascades. Agronomic interpretations of these soil tests are given in Table 3.

When P soil test values are low to medium (Bray P1 test below 40 ppm; Olsen P test below 25 ppm), a biosolids application is likely to correct soil P deficiency and increase crop yield (Figure 3). When soil test values are in the high or excessive range, biosolids P is unlikely to benefit crop production and may increase the risk of P loss to nearby water bodies at sensitive locations.

It is important to keep in mind that soil test P is only one of many factors that affect a field’s overall risk of P loss to water. The USDA Natural Resources Conservation Service (NRCS) Phosphorus Index uses P soil test values, together with other site and management factors, to evaluate this risk. Field distance to a water body and soil erosion risk are usually the most important factors that determine field susceptibility to P loss.

**Biosolids P versus fertilizer P**

Compared to inorganic P fertilizers, a smaller fraction of the total P in biosolids is plant-available. Research in the Pacific Northwest has demonstrated that plant-available P is typically 20 to 60 percent of total biosolids P.

<table>
<thead>
<tr>
<th>Soil test category</th>
<th>West of Cascades Bray P1 test (ppm)</th>
<th>East of Cascades Olsen P test (ppm)</th>
<th>Is P fertilizer recommended?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>below 20</td>
<td>below 10</td>
<td>Yes, for most crops</td>
</tr>
<tr>
<td>Medium</td>
<td>20 to 40</td>
<td>10 to 25</td>
<td>Yes, for some crops</td>
</tr>
<tr>
<td>High</td>
<td>40 to 100</td>
<td>25 to 50</td>
<td>Only starter P fertilizer for a few crops</td>
</tr>
<tr>
<td>Excessive</td>
<td>above 100</td>
<td>above 50</td>
<td>No</td>
</tr>
</tbody>
</table>

The example below shows how to estimate plant-available P per dry ton of biosolids to obtain a rough estimate of P fertilizer replacement value.

**Question:** How much P fertilizer \((P_2O_5)\) can be replaced by a dry ton of biosolids when total biosolids P is 2 percent and plant-available P is estimated at 40 percent of total P?

**Equation:** \((\%\text{ total P in biosolids x 2,000 lb/ton}) \times \%\text{ plant-available P} \times 2.29\) conversion factor

\[
\text{Answer: } (0.02 \times 2,000) \times 0.4 \times 2.29 = 37 \text{ lb } P_2O_5/\text{dry ton of biosolids}
\]

Chemical characterization of a particular biosolids product can provide a more accurate representation of P availability. See the Appendix for details.

### Biosolids potassium (K)

Biosolids contain only a small amount of K relative to other macronutrients. In most situations, the contribution of biosolids to soil K fertility is insignificant. The lack of K in biosolids can have crop management implications in a few situations.

- When soil K is deficient, K must be supplied from fertilizer or another source. Agronomic soil testing is used to forecast the need for K fertilizer application. Consult university fertilizer or nutrient management guides for crop-specific interpretation of soil test K values.
- Fertilizers that are low in K, such as biosolids, can be beneficial for some ornamental crops that are very sensitive to soluble salts or excess K. Examples include rhododendrons and azaleas.
- Potassium can accumulate in plant tissue when plants are grown on soils that are high in K. High concentrations of K in grass or legume forages can exacerbate animal nutritional disorders (such as grass tetany disorder in cattle). Biosolids are a low-K fertilizer alternative for forage production on soils that contain excessive K (see the sidebar “Fertilizing grass for forage”).

### Biosolids sulfur (S)

Biosolids application rates designed to supply adequate N provide sufficient S, even for crops that have a high S demand (e.g., canola). Biosolids supply both rapidly available S (from oxidation of sulfides) and slow-release S (from decomposition of biosolids organic matter). Approximately 15 to 40 percent of biosolids S is oxidized to the plant-available form (sulfate-S) during the first year after biosolids application.

For more information about using biosolids to meet fertilizer needs, see “Using university fertilizer guides with biosolids application,” page 8.

### Salts

Biosolids contain lower concentrations of salts than most animal manures. Most of the salts present in wastewater are discharged from treatment facilities in treated water. Liquid biosolids contribute higher amounts of salt than biosolids that are processed to reduce moisture content. After application to soil, some salts are released from biosolids by decomposition of organic matter.

Repeated biosolids applications have not resulted in detrimental salt accumulations in soil.
even at sites with low annual precipitation and no irrigation.

**Example:** Dewatered cake biosolids (80 percent moisture) have been applied annually for more than 10 years to dryland pastures near Hermiston, OR (6-inch annual precipitation). At this site, electrical conductivity (a measure of soluble salts in soil) has not increased above 1 mmho/cm, a value considered low (see OSU Extension publication EC 1478, *Soil Test Interpretation Guide*).

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**Using university fertilizer guides with biosolids application**

Nutrient management practices for biosolids can differ from recommendations found in university fertilizer/nutrient management guides. Because biosolids nutrient management is more complex than commercial fertilizer management, it may be helpful to consult a certified soil scientist or other agricultural professional specializing in nutrient management planning and monitoring.

This sidebar presents examples of special considerations for biosolids application.

**Nitrogen**

Agronomic application rates for biosolids (calculated using PNW 511-E) are designed to replace fertilizer N. PNW 511-E estimates crop N need using university fertilizer or nutrient management guides. However, subtle differences in management between soluble N fertilizers and biosolids can be important.

**Example 1:** The OSU fertilizer guide for western Oregon pastures recommends application of N in fall and early spring. Research demonstrates that a single application of biosolids in late summer or fall can substitute for both fall and spring pasture fertilization with commercial N fertilizer.

**Example 2:** Fertilizer guides are not available for all crops, and some fertilizer guides do not reflect current management practices. In such cases, the regulatory agency typically consults with agronomists or university faculty regarding initial biosolids application rates and requires soil and/or plant tissue testing to confirm that N supplied is not excessive. This approach was used to determine biosolids application rates for dryland pastures in eastern Oregon near Hermiston, a setting for which a fertilizer guide was not available.

**Phosphorus**

Biosolids P is less plant-available than is P from commercial fertilizer. Biosolids P has a typical fertilizer replacement value of 40 percent, but this estimate varies considerably among biosolids sources. Keep in mind the lower availability of biosolids P when using university fertilizer guides. See also pages 18–19.

Note the following situations in which biosolids P application recommendations may differ from those found in fertilizer guides.

**Example 1:** Sometimes, biosolids application is justified where soil test P is high or excessive, situations in which fertilizer guides would recommend no P application. This situation can occur where other benefits (nutrient supply and improved soil quality) are expected from biosolids application, the field is not close to a water body, and the P is unlikely to damage water quality. This scenario is common in dryland cropping systems east of the Cascades.

**Example 2:** Fertilizer/nutrient management guide recommendations for P fertilizer application are based on the probability of obtaining a profitable crop response to P fertilizer application. Recommendations are for a single growing season. Biosolids application is often practical only once per crop rotation (every 3 to 6 years). When biosolids are applied infrequently, some of the P not used by the initial crop will remain in the soil and meet needs of other crops in the rotation. Soil testing every 3 to 5 years is usually the best way to assess cumulative effects of biosolids P application.

To get meaningful soil test P data, sampling and testing protocols must be consistent. Always sample to the same soil depth and avoid including crop residues present on the soil surface in the soil sample. Additional soil sampling considerations are described in publications listed under “For more information” on page 16. Agricultural soil testing laboratories that meet professional standards are listed on the North American Proficiency Testing, Proficiency Analysis Program (NAPT-PAP) website (http://www.naptprogram.org/pap).
Soil pH

Maintaining an appropriate soil pH is essential for continued productivity of cropping systems. Biosolids application can increase or decrease soil pH, depending primarily on whether alkaline materials are used in biosolids processing (Table 4).

Alkaline-stabilized biosolids

Some biosolids are stabilized with alkaline materials (calcium oxide or calcium hydroxide) to reduce odors and meet USEPA pathogen reduction requirements. In a typical alkaline stabilization process, the biosolids/alkaline material mixture reaches a pH of 12 or greater for at least 2 hours. At this high pH, ammonia loss is rapid.

After land application, the residual alkaline material rapidly neutralizes soil acidity, thereby increasing soil pH (the first process in Table 4). Thus, alkaline-stabilized biosolids act as a replacement for agricultural limestone. Alkaline-stabilized biosolids sometimes contain 20 to 40 percent lime (equivalent to 0.2 to 0.4 ton of agricultural lime per dry ton of biosolids). The extent of the increase in soil pH and exchangeable soil Ca following biosolids application can be used to determine the liming value of a biosolids/alkaline materials application.

It is important to consider current soil pH and the crops that might be grown in rotation before applying alkaline-stabilized biosolids. Increasing soil pH may not be beneficial for acid-loving crops such as blueberries and some nursery crops (rhododendrons and maples).

East of the Cascades, take care when applying alkaline-stabilized biosolids to high-pH soils (pH above 7). In high-pH soils, the nutrients in alkaline-stabilized biosolids can be beneficial, but the added lime is not.

Biosolids stabilized without alkaline materials

Following application of biosolids that do not contain added alkaline materials, the change in soil pH is the net result of the last three factors listed in Table 4. Shortly after application, a drop in soil pH (acidification) may be observed, usually 0.2 to 0.5 pH unit. This pH decrease is caused by the addition of soluble salts and by the oxidation of organic N and S compounds. This pH drop usually is short lived and is balanced by the Ca and Mg added by biosolids.

In most situations, biosolids application does not have a major effect on the need for liming or S application to adjust soil pH. Long-term field trials (over 10 years) in the Pacific Northwest have demonstrated that soil pH values were similar (within 0.2 to 0.4 pH unit) when crops were fertilized with dewatered, anaerobically digested biosolids or with commercial N fertilizers. In a 5-year trial on a silt loam soil in Oregon, biosolids compost acidified soil by 0.5 pH unit (compared to a no-compost control). In contrast, yard debris

<table>
<thead>
<tr>
<th>Table 4. Biosolids effects on soil pH.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of biosolids</td>
</tr>
<tr>
<td>Alkaline-stabilized</td>
</tr>
<tr>
<td>All</td>
</tr>
<tr>
<td>All</td>
</tr>
<tr>
<td>All</td>
</tr>
</tbody>
</table>
compost increased soil pH by 0.3 unit versus the no-compost control.

Because several factors are involved in determining how biosolids application will affect soil pH, monitoring of soil pH is recommended. Monitor the long-term effects of biosolids application on soil pH with soil testing every 3 to 5 years.

**Soil quality**

Biosolids application also affects soil chemical, physical, and biological properties. Together, these properties determine soil quality. Biosolids supply both nutrients and organic matter for soil quality improvement. The changes in soil quality accompanying biosolids application generally improve the capacity of crops to utilize nutrients. Potential benefits of biosolids application on soil quality are listed in Table 5.

The organic matter provided by a single biosolids application does not by itself increase soil organic matter a great deal. However, when combined with other soil management practices that favor accumulation of organic matter (e.g., reduced tillage and use of cover crops), biosolids application helps improve soil quality.

When biosolids are applied at a site for many years, they can directly increase soil organic matter. For example:

- In a dryland wheat-fallow rotation in Douglas County, WA, experimental plots were treated with agronomic rates of biosolids (3 dry ton/a every 4 years from 1994 through 2010 for a total of 15 dry tons). Of total biosolids carbon applied, 60 percent was stored in soil organic matter.

<table>
<thead>
<tr>
<th>Physical</th>
<th>Chemical and biological</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Greater water-holding capacity</td>
<td>• Increased cation exchange capacity</td>
</tr>
<tr>
<td>• Improved tilth</td>
<td>• Slow release of plant-available N and S from organic forms</td>
</tr>
<tr>
<td>• Reduced soil erosion</td>
<td>• Correction of micronutrient deficiencies</td>
</tr>
</tbody>
</table>

**Table 5. Ways in which biosolids can improve soil quality.**

The most dramatic improvements in site productivity are observed when biosolids are applied to land that is severely eroded or affected by excess sodium. For example:

- Agronomic applications of biosolids have been successful in stabilizing sandy “blow-out” areas (small sand dunes) in dryland pastures near Hermiston, OR. Before biosolids application, revegetation of the blow-outs had not occurred for more than 45 years following range fires. Vegetation establishment accompanying biosolids application was likely due to several positive effects of biosolids on soil quality: increased aggregation of soil at the surface, improved soil nutrient status, and greater water-holding capacity.

- In a replicated field trial, WSU scientists demonstrated that high rates (30 ton/a) of aged lagoon biosolids improved wheat establishment on a sodic (sodium-affected) soil. The untreated soil had an exchangeable sodium percentage of 40 percent and pH above 9.5. No vegetation was present. Soil that was amended with both biosolids and gypsum had better wheat growth than soil treated with gypsum alone. Biosolids increased soil organic matter and improved soil aggregation in samples taken 18 months after application. Plant response was dramatic even though changes in soil test values for pH, exchangeable sodium, compaction, and water infiltration were small.

- In a 3-year trial on a field with exposed subsoil at WSU-Prosser (Yakima Valley), biosolids fertilization increased corn grain yield by 10 percent over that attained with commercial N fertilizer. In this trial, some of the yield increase with biosolids was associated with correction of Zn deficiency.

Because most of the nutrients provided by biosolids remain near the soil surface, biosolids application may increase growth of some weedy species. For example, east of the Cascades, cheatgrass (*Bromus tectorum*) growth is stimulated by biosolids application. On dryland pastures, where cheatgrass can be grazed effectively in early spring, the increase in cheatgrass growth is an asset to beef production. In dryland wheat cropping systems where cheatgrass is present, biosolids application may increase cheatgrass competition with the crop.
The addition of biosolids increased soil organic matter (measured in 2012) from 1.6 to 2.9 percent in the 0- to 4-inch soil depth. This result was seen in a conventionally tilled system that did not favor organic matter preservation.

- Biosolids were applied at an agronomic rate (6 dry ton/a/year) to the surface of a cool-season perennial grass crop at WSU-Puyallup for 10 consecutive years. The result was a long-term increase in soil organic matter. Nine years after the final biosolids application, organic matter in the 0- to 6-inch depth was 4.8 percent in the plots that received biosolids, compared to 3.9 percent in plots that received inorganic N fertilizer.

A smaller, but significant, long-term increase in organic matter occurred in the 6- to 12-inch depth. The increase in organic matter below the surface layer was likely due to the action of earthworms and increased root growth, because the site was not tilled. The amount of carbon stored in the soil following biosolids application was equivalent to 27 percent of the biosolids carbon applied.

Biosolids that are composted or aged for many years in treatment lagoons can be applied at high rates, supplying large quantities of organic matter. These biosolids are suited for high-rate applications because they usually contain very low amounts of plant-available N (3 to 5 lb/dry ton) relative to biosolids produced via short-term aerobic or anaerobic digestion (more than 30 lb available N/dry ton).

See the sidebar “Biosolids effects on soil quality” (page 10) for more information.

### Biosolids quality

Biosolids quality is based on the following:

- Trace element concentrations in biosolids
- The completeness of the pathogen reduction process used by the wastewater treatment facility
- Organic matter stabilization achieved by digestion, composting, or other processes

at the wastewater treatment facility.

Stabilization, called “vector attraction reduction” in USEPA biosolids rules, is important for reducing odors and making biosolids less attractive to pests such as insects and rodents.

Together, these quality factors determine whether site approvals by a regulatory agency are required for biosolids application.

### What about heavy metals?

Heavy metals were a concern when land application of biosolids began in the 1970s. However, since then, source control activities have been very effective in decreasing metal inputs to wastewater treatment facilities.

- Wastewater treatment facilities limit metals in incoming wastewater by issuing permits to industrial wastewater sources. To meet permit requirements, industries adopt cleaner manufacturing processes or pretreat wastewater to remove metals. Industrial sources are required to routinely monitor for specific metals in their wastewater.
- Adjustment of city water supplies to a higher pH has reduced pipe corrosion and the concentrations of Zn, Cu, and Fe in wastewater.
- The use of PVC pipe instead of metal pipe also has reduced metal concentrations.

Metals in Portland biosolids have been reduced by a factor of 2 to 10 since 1981 (Table 6). Today, biosolids metal concentrations are similar for cities with industrial inputs (Portland, Table 6) and smaller cities with few industrial inputs (Oregon average, Table 7, page 12).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>40</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Copper</td>
<td>1,000</td>
<td>481</td>
<td>384</td>
<td>374</td>
</tr>
<tr>
<td>Lead</td>
<td>900</td>
<td>181</td>
<td>108</td>
<td>85</td>
</tr>
<tr>
<td>Nickel</td>
<td>190</td>
<td>39</td>
<td>49</td>
<td>50</td>
</tr>
<tr>
<td>Zinc</td>
<td>2,200</td>
<td>834</td>
<td>921</td>
<td>1,165</td>
</tr>
</tbody>
</table>

*a1981 concentrations are approximate values. Data for 1996–2013 were derived from City of Portland biosolids management reports to Oregon DEQ.*
Trace elements

The federal rule administered by USEPA sets thresholds for trace element concentration in biosolids. Some of the regulated elements are plant nutrients (Cu, Mo, and Zn), so in some situations plants benefit from trace element application.

There are two sets of trace element concentration thresholds: ceiling concentration limits (the maximum allowed) and a more stringent set, exceptional quality (EQ) limits. Sewage solids that exceed the ceiling concentration limits cannot be called biosolids and cannot be land applied. University research conducted for many years at many sites supports these limits. The EQ limits are for biosolids products distributed directly to the public.

Table 7 shows the USEPA ceiling concentration limit and EQ limit for various trace elements in biosolids, as well as Oregon and national averages for these elements.

See the sidebar “What about heavy metals?” page 11, for more information.

Pathogen reduction

Pathogens are organisms, such as bacteria, that can cause disease. Before application to cropland, biosolids must be processed to meet either USEPA Class A or Class B pathogen reduction standards for pathogens that can cause disease in humans.

Class A biosolids are essentially pathogen-free and usually are sold or distributed in urban areas for landscaping or turf fertilization. See the sidebar on page 13, “Using biosolids in gardens and landscapes,” for more information. Because of the greater flexibility in management afforded by Class A treatment, many facilities are moving toward Class A biosolids production.

Class B biosolids have been processed to significantly reduce, but not eliminate, pathogens. Biosolids of Class B quality usually are delivered to farmers for land application. The most common processing methods for Class B biosolids are

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Table 7. Trace elements in biosolids: USEPA concentration limits and average concentrations.

<table>
<thead>
<tr>
<th>Trace element</th>
<th>USEPA ceiling concentration limit (mg/kg)a</th>
<th>USEPA exceptional quality limit (mg/kg)a</th>
<th>USEPA National Survey (2010) (mg/kg)b</th>
<th>Oregon biosolids average (2011) (mg/kg)c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>75</td>
<td>41</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Cadmium</td>
<td>85</td>
<td>39</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Copper</td>
<td>4,300</td>
<td>1,500</td>
<td>558</td>
<td>296</td>
</tr>
<tr>
<td>Lead</td>
<td>840</td>
<td>300</td>
<td>77</td>
<td>36</td>
</tr>
<tr>
<td>Mercury</td>
<td>57</td>
<td>17</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>75</td>
<td>75d</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>Nickel</td>
<td>420</td>
<td>420</td>
<td>49</td>
<td>31</td>
</tr>
<tr>
<td>Selenium</td>
<td>100</td>
<td>100</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Zinc</td>
<td>7,500</td>
<td>2,800</td>
<td>994</td>
<td>719</td>
</tr>
</tbody>
</table>

aSource: USEPA Guidelines for Pollutant Concentrations in Biosolids (40 CFR Part 503). The ceiling concentration limit is the maximum allowed for land application of biosolids. The exceptional quality limit applies to biosolids suitable for distribution without site approvals. To be called "exceptional quality biosolids" by USEPA, biosolids must also be Class A for pathogen reduction.

bSource: Brobst, USEPA Targeted National Sewage Sludge Survey summary for trace elements (2010).

cAverage across the 17 largest Oregon municipal wastewater treatment facilities as reported to Oregon DEQ for 2011. Source: R. Doughten, Oregon DEQ.

dThe USEPA exceptional quality limit for Mo is currently under review.
aerobic or anaerobic digestion. Some treatment facilities add alkaline materials such as calcium hydroxide to kill pathogens and meet Class B standards.

After land application, pathogens in Class B biosolids are killed by exposure to sunlight, drying conditions, unfavorable pH, and other environmental factors. Site management practices required at Class B biosolids application sites, including setbacks and access restrictions, protect public health.

**Organic matter stabilization**

Both Class A and Class B biosolids must meet stabilization standards to reduce odors and to reduce attractiveness to insects and rodents.

**Site approvals for biosolids application**

**Is site approval needed?**

Whether you need a permit or site approval for biosolids application to cropland depends on the following:

- Trace element concentrations in the biosolids relative to USEPA standards
- Whether the biosolids meet USEPA Class A or Class B pathogen reduction requirements

Site approvals are required for all Class B biosolids application, regardless of trace element concentrations in the biosolids.

Site approvals may be required for Class A biosolids application if trace element concentrations exceed exceptional quality (EQ) limits, or if the biosolids are not stabilized sufficiently via digestion or composting. See “Biosolids quality” for details on these regulatory requirements.

**Who obtains site approval?**

When needed, site approvals for biosolids application generally are obtained by wastewater treatment facility representatives. Some private companies, working under contract with a wastewater treatment facility, may assist in obtaining site approval.

**Using biosolids in gardens and landscapes**

Biosolids that meet Class A pathogen reduction and EQ trace element standards can be used in gardens and landscapes. Three types of Class A biosolids are produced and marketed for garden and landscape use: heat-dried products, biosolids composts, and Class A blends.

Heat-dried biosolids have similar nutrient concentrations and availability as Class B cake used in agriculture, except that the ammonium is lost during drying. Heat-dried biosolids are applied at agronomic rates for lawn and garden fertilization.

Biosolids composts are made from biosolids composted with yard debris or wood waste. They have low N availability, similar to other composts, and are applied at high rates to quickly build soil organic matter.

Class A blends contain Class A dewatered cake mixed with other organic and mineral materials such as sawdust, aged bark, or screened sand. Class A blends have a variety of uses, depending on the composition of the blend. Different blends are used as top-dressing for lawns, potting mixes, soil builders, and raised bed amendments, or as manufactured topsoil.

![Figure 7. Research has shown the benefits of biosolids application for many landscape plants. Top: Soil amended with biosolids. Bottom: No biosolids application.](Dan_M._Sullivan_©_Oregon_State_University)
What agency supervises site approvals for biosolids application sites?

Oregon: Department of Environmental Quality
Washington: Washington State Department of Ecology
Idaho: Department of Environmental Quality

All state agencies use a site approval process that conforms with USEPA rules. Detailed information on site approval processes can be found on state agency websites.

Questions about biosolids

What limits the rate of biosolids that can be applied?
Agronomic application rates are based on matching plant-available N supplied by biosolids to the plant-available N needs of the crop.

How are biosolids odors managed?
The same processes that kill pathogens in biosolids (e.g., digestion) reduce odor after application. The processing method used affects odor potential. Biosolids that are dewatered with centrifuges are more likely to cause odor problems than biosolids from belt filter presses. When lime is used for stabilization, the organic matter in biosolids is usually not fully digested and is more likely to cause odor. Biosolids dried to below 40 percent moisture are less odiferous.

Tillage after biosolids application further reduces odor, but tillage is not practical when biosolids are applied to established perennial crops, such as grass pastures.

Minimizing odor should be a primary consideration in choosing fields for biosolids application, the timing and method of application, and the location of biosolids delivery/storage on the farm. Most odor complaints arise on days with air inversions that trap the odiferous air near ground level.

How much time is required for biosolids application relative to conventional inorganic fertilizer application?
Biosolids application is much slower than conventional fertilizer application, because of the large quantities of material involved. Several weeks may be required to complete application to large fields. For this reason, perennial grass pastures are one of the most common application sites. Dryland wheat grown on a wheat-fallow rotation (crop planted every 2 years) offers a good opportunity for biosolids application during the fallow year. Annual crops can be fertilized with biosolids, but careful scheduling is required.

If biosolids are a valuable resource, why are they provided at no charge to the landowner?
Not all biosolids are free. Some municipalities charge a transportation fee, an application fee, or a fee equal to the N value of the biosolids. Municipalities that produce Class A biosolids for gardens and landscapes often sell their products to the public and can gain significant cost recovery.

In some cases, biosolids application to agricultural crops is free, which compensates landowners for their time and effort. Often, field operations must be scheduled to accommodate biosolids application, and management practices specified by the regulatory agency must be followed after application.

Can biosolids be used on farms that produce crops under organic certification?
Under USDA National Organic Program (NOP) rules, biosolids application is prohibited. This prohibition is based on produce marketing considerations, not on a scientific risk assessment.

In terms of the risk of human pathogen infection, Class A biosolids are likely to be safer than manure processed under NOP rules. Treatment facilities producing Class A biosolids are required to demonstrate that their treatment process meets prescribed time and temperature standards. They are also required to monitor biosolids products for human pathogen indicator
organisms, such as *Salmonella*. In contrast, under NOP rules, requirements for documentation of temperatures achieved during composting are less stringent, and composted manure does not have to be tested for the presence of human pathogen indicator organisms before use on organically certified crops.

**Should I be concerned about contaminants in biosolids that are not addressed under federal and state biosolids rules?**

Wastewater contains a variety of synthetic organic compounds, and research on the effects of these compounds is ongoing. Recent research has focused on personal care products (pharmaceuticals, cosmetics, etc.) and fire retardants. Research indicates that risks to human health and the environment from these compounds are negligible when biosolids are managed according to state and federal rules. These compounds are unlikely to endanger human health or the environment for three reasons.

- Synthetic organic compounds that survive wastewater treatment are degraded or strongly bound to organic matter in soil.
- Plant roots do not take up significant amounts of these compounds.
- Site management practices for biosolids (such as buffer zones and restrictions on application timing) reduce the opportunity for these compounds to move to water bodies.

**How do biosolids utilization practices affect greenhouse gas emissions?**

Analyses of the energy impacts of biosolids utilization practices are now a part of engineering analyses performed when wastewater treatment facilities are upgraded. These analyses consider overall greenhouse gas emissions resulting from biosolids processing and utilization.

Land application of biosolids almost always results in lower greenhouse gas emissions than competing practices (burning biosolids or burying them in a landfill). Land application of biosolids puts carbon into the soil for an extended period.

When biosolids replace commercial fertilizers derived from fossil fuels, they reduce greenhouse gas emissions. It takes the equivalent of about 3,000 cubic feet of natural gas to manufacture a ton of commercial fertilizer N.¹

Stabilizing biosolids with lime uses a lot of energy. Limestone (calcium carbonate) is mined, transported, and processed to make the “quick lime” used to kill pathogens in biosolids products. Heat-drying biosolids also uses considerable energy.

Transportation of biosolids to field application sites consumes energy, although transportation emissions are small compared with emissions savings from replacing inorganic fertilizer with biosolids. Nonetheless, finding ways to utilize biosolids close to urban centers will further increase emissions savings.

¹Sawyer, John E., Mark Hanna, and Dana Petersen. 2010. *Energy Conservation in Corn Nitrogen Fertilization*. Iowa State University Extension publication PM 2089i. https://store.extension.iastate.edu/Product/pm2089i-pdf
For more information

Agronomic rate worksheet
Excel worksheet with calculations from PNW 511 is available via the WSU-Puyallup website: http://puyallup.wsu.edu/soilmgmt/Biosolids.html

Soil sampling and testing

Biosolids in home landscapes and gardens

Forage production with biosolids

Biosolids benefits, contaminant risk, and regulations
Acknowledgments

The authors thank the following reviewers for their helpful suggestions for improving the technical merit and readability of this publication:

Greg Charr, City of Portland
Mark Cullington, Kennedy/Jenks
Joan Davenport, Washington State University-Prosser
David Granatstein, Washington State University-Wenatchee
Kate Kurtz, King County, WA
Amber Moore, University of Idaho-Twin Falls
Tressa Nichols, Idaho Department of Environmental Quality
Peter Severtson, Washington Department of Ecology
Steve Wilson, Brown & Caldwell

Field research references:

**Biosolids nutrient management in the Pacific Northwest**

**Listed in chronological order**


See the Appendix for phosphorus references.
Biosolids processing methods affect the value of biosolids as a P fertilizer, as well as the risk of P loss in runoff from fields after application. Soluble P carried by runoff to water bodies can damage water quality.

This section discusses two laboratory analyses that can help characterize the fertilizer value of biosolids and their risk to water quality. Both tests have been validated by research in Oregon and across the United States.

**Water-extractable phosphorus (WEP) as a fraction of total P**

**Rationale:** The greatest hazard to water quality occurs when a highly soluble P source is surface applied to soil and application is followed by heavy precipitation. The water-extractable P (WEP) test was created to rank organic fertilizers for water quality risk.

**Method overview:** Biosolids P is extracted by shaking with water. The P concentration in the water is then measured. The national protocol for use with organic fertilizers uses a 1:100 dry biosolids to water ratio (Kleinman et al., 2007).

The biosolids WEP value is expressed in relation to biosolids total P (WEP/total P) to estimate relative P solubility. This ratio is typically less than 0.2 for biosolids, 0.3 to 0.5 for manures, and 0.8 to 1.0 for commercial P fertilizers.

**Interpretation:** Research has shown that higher WEP values indicate higher risk of P loss in runoff. For example, in a rainfall simulator study, the concentration of P in runoff was 5 to 10 times greater for animal manures (beef, dairy, poultry; n=7) than for dewatered biosolids (n=5). Both biosolids and manures were applied at equivalent total P application rates, but manures had higher WEP than biosolids (Kleinman et al., 2007).

**Application:** Simulation models can predict P loss in runoff for many field management scenarios. Recent versions of nutrient management planning software developed by the Natural Resources Conservation Service (NRCS) employ WEP values to predict short-term risk of P loss in runoff.

**Phosphorus Sorption Index (PSI)**

**Rationale:** Some biosolids processing facilities add Al (aluminum sulfate) or Fe (ferric chloride). Iron and Al bind P in insoluble forms.

**Method overview:** Biosolids samples are digested in strong acid to determine total P, Al, and Fe concentrations. Lab data are then expressed as the molar ratio of P to Al plus Fe: [P/(Al + Fe)]. This ratio is termed the Phosphorus Sorption Index (PSI).

**Interpretation:** PSI is used to compare P solubility of different biosolids. A low PSI indicates low P solubility, because Al and Fe are present to bind P in insoluble forms.

OSU research (Choate, 2004) showed that digestion of biosolids for total metals analysis by strong acid digestion (nitric acid plus hydrogen peroxide; similar to USEPA 3051 digestion method) yielded similar PSI values to those obtained by the most common research digestion method (acid-ammonium oxalate extraction). Digestion of biosolids for total metals analysis is routinely performed by commercial analytical laboratories that serve the biosolids industry, while the acid-ammonium oxalate extraction method is a research method, not commonly performed by commercial laboratories.

**Application:** At PSI values above 0.6, WEP values increased (Figure 9, page 19), indicating greater potential risk to water quality. OSU research also found that PSI was a rough indicator of the relative P fertilizer value of different biosolids sources (Figure 10, page 19, and Choate, 2004).

PSI analysis can be included as part of routine biosolids analysis done for regulatory compliance. Ask the lab to determine total Fe and Al present after biosolids sample digestion in strong acid using an ICP spectrophotometer.
Phosphorus references

Listed in chronological order


