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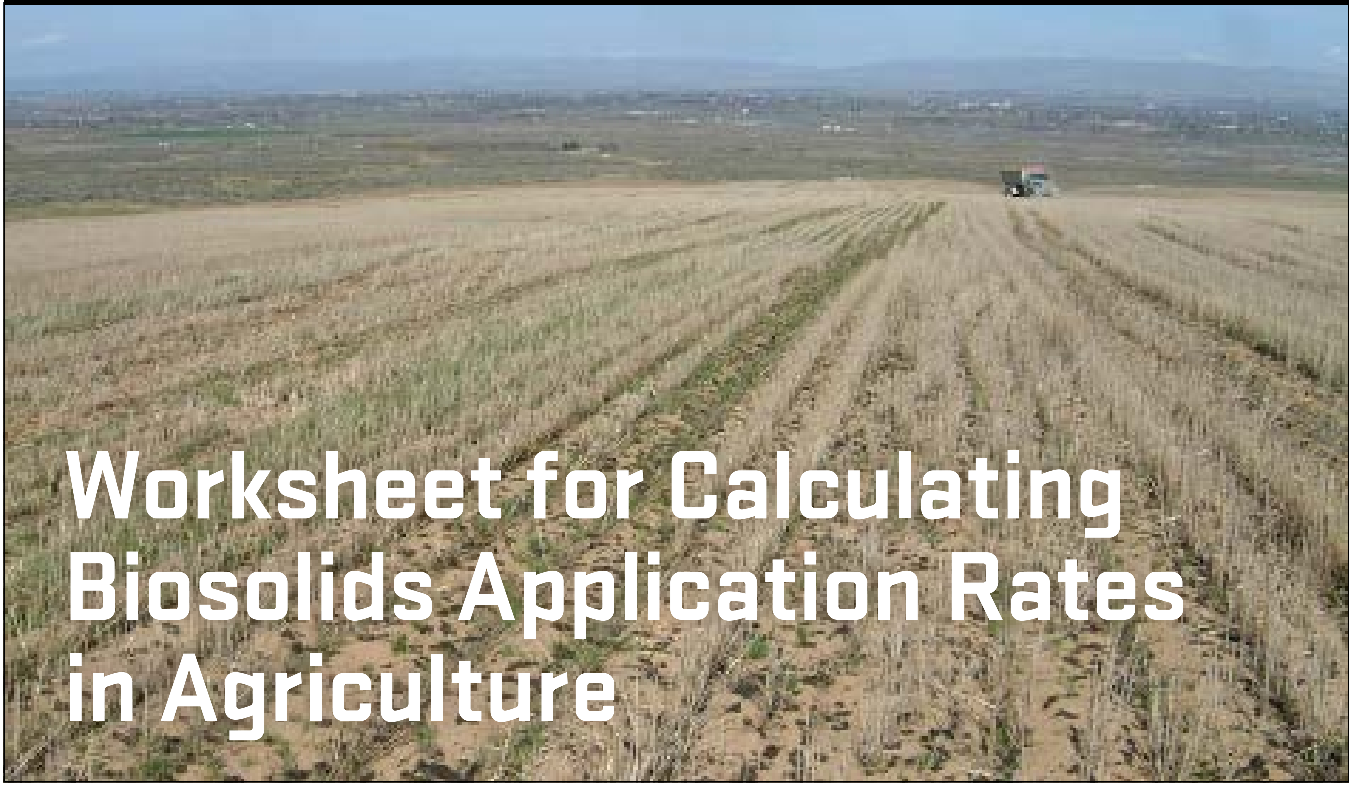

Worksheet for Calculating Biosolids Application Rates in Agriculture

Photo: Brian Campbell, Natural Selection Farms

Dan M. Sullivan, Deirdre Griffin LaHue, Biswanath Dari, Andy I. Bary and Craig G. Cogger

Biosolids are a product of municipal wastewater treatment. Raw sewage solids must be processed to meet U.S. Environmental Protection Agency standards before they can be called biosolids. Biosolids contain organic matter and nutrients that are beneficial for soil and crop productivity.

This publication focuses on matching the nitrogen (N) supplied by biosolids to the nitrogen needs of the crop. Regulatory agencies require agronomic rate calculations for most biosolids applications to cropland.

Overview: agronomic rate calculation

There are six steps to calculate the agronomic rate of a biosolids application:

1. Collect information on the site and crop, including crop N requirement.
2. Estimate the plant-available N needed from the biosolids application.
3. Collect biosolids N data.
4. Estimate plant-available N per dry ton of biosolids.
5. Calculate the agronomic biosolids application rate on a dry ton basis.
6. Convert the application rate to an "as is" basis.

In determining biosolids application rates, it's important to evaluate trace element concentrations in biosolids and the regulatory limits for trace element application (see Appendix A). However, in almost all cases, nitrogen controls the biosolids application rate.

A companion publication, *Fertilizing with Biosolids* (PNW 508), provides additional information about the value of biosolids as a fertilizer. The "For more information" section of this publication gives a summary of Pacific Northwest research and Extension publications on land application of municipal biosolids.

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WORKSHEET

For guidance on completing this worksheet, see "How to Use the Worksheet," starting on page 5.

Step 1. Collect site information

Soil and crop information:

Line number		Your information	Example
1.1	Soil series and texture (NRCS soil survey)		Puyallup sandy loam
1.2	Yield goal (units/acre/year*) estimated from grower records or by agronomist**		5 tons/acre
1.3	Crop rotation (grower; e.g., wheat, fallow, wheat)		perennial grass
1.4	Plant-available N needed to produce yield goal (university fertilizer/nutrient management guide; agronomist) (lb N/acre/year)		200 lb N/acre

Plant-available N provided by other sources:

Line number		Your calculation	Example	Unit
Pre-application testing				
1.5	Nitrate-N applied in irrigation water		10	lb N/acre
1.6	Preplant nitrate-N in root zone (east of Cascades)***		—	lb N/acre
Adjustments to typical soil N mineralization				
1.7	Plowdown of cover or green manure crop***		—	lb N/acre
1.8	Previous biosolids applications (see Table 1, page 7)		30	lb N/acre
1.9	Previous manure applications		—	lb N/acre
Grower information				
1.10	N applied at seeding (starter fertilizer)		—	lb N/acre
Total				
1.11	Total plant-available N from other sources = sum of lines 1.5 through 1.10		40	lb N/acre

* Yield goals may be expressed in weight (tons, pounds, etc.) or in volume (bushels).
** The American Society of Agronomy certifies professional agronomists as Certified Crop Advisors (CCAs). See https://www.certifiedcropadviser.org for more information.
*** Do not list here if these N sources were accounted for in the nitrogen fertilizer recommendation from a university fertilizer/nutrient management guide.

Step 2. Estimate the amount of plant-available N needed from biosolids

Line number		Your calculation	Example	Unit
2.1	Plant-available N needed to produce yield goal (from line 1.4)		200	lb N/acre
2.2	Plant-available N from other sources (from line 1.11)		40	lb N/acre
2.3	Amount of plant-available N needed from biosolids = line 2.1 – line 2.2		160	lb N/acre

Step 3. Collect biosolids data

Application information:

Line number		Your information	Example
3.1	Moisture content of biosolids		liquid
3.2	Biosolids processing method (see Table 3, page 10)		anaerobic
3.3	Method of application (surface or injected)		surface
3.4	Number of days to incorporation of biosolids		no incorporation
3.5	Expected application season		March to September

Laboratory biosolids analysis (dry weight basis):

If your biosolids analysis is on an "as is" or wet weight basis, you will need to divide your analysis by the percent total solids (line 3.10) and multiply the result by 100 to convert to a dry weight basis.

Line number		Your calculation	Example	Unit
3.6	Total Kjeldahl N (TKN)*		50,000	mg/kg
3.7	Ammonium N*		10,000	mg/kg
3.8	Nitrate N *,**		not analyzed	mg/kg
3.9	Organic N*,*** = line 3.6 – line 3.7		40,000	mg/kg
3.10	Total solids		2.5	percent

* If your analysis is in percent, multiply by 10,000 to convert to mg/kg.
** Nitrate-N analysis required for composted or aerobically digested biosolids, but not for anaerobically digested biosolids.
*** Organic N = total Kjeldahl N – ammonium N.

Step 4. Estimate plant-available N per dry ton of biosolids

Convert biosolids N analysis to lb per dry ton:

Line number		Your calculation	Example	Unit
4.1	Total Kjeldahl N (TKN)*		100	lb N/dry ton
4.2	Ammonium N*		20	lb N/dry ton
4.3	Nitrate N*		not analyzed	lb N/dry ton
4.4	Organic N = line 4.1 – line 4.2		80	lb N/dry ton

*Multiply mg/kg (from lines 3.6 through 3.9) × 0.002. If your analyses are expressed in percent, multiply by 20 instead of 0.002.

Estimate inorganic N retained:

Line number		Your calculation	Example	Unit
4.5	Percent of ammonium-N retained after application (see Table 2, page 9)		55	percent
4.6	Ammonium-N retained after application = line 4.2 × (line 4.5 ÷ 100)		11	lb N/dry ton
4.7	Biosolids inorganic N retained = line 4.3 + line 4.6		11	lb N/dry ton

Estimate organic N mineralized:

Line number		Your calculation	Example	Unit
4.8	Percent of organic N that is plant-available in Year 1 (see Table 3, page 10)		35	percent
4.9	First year plant-available organic N = line 4.4 × (line 4.8 ÷ 100)		28	lb N/dry ton

Plant-available N:

Line number		Your calculation	Example	Unit
4.10	Estimated plant-available N = available inorganic N (line 4.7) + available organic N (line 4.9)		39	lb N/dry ton

Step 5. Calculate the agronomic biosolids application rate

Line number		Your calculation	Example	Unit
5.1	Amount of plant-available N needed from biosolids (from line 2.3)		160	lb N/acre
5.2	Estimated plant-available N in biosolids (from line 4.10)		39	lb N/dry ton
5.3	Agronomic biosolids application rate = line 5.1 ÷ line 5.2		4.1	dry ton/acre

Step 6. Convert to "as is" biosolids basis

Desired units		Your calculation	Example
Gallons per acre =	(line 5.3 ÷ line 3.10) × 24,000		39,400
Inches per acre =	(line 5.3 ÷ line 3.10) × 0.88		1.44
Wet tons per acre =	(line 5.3 ÷ line 3.10) × 100		164

HOW TO USE THE WORKSHEET

Step 1. Collect site information

Soil series and surface soil texture (line 1.1)

Find the location on the Natural Resources Conservation Service (NRCS) soil survey. Record the series name and surface texture of the predominant soil. NRCS soil survey data is available online at https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

Crop yield goal (line 1.2)

Field records are the best source for crop yield estimates. You can find proven yields for most grain farms from the local Farm Service Agency office. For most other cropping systems, grower records are the only source available. Be sure to note whether the yield records are on an "as is" or dry matter basis.

A site used repeatedly for biosolids application should have yield data collected each year. Use this accumulated data for determining crop nitrogen requirement.

Yield data is typically not available for grazed pastures because grazing animals consume the crop in the field. In these cases, omit the yield goal and go directly to line 1.4. Estimate plant nitrogen needs from the appropriate university fertilizer/nutrient management guide, based on the level of pasture management.

Crop rotation (line 1.3)

Consult with the grower and discuss possible crop rotations. Rotations that include root crops or other crops with long post-application waiting periods are not suitable for Class B biosolids application. A companion publication (*Fertilizing with Biosolids*, PNW 508) provides more information about USEPA standards for Class A and Class B biosolids.

Plant-available N needed to produce yield goal (line 1.4)

You can estimate plant-available N needs by referring to university fertilizer/nutrient management guides.

University fertilizer and nutrient management guides

Land grant universities (for example, Washington State University, Oregon State University, and the University of Idaho) publish fertilizer and nutrient management guides that estimate plant-available N needs. Use the guide most appropriate for the site and crop. For major crops, guides may cover irrigated or rainfed (dryland) cropping and different geographic areas. Don't use guides produced for irrigated sites when evaluating dryland sites. When appropriate guides do not exist, consult university Extension agronomists/

soil scientists or professional agronomists (Certified Crop Advisors) who have expertise working within the cropping system.

Nitrogen fertilizer application rates listed in the fertilizer/nutrient management guides are based on field trials conducted under the specified climate and cultural conditions. Growth trial results are averaged over a variety of soil types and years. Note that guide recommendations are not the same as crop uptake. This is because the guides account for N available from mineralization of soil organic matter and the efficiency of N removal by the crop.

The N rate recommended in fertilizer/nutrient management guides assumes average yields, good management practices, and removal of N from the field through crop harvest or grazing. In terms of satisfying crop N needs, plant-available N from biosolids application is considered equal to fertilizer N.

Agronomist calculations

Because of the general nature of university fertilizer and nutrient management guides, it may be worthwhile to have a professional agronomist calculate how much plant-available N is needed for a specific field. The American Society of Agronomy certifies professional agronomists as Certified Crop Advisors (CCAs). See https://www.certifiedcropadviser.org for more information.

Always use the same method to calculate the N requirements. You will need to document your reasons for using agronomist calculations instead of the university guide.

Photo: Andy Bary, ©Washington State University

Dewatered biosolids stockpile at field application site

Plant-available N provided by other sources (lines 1.5 to 1.11)

To make sure there isn't too much nitrogen applied to a crop, you must determine how much nitrogen comes from sources other than biosolids and soil organic matter. These sources of N are grouped into three categories in the worksheet:

- Plant-available N estimated by pre-application testing
- Adjustments to typical soil organic N mineralization (usually obtained from an agronomist)
- Information supplied by the grower

N estimated by pre-application testing (lines 1.5 to 1.6)

Irrigation water

Since the amount of nitrate-N in irrigation water varies, it should be determined by water testing. Irrigation water containing 5 mg nitrate-N per liter will contribute 1.1 pounds of nitrogen per acre-inch applied; irrigation water containing 10 mg nitrate-N per liter will contribute 2.3 pounds of N per acre-inch.

Preplant nitrate-N in the root zone (east of Cascades)

You can estimate the preplant nitrate-N in the root zone by testing the soil in early spring. Sample in 1-foot increments to a depth of at least 2 feet.

Some university fertilizer/nutrient management guides use preplant soil nitrate-N when calculating N fertilizer application rates. If you use these guides, don't count soil test nitrate-N in our worksheet—it has already been accounted for in the recommended fertilizer N rate prescribed in the university fertilizer/nutrient management guide.

In dryland cropping systems, soil testing below 3 feet is used to assess long-term N management. Accumulation of nitrate below 3 feet indicates that past N applications were not efficiently utilized by the crop. However, soil nitrate-N below 3 feet is typically not included as a credit when making a N fertilizer recommendation.

Adjustments to typical soil N mineralization (lines 1.7 to 1.9)

Nitrogen mineralization is the release of nitrogen from organic forms to plant-available inorganic forms (ammonium and nitrate). Soil organic matter supplies plant-available N through mineralization, but this is accounted for in the university fertilizer/nutrient management guides. Sites with a history of cover crops, biosolids applications, or manure applications supply more plant-available N than do sites without a history of these inputs, and biosolids recommendations must be adjusted based on this additional supply of N.

Plowdown of cover crops

Cover crops are not removed from the field, but are recycled back into the soil. You can get an estimate of the total N contributed by estimating the biomass dry matter (lb per acre) and the nitrogen concentration (percent total) in the cover crop. Plant-available N provided by a cover crop typically ranges from 10 to 40 percent of the total N contained in aboveground cover crop biomass. Consult *Estimating Plant-Available Nitrogen Release from Cover Crops* (PNW 636) for more information.

Previous biosolids applications

Previous biosolids applications contribute to plant-available nitrogen in the years after the initial application. In the worksheet, they are considered as "N from other sources." We estimate that 8, 3, 1, and 1 percent of the organic N *originally applied* mineralizes in Years 2, 3, 4, and 5, respectively, after application (Table 1). After Year 5, biosolids N is considered part of "stable" soil organic matter and is not included in calculations.

In using Table 1, consider the following example. Suppose:

- You applied biosolids with an average organic N content of 30,000 mg/kg
- Applications were made the previous 2 years
- The application rate was 4 dry tons per acre

Table 1 gives estimates of nitrogen credits *in terms of the organic N originally applied*. Look up 30,000 mg/kg under Year 2 and Year 3 columns in the table. The table estimates 4.8 lb plant-available N per dry ton for year 2, and 1.8 lb plant-available N for year 3 (two-year credit of 6.6 lb N per dry ton). To calculate the N credit in units of lb per acre, multiply your application rate (4 dry ton per acre) by the N credit per ton (6.6 lb N per dry ton). The N credit is 26.4 lb plant-available N per acre.

Previous manure applications

Previous manure applications contribute to plant-available nitrogen in a similar manner to previous biosolids applications. To estimate this contribution, consider field history (manure type, application rate, and date of application). The Extension publication *Fertilizing with Manure and Other Organic Amendments* (PNW 533) provides plant-available N estimates.

Information supplied by the grower (line 1.10)

N applied at seeding

Some crops need a starter fertilizer (N applied at seeding) for best growth. These fertilizers usually supply N, P, and S. Examples are 16-20-0, 10-34-0. Starters are usually applied at rates that supply 10 to 30 lb N per acre. Enter all N supplied by starter fertilizer on line 1.10 in the worksheet.

Table 1. Estimated nitrogen credits for previous biosolids applications at a site

	Years after biosolids application			
	Year 2	Year 3	Year 4 and 5	Cumulative (Years 2, 3, 4, and 5)
	Percent of organic N applied first year			
	8	3	1	13
Biosolids organic N as applied (mg/kg dry weight basis)	**Plant-available N released (lb N per dry ton)**			
10,000	1.6	0.6	0.2	2.6
20,000	3.2	1.2	0.4	5.2
30,000	4.8	1.8	0.6	7.8
40,000	6.4	2.4	0.8	10.4
50,000	8.0	3.0	1.0	13.0
60,000	9.6	3.6	1.2	15.6

Photo: Brian Campbell, Natural Selection Farms

Dewatered biosolids application to dryland wheat during fallow

Step 2. Estimate plant-available N needed from biosolids

Next you will estimate the amount of plant-available N the biosolids must provide. This is the difference between the total plant-available N needed to produce the yield goal and the plant-available N from other sources.

Step. 3. Collect biosolids data

To make the calculation, managers will need the following analyses:

- Total Kjeldahl N (TKN)
- Ammonium-N (NH_4-N)
- Nitrate-N (NO_3-N; composted or aerobically digested biosolids only)
- Percent total solids

If your laboratory results are on an "as is" or wet weight basis, you must convert them to a dry weight basis. To convert from an "as is" to a dry weight basis, divide your analysis by the percent solids in the biosolids and multiply the result by 100. Total Kjeldahl N includes over 95 percent of the total N in biosolids. In using the worksheet, we will assume that total Kjeldahl N equals total N.

Ammonium-N usually makes up most of the inorganic N present in biosolids. Depending on your laboratory, results for ammonium-N may be expressed as either ammonia-N (NH_3-N) or ammonium-N (NH_4-N). Make sure that the laboratory determines ammonium-N on a fresh (not dried) biosolids sample. The ammonium-N present in fresh biosolids is lost as gaseous ammonia when biosolids are dried.

There may be significant amounts of nitrate in aerobically digested biosolids or in composts. There is little nitrate in anaerobically digested biosolids; therefore, nitrate analysis is not needed for these materials.

Determine biosolids organic N by subtracting ammonium-N from total Kjeldahl N (line 3.6 minus line 3.7). Percent total solids analyses are used to calculate application rates. Biosolids applications are calculated as the dry weight of solids applied per acre (e.g., dry tons per acre).

Step 4. Estimate plant-available N per dry ton of biosolids

The estimate of plant-available N per dry ton of biosolids includes:

- Some of the ammonium-N
- All of the nitrate-N
- Some of the organic N

Inorganic N retained (lines 4.5 to 4.7)

Ammonium-N (lines 4.5 to 4.6)

Under some conditions, ammonium is readily transformed to ammonia and lost as a gas. This gaseous ammonia loss reduces the amount of plant-available N supplied by biosolids. The following section explains the factors used to estimate ammonia-N retained in plant-available form after application.

Biosolids processing

The following types of biosolids processing cause most of the ammonia-N to be lost as ammonia gas or converted to organic forms before application:

- Drying beds
- Alkaline stabilization at pH 12
- Composting

Application method

Ammonia loss occurs only with surface application. Injecting liquid biosolids eliminates most ammonia loss, since the injected liquid is not exposed to the air. Surface applications of liquid biosolids lose less ammonia than do dewatered biosolids. For liquid biosolids, the ammonia is less concentrated and is held as NH_4^+ on negatively-charged soil surfaces after the liquid contacts the soil.

Ammonia loss is fastest just after application to the field. As ammonia is lost, the remaining biosolids are acidified—that is, each molecule of NH_3 lost generates H^+ (acidity). Acidification gradually slows ammonia loss.

Biosolids that remain on the soil surface will eventually reach a pH near 7, and further ammonia losses will be small. Ammonia loss takes place very rapidly after application, with most of the loss occurring during the first two days after application.

Time to soil incorporation

Tillage to cover biosolids can reduce ammonia loss by adsorption of ammonium-N onto soil particles.

Table 2 estimates the amount of ammonium-N retained after field application. To use this table, you will need information on biosolids stabilization processes, method of application (surface or injected), and the number of days to soil incorporation.

Nitrate-N (line 4.3)

We assume 100 percent availability of biosolids nitrate-N.

Photo: City of Portland, Bureau of Environmental Services

Spring grass growth on dryland pasture following dewatered biosolids application (top) vs. no biosolids (bottom)

Organic N mineralized (lines 4.8 to 4.9)

Biosolids organic N, which includes proteins, amino acids, and other organic N compounds, is not available to plants at the time of application. Plant-available N is released from organic N through microbial activity in soil. This process is called mineralization. It is more rapid in soils that are warm and moist, and is slower in soils that are cold or dry. Biosolids organic N mineralization rates in soil also depend on the treatment plant processes that produced the biosolids.

Use Table 3 (page 10) to estimate biosolids mineralization rates based on processing. Use the middle of the range presented, unless you have information specific to the site or biosolids that justify using higher or lower values within the range.

Step 5. Calculate the agronomic biosolids application rate

Perform this calculation using the results of the previous sections, as shown in lines 5.1 through 5.3.

Step 6. Convert agronomic biosolids application rate to "as is" basis

Use the appropriate conversion factors (given in Table 4, page 10) to convert to gallons, acre-inches, or wet tons per acre.

Table 2. Estimates of ammonium-N retained after biosolids application

	Surface-applied			Injected
	Liquid biosolids	Dewatered biosolids	Composted, air-dried, or heat-dried biosolids	All biosolids
Time to incorporation by tillage	**Ammonium-N retained (percent of applied)**			
Incorporated immediately	95	95	100	100
After 1 day	70	50	100	100
After 2 days	60	30	100	100
No incorporation	55	20	100	100

Table 3. First year mineralization estimates for organic N in biosolids

Processing	First-year organic N mineralization rate (percent of organic N)
Fresh*	
Anaerobic digestion, liquid or dewatered	30–40
Aerobic digestion, liquid or dewatered	30–40
Drying bed	30–40
Heat-dried	30–40
Lagoon	
Less than 6 months	30–40
6 months to 2 years	20–25
2 to 10 years	10–20
More than 10 years	5–10
Composting	0–10
Blends and soil products	†

*"Fresh" includes all biosolids that have not been stabilized by long-term storage in lagoons or composting.

†Because blends (with woody materials) and soil products that contain biosolids vary widely in composition and age depending on intended use, available N may vary widely among products. For blends, available N can be estimated through laboratory incubation studies.

Table 4. Conversion factors

1%	=	10,000 mg/kg or ppm 20 lb/ton
1 mg/kg	=	1 ppm 0.0001 % 0.002 lb/ton
1 wet ton	=	1 dry ton ÷ (percent solids × 0.01)
1 dry ton	=	1 wet ton × (percent solids × 0.01)
1 acre-inch	=	27,000 gallons

Other considerations for calculations

Small acreage sites without a reliable yield history

Some communities apply biosolids to small acreages managed by part-time farmers. In many of these cases, there is no reliable yield history for the site, and the goal of management is not to make the highest economic returns. You can be sure of maintaining agronomic use of biosolids nitrogen on these sites by applying at a rate substantially below that estimated for maximum yield.

Equipment limitations at low application rates

At some low-rainfall dryland cropping locations east of the Cascades, the agronomic rate calculated with the worksheet will be lower than can be spread with manure spreaders (usually 2 to 3 dry tons per acre). At these locations, you may be able to apply the dewatered biosolids at the equipment limit, but check with your permitting agency for local requirements.

Appendix A: Cumulative loading of trace elements

Under EPA regulations (40 CFR Part 503.13), managers must maintain records on cumulative loading of trace elements only when bulk biosolids do not meet EPA Exceptional Quality Standards for trace elements (Table 5). Contact your regulatory agency for details on record keeping if your biosolids do not meet the standards in Table 5.

Table 5. Trace elements concentration limits for land application

Element	Symbol	Concentration limit	
		Exceptional quality standard (EPA Table 3)* (mg/kg)	Ceiling limit (EPA Table 1)* (mg/kg)
Arsenic	As	41	75
Cadmium	Cd	39	85
Copper	Cu	1,500	4,300
Lead	Pb	300	840
Mercury	Hg	17	57
Molybdenum	Mo	**	75
Nickel	Ni	420	420
Selenium	Se	100	100
Zinc	Zn	2,800	7,500

Source: EPA 40 CFR Part 503

*EPA Table 3 and Table 1 refer to tables in EPA biosolids rule (40 CFR Part 503).

**Molybdenum concentration standard level is under review by the EPA.

For more information

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