Virginia Cooperative Extension
Virginia Tech • Virginia State University

Part XII.

Land Application of Biosolids

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Biosolids are solid, semisolid, or liquid materials – the result of domestic sewage treatment – that have been sufficiently processed to permit these materials to be land-applied safely. The term was introduced by the wastewater treatment industry in the early 1990s. It has since been adopted by the U.S. Environmental Protection Agency (USEPA) to distinguish high-quality, treated sewage sludge from raw sewage sludge and from sewage sludge containing large amounts of pollutants.

Benefits of Land Application of Biosolids

Biosolids can be considered a waste to be disposed of or a beneficial soil amendment. As an alternative to disposal by landfilling or incineration, land application seeks to beneficially recycle the soil property-enhancing constituents in biosolids. Biosolids are approximately 50% mineral and 50% organic matter. The mineral matter includes essential plant nutrients, and the organic matter is a source of slow-release nutrients and soil conditioners. Land application returns those materials to the soil where they can contribute to improved crop production.

Farmers can benefit from biosolids application by reducing fertilizer costs. The main fertilizer benefits are through the supply of nitrogen (N), phosphorus (P), and lime (from lime-stabilized biosolids). Biosolids also ensure against unforeseen nutrient shortages by supplying essential plant nutrients that are rarely purchased by farmers because crop responses to their application are unpredictable. These include elements such as sulfur (S), manganese (Mn), zinc (Zn), copper (Cu), iron (Fe), molybdenum (Mo), nickel (Ni), and boron (B). In addition to biosolids' nutrient-supplying and liming benefits, the byproduct can improve soil quality by enriching soil organic matter (**www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_Benefits.pdf**) and enhance crop yield and quality by biostimulation (**www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_Biostimulant.pdf**).

Land application is usually less expensive than alternative methods of disposal. Consequently, wastewater treatment facilities and the public they serve benefit through cost savings. The recycling of nutrients and organic matter can be attractive to citizens concerned with environmental protection and resource conservation. See the following websites for more detailed information on land-applying biosolids for:

- **Row crops, forage, and hay lands**
  www.virginiabiosolids.com/wp-content/uploads/2019/02/Biosolids-Use-for-Row-Crop.pdf.
- **Forestry**
  www.virginiabiosolids.com/wp-content/uploads/2019/01/VBC_Biosolids-Use-in-Forestry.pdf.
- **Land reclamation**
  www.virginiabiosolids.com/wp-content/uploads/2019/04/VBC_Land-Reclamation.pdf.
- **Urban landscapes**
  www.virginiabiosolids.com/wp-content/uploads/2019/04/VBC_Urban-Landscapes.pdf.

Production and Characteristics of Biosolids

Understanding how biosolids are produced can elucidate the basis for their composition. The composition of biosolids defines their quality and potential use. The following sections describe biosolids production methods and characteristics.

How Are Biosolids Produced?

Biosolids are produced through physical, biological, and chemical treatment of domestic wastewater (**fig. 1**). Treatment to generate a beneficial product must sanitize wastewater solids to control disease-causing organisms and reduce characteristics that could attract disease vectors (e.g., rodents, flies). The type and extent of processes used to treat wastewater affect the degree of pathogen reduction achieved and the potential for odor generation. Common stabilization processes and their effects on biosolids' properties and land application practices are summarized in **table 1 (page 154)**. More **detailed descriptions of treatment practices and objectives** can be found at www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_Wastewater.pdf.

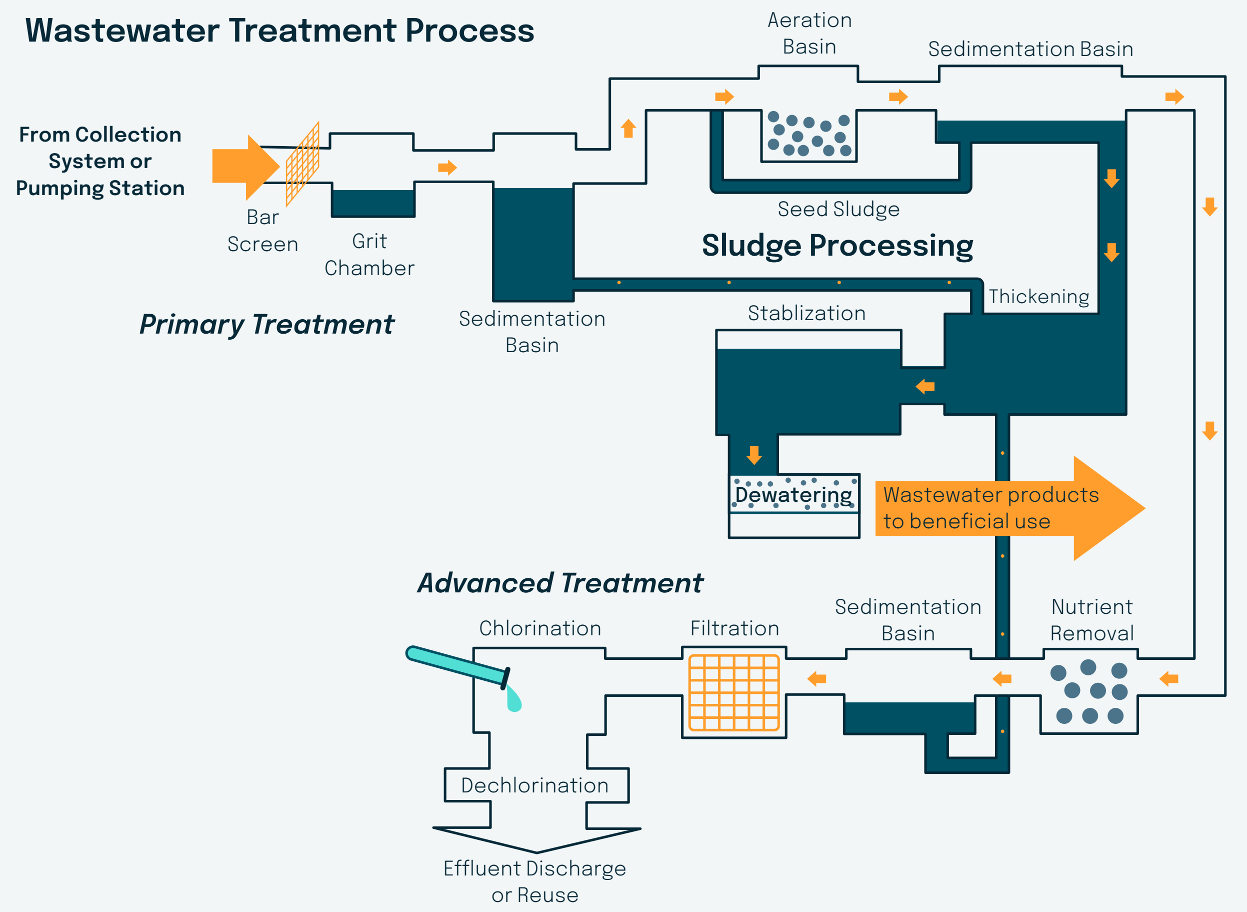

Figure 1. Schematic diagram of a wastewater treatment facility (USEPA 1995).

Table 1. Description of various wastewater stabilization processes and their effects on land application practices. (Adapted from USEPA [1984].)

Process/method	Process definition	Effect on biosolids	Effect on land application process
Digestion (anaerobic and/or aerobic)	Biological stabilization through conversion of organic matter to carbon dioxide, water, and methane.	Reduces biological oxygen demand, pathogen density, and attractiveness of the material to vectors (disease-spreading organisms).	Reduces the quantity of biosolids and the concentration of organic matter.
Alkaline stabilization	Chemical stabilization through the addition of alkaline materials (e.g., lime, kiln dust).	Raises pH > 12 and provides liming capability. Temporarily decreases biological activity. Reduces pathogen density and attractiveness of the material to vectors.	High pH (i.e., >12) results in loss of nitrogen as ammonia. Could limit application rate on sandy soils whose pH is already adequate.
Heat drying	Thermal drying of biosolids.	Destroys pathogens, eliminates nearly all moisture (solids > 95%).	Increases nutrient density.
Composting	Aerobic, thermophilic, biological stabilization in a windrow, aerated static pile or vessel.	Destroys pathogens, generates humus-like material, increases density of beneficial microbes, and reduces nitrogen content and availability.	Excellent soil conditioning properties. Contains less plant-available nitrogen than other biosolids.

Characterizing Biosolids

The suitability of biosolids for land application can be determined by their biological, chemical, and physical attributes. Biosolids' composition depends on wastewater constituents and treatment processes. The resulting properties will determine application method and rate, and the degree of regulatory control required. Several of the more important properties of biosolids are described below.

Total solids include suspended and dissolved solids and are usually expressed as the concentration present in biosolids. The content of total solids depends on the type of wastewater process and the biosolids' treatment prior to land application. Typical solids contents of various biosolids' processes are liquid (2%-10%), dewatered (25%-30%), composted (50%-60%), and (air- or thermally) dried (60%-95%).

Volatile solids provide an estimate of the readily decomposable organic matter in biosolids and are usually expressed as a percentage of total solids. Volatile solids content is an important determinant of potential odor problems at land application sites. Treatment processes such as anaerobic digestion, aerobic digestion, and composting reduce volatile solids content and thus the potential for odor.

Soil pH and calcium carbonate equivalent are measures of the degree of acidity or alkalinity of a substance. CCE is the relative liming efficiency of the biosolids that is expressed as a percentage of calcium carbonate (calcitic limestone) liming capability. The pH of biosolids can be raised with alkaline materials to reduce pathogen content and the attraction of disease-spreading organisms (vectors).

High pH (greater than 12) kills virtually all pathogens. Alkaline addition also increases the gaseous loss (volatilization) of the ammonia (NH3) form of nitrogen, thus reducing the N-fertilizer value of biosolids.

Essential nutrients are elements required for plant growth that contribute to the economic value of biosolids. These include N, P, K, Ca, Mg, Na, S, B, Cu, Fe, Mn, Mo, Ni, and Zn. Concentrations of nutrients in biosolids can vary significantly (**table 2, page 156**); thus, the actual material being considered for land application should be analyzed. For **more information on essential nutrients**, see www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_NutrientContent.pdf.

Trace elements are found in low concentrations in biosolids. The trace elements of interest in biosolids are those commonly referred to as "heavy metals." Some of these trace elements (e.g., Cu, Mo, Zn) are nutrients needed for plant growth in low concentrations, but all of these elements can be toxic to humans, animals, or plants at excessive concentrations. Possible hazards associated with an accumulation of trace elements in the soil include their potential to cause phytotoxicity (i.e., injury to plants) or to increase the concentration of potentially hazardous substances in the food chain. Federal and state regulations have established standards for the following nine trace elements: arsenic (As), cadmium (Cd), copper, lead (Pb), mercury (Hg), molybdenum, nickel, selenium (Se), and zinc. For **more information on inorganic trace elements**, see www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_TraceElements.pdf.

Trace organic chemicals are complex compounds that include man-made chemicals from pharmaceutical and personal care products, flame retardants, detergents, other household products, and pesticides. Many of these compounds are toxic or carcinogenic to organisms exposed to high concentrations over time, but most are found at such low concentrations in biosolids that the USEPA concluded that the compounds do not pose significant human health or environmental threats. No organic pollutants are included in the current federal biosolids regulations due to the determination of low risk; however, toxicological research on many such compounds is ongoing. For **more information on trace organic chemicals**, see www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_TraceOrganic.pdf.

Pathogens are disease-causing microorganisms that include bacteria, viruses, protozoa, and parasites. Pathogens can present a public health hazard if they are transferred to food crops grown on land to which biosolids are applied, contained in runoff to surface waters from land application sites, or transported away from the site by vectors such as insects, rodents, and birds. For this reason, federal and state regulations specify pathogen and vector attraction reduction requirements that must be met by biosolids applied to land. For **more information on pathogens**, see www.virginiabiosolids.com/wp-content/uploads/2019/01/VBC_Pathogens-Biosolids-2.pdf.

Typical Nutrient Levels in Biosolids

There have been few comprehensive surveys of nutrient levels in biosolids during the past 25 years. One such recent study conducted by Stehouwer, Wolf, and Doty (2000) demonstrated that the macronutrient (N, P, and K) concentration of biosolids has changed very little from the late 1970s to the mid-1990s. The data in **table 2 (page 156)** represent the means and variability of more than 240 samples collected and analyzed from 12 publicly owned treatment works (POTWs) in Pennsylvania between 1993 and 1997. The POTWs generated between 110 and 60,500 tons of biosolids annually and implemented aerobic digestion (three POTWs), anaerobic digestion (four POTWs), or alkaline addition (five POTWs) as the stabilization treatment process.

Table 2. Means and standard deviation of nutrient concentrations[a] in biosolids collected and analyzed in Pennsylvania between 1993 and 1997 (Stehouwer, Wolf, and Doty 2000).

Nutrient	Total N[b]	NH_4-N	Organic N	Total P	Total K
	%				
Mean	4.74	0.57	4.13	2.27	0.31
SD[c]	1.08	0.30	1.03	0.89	0.27

[a] Concentrations on a dried solids basis.

[b] Determined as total Kjeldahl nitrogen.

[c] Standard deviation of the mean.

Regulations

Land application of biosolids involves some risks, which are addressed through federal and state regulations. Because small amounts of pollutants and pathogens are added to soil in biosolids, human and animal health, soil quality, plant growth, and water quality could be adversely affected if land application is not conducted in an environmentally sound manner. Nitrogen and phosphorus in biosolids, as for any fertilizer source, can contaminate groundwater and surface water if the material is overapplied or improperly applied. Whether handled by disposal or beneficial use, biosolids incur certain risks.

The Federal Part 503 Rule

As required by the Clean Water Act Amendments of 1987, the USEPA developed the regulation Standards for the Use or Disposal of Sewage Sludge (CFR 2021; Title 40, Code of Federal Regulations, Chapter 1, Part 503). This is commonly known as the **Part 503 Rule**. The Part 503 Rule establishes minimum requirements when biosolids are applied to land to condition the soil or fertilize crops or other vegetation grown in the soil. The Clean Water Act required that this regulation protect public health and the environment from any reasonably anticipated adverse effects of pollutants and pathogens in biosolids.

Federal regulations require that state regulations be at least as stringent as the Part 503 Rule. The underlying premise of both the federal and state regulations is that biosolids should be used in a manner that limits risks to human health and the environment. The regulations prohibit land application of low-quality sewage sludge and encourage the application of biosolids that are of sufficient quality that they will not adversely affect human health or the environment. Determination of biosolids' quality is based on trace element (pollutant) concentrations and pathogen and vector attraction reduction. **Additional information on the regulatory process** can be found at www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_WhoRegulates.pdf.

Pollutants and Concentration Limits

The Part 503 Rule identifies how biosolids can be used based on the concentrations of arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc **(table 3**).

Table 3. Regulatory limits (adapted from USEPA [1995]) and mean concentrations measured in biosolids from the National Sewage Sludge Survey (USEPA [1990]) and a survey of 12 publicly owned treatment works in Pennsylvania between 1993 and 1997 (Stehouwer, Wolf, and Doty 2000).

Pollutant	CCL[a,b] (ppm[f])	PCL[a,c] (ppm[f])	CPLR[a,d] (lb/A)	Mean[a,g] (ppm[f])	Mean[a,h] (ppm[f])
Arsenic (As)	75	41	36	10	5
Cadmium (Cd)	85	39	35	7	3
Copper (Cu)	4,300	1,500	1,340	741	476
Lead (Pb)	840	300	270	134	82
Mercury (Hg)	57	17	16	5	2
Molybdenum (Mo)	75	—[e]	—[e]	9	13
Nickel (Ni)	420	420	375	43	23
Selenium (Se)	100	100	89	5	4
Zinc (Zn)	7,500	2,800	2,500	1,202	693

[a] Dry weight basis.

[b] CCL (ceiling concentration limits) = maximum concentration permitted for land application.

[c] PCL (pollutant concentration limits) = maximum concentration for biosolids whose trace element pollutant additions do not require tracking (i.e., calculation of CPLR).

[d] CPLR (cumulative pollutant loading rate) = total amount of pollutant that can be applied to a site in its lifetime by all bulk biosolids applications meeting CCL.

[e] The Feb. 25, 1994, Part 503 Rule amendment deleted Mo PCL for sewage sludge applied to agricultural land but retained Mo CCL.

[f] ppm = parts per million.

[g] Data from U.S. EPA (1990).

[h] Data from Stehouwer, Wolf, and Doty (2000).

The following pollutant limits describe biosolids fitness for use.

Ceiling concentration limits are the maximum concentrations of the nine trace elements allowed in biosolids to be land applied. Sewage sludge exceeding the ceiling concentration limit for even one of the regulated pollutants is not classified as biosolids and therefore cannot be land applied.

Pollutant concentration limits are the most stringent pollutant limits included in Part 503 for land application. Biosolids meeting pollutant concentration limits are subject to fewer requirements than biosolids meeting ceiling concentration limits. Results of the USEPA's 1990 National Sewage Sludge Survey (USEPA 1990) demonstrated that the mean concentrations of the nine regulated pollutants are considerably lower than the most stringent Part 503 Rule pollutant limits.

The cumulative pollutant-loading rate is the total amount of a pollutant that can be applied to a site in its lifetime by all bulk biosolids applications meeting ceiling, but not pollutant, concentration limits. No additional biosolids meeting ceiling concentration limits can be applied to a site after the maximum cumulative pollutant-loading rate is reached at that site for any one of the nine regulated trace elements. Only biosolids that meet the more stringent pollutant concentration limits may be applied to a site once a cumulative pollutant-loading rate is reached at that site.

In 1987, the USEPA established pretreatment specifications (40 CFR Part 403) that required industries to limit the concentrations of pollutants, including trace elements and organic chemicals, in wastewater discharged to a treatment facility. An improvement in the quality of biosolids over the years has largely been due to pretreatment and pollution prevention programs (Shimp et al. 1994).

Part 503 does not regulate organic chemicals in biosolids because the chemicals of potential concern (1) have been banned or restricted for use in the United States, (2) are no longer manufactured in the U.S., (3) are present at low concentrations based on data from the USEPA's 1990 National Sewage Sludge Survey (USEPA 1990), or (4) because the limit for an organic pollutant identified in the Part 503 risk assessment is not expected to be exceeded in biosolids that are land applied (USEPA 1992a). The National Research Council concluded, in their review of the science the Part 503 Rule was based on, that additional testing of certain organic compounds should be conducted (National Research Council 2002). These included poly-brominated diphenyl ethers, nonyl phenols, pharmaceuticals, and other potential carcinogenic and endocrine-pathway-disrupting personal care products. Further research demonstrated that the typical concentrations of these chemical compounds found in biosolids pose minor risk that requires no regulation **(www.virginiabiosolids.com/wp-content/uploads/2018/10/VBC_TraceOrganic.pdf)**.

Pathogen Reduction Categories

Federal and state regulations require the reduction of potential pathogens and vector attraction properties. Biosolids intended for land application are normally treated by chemical or biological processes that greatly reduce the number of pathogens and odor potential in sewage sludge. Two levels of pathogen reduction, Class A and Class B, are specified in the regulations.

The goal of **Class B** requirements is to ensure that pathogens (including Salmonella sp., bacteria, enteric viruses, and viable helminth ova) have been reduced to **levels that are unlikely to cause a threat to public health and the environment under specified use conditions**. Processes that significantly reduce pathogens such as anaerobic or aerobic digestion, drying, heating, and high pH or their equivalent are most commonly used to ensure that biosolids meet Class B requirements. Because Class B biosolids contain some pathogens, certain site restrictions are required. These are imposed to minimize the potential for human and animal contact with the biosolids until environmental factors (temperature, moisture, light, microbial competition) reduce the pathogens to below detectable levels. The site restriction requirements in combination with Class B treatment is expected to provide a level of protection equivalent to Class A treatment. All biosolids that are land applied must, as a minimum, meet Class B pathogen reduction standards.

The goal of **Class A** requirements is to reduce the pathogens to **below detectable levels**. Class A biosolids can be land-applied without any pathogen-related site restrictions. The biosolids treatment methods termed Processes to Further Reduce Pathogens, such as those involving high temperature, high pH with alkaline addition, drying, composting, or their equivalent are most commonly used to ensure that biosolids meet Class A requirements. Biosolids that meet the Part 503 pollutant concentration limits, Class A pathogen reduction, and a vector attraction reduction option that reduces organic matter are classified as Exceptional Quality or EQ biosolids.

Vector Attraction Reduction

The objective of vector attraction reduction is to prevent disease vectors, such as rodents, birds, and insects, from transporting pathogens away from the land application site. There are 10 options available to ensure that land-applied biosolids meet vector attraction reduction requirements. These options fall into either of the following two general approaches: (1) reducing the attractiveness of the biosolids to vectors with specified organic matter decomposition processes (e.g., digestion, alkaline addition) and (2) preventing vectors from coming into contact with the biosolids (e.g., biosolids injection or incorporation below the soil surface within specified time periods).

Nitrogen, Phosphorus, and Lime Application Rate

Federal regulations specify that biosolids may only be applied to agricultural land at or less than the rate required to supply the nitrogen needs of the crop to be grown. This agronomic rate is "designed (1) [t] o provide the amount of N needed by the food crop, feed crop, fiber crop, or vegetation grown on the land; and (2) [t]o minimize the amount of N in the biosolids that passes below the root zone of the crop or vegetation grown on the land to the ground water." (40 CFR 503.11 [b])

Agronomic rate can also be based on crop phosphorus needs if it is determined that excessive soil phosphorus poses a threat to water quality.

Although not technically a nutrient, lime can also be used as a basis for agronomic biosolids application rate. Biosolids rate may be limited by the calcium carbonate equivalent if the application of alkaline-stabilized biosolids on an Nor P basis raises soil pH to a level that can induce a trace element deficiency. By signing the land application agreement with a biosolids contractor, the farmer is obligated to make every reasonable attempt to produce a crop on sites receiving biosolids that matches the agronomic rate applied.

Site Suitability

Federal, state, and local regulations, ordinances, or guidelines place limits on land application based on site physical characteristics that influence potential transport of nitrogen, phosphorus, and pathogens. These include topography; soil permeability, infiltration, and drainage patterns; depth to groundwater; and proximity to surface water. The requirement for buffer areas separating the application site from surface water, rock outcrops, roadways, residences, and other critical areas is designed to prevent biosolids constituents from being transported into environmentally sensitive areas **(fig. 2, page 160)**.

Potentially unsuitable areas for biosolids application include:

- Areas bordered by ponds, lakes, rivers, and streams without appropriate buffer zones.
- Wetlands and marshes.
- Steep areas with sharp relief.
- Undesirable geology (karst, fractured bedrock) if not covered by a sufficiently thick layer of soil.
- Undesirable soil conditions (rocky, shallow).
- Areas of historical or archeological significance.
- Other environmentally sensitive areas, such as floodplains.

Figure 2. Aerial view of a biosolids-amended farm showing light green, slightly N-deficient buffer areas that received no biosolids to protect sensitive landforms.

Managing Biosolids for Agricultural Use

Determining appropriate biosolids application rate requires knowledge of crops and soils to which the product will be applied. The following sections describe how to calculate biosolids application rate based on crop selection and soil properties.

Selecting Suitable Crops for Fertilization With Biosolids

Corn and grasses used for hay and forages have the highest annual nitrogen requirements of crops routinely fertilized with biosolids. Thus, cropping systems that include these crops are in high demand for biosolids recycling. Soybean also has high nitrogen assimilative capacity, but is not typically fertilized with biosolids because the crop can “fix” its needed nitrogen from atmospheric nitrogen gas.

Crops grown for their flowering parts, such as cotton, may produce undesirable amounts of vegetative growth if they continue to accumulate nitrogen late in the season; thus, slow-release nitrogen sources such as biosolids are not desirable fertilizer sources for such crops. Biosolids can, however, be used without concern on other crops in rotation with cotton. The tobacco industry has expressly forbidden the use of biosolids for fertilizing tobacco because the crop readily accumulates heavy metals such as cadmium.

Biosolids can be applied to vegetable crops, but green leafy vegetables accumulate higher concentrations of metals than do the grain of agronomic crops. Some scientists have cautioned against using biosolids on vegetable crops because they provide a direct pathway of potentially harmful trace elements from the soil to humans, while others (Chaney 1994) have demonstrated that soil and plant barriers prevent trace elements in biosolids of current quality from posing such risks. Regardless of one's interpretation of the trace element bioavailability evidence, grain and forage crops are better choices for biosolids application than vegetables due to other issues (for example, the time required by regulation between Class B biosolids application and permitted harvesting of crops that can be consumed by humans).

Determining Biosolids Application Rates

Biosolids supply some of all of the essential plant nutrients and soil property-enhancing organic matter. Land application rates, however, are primarily based on the ability of biosolids to supply nitrogen, phosphorus, and (in the case of alkaline-stabilized materials) lime. The general approach for determining biosolids application rates on agricultural land is summarized in the following steps.

1. Determine **nutrient needs** for crop yield expected for the soil on which the crop will be grown, and soil test nutrient and pH levels to account for residual nutrient availability.
2. Calculate **biosolids agronomic rates** based on either:
   - Crop N needs (normally) or soil test P levels (if excess P is a problem).
   - Soil lime requirement (when lime-supplying biosolids are used and will raise soil pH above the desirable range if they are applied on an N basis).
3. Calculate **supplemental fertilizer needs** by subtracting the amount of plant-available N, P, and K supplied by biosolids from the crop's N, P, and K needs.

Determining Nutrient Needs

Fertilizer recommendations are based on the nutrient-supplying capability of the soil and the additional nutrients needed by crops to achieve their potential yield. Soil testing is required prior to the application of biosolids to determine the suitability of soil pH and the availability of phosphorus and potassium. Soil testing can disclose whether limestone, phosphorus, or potassium is required for optimum crop productivity. Nitrogen application rates are based on crop needs for expected yields for a specific soil.

Determining Agronomic Rates

Biosolids are normally applied at rates to provide either the N needed or the rate that can be assimilated by the crop. This is known as the **agronomic N rate**. Fertilizer nitrogen is not normally applied to legumes, which can obtain the nutrient from the atmosphere; however, nitrogen assimilative capacity is used to establish agronomic N rates for legumes because they will use biosolids furnished nitrogen. The relative concentrations of nutrients in biosolids are rarely present in the proportions required by the target crop; thus, supplemental fertilization (for example, with K) may be needed to promote optimum vegetative growth and yield.

Biosolids should be applied at rates that supply no more than the agronomic N rate for the specific crop and soil type. Expected crop yields for different soils and nutrient rates for calculating biosolids' application rates have been established by the Virginia Department of Conservation and Recreation in the Virginia Nutrient Management Standards and Criteria handbook (DCR 2014).

Why is the application rate for biosolids usually based on crop nitrogen needs?

Nitrogen is required by crops in greater amounts than any other nutrient; thus, the crop's requirement for most other nutrients is normally met when the agronomic N rate is applied. Biosolids rate is further limited to N-supplying capacity because N (as nitrate) is the nutrient most likely to be lost to surface and groundwater if applied at greater than agronomic rates.

The following cautions regarding the determination of agronomic N rates should be considered: The amount of plant-available N can be underestimated or overestimated because the nitrogen composition of biosolids that is used to establish the average N concentration can vary significantly during the period of time that samples are collected and analyzed to establish the agronomic N rate.

The equations used to calculate plant-available N are not site- or source-specific, and the actual amounts of plant-available N may vary from the target rates.

These problems occur with other types of organic wastes, such as manures and yard waste composts, and are not unique to biosolids.

What is PAN, and how is it determined?

Only a portion of the total nitrogen present in biosolids is available for plant uptake. This **plant-available nitrogen or PAN** is the actual amount of nitrogen in the biosolids that is available to crops during a specified period. Equations for calculating PAN are relatively straightforward, but selecting precise site-and source-specific availability coefficients and reasonable input values is more challenging. Site-specific data, when available, should always be used in preference to "book" values.

Determining Availability of Ammonium in Biosolids

Nitrogen in biosolids can be found in the ammonium (NH_4+) or nitrate (NO_3) forms found in commercial inorganic fertilizers or in organically bound forms, such as amino acids and proteins. The amount of nitrogen that will be available to plants varies for each of its chemical forms. Nitrate is readily plant-available but is not found in high concentrations in most biosolids. Ammonium is also available to plants, but it can be lost to the atmosphere (via volatilization) as ammonia (NH_3) gas when biosolids are applied to land without prompt incorporation into the soil. The available (i.e., nonvolatilizable) fraction of NH_4+-N can be estimated based on the time of incorporation after application. Examples of nitrogen availability coefficients from the nonvolatized fraction of NH_3 used in Virginia are presented in **table 4 (page 163)**.

Table 4. Examples of estimated plant-available percentage of ammonia from biosolids (adapted from Virginia Department of Environmental Quality Biosolids Use Regulations; https://www.virginiabiosolids.com/wp-content/uploads/2013/09/Biosolids_Regulations_VPA_9VAC25-32_20130705.pdf).

Management practice	Biosolids with pH <10	Biosolids with pH ≥10
	available % NH_3	
Injection below surface	100	100
Surface application with:		
Incorporation within 24 hours	85	75
Incorporation within 1-7 days	70	50
Incorporation after 7 days	50	25

Determining Availability of Organic Nitrogen in Biosolids

Organic nitrogen must be transformed to ammonium (NH_4^+) via mineralization, and further, to nitrate (NO_3^-) via nitrification by soil microorganisms before this form of nitrogen is available for plants to use. Organic nitrogen is thus a slow-release form of nitrogen. The amount of plant-available N from organic N is estimated by using factors established by research (e.g., Gilmour et al. 2003), such as those presented in **table 5**. The largest portion of organic nitrogen in biosolids is converted to PAN during the first year after application to the soil.

For example, the percentages of organic nitrogen that will become available for non-irrigated corn uptake (E_{min}) from land-applied biosolids that have been treated by digestion, alkaline addition, or heating are

- 30% during the first year after application.
- 10% of the remaining organic N during each of the second and third years.
- 5% of the remaining organic N during the fourth year.

Table 5. Biosolids organic N mineralization factors recommended by Gilmour et al. (2000, 2003) for annual (K_{min}) and growing season (E_{min}) periods in Virginia under dryland and irrigated conditions. E_{min} is the effective mineralization factor for the growing season portion of the year. N-use efficiency for this period was determined to be 71%.

Table 5. Biosolids organic N mineralization factors recommended by Gilmour et al. (2000, 2003) for annual (K_{min}) and growing season (E_{min}) periods in Virginia under dryland and irrigated conditions.

E_{min} is the effective mineralization factor for the growing season portion of the year. N-use efficiency for this period was determined to be 71%.

	Nonirrigated				Irrigated			
	Year 1	Year 2	Year 3	Year 4	Year 1	Year 2	Year 3	Year 4
	K_{min}							
Annual	0.42	0.14	0.14	0.07	0.50	0.21	0.14	0.07
	E_{min}							
Growing season	0.30	0.10	0.10	0.05	0.35	0.15	0.10	0.05

The values in **tables 4 and 5 (page 163)** might not be the most appropriate for all biosolids applied to any soil, but such "book" values are normally used when site-specific data are not available. The amounts of available ammonium (NH_4^+) plus the available portion of the organic nitrogen are used to calculate the rate of biosolids needed to supply a given amount of plant-available nitrogen. Equations for calculating PAN are relatively straightforward, but selecting precise site- and source-specific availability coefficients is an imprecise exercise. Site-specific data should be used if it is available.

Will agronomic nitrogen rates of biosolids meet all crop nutrient needs?

Agronomic nitrogen rates of biosolids do not necessarily meet all crop nutrient requirements. For example, potassium is often recommended for agronomic crops grown in Virginia soils, but the nutrient is present in low concentrations in biosolids. Supplemental potassium fertilization based on soil testing may be required for optimum plant growth where biosolids are applied.

Can problems occur by applying biosolids at agronomic nitrogen rates?

Biosolids normally supply similar amounts of plant-available nitrogen and phosphorus, but crops require one-fifth to one-half as much phosphorus as nitrogen. Applying biosolids whose phosphorus is largely contained in forms that are readily soluble/plant available at rates to supply the nitrogen needs of crops will eventually supply more phosphorus than necessary. Many soils in the Chesapeake Bay region contain very high levels of phosphorus due to long-term manure application or repeated fertilization with commercial phosphorus fertilizer. Long-term application of N-based biosolids rates can increase the potential for phosphorus contamination of surface water where soil phosphorus levels are already high. To reduce the potential of phosphorus runoff or leaching in such cases, it is advisable to apply the biosolids at rates to meet the phosphorus, rather than the nitrogen, needs of the crop. The need to apply biosolids on a phosphorus basis can be verified with the use of a site-specific assessment tool, such as the P Index, which incorporates phosphorus transport risk in addition to soil quantity factors. Applying biosolids on a phosphorus basis would likely require a farmer to purchase fertilizer nitrogen to supplement crop needs.

How are plant availabilities of phosphorus and potassium from biosolids determined?

The U.S. Environmental Protection Agency (USEPA 1995) estimates that 50% of the phosphorus and 100% of the potassium applied in biosolids are available for plant uptake in the year of application. More recent research data has established that the availability of phosphorus in biosolids varies widely according to its composition of P-binding constituents (esp. aluminum, iron, and calcium) and the treatment processes that the wastewater was subjected to. The adoption of best management practices and improved testing procedures are recommended to protect water quality (**www.wef.org/globalassets/assets-wef/3---resources/topics/a-n/biosolids/technical-resources/1-page-p-fact-sheet-v25-jul-2016.pdf**). Biosolids' phosphorus source coefficients for use in the P Index can be calculated from water-extractable P (**www.extension.psu.edu/programs/nutrient-management/planning-resources/other-planning-resources/p-source-coefficient**).

The quantities of available phosphorus and potassium applied to soil with the biosolids may be credited against fertilizer recommendations in the year of application. Any phosphorus and potassium in excess of plant needs will contribute to soil fertility levels that can regularly be monitored via soil testing when determining fertilizer recommendations in succeeding years.

Using Soil pH and Calcium Carbonate Equivalent as the Basis for Determining Biosolids Rate

Soil pH influences the availability and toxicity of naturally occurring metals and metals applied to soil in biosolids. Most crops grow well in Virginia soils at pH levels between 5.8 and 6.5. Based on previous U.S. EPA guidance, some states require that soils treated with biosolids be maintained at a pH of 6.5 or higher to reduce metal uptake by crops. Federal regulations do not require a minimum soil pH because pH was factored into the Part 503 risk assessment on which the regulation was based (USEPA 1992b). It is advisable to maintain the pH of agricultural soils where biosolids have been applied in the optimum range for crop growth (i.e., 5.8 to 6.5) to avoid phytotoxicity due to naturally occurring soil or biosolids-supplemented metals.

The calcium carbonate equivalent of the alkaline-stabilized biosolids can be used to determine application rates. The pH of coarse-textured (i.e., sandy) soils can rise rapidly when limed. Deficiencies of manganese in wheat and soybean and zinc in corn have sometimes been caused by excessive liming (pH > 6.8) of coarse-textured, Coastal Plain soils. Application of lime-stabilized biosolids at agronomic nitrogen rates to such soils that already have high pH values can induce such deficiencies. Crop yield reductions can result if the deficiency is not corrected, and the nitrogen not utilized by the crop can potentially leach into groundwater. Thus, alkaline-stabilized biosolids should not be applied at rates that raise the soil pH in Coastal Plain soils above 6.5, and in all other soils above 6.8.

Magnesium deficiencies have been reported in row crops where repeated applications of calcitic (high Ca, low Mg) limestone has reduced soil Mg concentrations. Such soils can be identified by soil testing and should not receive further additions of “calcium-only” liming materials, including Ca-based, lime-stabilized biosolids.

Calculating Annual Agronomic Nitrogen Rate

Calculations for quantifying annual agronomic nitrogen rates are described in **Table 6**.

Table 6. Stepwise calculation of nitrogen-based biosolids application rates.

Step	Action
1	Determine N recommendation for the crop based on the expected yield level for the soil. Use state or private soil testing laboratory fertilizer nutrient recommendations or similar tool (DCR 2014).
2	Subtract anticipated N credits (i.e., other sources of N) from the recommended N rate, such as: • Residual N from a previous legume crop. • N that has already been applied or will be applied for the crop by fertilizer, manure, or other sources that will be readily available to plants. • Residual N remaining from application of previous byproduct (e.g., manure, biosolids).
3	Calculate the adjusted biosolids N rate by subtracting N available from existing and planned sources from the total N requirement of crop.
4	Calculate the PAN/dry ton of biosolids for the first year of application using the following equation (1): $\mathbf{PAN = NO_3\text{-}N + K_{vol}\,(NH_4^+\text{-}N) + K_{min}\,(Org\text{-}N)}$ **(1)** where: **PAN** = lbs plant-available N/dry ton biosolids. $\mathbf{NO_3\text{-}N}$ = lbs nitrate N/dry ton biosolids. $\mathbf{K_{vol}}$ = volatilization factor or plant-available fraction of NH_4-N (table 4). $\mathbf{NH_4\text{-}N}$ = lbs ammonium N/dry ton biosolids. $\mathbf{K_{min}}$ = mineralization factor or plant-available fraction of Org-N (table 5). **Org-N** = lbs organic N/dry ton biosolids (estimated by subtracting NH_4-N from total Kjeldahl N).
5	Calculate the amount of biosolids required to supply the crop's N needs using the following equation: **Dry tons biosolids required/acre = adjusted biosolids N rate (in lbs/A) ÷ PAN/dry ton biosolids.** Then divide the tons of dry biosolids by the percentage of solids to convert to the wet weight of biosolids required.

Calculating Annual Agronomic Phosphorus Rate

Applying biosolids to meet the phosphorus rather than the nitrogen needs of the crop is a conservative approach for determining annual biosolid application rates. A more scientifically balanced approach, which accounts for both phosphorus availability and transport, is the use of a tool such as the P Index (as described in Part XI. Fertilizing With Manure). Supplemental nitrogen fertilization will be needed to optimize crop yields (except for N-fixing legumes) if biosolids application rates are based on a crop's phosphorus needs.

The agronomic phosphorus rate of biosolids for land application can be determined by using the following equation (2):

Agronomic P rate = P_{req} ÷ Available P_2O_5/dry ton, **(2)**

where:

P_{req} = the P fertilizer recommendation for the harvested crop or the quantity of P removed by the crop.

Available P_2O_5 = K_p[a] (total P_2O_5/dry ton biosolids).

Total P_2O_5/dry ton = %P in biosolids x 20[b] x 2.3[c].

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[a] K_p = P availability factor = 0.5 (USEPA 1995).

[b] 20 is the factor to convert % to lbs/ton.

[c] 2.3 is the factor to convert lbs P to lbs P_2O_5.

Calculating Agronomic Lime Requirement

Application rates for lime-stabilized or lime-conditioned biosolids can be computed by determining the biosolids' calcium carbonate equivalent. The CCE provides a direct comparison of the liming value of the biosolids with calcium carbonate limestone, which is the basis for soil testing liming requirements. Biosolids conditioned or stabilized with lime typically have CCEs between 10% and 50% on a dry weight basis. The agronomic lime rate for a biosolid can be determined by using the following equation (3):

Dry tons biosolids/A = tons of CCE required/A ÷ biosolids CCE/100 **(3)**

Example: Determining nitrogen, phosphorus, and lime agronomic rates for a specific situation.

The following exercise is an example of calculating biosolids application rates based on N, P and lime needs.

A lime-stabilized biosolid has a pH > 10, a calcium carbonate equivalent of 40%, a nitrate-nitrogen (NO_3-N) concentration of 1,000 ppm (0.1%), an ammonium-nitrogen (NH_4-N) concentration of 2,000 ppm (0.2%), a total Kjeldahl (TKN) concentration of 27,000 ppm (2.7%), and a total phosphorus concentration of 21,000 ppm (2.1%) – all on a dry weight basis (% dry solids = 17.6%). Corn for grain is to be grown on a Kempsville sandy loam soil that has a pH of 6.2, "high" calcium, magnesium, and potassium soil test ratings and a "medium" phosphorus soil test rating. The biosolids will be surface-applied and disked into the soil within 24 hours.

Determining N, P, and Lime-Based Agronomic Rates

Determine N recommendation for the crop based on the expected yield level for the soil. The estimated yield potential of corn grown on a Kempsville soil is 120 bu/A (DCR 2014), which requires 132 lbs N/A (assumption: 1.1 lbs N per bu of corn).

1. **Calculate the N-based agronomic rate using (1),**
   a. Calculate the components of PAN in the biosolid:

      NO3-N = 1,000 ppm x 0.002 = 2 lbs/ton.

      NH4-N = 2,000 ppm x 0.002 = 4 lbs/ton.

      TKN = 27,000 ppm x 0.002 = 54 lbs/ton.

      Org-N = 54-(2 + 4) = 48 lbs/ton.

   b. Calculate PAN:

      PAN = 2 + 0.75 (4 lbs/ton) + 0.3 (48 lbs/ton) = 2 + 3 + 14.4 = 19.4 lbs/ton.

   c. Divide the adjusted fertilizer N rate (132 lbs N/dry ton) by the PAN/dry ton biosolids (19.4 lbs N/dry ton) to obtain the agronomic N rate (6.8 dry tons/A).

2. **Calculate the P-based agronomic rate using (2).**
   a. Calculate the total amount of P_2O_5 in a ton of biosolids:

      P_2O_5/dry ton = 2.1 x 20 x 2.3 = 96.6 lbs.

   b. Calculate the amount of plant-available P_2O_5 in a ton of biosolids (using the USEPA availability factor of 0.5):

      Plant-available P_2O_5/dry ton = 0.5 x 96.6 = 48.3 lbs.

   c. Calculate the agronomic P rate. The soil test rating of "medium" in Virginia requires 40-80 lbs P_2O_5/A (DCR 2014).

      The agronomic P rate = 60 lbs P_2O_5/A ÷ 48.3 lbs P_2O_5/dry ton = 1.24 dry tons/A (i.e., about 1/5 of the agronomic N rate for the same biosolids).

3. **Calculate the lime-based agronomic rate.**

   The coarse-textured Kempsville soil requires 0.75 ton limestone/acre to raise the pH to 6.5 (DCR 2014). Use **(3)** to determine the rate of lime-stabilized biosolids needed to provide 0.75 ton CCE/A:

   Lime-based biosolids rate = tons of CCE required/A ÷ biosolids CCE/100 (0.75 ton CCE/A) ÷ 40%/100 = 1.88 dry tons/A.

4. **Compare the rates calculated in steps 1, 2, and 3.**

   The N-based, P-based, and lime-based agronomic rates for the example above are 6.8, 1.24, and 1.88 dry tons/A, respectively. Dividing each of these rates by the fraction of solids in the biosolids (0.176) gives the wet weights of biosolids that must be applied to meet N-based (38.6 wet tons/A), P-based (7.04 wet tons/A), and lime-based (10.7 wet tons/A) application rates.

The P rate appears to be most limiting; however, transport risks as assessed by the P Index should also be considered before deciding on the "correct" agronomic rate. Finally, the capability of the equipment to spread very low rates and the economics of applying low rates may prevent biosolids from being applied at all.

Land Application Methods

The most appropriate application method for agricultural land depends on the physical characteristics of the biosolids and the soil, as well as the types of crops grown. Biosolids are generally land applied using one of the following methods.

- Sprayed or spread on the soil surface and left on the surface for pastures, range, and forestland.
- Incorporated into the soil after being surface-applied or injected directly below the surface for producing row crops or other vegetation.
- Applied to land with or without subsequent soil incorporation (both liquid and dewatered [or "cake"] biosolids).

Applying Liquid Biosolids

Liquid biosolids can be applied by surface spreading or subsurface injection. Surface methods include spreading by tractor-drawn tank wagons, special applicator vehicles equipped with flotation tires, or irrigation systems. Surface application with incorporation is normally limited to soils with less than a 7% slope. Biosolids are commonly incorporated by plowing or disking after the liquid has been applied to the soil surface and allowed to partially dry, unless minimum or no-till systems are being used.

Spray irrigation systems generally should not be used to apply biosolids to forage or row crops during the growing season, although a light application to the stubble of a forage crop following a harvest is acceptable. The adherence of biosolids to plant vegetation can have a detrimental effect on crop yields by reducing photosynthesis, and it provides a more direct pathway for pollutant consumption by grazing animals. In addition, spray irrigation increases the potential for odor problems and reduces the aesthetics at the application site.

Liquid biosolids can also be injected below the soil surface using tractor-drawn tank wagons with injection shanks and tank trucks fitted with flotation tires and injection shanks. Both types of equipment minimize odor problems and reduce ammonia volatilization by immediate mixing of soil and biosolids. Injection can be used either before planting or after harvesting crops, but it is likely to be unacceptable for forages and sod production. Some injection shanks can damage the sod or forage stand and leave deep injection furrows in the field.

Subsurface injection will minimize runoff from all soils and can be used on slopes up to 15%. Injection should be made perpendicular to slopes to avoid having liquid biosolids run downhill along injection slits and pond at the bottom of the slopes. As with surface application, drier soil will be able to absorb more liquid, thereby minimizing downslope movement. Liquid biosolids have largely given way to drier, dewatered products.

Applying Dewatered Biosolids

Dewatered biosolids can be applied to cropland by equipment similar to that used for applying limestone and animal manure (**figs. 3a, 3b**). Typically, dewatered biosolids will be surface-applied and incorporated by plowing or another form of tillage. Incorporation is not used when applying dewatered biosolids to forages or to crops being grown no-till. Biosolids application methods such as incorporation and injection can be used to meet Part 503 vector attraction reduction requirements.

Figure 3a. Dewatered biosolids are spread onto conventionally tilled land.

Figure 3b. Dewatered biosolids being spread onto pastureland.

Timing of Biosolids Application

The timing of biosolids application must be scheduled around the tillage, planting, and harvesting operations and will be influenced by crop, climate, and soil properties. Traffic on wet soils during or immediately following heavy rainfalls can cause compaction and leave ruts in the soil, making crop production difficult and reducing crop yields. Muddy soils also make vehicle operation difficult and can create public nuisances by carrying mud out of the field and onto roadways.

Applications should also be made when crops will soon be able to use the plant-available nitrogen contained in the biosolids. Failure to do so could result in potential nitrate contamination of groundwater due to leaching of this water-soluble form of nitrogen. It is advisable that biosolids applied to land between autumn and spring have a vegetative cover (i.e., permanent pasture, winter cover crop, winter annual grain crop) to reduce erosion of sediment-bound biosolids; runoff of N, P, and pathogens; and leaching of nitrate.

Split applications may be required for rates of liquid biosolids (depending on the solids content) in excess of 2-3 dry tons/acre. Split application involves more than one application, each at a relatively low rate, to attain a higher total rate when the soil cannot assimilate the volume of the higher rate at one time.

Biosolids Storage

In-field storage of biosolids at or near the application site is often needed. Storage facilities are required to hold biosolids during periods of inclement weather, equipment breakdown, frozen or snow-covered ground, or when land is unavailable due to growth of a crop. Liquid biosolids can be stored in digesters, tanks, lagoons, or drying beds, and dewatered biosolids can be stockpiled. Recommended guidelines for such storage have been specified by the Environmental Protection Agency (USEPA 2000).

Disadvantages of Land Application

Large land areas may be needed for agricultural use of biosolids because application rates are relatively low. Transportation and application scheduling that is compatible with agricultural planting, harvesting, and possible adverse weather conditions require careful management.

Biosolids are typically delivered to the application site by tractor-trailers containing approximately 20 tons (**fig. 4**), stockpiled at the staging area, and loaded into manure-type spreaders (**fig. 5**). At a solids content of 15%-25%, 20 tons of wet biosolids is approximately 3-5 dry tons per trailer, or about the amount of biosolids that is normally spread onto 1 acre of land for crops such as corn or hayland. Therefore, there will be considerable truck volume over the course of several weeks for large sites of several hundred acres. Increased traffic on local roads, odors, and dust are potential impacts on the local community that should be addressed by notifying neighbors in public informational meetings or public hearings. Working out delivery schedules that are least likely to be disruptive will minimize the problems caused by biosolids transportation.

Figure 4. Biosolids being stockpiled at staging area.

Figure 5. Dewatered biosolids being loaded into manure-type spreader for application.

Biosolids, even when properly treated, will have odors. Under unfavorable weather conditions, the odors may be objectionable, even to rural communities accustomed to the use of animal manure. Odors may be reduced by stabilization process, application method, storage type, climatological conditions, and site selection, as described below.

Stabilization reduces the biological activity and odor of biosolids. The products of digestion, heat treatment, and composting tend to result in the least objectionable odors. Lime-stabilized biosolids can generate odors if the liming agent has not been well-distributed throughout the product or, for surface-applied unincorporated biosolids, after the pH of the biosolids decreases.

Application method affects the odor potential at the site. Immediate soil incorporation or direct soil injection will reduce the potential for odor problems.

Biosolids storage can occur at the treatment plant, the site of application, or a temporary facility. Storage at the treatment plant (if isolated from the public) is the preferred method. Off-site storage requires proper site selection and management to minimize the potential for odor problems.

Weather conditions (i.e., temperature, relative humidity, wind) will affect odor severity when biosolids are surface-applied. Spreading in the morning when air is warming and rising will help dilute the odor in the immediate vicinity.

The selection of the application site is important to the success of the operation. Ideally, the site should be located away from residential areas.

Objectionable odors will sometimes be present despite adequate stabilization processes and favorable weather conditions. Complaints can be expected if adjacent property owners are subjected to persistent odors. A well-managed system with the proper equipment and stabilized biosolids will substantially reduce the potential for unacceptable odors.

References

Chaney, R. L. 1994. “Trace Metal Movement: Soil-Plant Systems and Bioavailability of Biosolids-Applied Metals.” *In Sewage Sludge: Land Utilization and the Environment*, edited by C. E. Clapp, W. E. Larson, and R. H. Dowdy, 27-31. Madison, WI: ASA, CSSA, SSSA Books.

DCR (Virginia Department of Conservation and Recreation). Division of Soil and Water Conservation. 2014. *Virginia Nutrient Management Standards and Criteria. Richmond*, VA: DCR.

CFR (Code of Federal Regulations). 2021 (last revised). 40 CFR 503.11(b).

Gilmour, J. T., C. G. Cogger, L. W. Jacobs, S. A. Wilson, G. K. Evanylo, and D. M Sullivan. 2000. *Estimating Plant-Available Nitrogen in Biosolids*. Project 97-REM-3. Alexandria, VA: Water Environment Research Foundation.

Gilmour, J. T., C. G. Cogger, L. W. Jacobs, G. K. Evanylo, and D. M Sullivan. 2003. “Decomposition and Plant-Available Nitrogen in Biosolids: Laboratory Studies, Field Studies, and Computer Simulation.” *Journal of Environmental Quality* 32:1498-1507.

National Research Council. 2002. Biosolids Applied to Land: Advancing Standards and Practices. Washington, DC: National Academies Press.

Shimp, G., K. Hunt, S. McMillian, and G. Hunter. 1994. “Pretreatment Raises Biosolids Quality.” *Environmental Protection* 5 (6).

Stehouwer, R. C., A. M. Wolf, and W. T. Doty. 2000. “Chemical Monitoring of Sewage Sludge in Pennsylvania: Variability and Application Uncertainty.” *Journal of Environmental Quality* 29 (5): 1686-95.

USEPA. 1984. *Environmental Regulations and Technology: Use and Disposal of Municipal Wastewater Sludge*. EPA/625/10-84/003. Washington, DC: USEPA.

USEPA. 1990. “National Sewage Sludge Survey: Availability of Information and Data, and Anticipated Impacts on Proposed Regulations.” *Federal Register* 55 (218).

USEPA. 1992a. *Technical Support Document for Land Application of Sewage Sludge,* Vol. I. EPA/822/R-93/900/9. Washington, DC: USEPA.

USEPA. 1992b. *Technical Support Document for Land Application of Sewage Sludge,* Vol. I. EPA/822/R-93/001a. Washington, DC: USEPA.

USEPA. Office of Research and Development. 1995. *Process Design Manual: Land Application of Sewage Sludge and Domestic Septage*. EPA/625/R-95/001. Washington, DC: USEPA.

USEPA. Office of Wastewater Management. 2000. *Guide to Field Storage of Biosolids*. EPA/832-B-00-007. Washington, DC: USEPA.