

**GUIDELINES FOR
APPLICATION OF SEWAGE
BIOSOLIDS TO AGRICULTURAL
LANDS IN THE NORTHEASTERN U.S.**

APRIL 2007

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As delineated by the US Department of Agriculture, the Northeast region includes: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia and West Virginia.

This document is the product of the NE 1001 multi-state research committee that in 2006 became a regional coordinating committee (NECC 1010: Use of Residuals in Agriculture in the Northeast). Participating scientists are from Maine, New Hampshire, Massachusetts, New York, New Jersey and Pennsylvania as well as Ontario, Canada. This report is available at www.rce.rutgers.edu/pubs. Other information on the committee's work is available at: <http://cwmi.css.cornell.edu/NERA/NEhome.html>.

This document benefited by comments from 13 scientists, field staff and regulators. The authors greatly appreciate their contributions.

GUIDELINES FOR APPLICATION OF SEWAGE BIOSOLIDS TO AGRICULTURAL LANDS IN THE NORTHEASTERN U.S.

PREFACE

In 1985, a group of scientists from Land Grant universities in the Northeastern United States and cooperating federal agencies authored a publication titled *Criteria and Recommendations for Land Application of Sewage Sludge in the Northeast* (NEC-28, 1985). Since that time, new scientific evidence and regulatory policy have emerged with respect to [sewage biosolids](#) ([sewage sludge](#)) recycling on land. Recognizing that use of sewage biosolids on agricultural soils has expanded and that our knowledge regarding the practice has increased over the past 20 years, a multi-state research committee of faculty from Land Grant universities in the Northeast U. S. (NE 1001: Application of Sewage Biosolids to Agricultural Soils in the Northeast: Long-term Impacts and Benefit) was convened in 2000 to reconsider the topic. As delineated by the US Department of Agriculture, the Northeast region includes: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia and West Virginia. This document is the product of the five-year work of the NE 1001 multi-state research committee including participating scientists from Maine, New Hampshire, Massachusetts, New York, New Jersey and Pennsylvania as well as Ontario, Canada.

The most significant change since 1985 was the regulatory framework promulgated by USEPA in 1993 (40 CFR Part 503) that established *minimum* standards for land application of sewage biosolids. An underlying objective of the federal rule was to encourage regulatory uniformity for sewage biosolids recycling. The Part 503 rule was a risk-based approach designed to protect public health and the environment from “any reasonably anticipated adverse effects of certain pollutants and contaminants” present in sewage biosolids (USEPA, 1994). A review by the National Research Council (2002) found “the technical basis of the 1993 chemical standards for biosolids to be outdated” and concluded that while “the committee did not find documented scientific evidence that the Part 503 regulations had failed to protect public health”, but that “additional scientific work is needed to reduce uncertainties about the potential for adverse human health effects from exposure to biosolids.”

There are areas in the Northeastern United States where land application of sewage biosolids to agricultural soils in accordance with existing state and federal regulations will present a low risk of adverse effects on agriculture, human health or the environment. However, the range of soil conditions, farming practices, and demographic factors in the Northeast lead some scientists to believe that the baseline CFR40 Part 503 regulations may not be adequately protective under all agricultural use scenarios in this region. What follows is a discussion of management practices that address these circumstances. These guidelines are not meant to supersede or replace existing state regulations, although states may want to consider additional management requirements based on the following recommendations. The purpose is to inform potential users of sewage biosolids (including landowners, farmers and their advisors) of situations where additional management practices beyond current state and federal regulations can be

implemented to promote sustained productivity of farmland and to better protect public health and the environment.

Circumstances, Conditions, or Issues to be Addressed:

1. Recommendations for testing to promote accurate application rates.
2. Alternative trace element loadings for shallow soils with limited buffering capacity.
3. Conditions where [molybdenosis](#) or [hypocuprosis](#) are a potential concern to grazing ruminants (cattle, sheep).
4. Recommendation that a farm-scale nutrient mass balance plan be in place for sewage biosolids sites that addresses both N and P application.
5. Recommendation regarding appropriate application rates for all highly alkaline materials ([lime-stabilized](#) biosolids, advanced alkaline stabilized products).
6. Recommendations regarding soil [incorporation](#) for N conservation, odor control, [vector attraction reduction](#), and reducing potential for public exposure.
7. Soil pH recommendations.
8. Recommendations for record keeping.

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SUMMARY OF THE GUIDELINES

1. These guidelines refer to [bulk application](#) of both “[exceptional quality](#)” (EQ) and non-EQ sewage biosolids.
2. Any farm considering the application of sewage biosolids should construct a farm-scale nutrient balance to ensure a demonstrated need for the additional nutrients.
3. Apply the highest quality sewage biosolids available. Maximum concentrations (expressed as [parts per million](#) (ppm; mg/kg) of 18 ppm arsenic (As), 8 ppm cadmium (Cd), 160 ppm chromium (Cr), 1,100 ppm copper (Cu), 180 ppm lead (Pb), 3 ppm mercury (Hg), 33 ppm molybdenum (Mo), 70 ppm nickel (Ni), 15 ppm selenium (Se), and 1,500 ppm zinc (Zn), on a dry weight basis are suggested. These are approximately the [95th percentile](#) values for several different data sets representing Northeastern U.S. sewage biosolids as of 2005. These are not risk-based values nor regulatory limits, but rather provide reference points to determine general quality of the material.
4. Apply material that has consistent quality. Nitrogen concentrations in sewage biosolids from one wastewater treatment plant can be highly variable, making accurate calculation of appropriate agronomic application rates difficult. Some WWTPs produce sewage biosolids with relatively low trace element concentrations in comparison to other facilities. The best strategy is to choose sewage biosolids from facilities that have consistent nutrient and trace element concentrations and also low trace element concentrations. For [trace elements](#), a rolling average including at least four analyses per year is recommended for sewage biosolids from each wastewater treatment plant (WWTP) source. Seasonal and operational variations need to be taken into account.
5. Maximum recommended cumulative soil trace element concentration limits for sites to which sewage biosolids are applied are intended to address and protect the agricultural productivity under Northeast soil conditions and for Northeast farming practices and demographics some of which are unique to this region (Table 2).
6. Test soils before application and again when it is estimated that the soil trace element concentrations have reached approximately one half of the recommended maximum soil concentration (see Table 2).
7. The potential for induced copper deficiency in ruminant animals due to molybdenum (Mo), iron (Fe), cadmium (Cd) and sulfur (S) in sewage biosolids requires careful consideration of livestock dietary intakes.
8. Alkaline-stabilized sewage biosolids should not be applied at rates greater than the soil liming requirements, and the nutrients present in the product (N,P) must be accounted for.
9. Wherever possible, sewage biosolids should be incorporated (injected into, mixed into, or turned under the surface) in the soil within twenty-four hours of application. When stockpiling material, caution is advised to minimize odor and leaching problems.
10. Care is needed to spread uniformly and avoid creating “hot spots” in a field where sewage biosolids are over-applied locally.
11. Soil pH of 6 or above should be maintained as long as the land to which sewage biosolids have been applied is used for crop production.

12. Use of sewage biosolids on soils used to grow vegetable or fruit crops is not recommended.
13. Farmers should keep records of the source, quantity and quality of materials applied. Records should be kept of when, how, and by whom sewage biosolids are applied, as well as any concerns (such as odors, etc.) noted during application.
14. Farmers using sewage biosolids may wish to obtain written assurance from the supplier that any sewage biosolids being land applied are of appropriate quality (pollutants, pathogen reduction, vector attraction reduction) and have been properly treated and that the application procedures meet federal and state regulations.

INTRODUCTION

Management of municipal sewage biosolids (sewage sludge) in an environmentally acceptable and affordable manner is a significant challenge. Currently in the U.S., management of sewage biosolids is accomplished by three primary methods: land spreading, incineration, or landfilling. Following the prohibition of ocean dumping in 1991 and promulgation of the Part 503 federal regulation in 1993, land application has increased as a management method in the Northeast and elsewhere. Nevertheless, landfilling and incineration remain major management methods for sewage biosolids in the Northeast.

The benefits of amending soils with sewage biosolids are well documented, primarily linked to the fact that sewage biosolids return nutrients and organic matter to the soil. However, management practices for sewage biosolids must include an awareness of potential adverse impact on soil, animal and human health. The presence of trace elements, [synthetic organic chemicals](#) and disease-causing organisms (pathogens) places constraints on the management of sewage biosolids by land application.

A lack of knowledge hampers our ability to evaluate practices and make recommendations. Because no sewage biosolids management method is risk free, establishing guidelines requires acceptance of a certain degree of risk that is not fully knowable or quantified. The alternatives to land application have other environmental consequences and trade-off considerations that are beyond the purview of agricultural scientists. However, as agricultural scientists, we have a responsibility to provide advice, based on current knowledge and the best science available, that seeks to protect the land resource base with an emphasis on protecting agricultural productivity in perpetuity. This document represents our judgments and our experiences with specific soils and crops in the Northeast. This document focuses on agronomic and not on economic, social and legal issues. Further information on these latter issues can be found in a fact sheet from Rutgers University (Bamka, et al., 1999).

The purpose of this document is to provide criteria and recommendations for land application of sewage biosolids in the Northeast in a manner that will minimize risks to land productivity and the food chain. These guidelines are an attempt to develop guidelines for the entire Northeast, but modifications or additional guidelines may be necessary to address local and state conditions. Federal and state regulations establish numerous requirements pertaining to the use of sewage biosolids on agricultural lands. Some municipalities have also adopted rules. These requirements vary among the states and localities and must be followed.

Soil conditions, farming systems and the population density of the Northeast dictate a cautionary approach to land spreading of sewage biosolids. In the Northeast, relatively acidic, shallow, low organic matter soils are common. The chemistry and hydrology of these soils contrast sharply with the deep, high organic matter mollisols of the Corn Belt in the Midwest or the calcareous aridisols of the west, for example. These Northeast soils have been shown to have lower heavy metal sorption capacities than do soils with higher pH or more organic matter. This situation places the Northeast in a position of having some soils that are less suitable for application of sewage biosolids.

Dairy farming is the primary agricultural system in most states in the Northeast. On many dairy farms, applications of farm manure supplies more nutrients than required for on-farm crop production (due to feed importation), resulting in the potential for excess nutrients causing pollution of ground and surface waters. The addition of sewage biosolids in such systems may further exacerbate this nutrient imbalance. Furthermore, certain elements in sewage biosolids (such as S and Mo) have the potential to result in Cu deficiency in cattle (as well as sheep and goats) if there are dietary imbalances.

Fruit and vegetable production is another important agricultural system in the Northeast and both are sensitive commodities with regard to public perception. A decision to land-apply sewage biosolids on a fruit or vegetable crop can directly affect a farmer's livelihood because some supermarket chains, food processors and wholesalers do not accept produce from farms where sewage biosolids have been used.

The term EQ (Exceptional Quality) is used to indicate sewage biosolids that meet Part 503 "[Class A](#)" [pathogen levels](#) and meet applicable options for the control of [vectors](#) and also meet certain standards for the concentration of 9 trace elements. Federal and most state rules regulate the *production* of EQ sewage biosolids but do not regulate the *use* of the EQ product if prepared according to the approved standards.

The recommendations contained in this document pertain to both EQ and non-EQ (including [Class B](#)) sewage biosolids applied in bulk. It is recommended that state and federal requirements that address setbacks from watercourses, record keeping and application rates for non-EQ materials also be implemented for application of EQ materials.

CRITERIA USED FOR GUIDELINES

The following criteria were used to establish the various recommended guidelines in this publication.

1. The unique soils and situations in the Northeast U.S. warrant specific guidelines to protect agricultural productivity and soil and water resources.
2. Water quality considerations were used to address phosphorus (P) and nitrogen (N) applications.
3. Trace elements added to soils are expected to persist for many years.

4. Sustained soil productivity was used to set the upper limits on cumulative Cu, Ni and Zn applications.

COMPOSITION OF SEWAGE BIOSOLIDS

To determine appropriate application rates and to ensure low pollutant levels in land-applied sewage biosolids, knowing the chemical composition of sewage biosolids is of great importance.

A principal benefit of recycling sewage biosolids on land is the supply of plant nutrients that they contain. This includes the major nutrients (nitrogen [N], phosphorus [P], and potassium [K]), secondary nutrients (calcium [Ca], magnesium [Mg], and sulfur [S]) and many micronutrients (e.g., Fe, Cu, Zn). Typical values for the total levels of major nutrients in stabilized wastewater sewage biosolids are 4.5% N, 5% P as P₂O₅ and 0.4% K as K₂O, although these values vary widely depending on influent wastewater and treatment conditions. The majority of N in sewage biosolids is an organic form ([organic nitrogen](#) or org-N), originating from proteins, nucleic acids, amines and other cellular components. However, biosolids also contain [inorganic nitrogen](#) as [ammonium nitrogen](#) (NH₄-N) and sometimes a small amount of [nitrate-N](#) (NO₃-N) depending on the treatment processes used. Most of the P and K in sewage biosolids exists in inorganic forms. For most commercial crops, applying sewage biosolids to meet N fertility requirements provides excessive P but suboptimal levels of K to the crop.

Determining the appropriate N-based agronomic application rate for sewage biosolids requires knowledge of the N content of the material being applied. There are different forms of N in sewage biosolids and they are generally reported as ammonia N (NH₄-N), organic N, [total Kjeldahl N](#) (TKN) and/or [total N](#). (It is therefore important to pay attention to the particular analyses that may be reported in laboratory tests.) The rates at which the different forms of N provide N to meet crop needs varies, with ammonium N being immediately available whereas the organic N becomes available to crops over a number of years. The Nutrient Management section of this document discusses how the appropriate application rate is calculated. The amount of the several forms of N measured in sewage biosolids varies widely among WWTPs, but also varies over time at a single WWTP. This variation makes it difficult to determine a sewage biosolids application rate that will supply crop N needs and not result in excess N application.

Over the last 30 years, implementation of the Clean Water Act has produced changes in industrial operations and pretreatment of industrial wastewater that have resulted in significant reductions in some pollutants entering WWTPs. Nevertheless, sewage biosolids still contain pollutants that need to be monitored. Federal and state regulations require periodic testing of some nutrients and trace elements present in sewage biosolids applied to land. The frequency of testing required depends on the size of the WWTP. Such analytic data are public information.

Some WWTPs produce sewage biosolids with relatively low trace element concentrations in comparison to other facilities. The chemical composition of sewage biosolids is affected by the wastewater influent (e.g., local and regional differences, industrial input, seasonality of industries, street run-off) and the WWTP processes used (e.g., lime additions, dewatering, digestion). The best strategy is to choose sewage biosolids from WWTPs with low mean trace

element concentrations and little variation among the concentrations measured in different samples of the sewage biosolids at different times.

As an indication of chemical quality, the concentration of chemical constituents in the material under consideration can be compared to the quality of other sewage biosolids. For the purposes of this document, an average of the 95th percentile concentrations for recent data sets from several Northeast states was calculated as a benchmark (see Appendix 1). These are suggested as *maximum* contaminant concentrations for land-applied sewage biosolids: 18 ppm arsenic (As), 8 ppm cadmium (Cd), 160 ppm chromium (Cr), 1,100 ppm copper (Cu), 180 ppm lead (Pb), 3 ppm mercury (Hg), 33 ppm molybdenum (Mo), 70 ppm nickel (Ni), 15 ppm selenium (Se), and 1,500 ppm zinc (Zn), on a dry weight basis. These are not risk-based values, but rather provide a reference point to determine general quality of the material. Most sewage biosolids have contaminant concentrations below these values, but use of the cleanest sewage biosolids available is always desirable.

As noted previously, the chemical composition of sewage biosolids is variable, varying not only among the different WWTP sources but also over time from any one facility. While having an actual analysis of nutrients and trace element in the batch of sewage biosolids to be land-applied is the most precise way to determine accurate nutrient-based application rates (as opposed to basing rates on recent historical data), this practice is rarely practical. If historical data are used, calculating an annual rolling average of sewage biosolids concentrations (including at least four analyses per year) is recommended. However, when using a rolling average, seasonal and operational variability needs to be taken into account. For example, wastewater from a seasonal food processing plant might cause seasonal cycling of the nutrient content of the sewage biosolids at the WWTP that receives the wastewater. For some small WWTPs, sewage biosolids may be accumulated in-plant and distributed for use only once a year. In that case, a single set of analyses taken before application will represent the material that would be applied. Another option when historical data are used to determine nitrogen-based application rates is to apply sewage biosolids at rates that are less than the [agronomic rate](#) and to supply additional N later if the [pre-sidedress soil nitrate test](#) (PSNT) or other soil test determines a need.

Scientific knowledge seldom has been adequate in answering all questions associated with any practical management scheme; land application of sewage biosolids is no exception. The risks potentially associated with synthetic organic chemicals are a prime example. Because wastewaters contain detectable amounts of industrial and agricultural organic byproducts, pharmaceuticals, personal care products, and cleaners and detergents, many trace organic chemicals can be found in sewage biosolids. Some of these compounds are toxic, carcinogenic, or cause reproductive or developmental effects in mammals. Their concentrations and the rates at which they degrade in soil vary widely and questions remain about potential health and environmental effects. Their presence in sewage biosolids at present is acknowledged, but an inadequate research base precludes making quantitative recommendations for specific synthetic organic chemicals.

There are no federal regulations requiring testing for organic chemicals in sewage biosolids nor are there established maximum contaminant levels for them. A few states have established limits for dioxins and/or polychlorinated biphenyls (PCBs).

MAXIMUM TOTAL TRACE ELEMENT CONCENTRATIONS IN SOILS

Almost all trace elements naturally occur at low concentrations in soils (hence the term trace elements; some of these are listed in Table 1). Many trace elements will cause adverse effects on human, animal, plant, and environmental health if their concentrations and availability in soil are increased to sufficiently high levels. Furthermore, most trace elements are strongly retained in soils and losses from soil by leaching or plant uptake are relatively minor in most cases. Additions of most trace elements to soils should thus be considered essentially permanent constituents of the soil. However, most scientists agree that only a relatively short list of trace elements are common enough to present a potential environmental risk in agricultural soils and/or in sewage biosolids. These include: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), and zinc (Zn). At high enough concentrations (Table 2), several of these trace elements (Cu, Ni, Zn) can be especially harmful to plants (phytotoxic), whereas others may present a particular risk to livestock (Mo, Se) or to human health (As, Cd, Pb, Hg). In this document, we provide maximum soil concentration guidelines for Cd, Cu, Ni, Pb and Zn for which there are sufficient data to make recommendations. Mo is addressed in the section on animal nutrition, but a maximum recommended soil concentration is not specified.

Table 1. Typical Northeast Background Soil Metal Concentrations¹

State	Number of samples	Cd	Cu ²	Ni	Pb	Zn
ME	27	0.17	65	41	13	72
NJ	114	0.09	11	8	13	29
NY	74	0.17	27	20	15	61
PA	40	0.19	28	25	20	84

(values in ppm) ³

¹Values are the geometric mean of total metal concentrations of mineral agricultural soil sampled in each state (Holmgren, et al, 1993).

²The background soil metal concentrations are high for ME (likely due to historical copper use on potatoes). Lower mean background soil copper concentrations for agricultural soils have also been measured in NY (13.9; McBride and Cherney, 2004) and PA (14.5; Stehouwer, 2006, personal communication).

Table 2. Trace Element Effects (from Brady and Weil 1996, and Adriano 1986).

Element	Essential for plant growth	Toxic*
Arsenic (As)	No	P, A, H
Cadmium (Cd)	No	P, A, H
Copper (Cu)	Yes	P
Lead (Pb)	No	A, H
Mercury (Hg)	No	A, H
Molybdenum (Mo)	Yes	P, A, H
Nickel (Ni)	Yes	P , A
Selenium (Se)	No	P, A, H
Zinc (Zn)	Yes	P , A

*P = plants; A = animals; H = humans. Bold designates the route of exposure most likely to limit the cumulative application of sewage biosolids.

Trace element additions to agricultural soils can come from many sources. Several elements present in sewage biosolids also may be present in other soil amendments such as pesticides, fertilizers, animal manures, composts, and by-product liming materials at concentrations above those that naturally occur in soils. Activities such as metal smelting and other industrial processes have resulted in atmospheric deposition of trace element on agricultural soils in the Northeast. Because of the permanence of most of these elements in soil, either historic or ongoing additions can increase the total concentration of trace elements in soils.

The concentration at which these elements begin to present an environmental risk depends on their *bioavailability*, the extent to which the elements are able to interact with and affect biological and biochemical processes. Bioavailability is controlled by a complex array of soil factors, the more important ones being soil pH, soil organic matter content, and soil texture. In general, bioavailability for most elements is increased as soil pH, organic matter content, and clay content decrease. (Bioavailability thus tends to be greatest in acidic, coarse soils with low organic matter content.) In addition, the original form and source of the trace element are also important. Trace elements naturally occurring in soils tend to be less bioavailable than those newly applied to or deposited on soils. The bioavailability of trace elements in sewage biosolids depends in part on the type of processes by which the wastewater and the sewage biosolids have been treated.

Federal and state regulations for agricultural use of sewage biosolids require that the total amount, or cumulative loading, of the trace elements listed above be calculated for all applications of non-EQ sewage biosolids. Recognizing that there are other potential sources of trace element additions and that calculated loadings may not accurately reflect soil concentrations, we recommend that farmers who use sewage biosolids monitor the total concentration of trace elements in their soil as a means of tracking and planning additions. It is recommended that soil trace element concentrations not exceed the threshold values given in Table 3 for soils maintained at a pH 6 or above. Separate limit values are given for soils of different textural classes, with the lowest limits for coarse-textured sandy soils (where, as noted before, bioavailability tends to be greatest because of lower soil cation exchange capacity, lower

organic matter content, and buffering capacity than in fine-textured soils.) Conversely, thresholds are highest for fine-textured silts and clay soils.

Table 3. Recommended Maximum Soil Trace Element Concentrations for the Northeast US

Metal	Recommended maximum soil concentration (mg/kg) ¹		
	Sand & loamy sand	Sandy loam to silt loam	Silt to clay
Cd	1.2	2	3
Cu	50	75	120
Ni	30	40	60
Pb ²	120	120	120
Zn ³	90	150	230

¹The lower concentrations are for loamy sand and the higher concentrations are for finer textured soils. The values in this table represent total elemental concentrations; some fraction is likely to not be bioavailable. The recommendations apply to soils maintained at pH of 6 or greater.

² This is the plant health Ecological Soil Screening Level established by USEPA (USEPA. 2005).

³ Limit to prevent phytotoxicity. Higher concentrations can be tolerated in calcareous soils with pH >7.

The threshold values for total soil trace elements in Table 3 are based on the findings in the 1985 Northeast document as well as a review of more recent research on long-term additions of trace elements at concentrations that approach the maximum recommended cumulative limits. The 1985 document recommended *maximum cumulative elemental additions* from application of sewage biosolids. In Table 3, we recommend *maximum soil elemental concentrations*¹ since these can be measured at any point and are what the plants are responding to. Although only a portion of the total trace elements in the soil are bioavailable, the research on which these recommendations are based was developed primarily using *total* trace element data, and thus the relative bioavailability was already accounted for in the data.

These recommendations are made to protect long-term soil productivity and human health. The recommended limits are soil trace element concentrations that are expected to result in not more than a 10% yield reduction for crops regardless of the source of added elements (recognizing that even a 10% reduction would be unacceptable to many producers) (see Appendix 2). These recommended threshold limits also protect crop productivity on those soils in the Northeast U.S. that are acidic and low in organic matter and thus have a greater risk of copper, nickel and/or zinc [phytotoxicity](#). There is evidence that the phytotoxicity impacts of Cu and Zn (which always occur together in sewage biosolids) are additive. Cadmium and lead are highly toxic to humans. Potential exposure that might result from agricultural application of sewage biosolids through ingestion of soil or crops or through water should thus be limited.

These recommendations do not address all functions of the soil habitat. Some European countries limit cadmium and chromium even further to protect soil organisms. Similarly, the USEPA derived lower concentrations for Cd, Pb and other elements based on soil invertebrates. However, limiting the copper soil concentration to the recommended levels of these guidelines (Table 3) will result in relatively low concurrent soil levels of cadmium, chromium and lead.

¹ It was assumed that the recommended maximum cumulative addition was mixed in to a depth of 15 cm into a soil with a bulk density of 1.33g/cm and the resulting value was added to the average background soil concentration to arrive at the recommended maximum soil concentration.

Soils should be tested to determine initial (or “background”) elemental concentrations before sewage biosolids are first applied. Since soil concentrations can vary within a field, obtaining a representative composite sample is important. (Follow instructions for soil sampling provided by Cooperative Extension.) Thereafter, soils should be retested when loading calculations indicate that approximately one half of the recommended maximum soil concentration for any elemental of concern has been reached. It is recommended that this calculation be conducted not only for additions of sewage biosolids, but also take into account the loadings of any soil amendment with trace element concentrations greater than the background soil levels. This will indicate whether the soil concentrations are consistent with calculated values, so that the total amount applied in the future may be adjusted. A sample calculation is provided in the box below.

Estimation of Soil Elemental Concentration Increases

Increases in soil elemental concentrations may be estimated using the sewage biosolids elemental concentrations and application rates. (Elemental losses due to leaching or crop uptake are not included in this estimate.) Concentrations are converted to metric units to be consistent with Part 503 values.

An increase in soil elemental concentrations can be estimated by the following formula:

Increase in soil heavy elemental concentration (ppm or mg/kg of soil)
= concentration in sewage biosolids (mg/kg dry sludge) * applications rate (dry ton/acre) * 2000 lb/ton * 2.47 acre/ha * 0.454 kg dry sludge/lb dry sludge / $2 * 10^6$ kg/ha

or simplified

= concentration in sewage biosolids (ppm or mg/kg) * application rate (dry ton/acre) * 0.00112

This increase should be added to the pre-application measured soil concentration to estimate the final soil concentration that would result from the sewage biosolids addition.

The increase in soil concentration resulting from several applications can be estimated by adding the individual increases resulting from each application.

Consistent with the USEPA risk assessment, a depth of mixing of 6 inches (15 cm) and weight of $2 * 10^6$ kg dry soil/ha into assumed.

When sewage biosolids are applied to a field repeatedly over several years, the concentrations of trace elements in the soil will gradually increase. This document presents recommended maximum soil concentrations for several trace elements. Based on the typical concentrations of various trace elements in sewage biosolids, Cu is frequently the element that would first reach recommended maximum soil concentrations and thus limit cumulative application. Molybdenum may be the limiting element in some situations.

The total amount of sewage biosolids that could be applied before the limit is reached depends on:

1. The concentration of Cu in the sewage biosolids that are applied, and.
2. Loss of added Cu from the soil via crop removal and leaching or erosion.

Because of these variables it is difficult to accurately predict the total quantity of sewage biosolids that could be added to a soil. If we assume addition of sewage biosolids containing 548 mg Cu/kg of sewage biosolids (which is approximately the *median* Cu concentrations for sewage biosolids in the Northeast U.S.), we estimate that the total quantities of sewage biosolids (dry weight basis) that could be applied before reaching the recommended maximum are:

- 79 tons/acre for a coarse textured soil (sand and loamy sand),
- 115 tons/acre for a medium textured soil (sandy loam to silt loam), and
- 186 tons/acre for a fine textured soil (silt to clay).

In contrast, if the sewage biosolids applied have a higher Cu concentration of 1100 mg Cu per kg of sewage biosolids (which is approximately the *95th percentile* concentration for copper in the Northeast U.S.), then the estimated total quantities of sewage biosolids that could be applied are reduced to:

- 40 tons/acre for a coarse textured soil (sand and loamy sand),
- 57 tons/acre for a medium textured soil (sandy loam to silt loam), and
- 93 tons/acre for a fine textured soil (silt to clay).

These estimates assume initial background copper concentrations in these soils of 8, 15, and 25 mg Cu/kg soil for coarse, medium, and fine textured soils, respectively. Although these are reasonable values for such soils, the initial soil concentrations have a large impact on the total quantity of sewage biosolids that could be applied, especially for coarse-textured soils.

This estimate also assumes that all Cu added with the sewage biosolids will remain in the upper 6 inches of soil and that all added organic material will decompose. However, since not all organic material will decompose, and some loss of copper will occur due to crop harvest removal, leaching deeper in the profile, and erosion of topsoil, our calculations likely underestimate the quantity of sewage biosolids that could be added before the soil concentration threshold is reached. This underscores the importance of soil sampling to confirm actual concentrations resulting from sewage biosolids applications.

NUTRIENT MANAGEMENT

Sewage biosolids should be applied only where the N and P are needed. For many livestock farms in the Northeast, net importation of animal feed means that land application of livestock manure can provide more than enough N and P for typical crops. A nutrient management balance that allocates on-farm nutrient sources and quantifies supplemental nutrients from all sources for each field should be followed on farms using sewage biosolids.

Application rates of sewage biosolids for agricultural production are based on crop nutrient and soil lime requirements. Part 503 requires that biosolids be applied to agricultural land at agricultural agronomic rates. Generally that application is calculated as the amount of N required by the crop, although in soils with elevated P levels, P may dictate allowable agronomic additions of sewage biosolids.

Calculating the nutrient value of sewage biosolids depends on both the concentration of nutrients in the material and the fraction of the nutrients that are expected to be available for plant use in a

specified period of time (e.g., first or second growing season after application). Since much of the N in sewage biosolids is in an organic form, it gradually becomes available to crops over time through mineralization processes which convert organic N to ammonium N. The rate at which mineralization takes place varies among different sewage biosolids depending on how it was processed in the wastewater treatment plant. A sample calculation is provided in Appendix 3.

Typically, the P to N ratio in most sewage biosolids is much greater than the ratio required by crops. Application of sewage biosolids at rates required to supply the N needs of the crop often results in excess soil P that can raise water quality concerns. Sewage biosolids are typically low in K, so an additional K source may be required if sewage biosolids are used to meet N or P requirements. Most of the P and K in sewage biosolids exist in inorganic forms and it is often assumed that the 50% of P and 100% of K in sewage biosolids are available for plant uptake (USEPA, 1995). For most commercial crops, applying sewage biosolids to meet N fertility requirements provides excessive P but suboptimal levels of K to the crop.

Nutrient Fertilizer Equivalent

Sewage biosolids are a low-nutrient content fertilizer with the following fertilizer equivalents on a dry weight basis:

Nitrogen fertilizer equivalent (see Appendix 3 for agronomic rate calculation)

$$= (\% \text{ organic N in the sewage biosolids} * B) + \\ \% \text{ inorganic N in the sewage biosolids}$$

Note: $\% \text{ inorganic N} = \% \text{ ammonium N} + \% \text{ nitrate N}$

B = fraction of organic N that becomes plant available;
assume: 0.1 for composted, 0.2 for [anaerobically digested](#) and other, 0.3 for [aerobically digested](#) and 0.4 for lime-stabilized sewage biosolids)

Phosphorus fertilizer equivalent

$$= \% \text{ total P}_2\text{O}_5 \text{ in the sewage biosolids, or} \\ = \% \text{ total P in the sewage biosolids} * 2.29$$

Potassium fertilizer equivalent

$$= \% \text{ total K}_2\text{O in the sewage biosolids, or} \\ = \% \text{ total K in the sewage biosolids} * 1.2$$

A “typical” fertilizer N-P₂O₅-K₂O equivalent of sewage biosolids is:

$$\text{N (available) - P}_2\text{O}_5 - \text{K}_2\text{O} \\ 4.5 - 5 - 0.4$$

(Because the fertilizer equivalent of sewage biosolids can vary substantially, these values cannot be used to determine application rates.)

Application rates based on crop N needs

The calculations in Appendix 3 provide an example of how the application rate for sewage biosolids based on crop N needs can be calculated. The N available for crop use during the first year after sewage biosolids application can be assumed to include 100% of the inorganic N plus some percentage of the organic N, depending upon the sewage biosolids treatment method. In subsequent years, a diminishing fraction of the remaining organic N will continue to be mineralized and become available to crops. State rules should be consulted because there may be state-specific methods for determining agronomic application rates.

To minimize the potential leaching of excess N if sewage biosolids are applied in the fall, a “[catch crop](#)” should be planted to take up N that becomes available in the fall. If applying sewage biosolids to a corn crop, apply only 80% of the required N as sewage biosolids and use a PSNT or similar test to determine whether further N is needed. The PSNT test is calibrated also for some other annual crops. Contact your Cooperative Extension office to obtain more information concerning the PSNT or similar tests.

P-Based Applications

Because a [nutrient management plan](#) is recommended for sites where sewage biosolids are applied, the appropriate state P Index should be evaluated for the site. In response to water quality concerns, all states in the Northeast have developed P index protocols, although the methods of calculating a site index vary. Depending on the P index of the site, biosolids application can be based on the N requirement of the crop or on the P requirement of the crop, or

additional P applications may be prohibited. Policies are evolving at the state level and farmers need to be aware that P-based nutrient management will likely impact the agricultural use of sewage biosolids in the future.

Application rates based on soil lime needs

Lime-stabilized and [advanced alkaline stabilized](#) products can be so alkaline that they should be applied only as a liming material at a rate designed to raise soil pH to desired levels. The liming potential of the material should be determined by a calcium carbonate equivalent analysis. These alkaline products also contain nutrients that must be accounted for in nutrient management planning. The actual application rate of such materials may be based on either the application rate necessary to supply the N or P requirement of the crop or on the application rate necessary to fulfill the lime requirement of the soil, whichever amount is smaller.

ANIMAL NUTRITION AND COPPER DEFICIENCY

Several elements, notably S, Mo, Fe and Cd, can reduce Cu absorption by ruminant animals. The result is sub-clinical (hidden) or clinical copper deficiency (hypocuprosis). Subclinical hypocuprosis in grazing ruminants can lead to reduced weight gain, lower productivity and less reproductive success. Acute hypocuprosis can be fatal.

Sewage biosolids contain generally higher concentrations of total Mo, S and Cd than manures and have the potential to increase these elements in soils. All three of these elements are taken up by crops relatively easily. Forage S tends to be elevated in sewage biosolids-amended fields. Soil pH determines whether additions of Cd or Mo to the soil have a substantial effect on levels of these trace elements in forage crops. Thus producers should regularly monitor soil pH and adjust it by amending soils as needed. Molybdenum availability in soils increases markedly above pH 6.5, so that even relatively small loadings of Mo from sewage biosolids can lead to problems in forages and legume crops. Elevated Mo uptake by forage crops has been shown to persist for decades following application of sewage biosolids. (See Appendix 4 for more information.)

A dietary Cu level of 10 ppm in feed is generally sufficient for cattle. However, Cu supplementation could be required to counter elevated levels of Mo, Fe and Cd, and to avoid sub-clinical or clinical hypocuprosis. The tolerable Cu:Mo ratio is probably not a fixed value, but rather appears to decline from 5:1 to 2:1 as pasture soil Mo concentrations increase from 2 to 10 ppm. Diets falling below these ratios are more likely to result in hypocuprosis.

On farms where ruminant livestock are fed a substantial component of their diet from crops grown on biosolids-amended fields, testing of the forage tissue for Mo, S and Cd is recommended, especially if Mo concentrations in the sewage biosolids exceed 10 ppm (dry weight). Since concentrations in plant tissue can be highly variable within a field, it is important to obtain a representative composite sample.

As a guideline, it is advisable to keep forage Cd less than 0.5 ppm (dry weight basis), and Mo less than 2.5 ppm, to protect cattle health. Soil pH management is critical, with low pH favoring Cd uptake and high pH favoring Mo uptake into forages.

It is generally recommended that feed Cu be supplemented if S exceeds 0.2% in the feed at an addition rate of 5 ppm in feed for each 0.05% increase in feed S above 0.2%. Similarly, Cu supplementation is advised to keep the Cu:Mo ratio in the feed in the 5:1 to 8:1 range. Iron has a strong antagonistic effect on Cu absorption by cattle, and Cu supplementation is recommended at Fe levels over 300 ppm in the whole diet. High Fe intake is usually the result of soil ingestion when pastures are very sparse or when muddy conditions prevail.

MANAGEMENT OF SEWAGE BIOSOLIDS FARM OPERATIONS

Stockpiling, Spreading and Incorporation

Be a good neighbor. Sewage biosolids can generate strong odors. Selection of a well-stabilized product, rapid incorporation into the soil, and exercising caution in stockpiling can help minimize odors. Time of application, wind direction, weather conditions and application methods also influence odor generation and movement.

Cold weather reduces volatilization and resultant odors. Morning may be best time for application in warm weather since increasing air temperatures cause air to rise and carry odors away. Drying during the day also reduces odors before neighbors' evening activities begin. Avoid spreading immediately before weekends and holidays when neighbors are likely to be engaged in outdoor recreational activities. Dry, windy days produce fewer odors than calm, humid days. The wind provides greater dilution of the odors. However, strong winds may blow sewage biosolids odors off-site.

To avoid potential odor and leachate problems, caution is advised regarding stockpiling of sewage biosolids. Odors can be generated as a result of renewed bacterial activity in stored materials, which can occur if dried materials are rewetted, if the pH of limed stabilized materials decreases, if the pile becomes anaerobic or if the material has not been adequately stabilized at the wastewater treatment plant. A crust will often form on [stockpiled](#) materials which, when broken, may release trapped odors. Leachate and runoff can be minimized by proper siting and by diverting water. (See the USEPA, 2000, Guide to Field Storage for further information).

When possible, sewage biosolids should be injected into, mixed into, or turned under the surface soil within twenty-four hours of application. If sewage biosolids are surface-applied to no-till crops, perennial forages, pastures, or turf grasses, careful management will be required to prevent odor problems, ingestion of sewage biosolids by animals, or enrichment of surface runoff with P and other constituents. Also, much of the N will be lost by volatilization of ammonia from biosolids that lie on the surface of the land.

There is the potential for livestock to ingest sewage biosolids directly either through grazing or through materials adhering to foliage. Direct ingestion poses risks due to potential ingestion of chemical contaminants (such as synthetic organic chemicals and copper antagonists). Management measures should be taken to avoid such ingestion. If applied to forage crops, it is advised to minimize the amount that may remain on plant surfaces by applying just after cutting and allowing regrowth and rain washdown to occur before recutting or allowing animals to graze.

Uniform spreading can be difficult, particularly when desired application rates are low and if the material tends to clump. This can create spots where excessive amounts of sewage biosolids are applied and conversely, other areas that are underfertilized. Some spreading equipment may not be able to reliably deliver material at a low enough rate to satisfy agronomic application rate limits.

pH

Soil pH (as determined by 1:1 soil-water paste) should be adjusted to 6.5 to 7.0 at the time sewage biosolids are applied, and it is recommended that the pH be maintained at 6 to 7 as long as the land is used for crop production. Keeping the pH above 6 minimizes the availability of most trace elements. An exception is Mo which is more available at higher pH.

Care should be taken when using alkaline stabilized biosolids if soil pH is already above 7. Agronomic crops do not require higher pH for good performance and when soil pH approaches 8 or higher, herbicide efficacy as well as micronutrient availability can be affected adversely. When used to raise pH, application rates of alkaline biosolids should be based on a lime equivalency test. Soils should be retested during the year after application to determine if additional lime is required.

Crops

These guidelines apply to bulk use of both EQ and non-EQ sewage biosolids applied to field crops. It is suggested that sewage biosolids not be applied to fruit or vegetable crops due in part to public perception and liability issues. As a result of such concerns, most food processors and fresh market wholesalers in the Northeast will not accept fruits and vegetables produced on land to which sewage biosolids are applied. Although application to vegetables and fruits is permitted (with specified waiting periods), ongoing uncertainty in regard to pathogens and contaminants is an additional reason to avoid use on these crops. Sewage biosolids may not have been used in the previous three years to grow crops that meet USDA-certified organic requirements.

Record Keeping

Keep records of the source(s), quality, quantity, application rates, dates and storage and application practices. Any concerns such as odors should be noted.

Talking with other farmers who have used the specific material in question is helpful. It is important to be able to know and trust those supplying the material. The farmer should obtain written assurances from the supplier that any sewage biosolids being land applied are of appropriate quality (meeting requirements for pollutants, pathogen reduction, vector attraction reduction) and have been properly treated, and that the application procedures meet federal and state regulations.

If applying sewage biosolids or [sewage biosolids products](#) to leased or rented land, prior written permission attested by a notary public should be obtained from the landowner for such applications.

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GLOSSARY

Advanced alkaline stabilization

The process of blending sludge with high pH materials such as kiln dust and quick lime to generate a product that is commonly used as a liming material. During the process, the material undergoes a chemical reaction that essentially pasteurizes the product by raising the pH to greater than 12 for 72 hours or longer, maintaining the temperature above 52°C (126°F) for at least 12 hours during the period that the pH is greater than 12, and air drying to over 50 percent solids after the 72-hour period of elevated pH. Meadow Life®, Bio-Fix®, N-Viro® and ECO LIME® are examples of products that have undergone this process. (The trade or brand names are supplied with the understanding that no discrimination is intended and no endorsement is implied). [back](#)

Aerobic digestion

The degradation of concentrated wastewater solids, during which aerobic bacteria (bacteria which need the presence of oxygen) break down the organic material into stabilized solids, carbon dioxide, and water in the presence of oxygen. [back](#)

Agronomic rate

Application rate calculated based on supplying a crop's nutrient need (generally for N or sometimes P). [back](#)

Ammonium nitrogen (ammonical nitrogen)

(NH₄⁺-N) The amount of nitrogen in the ammonium form. Each 100 pounds of ammonium contains 78 pounds of actual nitrogen. [back](#)

Anaerobic digestion

The degradation of concentrated wastewater solids, during which anaerobic bacteria (bacteria which can not live in the presence of oxygen) break down the organic material mainly into stabilized solids, carbon dioxide, and methane in the absence of oxygen. [back](#)

Bulk application

Application of sewage biosolids that were delivered for agricultural use in bulk and not in a bags or in a containers. [back](#)

Catch crop

A rapidly growing crop that can be intercropped between rows of the main crop, often used as green manure. [back](#)

Class A pathogen reduction level

Level of treatment that reduces the concentration of viable pathogens to level that regulatory agencies believe do not present a risk due to pathogens. This is accomplished by meeting one of six alternatives for Class A pathogen reduction requirements: 1) being thermally treated at a defined time temperature regime, 2) being treated in a high pH and high temperature process 3) monitoring of bacteria, enteric viruses, and viable helminth ova to demonstrate adequate reduction of pathogens, 4) although the past history of the sewage biosolids and the process it has undergone is not known, the sewage biosolids meet Class A requirements at the

time they are disposed, sold, or given away, 5) being treated in a process to further reduce pathogens (PFRP), and 6) being treated in a process equivalent to a PFRP as determined by the permitting authority. In addition to meeting one of these six alternatives, either the *Salmonella* spp. density must be less than 3 MPN (most probable number) per 4 grams of total solids (dry weight basis) or the density of fecal coliform must be less than 1,000 MPN (most probable number) per gram total solids (dry weight basis). (40 CFR Part 503.32(a)) [back](#)

Class B pathogen reduction level

Level at which pathogens in the sewage biosolids are detectable, but have been reduced. Site restrictions that prevent crop harvesting, animal grazing, and public access for specified time periods are required where Class B materials are used. To meet Class B pathogen reduction levels the sewage biosolids must meet one of three alternative requirements. These are complying with certain indicator organism levels, being treated in a process to significantly reduce pathogens (PSRP), or being treated in a process equivalent to a PSRP. (40 CFR part 503.32(b)) [back](#)

Exceptional Quality (EQ)

Sewage biosolids that meet the requirements of a) the Table 3 pollutant concentration limits (40 CFR 503.13(b)(3)), and b) one of the Class A pathogen reduction requirements (40 CFR Part 503.32(a)), and c) one of the first eight vector attraction reduction options (40 CFR Part 503.33). The trace element EQ limits in ppm are: As-41; Cd-39; Cu-1500; Pb-300; Hg-17; Ni-420; Se-100; Zn-2800. [back](#)

Hypocuprosis

Copper deficiency. Several elements, notably S, Mo, Fe and Cd, can reduce Cu absorption by ruminant animals. The result is sub-clinical (hidden) or the more severe clinical copper deficiency. Hypocuprosis is believed to be fairly common in grazing ruminants, leading to reduced weight gain, lower productivity and less reproductive success. Acute hypocuprosis can be fatal. [back](#)

Incorporation

The process of mixing sewage biosolids with the soil through [injection](#), moldboard plowing, rototilling, chisel or disk plowing, or tandem disk harrowing. [back](#)

Injection

Depositing of sewage biosolids beneath the soil surface without turning the soil over. This minimizes disturbance of sod and other vegetation. [back](#)

Inorganic nitrogen

Nitrogen in the ammonium (NH_4^+), nitrite (NO_2^-), or nitrate (NO_3^-) form. The nitrite concentration in sewage sludge is very low and may be neglected. [back](#)

Lime stabilization

Process of adding a sufficient amount of lime to sewage biosolids to raise the pH to 12 for 2 hours. This is done to substantially reduce the number and prevent the regrowth of pathogenic and odor-producing organisms. [back](#)

Molybdenosis

Toxicity in cattle caused by ingesting excessive molybdenum. Clinical symptom develop rapidly. [back](#)

Ninety-fifth (95th) percentile (of trace element concentrations)

The concentration of a specified element which is greater than 95% of the trace element concentrations in a set of values is said to be the 95th percentile. Ninety-five percent of the reported concentrations would be at or below that concentration while 5% would be greater. [back](#)

Nitrate nitrogen

(NO₃⁻-N) The amount of nitrogen in the nitrate form. Each 100 pounds of nitrate contains 22.5 pounds of actual nitrogen. [back](#)

Nitrite nitrogen

(NO₂⁻-N) The amount of nitrogen in the nitrite form. Each 100 pounds of nitrite contains 30 pounds of actual nitrogen.

Nutrient Management Plan

A plan outlining the nutrient management practices on a field-by-field basis on a farm. The plan must be prepared by a certified planner and must take into account all sources of nutrients. [back](#)

Organic nitrogen

Organic form, originating from proteins, nucleic acids, amines and other cellular compounds. Organic nitrogen is calculated as TKN minus ammonium N. [back](#)

Parts per million (ppm)

The number of 'parts' by weight of a substance per million parts of dry sample (soil, plant tissue) or water. This unit is commonly used to represent pollutant concentrations. This can also be expressed as milligrams per kilogram (mg/kg). [back](#)

Phytotoxicity

Reduction in vegetative growth which, for example, can be caused by high metal concentrations in the soil. [back](#)

Pre-sidedress Nitrate Test (PSNT)

A soil test performed at an early growth stage of an annual crop to measure the concentration of nitrate nitrogen in the surface 12 inches of soil for the purpose of predicting if there is a need to apply supplemental nitrogen fertilizer. More information can be found at: <http://www.rcrc.rutgers.edu/pubs/publication.asp?pid=E285>. [back](#)

Sewage biosolids

Sewage sludge processed to meet standards for land-based recycling. Sewage biosolids have been treated through one or more controlled processes that reduce pathogens and vector attraction adequate to permit land application. Sewage sludges that do not conform to regulated

pollution, pathogen, and vector attraction reduction treatment requirements are not considered sewage biosolids. In this document, sewage biosolids products such as certain composts, heat dried pellets and advanced alkaline stabilized materials are included in the term sewage biosolids. [back](#)

Sewage biosolids products

Sewage sludge that has been treated and then altered, either physically or chemically, to be put into a form that can be marketed. Some examples are advanced alkaline stabilized, composted, and pelletized sewage biosolids. [back](#)

Sewage sludge

Solid, semi-solid, or liquid materials derived from primary, secondary, or advanced treatment of domestic wastewater and, under certain provisions, industrial wastewater. [back](#)

Stockpile

A temporary or seasonal storage area for sewage biosolids at an application site. [back](#)

Synthetic organics

Synthetic (man-made) organic substances, including some pesticides, and various industrial chemicals and solvents, some of which are persistent in the environment (slow to decompose). [back](#)

Total Kjeldahl nitrogen (TKN)

The total amount nitrogen, commonly organic and ammonical (NH_3 , NH_4) nitrogen, as determined by Kjeldahl digestion and distillation. Nitrate may be determined in carbon-rich materials or in certain modified procedures. [back](#)

Total N

The total amount of organic, ammonical (NH_3 , NH_4), nitrate and nitrite nitrogen present. [back](#)

Trace Element

Chemical elements present in small concentrations. Trace elements include the heavy metals that may be present. Examples of trace elements are cadmium (Cd), copper (Cu), zinc (Zn), lead (Pb), molybdenum (Mo), selenium (Se), arsenic (As), mercury (Hg), nickel (Ni), chromium (Cr). [back](#)

Vector

Rodents, flies, mosquitoes, or other organisms capable of transporting infectious agents. [back](#)

Vector attraction reduction

Methods that reduce the attractiveness of sewage sludge to vectors. Methods include but are not limited to the reduction of the organic matter content, additional aerobic digestion or anaerobic digestion, lime stabilization, reduction of moisture content, injection, and incorporation. [back](#)

APPENDIX 1: SEWAGE BIOSOLIDS QUALITY DATA

Trace element concentration data for sewage biosolids was collected for the participating Northeast states. Not all states had comparable data and thus only data from four states was used to calculate the recommended maximum pollutant level.

Element	ME	NY	PA	VT	Ave of 95%iles	2007 NE Guidelines Recommended Max Pollutant Level
	95%ile biosolids 93-2003	95%ile 2004	95%ile 1997-8	95%ile 2004		
As	13	20	19	20	18	18
Cd	6	10	7	10	8	8
Cr	87	123	314	120	161	160
Cu	842	992	1382	992	1052	1100
Pb	115	197	202	197	178	180
Hg	3	4	6	0.8	3	3
Mo	34	30	36	30	33	33
Ni	43	70	85	70	67	70
Se	8	17	8	17	13	15
Zn	1128	1392	1985	1392	1474	1500

ME: Data from DEP for 1993-1997 and 1999, 2002.

PA: Data for sewage biosolids based on Stehouwer et al. 2000.

NY: Data from NYSDEC for 2004.

VT: Data from 1997 DEP report.

APPENDIX 2: TOXICITY LIMITS FOR CROPS IN FIELD AND GREENHOUSE

Addition of excessive amounts of selected metals (notably copper, nickel and zinc) can cause phytotoxicity. Experiments are able to measure yield reductions of about 25% or more, but smaller reductions in yield are harder to prove statistically due to variability and experimental error. The table below lists the soil concentrations associated with documented yield reductions. Since elemental additions are essentially permanent and any yield reduction is undesirable, a safety factor is applied in making recommendations regarding maximum acceptable soil concentrations.

(excluding strongly acid soils and very metalliferous sludges)

Metal (mg/kg)	Sludge-treated Mineral Soils	Organic Soils, Pure Composts & Sludges
Copper	70-150 (McGrath, et al., 1995) clover yield loss 100-125 (Sauerbeck and Styperek, 1986, Webber, 1972) protect most sensitive field crops 100 (Jarausach-Wehrheim, et al., 1996) toxicity to maize roots 220 (Unwin, 1981) red beet affected 350 (Reith, et al., 1979) toxic to rape field crop 500 (Rohde, 1962) chlorosis in most crops	1000-1500 (Smilde, 1981) sludge pot study (oat, corn, spinach, etc.) 1100-1900 (Handreck, 1994) compost pot study (cabbage, bean, chard, etc.) 2000 (Roth, et al., 1971) peat pot studies (soybean, carrots, onion)
Zinc	180-280 (McGrath, et al., 1995) clover yield loss 200-250 (Sanders, et al., 1987, Webber, 1972) protect most sensitive field crops 320 (Sauerbeck and Styperek, 1986) ryegrass limit in pot study 360 (Giordano, et al., 1975) field bean yield loss 390 (Lubben, et al., 1991) field oat, wheat yield loss 600-700 (Rohde, 1962, Williams, et al., 1986) field crop toxicity 1000 (McBride, 1995) corn growth reduction	1000 (Staker and Cummings, 1941) field vegetables on muck 2200 (Handreck, 1994) compost pot study (cabbage, bean, chard, etc.) 2000-3000 (Smilde, 1981) sludge pot study (oat, corn, spinach, etc.) 800 (pH 4-5) (Bucher and Schenk, 1997) compost-peat pot study (petunia)

	1500 (Sauerbeck and Styperek, 1986) field grasses, cereals	
Nickel	50 (Sauerbeck and Styperek, 1986) red beet toxicity 200-220 (Lubben, et al., 1991, Sauerbeck and Styperek, 1986) protect most field crops	250-750 (Smilde, 1981) sludge pot study (oat, corn, spinach, etc.) 1500 (Frank, et al., 1982) field vegetables on muck 1800 (Roth, et al., 1971) peat pot study (soybean)

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APPENDIX 3: SAMPLE AGRONOMIC RATE CALCULATION BASED ON N

The rate of application of sewage biosolids is often based on fulfilling the nitrogen requirement of the crop. Here we provide a sample calculation to determine the amount of sewage biosolids to apply based on formulas contained in the NYS Department of Environmental Conservation regulations (6 NYCRR Part 360 Solid Waste Management Facilities. April 1995. 360-4.4(c)).

Note: Individual states may have specific methods for calculating agronomic rates.

As an **example**, we assume:

- Crop N requirement = 150 lb/acre
- The sewage biosolids is anaerobically digested sewage biosolids cake at 25 % dry matter. The N values are based on dry weight analysis.
- The sewage biosolids contains 5.0 % N as Kjeldahl N (TKN); 1.2 % N as ammonium N; and no nitrate N.

Hence in the following sample calculation:

inorganic N = ammonium N = 1.2%; and

organic N = TKN minus ammonium and nitrate= 5.0%-(1.2% + 0)=3.8% .

The ammonium N is volatile and unless incorporated immediately after spreading may be lost to the air.

Only a portion of the organic N will become available over the growing season, leaving some residual organic N that will become available in subsequent years.

In the following equations, pounds of **available** N per ton of dry sewage biosolids is expressed as “N/ton”.

In the following examples, “A” is a coefficient that reflects the availability of the organic N in different sewage biosolids products.

	Values for “A”
composted sewage biosolids	2
anaerobically digested & other	4
aerobically digested	6
lime stabilized	8

Example 1: If sewage biosolids are **incorporated** into the soil within a few hours after spreading (thus there is no volatilization of ammonium N):

$$\begin{aligned}
 \text{N/ton} = & \quad (\% \text{ ammonium N} / 100) * 2000 \text{ lb/ ton} \\
 & + (\% \text{ nitrate N} / 100) * 2000 \text{ lb/ ton} \\
 & + \% \text{ organic N} * A
 \end{aligned}$$

or simplified

$$= (\% \text{ ammonium N} * 20) + (\% \text{ nitrate N} * 20) + (\% \text{ organic N} * A)$$

Thus in our example for immediate incorporation of anaerobically digested sewage biosolids:

$$\text{N/ton} = (1.2 * 20) + (0 * 20) + (3.8 * 4) = 24 + 15.2 = 39.2 \text{ lb N/ton}$$

To supply 150 pounds of N per acre we need:

$$150 \text{ pounds} / 39.2 \text{ pounds/ton} = 3.8 \text{ ton of dry sewage biosolids/acre.}$$

Since the example sewage biosolids have 25% dry matter, the wet weight is $3.8 / 0.25 = 15.2$ wet ton/ acre.

Example 2. If not immediately incorporated (assuming half of the ammonium N is volatilized), the equation becomes:

$$\text{N/ton} = (\% \text{ ammonium N} * 10) + (\% \text{ nitrate N} * 20) + (\% \text{ organic N} * A)$$

Thus in our example where anaerobically digested sewage biosolids are incorporated:

$$\begin{aligned} \text{N/ton} &= (1.2 * 10) + (3.8 * 4) = 12 + 15.2 \\ &= (1.2 * 10) + (3.8 * 4) = 27.2 \text{ lb N/ton} \end{aligned}$$

To supply 150 pounds of N per acre we need $150 \text{ pounds} / 27.2 \text{ pounds/ton} = 5.5$ ton of dry sewage biosolids/acre.

Since the example sewage biosolids have 25% dry matter, the wet weight is $5.5 / 0.25 = 22.0$ wet ton / acre.

Residual N available in subsequent years

As illustrated above, only a portion of the organic N in the sewage biosolids will decompose and be available to plants in the year of application. Accordingly, NYSDEC has provided a way to estimate residual effects of previously applied sewage biosolids. The residual N would be an additional amount of N resulting from previous applications. This residual N would be added to the amount available in the first year as calculated above to come up with the total amount of N available. The sewage biosolids are assumed to continue to contribute residual N in decreasing amounts over 4 years after initial application.

In the following examples, “B” is a coefficient that reflects the availability of the organic N in different sewage biosolids products for 4 years after application.

Type of Sewage Biosolids	Years following application			
	1	2	3	4
Composted	0.9	0.51	0.5	0.48
Anaerobically digested & other	1.6	0.72	0.41	0.4
Aerobically digested	2.1	0.95	0.55	0.31
Lime stabilized	2.4	0.96	0.43	0.25

The assumed residual effect is as follows:

$$\text{N/acre} = (\text{original application rate in dry tons/acre}) * (\text{initial \% organic N}) * (\text{B})$$

Thus for example 1 above there will be residual N in the year after application of:

$$3.8 * 3.8 * 1.6 = 23 \text{ lb N/acre}$$

and after two years if no new sewage biosolids are added there will be residual N of:

$$3.8 * 3.8 * 0.72 = 10.4 \text{ lb N/acre}$$

APPENDIX 4: COPPER, MOLYBDENUM, SULFUR AND CATTLE HEALTH

Although sewage biosolids application generally adds much more Cu than Mo to soils, studies in New York farm fields, experimental fields and greenhouse studies with a range of important forage crops, including bromegrass, alfalfa, and red clover have shown in most cases that increased sewage biosolids (and therefore Mo and Cu) loading leads not only to higher plant tissue Mo concentration, but also lower Cu:Mo ratios in the forage, sometimes declining to the critical 2:1 value. (This reduced Cu:Mo ratio is a consequence of the greater barrier to plant uptake of Cu compared to Mo.) This trend of lowered Cu:Mo ratio in forage following application of sewage biosolids products has also been observed in Pennsylvania, where alkaline-stabilized biosolids was applied on alfalfa fields.

Despite significant potential for leaching loss of Mo in non-acid soils, this effect on forage quality has been shown in long-term field experiments to persist for decades following application of sewage biosolids. Increased concentrations of S in forages that may result from sewage biosolids application can further exacerbate the problem, as the combined effect of elevated dietary S and Mo is to induce hypocuprosis in ruminant animals.

Research has shown that sewage biosolids application to soils tends to increase both easily-extractable S in soils and the concentration of S in forage crops. Although S is an essential element, and not considered inherently toxic to crops or animals, it is a well-known antagonist of Cu availability in ruminant animals, even in the fairly commonly encountered range of 2,000-4,000 mg/kg total S. The maximum tolerable S level in ruminant feed is reported to be 4,000 mg/kg. Forage S was reported to be elevated in sewage biosolids-amended grass pastures in Florida (3,000- 4,700 mg/kg), quite possibly explaining the fact that beef heifers grazing on these pastures for about 6 months developed Cu deficiency as indicated by liver Cu reserves declining below the critical deficiency level. Unfortunately, no similar animal assay has been done to date on grazing livestock under the very different Northeastern soil and crop conditions.