CHAPTER 36

Fertilizing Grass with Municipal Biosolids

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What are biosolids?

As defined in the United States Environmental Protection Agency (USEPA) regulations, biosolids are the solid residuals of municipal wastewater treatment that **meet standards for land application**. Raw sewage solids become biosolids after stabilization by digestion, composting, high-temperature drying, lime addition or other approved processes. Biosolids must not exceed limits for nine regulated trace elements, including cadmium, zinc and arsenic. Biosolids processes can reduce (Class B) or eliminate human pathogens (Class A). Class B biosolids are usually applied on farmland. Site specific permits are required with setbacks and access restrictions. Class A biosolids are essentially pathogen-free and can be sold or distributed without a federal (USEPA) permit.

Biosolids can be transported and applied as a liquid (2–6% DM) or solid (>18% DM). Liquid biosolids are available only to farms close to the treatment plant because of transport cost. Class B dewatered or “cake” biosolids (20–25% DM) are used for more distant farms and grassland.

Biosolids and grasslands: big picture views

Biosolids represent a potential for the critical return of waste nutrients from cities back to farmland (Fig. 1). Often, forages represent the most cost-efficient and safe recipient crop for recycling biosolids as nutrients or soil amendment. Grasslands are one of the most common managed ecosystems, are often close to cities, and often in need of nutrients. The big challenge for “city to farm” biosolids

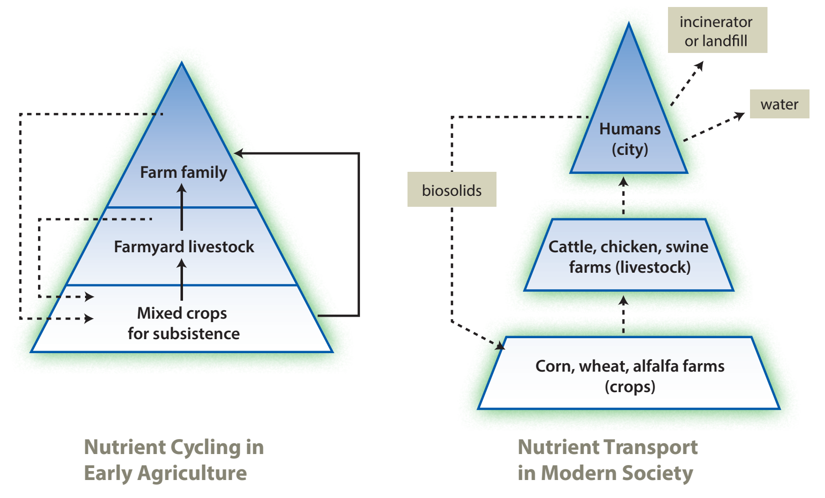
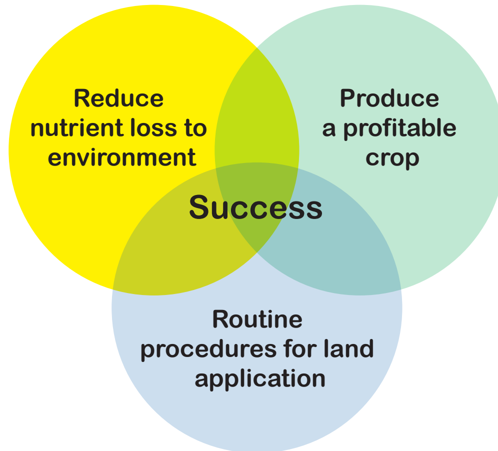


Figure 1. Nutrient cycling in early agriculture (left) vs. nutrient transport from large, specialized farms to cities (right).

management is to meet the needs of both farmers and cities under changing regulations and public perceptions. Biosolids application to farmland provides a pathway for nutrient recycling from city to farm. When biosolids are not recycled to crops, the current alternatives (landfill or incineration) result in a dead-end for nutrients. Before the advent of wastewater treatment, nutrients from cities were routinely discharged to water, making rivers and other surface waters hazardous to humans and fish.



Successful biosolids management involves compromise between goals of farmers, biosolids managers and public policy.

Farmers, regulators and cities have different goals

Farmers, regulators, cities and the public have different criteria for the "best" way to manage biosolids. Farmers want biosolids because of their fertilizer and soil conditioning value. Regulatory agencies seek to verify that standards are followed so that public and environmental health is protected. Cities seek to control costs and maintain good relationships with farmers. Biosolids users and their communities want predictable, clean, safe and efficient biosolids management that minimizes odors, dust and other nuisance factors. For convenience, managers and regulators identify suitable field sites, and then repeat applications as often as allowed. This strategy often does not make best use of the nutrients in biosolids.

Biosolids as a nutrient source

Biosolids are a "subsidized" fertilizer; it costs the public much more to treat, haul and apply biosolids (typically \$300/dry t) than the biosolids are worth as fertilizer. The typical total macro-nutrient analysis of digested biosolids is shown in Table 1. Biosolids also supply essential micronutrients for crops (e.g. Zn, Cu, Mo) and for animals (e.g. Se).

Table 1. Typical organic matter and macronutrient analysis of digested biosolids in the Pacific Northwest, USA. Excludes lime-stabilized and composted biosolids.

Nutrient	Range	Average (wet @ 20% DM)	
	% dry wt.	*lb/ English ton*	*kg/metric ton*
Organic matter	45 to 70	230	115
Nitrogen (N)	3 to 8	22	11
Phosphorus (P)	1.5 to 3.5	10	5
Sulfur (S)	0.6 to 1.3	3.8	1.9
Calcium (Ca)	1 to 4	10	5
Magnesium (Mg)	0.4 to 0.8	2.4	1.2
Potassium (K)	0.1 to 0.6	1.4	0.7

The organic matter in biosolids also provides long-term benefit to soil chemical, physical and biological properties. Because biosolids are a product of digestion, they persist longer in soil than fresh organic matter such as crop residues.

The nutrients supplied by biosolids are not in the same ratios as required by crops. Biosolids applied at optimum rate for N will supply excess P and insufficient K. Grass removes 35–45 kg K per tonne DM, so soil test values can decline rapidly. Annual soil testing is recommended.

The N fertilizer replacement value of biosolids is about \$20 per dry ton or tonne in the application year (35% of biosolids-N available; N from mineral fertilizer = \$0.57/lb or \$1.25 /kg). In P deficient soils, the value of P is \$25/dry t (40% biosolids-P available; mineral P from fertilizer = \$1.24/lb or 2.73/kg).

Nitrogen

Nitrate-N is absent in most biosolids. The proportions of ammonium and organic N in biosolids are related to treatment process. Liquid, anaerobically-digested biosolids often contain more NH_4-N than organic N. Biosolids produced by anaerobic digestion and dewatering (the most common product offered to farmers) contain about 50 kg N per t DM (40 kg organic-N, 10 kg NH_4-N). Heat-dried biosolids contain 90+% organic N with a trace of NH_4-N.

Ammonium-N from biosolids behaves in the same way as NH_4-N from manures. Most biosolids have an alkaline pH (>7.5) that causes rapid volatilization loss of ammonia gas; typically only 20–50% of biosolids NH_4-N is retained after broadcast application. Ammonium-N retention can be increased with immediate sprinkler irrigation, or with directed liquid application (sleigh-foot). About 30–40% of biosolids organic-N is mineralized to plant-available forms in the year of application. An additional 8, 3, and 1% of biosolids organic N is mineralized in the second, third and fourth years following application. When applied for 3+ yr to the same field, the cumulative N provided by biosolids approaches 50% of the

Substituting biosolids for N fertilizer or manure for grass

Biosolids vs. scraped dairy manure

Biosolids, scraped dairy manure or urea fertilizer were broadcast on established prairiegrass (Bromus unioloides cv. *Matua*) following May, July and August grass harvests (Sullivan et al. 1997). Biosolids N was rapidly-available to grass, it had lower C:N and higher NH_4-N analysis than manure. Cumulative (2-year) plant-available N for biosolids or manure was equal (100 kg total N applied as biosolids or manure = 36 kg fertilizer N).

Biosolids processing method

Biosolids were applied to tall fescue during the first year of a 2-yr study. Plant-available N for most biosolids was 30–40% in the application year, and 5–15% in the year after application. Biosolids that had been stored in lagoons (3+ yr) supplied less plant-available N. After 2-yr, cumulative plant-available N from most biosolids was 40–50% (100 units of total N as biosolids = 40–50 units as ammonium nitrate).

Long-term residual effects of biosolids on Plant Available Nitrogen

Biosolids (600 kg N/ha) or N fertilizer (340–400 kg N/ha) were applied annually to tall fescue in year 2–10. The net increase in grass N uptake (above the zero-N control) was determined for 8 years after biosolids application ceased (Fig. 2). Biosolids built soil capacity to provide N to grass for many years after application ceased compared to fertilizer. Nitrogen recovery averaged 80 kg/ha in years 10–14, and 40 kg/ha in years 15–18 and another 11% of applied N was recovered in years 11–18.

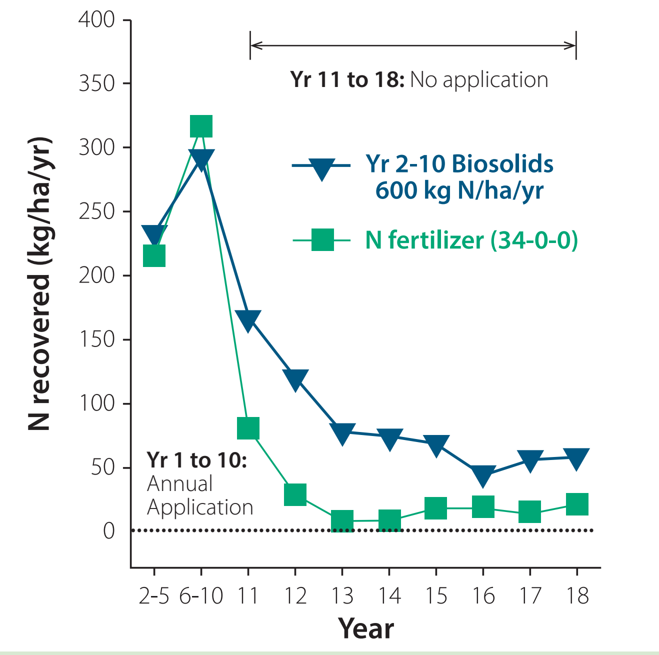


Figure 2. Residual effects of biosolids application history on grass N uptake by tall fescue (for lb/ac multiply by 0.9) (Cogger et al. 2013).

annual total N application rate. Calculations to estimate plant-available N are given in Pacific NW Extension Bulletin 511 (Cogger et al. 2007).

Phosphorus

Because of their high P content, biosolids provide a long-term benefit to P-deficient soils but also increase the risk of P loss from field to surface water.

The solubility of P from anaerobically or aerobically-digested biosolids is typically 40% relative to commercial P fertilizer. Biosolids processing method affects P solubility. Biosolids treated with aluminum (aluminum sulfate) or iron (ferric chloride) or calcium (lime) have lower P availability. Biosolids composts prepared with woody feedstocks have lower total P analysis, more organic P, and less soluble P than digested biosolids.

Sulfur

After application, biosolids sulfides are oxidized to the plant-available sulfate form. Biosolids also contain slower-release S (from decomposition of biosolids organic matter). Biosolids application rates for optimum N will provide sufficient S, even for crops like canola that require ample S.

Soil pH

Biosolids acidify soils at similar or lower rates than ammonium nitrate fertilizer; in western Washington, after seven years of application at equivalent N rates, soil pH was 5.3 with ammonium nitrate vs. pH 5.6 with biosolids (Cogger et al. 2001). Biosolids acidify soil more than manure, because they contain more organic S and less Ca, Mg and K than manures. Biosolids produced in some small treatment plants, where hydrated lime instead of digestion is used to kill pathogens, have significant liming value.

Salts

Biosolids contain very low concentrations of soluble salts so even repeated applications have not resulted in salt accumulations in soil. For example, soils receiving anaerobically-digested dewatered cake biosolids, applied for over 10 years to dryland pastures in eastern Oregon (15 cm or 6 in annual precipitation) had modest electrical conductivity values (< 1 dS/m or 1 mmhos/cm).

Using biosolids for maximum benefit

Farmers that grow crops on marginal or poor quality soils are most likely to benefit from biosolids. Over half of the biosolids from western Oregon cities go to eastern Oregon pastures on non-irrigated, droughty soils resulting in dramatic yield increases. Biosolids benefit grasslands in western Oregon that have low soil test values and a history of limited manure application.

To maximize nutrient use, biosolids should be applied only occasionally to the same land. Often, it takes only one or two biosolids applications to correct most of the nutrient deficiencies, and to jump-start soil productivity. Additional applications will provide mainly a N benefit. The most efficient way to use biosolids nutrients for high yielding grass is to supply only about 100 kg plant-available N/ha with biosolids, and to supply the rest of crop N requirement with urea or other N fertilizer. Supplying all of crop N requirement with biosolids can result in excessive N mineralization in late summer and fall, and increased risk of nitrate leaching.

Grasslands are convenient for biosolids application scheduling because of the strength of sod in supporting application equipment, the multiple cycles of grass growth per year, and a relatively small required waiting period between application and crop harvest (30 days).

In Oregon and Washington, groups of farmers have successfully organized businesses to make judicious use of biosolids, and provide additional farm income. These farmers have learned to navigate local politics and to provide biosolids application services for neighboring farms. The result is more efficient use of biosolids nutrients on a larger land area.

Table 2. Metal concentrations in tall fescue forage following 10-yr annual biosolids application (Cogger et al. 2012). Tissue concentrations averaged across three sample events.

Fertilizer	Forage Concentration		
	Zinc *mg/kg*	Copper *mg/kg*	Cadmium *mg/kg*
Biosolids	31	7	0.17
Ammonium nitrate	17	6	0.11

Note: Cumulative (10-yr) biosolids rate = 134 Mg DM/ha, supplying 114 kg/ha zinc, 93 kg/ha copper and 0.6 kg/ha cadmium.

Forage Quality

High quality grass hay or grass silage can be produced with biosolids. With abundant N and S (key nutrients in protein), biosolids application is particularly effective in increasing forage protein. When similar amounts of available N are supplied with biosolids or fertilizer N, the biosolids-fertilized forage usually has higher P and S, but lower K. Biosolids-fertilized forage is often higher in micronutrients such as copper, zinc, and manganese but levels in grasses are usually far below those considered detrimental to animals (Table 2).

Odor control

In the maritime Pacific Northwest, most biosolids are applied to forage in July to September when biosolids dry rapidly and odors dissipate rapidly. Biosolids can also be applied and tilled in prior to new seedings. To minimize forage contamination, biosolids are best applied to established grass immediately after harvest, when the field is relatively dry.

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

Biosolids processing method affects odor potential. Biosolids that are dewatered with centrifuges are usually more likely to cause odor problems than biosolids from belt filter presses. When lime is used for stabilization, the organic matter in biosolids is not fully digested, and it is more likely to cause odor. Biosolids dried to below 40% moisture are less odiferous.

Slurry biosolids can be applied with the same "trailing shoe" or "sleigh-foot" applicators used for slurry manure application. This application method is especially useful when biosolids are applied to fields that are very close to neighbors. The biosolids are placed at ground level, under the forage canopy. This application method also conserves N, and it provides a longer scheduling window for application. Sleigh-foot application is currently rarely used for biosolids, but it deserves consideration for small cities that produce liquid biosolids and have fields very close to town.

Contaminants in biosolids

Because biosolids suffer from perception of being "unclean", a brief summary of biosolids contaminant research is provided. More detailed discussion of regulations, risk, and contaminant limits for biosolids are provided in "For More Information" (Stehouwer 1999; Jacobs and McCreary 2001; Stehouwer 2003; Evanylo 2009; American Society for Microbiology 2011). In general, these publications conclude that biosolids are safe when used according to regulations.

Metals or trace elements

Accumulation of trace (heavy) metals and other minerals is a well-known risk of biosolids application. Many of the metals and trace elements are also essential elements for plants and animals, so safety is a question of dose. Trace element hazard from biosolids has been studied for over 30 years. City wastewater treatment facilities have reduced

Table 3. Typical biosolids analysis (Oregon, USA) as compared to United States and British Columbia (Canada) concentration limits.

Trace Element	Oregon Biosolids Analysis (2005)	USEPA Ceiling Limit for Biosolids (1993)	British Columbia Organic Matter Std (2002)
		mg/kg or ppm	
Arsenic	6	75	75
Cadmium	3	85	20
Cobalt	not regulated	not regulated	150
Chromium	not regulated	not regulated	1060
Copper	448	4300	2200
Lead	76	840	500
Mercury	2	57	15
Molybdenum	14	75	20
Nickel	36	420	180
Selenium	6	100	14
Zinc	852	7500	1850

trace element concentrations considerably since the 1970s, when "worst case" research was performed. Trace elements found in Oregon biosolids, and trace element limits for the United States and for British Columbia, Canada are shown in Table 3**.** It is apparent that today's biosolids are well below U.S. and Canada concentration limits.

Limits for trace element concentration in biosolids vary among countries, and in Canada among provinces. Most provinces have additional regulations that limit cumulative loading of trace elements. In British Columbia, soils are tested before biosolids application begins to determine site-specific loading limits.

Regardless of regulatory scheme, in almost all cases, the regulatory limit for N (i.e. agronomic rate) controls trace element loading. Table 4 shows Canada's limit for cumulative trace element loading and the quantity of biosolids required to reach that limit. The column at the far right (years to limit) show that copper and molybdenum in biosolids limit cumulative biosolids application rates more than other trace elements (with respect to Canada limits).

Synthetic Organics

Currently, synthetic organic compounds in biosolids are not regulated in the USA (except PCBs). Risk assessments have

Table 4. Example: Biosolids application rate required to reach cumulative limit given in Canadian fertilizer regulations.

Trace Element	Canada Trade Agreement Loading Limit (1997) *kg/ha/45 yr*	Cumulative application to reach limit *Mg DM/ha*	Years of application to Canada limit (10 Mg DM/ha/yr) *yr*
Arsenic	15	2500	250
Cadmium	4	1333	133
Cobalt	30	not regulated	not regulated
Chromium	210	not regulated	not regulated
Copper	150	335	33
Lead	100	1316	132
Mercury	1	500	50
Molybdenum	4	286	29
Nickel	36	1000	100
Selenium	2.8	467	47
Zinc	370	434	43

Note: Assumes typical biosolids trace element concentrations (Association of Clean Water Agencies survey in Oregon in 2005; Table 3) been conducted for many synthetic organic contaminants, but USEPA found that these contaminants did not warrant regulation (very low risk). USEPA published data from a National Sewage Sludge Survey in 2009 that evaluated the prevalence and concentration of synthetics.

Risk assessment of "new" synthetic compounds continues. Current research is investigating hazards associated with pharmaceuticals (including antibiotics), personal care products and flame retardants. In general, chemical concentrations and risk of exposure to these chemicals via biosolids is very low in comparison to other routes of exposure. For example, human exposure to flame retardant chemicals is much greater from household dust than from municipal biosolids.

When biosolids are applied to fields according to federal standards, risk to human health and the environment from synthetic organic compounds is minimized by a number of barriers, including:

- Synthetic organic compounds that survive wastewater treatment are strongly bound to organic matter in soil, so they are not very soluble in soil.
- Plant roots do not take up significant amounts of these compounds.
- Required 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.

Tanker application of liquid biosolids to grass. PHOTO COURTESY BIOGRO PROGRAM, CITY OF SALEM (OR)

Table 5. Mean pathogen concentrations reported in biosolids and manure. CFU = colony forming units; PFU = plaque-forming units (higher values indicate greater pathogen count).

Organism	Source	CFU or PFU/g
BACTERIA		
Campylobacter jejuni	Manure[1,2]	1400
	Biosolids	2
E. coli 0157:H7	Manure[1,2]	110
	Biosolids	<1
Listeria monocytogenes	Manure[1,2]	210
	Biosolids	20
Salmonella	Manure[1,2]	180
	Biosolids	50
VIRUSES		
Adenoviruses	Biosolids	20
Enteroviruses	Biosolids	<1 to 30
PARASITES		
Cryptosporidium	Manure[1,2]	3
	Biosolids	2

1 Mean concentration of pathogen in multiple manure types.

2 Hutchinson, et al, 2005 reported mean values were weighjt

Note: Table adapted from: *American Society for Microbiology.* 2011. p. 9. In: Land Application of Organic Residuals: Public Health Threat or Environmental Benefit?

Human pathogens

To be called biosolids, the raw sewage must be treated to reduce human pathogens below regulatory limits. Grazing restrictions (30-day interval between biosolids application and grazing or forage harvest) and setbacks from wells and water bodies are the main safeguards used at the field level. After land application, pathogens in Class B biosolids are killed by exposure to sunlight, drying conditions, unfavorable pH and other environmental factors.

Risk assessments have recently been developed for the spread of human pathogens via biosolids. The recent risk assessments show lower human health risk for many microbial contaminants in municipal biosolids than for manures. Microbial risk to application site neighbors from biosolids application has also been recently evaluated, and found to be very low.

References available online at www.farmwest.com

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