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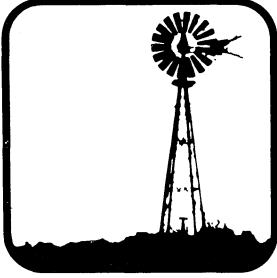Clifford D. Spies

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USE OF SEWAGE SLUDGE IN CROP PRODUCTION

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USE OF SEWAGE SLUDGE IN CROP PRODUCTION

The application of sewage sludge on cropland as an alternative disposal method is receiving considerable attention today, not only from municipalities, but also from agricultural producers who could benefit by receiving sludge on their land. This publication briefly looks at the practice, its advantages and drawbacks, then describes an approach for applying sludges to agricultural land that is consistent with guidelines of the Indiana State Board of Health and the U.S. Environmental Protection Agency.

At the end of the publication is a worksheet (with example) for calculating proper sludge application rates. Additional copies of the worksheet are available from county Cooperative Extension Service offices or the CES Mailing Room, AGAD Building, Purdue University, West Lafayette, IN 47907.

SEWAGE SLUDGE— WHAT IT IS

Sewage sludge is a general term used to describe the solids produced during the treatment of wastewater (sewage) in nearly all cities. Sewage treatment plants are designed to remove solids and organic matter from the sewage, resulting in a water which is clean enough to discharge into a nearby stream, river or lake. The solids removed from the sewage are then treated separately from the water.

Solids separated immediately after the sewage enters the treatment plant are referred to as 'primary' or 'raw' sludge. This material contains relatively large concentrations of coliforms and other pathogenic microorganisms and should not be applied to agricultural soils.

To further treat the raw sludge, decomposition in the absence of oxygen (anaerobic) or presence of oxygen (aerobic) is carried out in large tanks referred to as *digesters.* Typically, the sewage sludge applied to agricultural land will be removed from an aerobic or anaerobic digester at the treatment plant and transported to the application site as a slurry containing from 1 to 10 percent solids.

Some treatment plants may reduce the water content of sewage sludge by filtration, centrifugation or drying on a sand-drying bed prior to transporting the sludge to an agricultural land application site. However, this requires additional cost and utilization of energy.

Sewage sludge is a very heterogenous material, varying in composition from one city to another and even from day to day within the same city. Before developing plans for land application of sewage sludge, it is essential to obtain representative samples of the sludge over a period of time and have accurate chemical analyses made. A list of laboratories performing chemical analysis of sewage sludge is available from the authors upon request.

POTENTIAL BENEFITS OF SLUDGE APPLICATION TO CROPLAND

The application of sewage sludge on cropland can be of benefit to farmers, municipalities and the general public alike.

Farmers may benefit in two ways. First of all, sewage sludges contain the major nutrients required by all plants (nitrogen, phosphorus and potassium) *plus* essential micronutrients or trace elements, such as copper, zinc, iron, manganese, boron and molybdenum. Often, the nutrient content of sludge can be substituted for that in traditional fertilizers, which require much energy to produce.

Secondly, sewage sludges contain relatively large amounts of organic matter, which can improve the productive potential of both fine-textured clay soils by increasing infiltration and sandy soils by increasing water-holding capacity. In addition, any improvements in soil tilth can reduce the amount of energy required for seedbed preparation as well as increase yields.

Municipalities may benefit from the application of sewage sludge on cropland because it often proves to be cost effective and a viable alternative to other methods of disposal.

The general public benefits through savings in cost and energy to the municipalities and reduction in energy use per unit of crop produced by the farmer. Although sewage sludge can supply only a fraction of the total nutrient requirements of agricultural crops, it is nevertheless an efficient and effective source which can supplement total needs and help reduce overall energy use for crop production.

PROBLEMS ASSOCIATED WITH APPLYING SLUDGE ON CROPLAND

Sewage sludges contain constituents that are either non-essential or potentially detrimental to crops or animals (including man) consuming the crops. Examples of non-desirable components in sludges include lead; nickel; cadmium; chlorinated hydrocarbon pesticides, such as DDT, dieldrin, methoxychlor and chlordane; and other persistent organic compounds, such as PCB's.

There is no doubt that, for many crops, optimum yields can be maintained by substituting the plant nutrients in sewage sludge for those typically applied to soils in conventional fertilizer materials. However, since sludges also contain components not required by plants, it is essential that appropriate and sound management techniques be used to protect the environment and to minimize any impacts on human/animal health as well as to maintain soil productivity, whenever sewage sludges are applied to cropland.

Following are the major problems encountered in applying sewage sludges on agricultural land and how they are prevented, eliminated or minimized.

• *Leaching and movement of nitrate-nitrogen from surface soils into groundwater.* Excessive movement of nitrate-N from surface soils into groundwater will occur whenever the amount of nitrogen applied to soils exceeds the nitrogen required by the crop being grown. This principle applies to application of nitrogen whether in sewage sludges or in conventional nitrogen fertilizers (anhydrous ammonia, urea, etc.). The U.S. Environmental Protection Agency (EPA) has established that the maximum concentration of nitrate-N acceptable in groundwater is 10 parts per million (ppm).

• *Disease transmission to animals due to bacteria, parasites or viruses present in the sludge.* The principal means of overcoming this potential problem is proper and adequate treatment of the sludge before application. For this reason, all sludges applied to cropland must be treated by a stabilization process, such as anaerobic digestion, to minimize the amounts of potential pathogens in the sludge.

• *Contamination of crops by persistent organics.* Persistent organics, such as PCB's or chlorinated hydrocarbon pesticides, are not taken up to a great extent by the majority of crops. However, these organic compounds will adhere to the leaves of growing crops such as forages, if sludges are surface-applied. A potential problem with persistent organics can be minimized by incorporation of sludge into the surface soil prior to planting a crop.

• *Contamination of crops with cadmium.* Cadmium is a concern from a human health standpoint. Cadmium applied to soils in sewage sludge is taken up by the majority of agronomic crops, and can result in small increases in cadmium concentrations in the human diet. The concern is the potential for accumulation of cadmium in the human kidney over a period of 30 to 50 years, which can lead to a subclinical disease called proteinuria.

While no immediate human health problems are anticipated from slightly-elevated cadmium levels in crops, a greater exposure to cadmium will occur over a period of years. Because of this concern for human health, U.S. EPA has established regulations concerning the maximum amounts of cadmium that can be applied on agricultural soils used for growing food-chain crops, such as corn, wheat and soybeans. It should be noted that slightly increased levels of cadmium have no adverse effects on crop yields.

• *Reduced plant yields caused by heavy metals.* Sewage sludges contain the heavy metals lead, copper, zinc and nickel. Even though copper and zinc are required for normal plant growth, their addition to soils in relatively large amounts may result in reduced plant yields (phytotoxicity). Similarly, excess soil nickel can reduce plant growth. To maintain soil productivity, upper limits have been established for the amounts of copper, zinc and nickel that can be applied in sewage sludge soils.

DETERMINING SLUDGE APPLICATION RATES

Well-established principles of soil testing and fertilizer recommendations are used in conjunction with the characteristics of sewage sludge to determine proper rates of application. The *annual rate* of sludge addition is based on the lowest tonnage which will either: (1)

meet the nitrogen requirement of the crop *or* (2) limit cadmium additions to 1.8 pounds per acre.

The total amount of sludge addition during the life of an application site is controlled by the cumulative amounts of metals added (lead, zinc, copper, nickel or cadmium). The following discussion will consider the factors involved in determining: (a) the annual application rate, and (b) the total amount of sludge that can be applied over a period of years.

Annual Rate of Application

Nitrogen (N) Basis. Sludges may contain nitrogen in both organic forms and inorganic (ammonium and nitrate) forms. Nitrogen can be lost from soils through denitrification, nitrate leaching and ammonia volatilization.

Due to the potential harmful effects on human and animal health and the eutrophication of natural waters, the leaching of nitrates into groundwater should be minimized at a sludge application site. This is accomplished by adding only that amount of sludge which will provide plant-available N at a rate equal to the N requirements of the crop grown. Denitrification involves the conversion of nitrate to nitrogen gas by microbes in soils whenever excess water results in low oxygen levels. Ammonia volatilization is the loss of ammonia gas to the atmosphere and commonly occurs when sludges are applied to the soil surface and allowed to dry before tillage.

The plant-available nitrogen in sewage sludge consists of inorganic N plus a fraction of the organic N (20-30 percent). In general, fertilizer recommendations for various crops are based on field experiments where a portion of the fertilizer N applied is lost from the soil through leaching and denitrification. By using the fertilizer N recommendations for various crops, the annual rate of sludge application can be calculated based on the amount of (a) ammonia volatilization and (b) amount of organic N mineralization.

Ammonia volatilization will be a significant factor when sludges are applied to the soil surface and allowed to dry before incorporation. For surface application of sludges, it has been assumed that 50 percent of the ammonium N applied is lost through ammonia volatilization. However, recent research suggests that the extent of ammonia loss is influenced by both sludge and soil properties and may be only 20 percent of the applied ammonium N. Even so, ammonia losses have a significant impact on the annual rate during the first 5 years sludge is applied on the soil surface.

If sludge is incorporated into soil, only an insignificant amount of the ammonium added will be lost to the atmosphere as ammonia.

The decomposition of sludge organic N in soils will release inorganic N in a plant-available form. This process will continue for many years following waste application. To prevent accumulation of inorganic N in soils and thereby reduce the potential for nitrate leaching into groundwater, the annual rate of sludge N applied is adjusted downward on the basis of the residual N which will be released from previous sludge applications.

In general, the percentage of sludge organic N which decomposes will decrease each year after application. It is assumed that 20% decomposes the first year and then decreases to 3 percent of the remaining organic N each year for the next 3 years.

Cadmium (Cd) Basis. The second factor for determining the annual application rate for sewage sludge is the amount of cadmium added. Current recommendations can be summarized as follows for annual additions of Cd to soils.

1. *Soil pH.* The soil-sludge mixture must be pH 6.5 or above when sludge is applied.

2. *Tobacco, leafy vegetables and root crops.* Annual Cd applications must be less than 0.44 pound per acre.

3. *All other food-chain crops (e.g., corn, soybeans, small grains, forages).* The maximum allowable Cd application will decrease as follows: (a) present thru June 30, 1984 — 1.8 pounds per acre; (b) July 1, 1984 thru December 31, 1986 — 1.1 pounds per acre; and (c) after January 1, 1987 — 0.44 pound per acre.

Soils on which crops are grown that will be used only for animal feed can receive greater amounts of cadmium; but if such is the case, future crops will need to be monitored for Cd content. This approach is mainly applicable to sites dedicated for sludge disposal rather than for privately-owned farmland.

Total Sludge Additions

The life of a sludge application site is determined by the cumulative addition of metals. The following recommendations have been developed by joint efforts among researchers in universities, the U.S. Department of Agriculture and the U.S. EPA and is suggested in EPA guidelines.

The metals of primary importance are lead, zinc, copper, nickel and cadmium. The majority of plants do not accumulate lead; but there is concern about the potential for ingestion of lead by animals grazing sludge-treated lands. Zinc, copper and nickel applications are limited because of their potential to decrease crop yields if excessive amounts are added to soils; in general, these metals will be toxic to crops before their

Table 1. Maximum Amount of Metal Suggested for Agricultural Soils Treated with Sewage Sludge.

Metal	Maximum amount of metal when soil cation exchange capacity (meq/100g) is—		
	<5	5-15	>15
	lbs./acre		
Lead	440	880	1760
Zinc	220	440	880
Copper	110	220	440
Nickel	110	220	440
Cadmium	4.4	8.8	17.6

concentration in plant tissues reaches a level that is a problem in human or animal health. A limit for total cadmium additions is based on the same rationale as presented for the annual rate of Cd application. (*Note:* U.S. EPA regulations have been developed only for Cd.)

The maximum metal additions to soils are shown in Table 1. They assume that soil pH is maintained at 6.5 or above. If the soil becomes acid, it is likely that the yields of any metal-sensitive crops grown will be depressed.

The use of soil cation exchange capacity (CEC) in the table does *not* imply that metals added to soil in sludges are retained by the exchange complex of soils as an exchangeable cation. Rather, CEC was chosen as a single soil property that is easily measured and is also positively related to soil components that may minimize the plant availability of metals added to soils in sludges. In general, the three soil CEC categories correspond to sand, sandy loam and loam, and silt loam soils, respectively.

It should be emphasized that sludge applications cease when *any* one of the metal limits shown in Table 1 is exceeded. Furthermore, the soil pH *must* be maintained at 6.5 or above during and after sludge applications.

ADDITIONAL FACTORS AFFECTING SLUDGE APPLICATION RATES

PCB Limitations

The U.S. EPA has recently published regulations concerning the application of PCB's on cropland. No restrictions were imposed for sewage sludges containing less that 10 ppm PCB's. Contamination of forage crops with PCB's through adherence of surface-applied sludge is the primary problem anticipated; production of row crops such as corn, wheat and soybeans should not be affected to any extent by the application of PCB's contained in sewage sludges, even if the sludge contains greater than 10 ppm PCB's.

Sludges that contain greater than 10 ppm PCB's must be incorporated into the soil when the crop grown is used for animal feed. Incorporation is also required on pasture land. If the cattle feed produced from sludge-amended soils contain concentrations of PCB's less than 0.2 ppm or the milk from dairy cattle contains less than 1.5 ppm PCB's, then it is not necessary to incorporate the sludge into the soil.

An alternative approach is to limit PCB applications to soils to less than 0.4 pound per acre per year.

Disease Considerations

The U.S. EPA regulations require that all sewage sludges applied to soils be treated by a process which significantly reduces pathogen content of the sludges. Sludges treated by aerobic digestion, anaerobic digestion, air drying, composting and lime stabilization all fit this category.

The regulations also require that public access to the sludge application site be controlled for 12 months and that no grazing of animals be allowed for 1 month after sludge application if the animal product will be consumed by humans.

In addition, stricter sludge treatment processes (ones that further reduce the pathogen content) are required if crops are grown for direct human consumption within 18 months after sludge application. If there is no contact between sewage sludge and the edible portion of the crop, then the sludge does not have to be treated to further reduce pathogens.

Site Considerations

The following site considerations are recommended by the Indiana State Board of Health for soils treated with sludge.

1. *Slope.* Sludges can be surface-applied on soils with slopes up to 6 percent. If slope is 6 percent or greater, the sludge should be injected or incorporated into the soil during application.

2. *Depth to water table.* The minimum depth to groundwater should be 3 feet.

3. *Minimum distances.* A general guide to set-backs for sludge application sites has been established and is presented in Table 2.

Table 2. Set-Back Distances for Sludge Application.

| Feature | Distance from feature to sludge application site | | | | | |
| | 50-300 feet | | 300-1500 feet | | > 1500 feet | |
	Injection	Surface	Injection	Surface	Inject. & surf.	
Residential development	No	No	Yes	No	Yes	
Inhabitated dwelling	Yes	No	Yes	Yes	Yes	
Ponds and lakes	Yes	No	Yes	Yes	Yes	
Springs	No	No	Yes	Yes	Yes	
Ten-year high water mark of streams, rivers and creeks	Yes	No	Yes	Yes	Yes	
Water supply wells	No	No	Yes	Yes	Yes	
Public road right-of-way	Yes	No	Yes	Yes	Yes	

INFORMATION NEEDED TO CALCULATE APPLICATION RATES

Sludge Analysis

It is recommended that samples of sewage sludge be collected once every 2-3 months for a period of about a year to obtain a representative analysis of the sludge prior to land application. If liquid sludge is sampled, collect 1 quart per sample and store in plastic or glass containers to prevent evaporation of water. If dry sludge is sampled, a plastic bag will be sufficient for storage and transportation.

Chemical analysis of the samples should be made as soon as possible. However, if storage is required, it is recommended that samples be frozen or stored at 33-36°F (1-2°C). Where cold storage is not available, add muriatic acid (HCl) to the sample so that the pH is lowered to 0-1, then room temperature storage can be used.

Table 3 summarizes the analyses that are required in order to develop recommendations for application of sewage sludge on cropland. The data obtained are expressed on an oven-dry sludge solids basis. This is necessary because the percentage solids in sewage sludges varies appreciably from time to time in all treatment plants. To compare sludge composition from one sampling time to the next, it is necessary to have all data presented on a dry-solids basis.

Soil and Crop Data

The following soil and crop information is also needed to determine annual rates and total amounts of sludge that can be applied to soils.

1. Nitrogen fertilizer recommendation for the crop grown.

2. Soil test for available phosphorus and exchangeable potassium.

3. Potassium and phosphorus fertilizer recommendations for the crop grown.

4. Soil pH and lime requirement to adjust the soil to pH 6.5.

5. Soil cation exchange capacity.

Simplified fertilizer recommendations are presented in Tables 4-6 to assist in computing sludge and fertilizer application rates.

Table 3. Methods for Sludge Analysis.

Parameter	Suggested method
Percent solids*	Drying at 105°C for 16 hours
Total nitrogen*	Micro-Kjeldahl and steam distillation.**
Ammonium N*	Extraction with potassium chloride and steam distillation.**
Nitrate N*	Extraction with potassium chloride and steam distillation** after reduction.
Total phosphorus	Nitric acid-perchloric acid digestion and colorimetry.
Total potassium	Nitric acid-perchloric acid digestion and flame photometry.
Copper, zinc, nickel, lead and cadmium	Nitric acid-perchloric acid digestion and atomic absorption.

* Solids and nitrogen forms must be determined on the sludge sample prior to oven- or air-drying. Extensive loss of N will occur if samples are dried before analysis. Sludge samples can be dried before analyzing P,K and metals.

** Steam distillation followed by titration with standard acid.

Table 4. Soil Test Levels for Phosphorus and Potassium.

Soil test level	Phosphorus test	Potassium test
	lbs./acre	
Very low	0-10	0-20
Low	11-20	21-45
Medium	21-30	46-70
High	31-70	71-100
Very high	71+	100+

Table 5. Fertilizer Recommendations for Corn and Soybeans.

Expected yield	Nitrogen needed		P₂O₅ and K₂O needed if soil test level* is—				
			Very low	Low	Medium	High	Very high
bu./A	lbs./A				lbs./acre		
Corn							
100-110	120	P_2O_5 —	100	70	50	30	0
		K_2O —	100	70	50	30	0
111-125	140	P_2O_5 —	110	80	60	30	0
		K_2O —	120	90	60	30	0
126-150	170	P_2O_5 —	120	90	60	40	10
		K_2O —	150	120	70	40	0
151-175	200	P_2O_5 —	130	100	70	50	10
		K_2O —	180	140	90	60	0
176-200	230	P_2O_5 —	150	120	80	50	10
		K_2O —	200	160	120	80	0
Soybeans							
30-40	140**	P_2O_5 —	60	50	40	30	0
		K_2O —	100	80	50	40	0
41-50	175	P_2O_5 —	80	70	50	30	0
		K_2O —	120	90	60	60	0
51-60	210	P_2O_5 —	100	90	70	40	0
		K_2O —	150	120	90	60	0
61-70	245	P_2O_5 —	120	100	80	50	20
		K_2O —	180	150	120	80	0
71+	300	P_2O_5 —	120	100	80	50	20
		K_2O —	200	170	130	80	20

* See Table 4 for definition of soil test levels.
** Not recommended with conventional fertilization practices because of nitrogen fixation by soybeans.

Table 6. Fertilizer Recommendations for Small Grains and Forages.

Expected yield	Nitrogen needed		P₂O₅ and K₂O needed if soil test level* is—				
			Very low	Low	Medium	High	Very high
	lbs./A				lbs./acre		
Wheat and Rye (WR), Oats and Barley (OB)							
WR, 30-44 bu.	55	P_2O_5 —	90	60	30	20	20
OB, 70-85 bu.	55	K_2O —	90	60	30	0	0
WR, 45-54 bu.	65	P_2O_5 —	120	90	60	30	20
OB, 86-100 bu.	65	K_2O —	120	90	60	30	0
WR, 55-64 bu.	75	P_2O_5 —	120	90	60	30	20
OB, 101-115 bu.	75	K_2O —	120	90	60	30	0
WR, 65-74 bu.	85	P_2O_5 —	140	110	90	60	20
OB, 116-130 bu.	85	K_2O —	120	90	60	30	0
WR, 75+ bu.	95	P_2O_5 —	140	110	90	60	20
OB, 131+ bu.	95	K_2O —	120	90	60	30	0
Forage Crops (FC)							
FC, 4 tons	100	P_2O_5 —	100	80	50	30	20
		K_2O —	240	200	150	80	0
FC, 6 tons	200	P_2O_5 —	120	100	70	50	40
		K_2O —	360	300	240	180	120
FC, 8 tons	350	P_2O_5 —	140	120	90	70	50
		K_2O —	480	420	360	300	240

* See Table 4 for definition of soil test levels.

WORKSHEET FOR CALCULATING APPLICATION RATES OF SEWAGE SLUDGE ON CROPLAND

This worksheet is designed to be used in conjunction with Purdue Extension Publication AY-240, "Use of Sewage Sludge in Crop Production," which discusses the general principles of sludge application on soils. It works through an example situation, using hypothetical sludge analysis and soil/crop data ('our example'), and provides space for inserting data that reflects your specific situation ('your sludge'). The procedure is separated into five sections as follows:

1. Sludge composition and soil information.
2. Nutrient needs of crop.
3. Determining *annual* rate of sludge application.
4. Determining amount of *additional* fertilizer P and K needed.
5. Determining *total* amount of sludge allowed and number of years sludge can be applied.

Before proceding through the worksheet, it is necessary that the following information be available:

1. Sludge Composition Data
   a. Total nitrogen (N)
   b. Ammonium nitrogen (NH_4^+-N)
   c. Nitrate nitrogen (NO_3^--N)
   d. Phosphorus (P)
   e. Potassium (K)
   f. Lead (Pb)
   g. Zinc (Zn)
   h. Copper (Cu)
   i. Nickel (Ni)
   j. Cadmium (Cd)
   k. PCB's (if 10 ppm or greater, sludge must be incorporated into soil)

2. Soil and Crop Data
   a. Available P and K
   b. Fertilizer N, P and K recommendations for crop grown (either from soil test results or from Tables 4-6 in Publication AY-240)
   c. Soil pH and lime requirement to adjust soil to pH 6.5
   d. Soil cation exchange capacity (CEC)

SECTION A. SLUDGE COMPOSITION AND SOIL INFORMATION

Sludge* composition	Our example	Your sludge	Soil information	Our example	Your soil
Total N	5 %	___ %	Texture	LOAM	_____
Ammonium N	2 %	___ %	Soil pH	6.5	_____
Nitrate N	0 %	___ %	Available P	25 lbs./A	___ lbs./A
P	2 %	___ %	Exchange-able K	50 lbs./A	___ lbs./A
K	0.1 %	___ %	CEC	12 meq/100g	___ meq/100g
Zn	3000 ppm	___ ppm	Lime req'd (pH 6.5)	0 tons/A	___ tons/A
Pb	500 ppm	___ ppm			
Cu	1000 ppm	___ ppm			
Ni	50 ppm	___ ppm			
Cd	20 ppm	___ ppm			

* All sludge analyses reported on a dry weight basis.

SECTION B. NUTRIENT NEEDS OF CROP

	Our example	Your crop

Crop grown and yield per acre _CORN_ _____   _150 bu._ _____

Nutrients needed per acre (based on soil test report or data from Tables 4-6 in Publication AY-240)

N= _170_ lbs. _____ lbs.
P_2O_5= _60_ lbs. _____ lbs.
K_2O= _70_ lbs. _____ lbs.

SECTION C. DETERMINE ANNUAL RATE OF SLUDGE APPLICATION

1. **Amount of forms of N in sludge.**

   a. Percent organic N

   % total N − [% ammonium N (Sec.A) + % nitrate N (Sec.A)] = organic N

   Our example: _5_ − (_2_ + _0_) = _3_ % organic N

   Your sludge: _____ − (_____ + _____) = _____ % organic N

   b. Pounds of available organic N per ton of sludge

   % organic N (1.a) x 4 = lbs. available organic N/ton

   Our example: _3_ x 4 = _12_ lbs. N/ton

   Your sludge: _____ x 4 = _____ lbs. N/ton

   c. Pounds of ammonium N per ton of sludge

   % ammonium N (Sec.A) x 20 = lbs. ammonium N/ton

   Our example: _2_ x 20 = _40_ lbs. N/ton

   Your sludge: _____ x 20 = _____ lbs. N/ton

   d. Pounds of nitrate N per ton of sludge

   % nitrate N (Sec.A) x 20 = lbs. nitrate N/ton

   Our example: _0_ x 20 = _0_ lbs. N/ton

   Your sludge: _____ x 20 = _____ lbs. N/ton

2. **Amount of plant-available N in sludge.**

   a. Incorporated application of sludge

   Avail. organic N (1.b) + ammonium N (1.c) + nitrate N (1.d) = lbs. N/ton incorporated

   Our example: _12_ + _40_ + _0_ = _52_ lbs. N/ton incorporated

   Your sludge: _____ + _____ + _____ = _____ lbs. N/ton incorporated

   b. Surface application of sludge (assumes half the ammonium N will be lost by volatilization)

   Avail. organic N (1.b) + [ammonium N (1.c) ÷ 2] + nitrate N (1.d) = lbs. N/ton

   Our example: _12_ + [_40_ ÷ 2] + _0_ = _32_ lbs. N/ton surface applied

   Your sludge: _____ + [_____ ÷ 2] + _____ = _____ lbs. N/ton surface applied

3. Adjust N fertilizer recommendations to account for residual N from sludge applications in 3 previous years.

0.46 x % organic N x tons sludge/acre = lbs. residual N/acre

a. Sludge applied 1 year ago

Our example: 0.46 x _____O_____ x _____O_____ = _____O_____ lbs. residual N/acre

Your sludge: 0.46 x _____ x _____ = _____ lbs. residual N/acre

b. Sludge applied 2 years ago

Our example: 0.46 x _____O_____ x _____O_____ = _____O_____ lbs. residual N/acre

Your sludge: 0.46 x _____ x _____ = _____ lbs. residual N/acre

c. Sludge applied 3 years ago

Our example: 0.46 x _____O_____ x _____O_____ = _____O_____ lbs. residual N/acre

Your sludge: 0.46 x _____ x _____ = _____ lbs. residual N/acre

d. Total residual N

Step 3.a + Step 3.b + Step 3.c = total lbs. residual N/acre

Our example: _____O_____ + _____O_____ + _____O_____ = _____O_____ total lbs. residual N/acre

Your sludge: _____ + _____ + _____ = _____ total lbs. residual N/acre

e. Adjust N requirement

Lbs. N needed by crop (Sec.B) − lbs. residual N (3.d) = lbs. N required/acre

Our example: _____170_____ − _____O_____ = _____170_____ lbs. N required/acre

Your sludge: _____ − _____ = _____ lbs. N required/acre

NOTE: If no sludge was applied in last 3 years, use lbs. N from Section B as the final amount for lbs. N required/acre.

4. Annual sludge application rate based on amount of N needed by crop.

Adj. N required (3.e) ÷ lbs. avail. N/ton of sludge (2.a or 2.b) = tons sludge/acre

a. Incorporated application

Our example: _____170_____ ÷ _____52_____ = _____3.3_____ tons sludge/acre

Your sludge: _____ ÷ _____ = _____ tons sludge/acre

b. Surface application

Our example: _____170_____ ÷ _____32_____ = _____5.3_____ tons sludge/acre

Your sludge: _____ ÷ _____ = _____ tons sludge/acre

5. Annual sludge application rate based on Cd addition limitation.

a. Calculate amount of Cd per ton of sludge

ppm Cd (Sec.A) x 0.002 = lbs. Cd/ton of sludge

Our example: _____20_____ x 0.002 = _____0.04_____ lbs. Cd/ton

Your sludge: _____ x 0.002 = _____ lbs. Cd/ton

b. Calculate tons of sludge/acre to give 1.8 lbs. Cd/acre

1.8 lbs. Cd/acre ÷ lbs. Cd/ton (5.a) = tons sludge/acre

Our example: 1.8 ÷ _____0.04_____ = _____45_____ tons sludge/acre

Your sludge: 1.8 ÷ _____ = _____ tons sludge/acre

6. **Select proper annual sludge application rate per acre**

    a. Incorporated application—Step 4.a or Step 5.b, whichever is lower

    Our example: __3.3__ tons sludge/acre

    Your sludge: _____ tons sludge/acre

    b. Surface application—Step 4.b or Step 5.b, whichever is lower

    Our example: __5.3__ tons sludge/acre

    Your sludge: _____ tons sludge/acre

7. **Additional fertilizer N needed if annual sludge application rate is based on Cd addition limitation**

    Adj. N required (3.e) − [lbs. avail. N/ton (2.a or 2.b) x max. tons sludge/acre (5.b)] = lbs. additional fertilizer N/acre

    Your sludge: _____ − (_____ x _____) = _____ lbs. fertilizer N/acre

    NOTE: A negative answer means no fertilizer N is needed.

SECTION D. DETERMINE AMOUNT OF ADDITIONAL FERTILIZER P AND K NEEDED

1. **Phosphorus**

    a. P_2O_5 added in sludge

    Tons sludge/acre (6.a or 6.b) x % P (Sec.A) x 45.8 = lbs. P_2O_5/acre

    Our example: __3.3__ x __2__ x 45.8 = __302__ lbs. P_2O_5/acre

    Your sludge: _____ x _____ x 45.8 = _____ lbs. P_2O_5/acre

    b. Additional fertilizer P_2O_5 needed

    Total P_2O_5 needed (Sec.B) − P_2O_5 in sludge (1.a) = lbs. P_2O_5/acre

    Our example: __60__ − __302__ = __-242__ lbs. P_2O_5/acre

    Your sludge: _____ − _____ = _____ lbs. P_2O_5/acre

    NOTE: A negative answer means no additional P_2O_5 is needed.

2. **Potassium**

    a. K_2O added in sludge

    Tons sludge/acre (6.a or 6.b) x % K (Sec.A) x 24 = lbs. K_2O/acre

    Our example: __3.3__ x __0.1__ x 24 = __8__ lbs. K_2O/acre

    Your sludge: _____ x _____ x 24 = _____ lbs. K_2O/acre

    b. Additional fertilizer needed

    Total K_2O needed (Sec.B) − K_2O in sludge (2.a) = lbs. K_2O/acre

    Our example: __70__ − __8__ = __62__ lbs. K_2O/acre

    Your sludge: _____ − _____ = _____ lbs. K_2O/acre

    NOTE: A negative answer means no additional K_2O is needed.

SECTION E. DETERMINE TOTAL AMOUNT OF SLUDGE ALLOWED AND NUMBER OF YEARS SLUDGE CAN BE APPLIED

1. **Calculate amounts of sludge needed to reach limits of Pb, Zn, Cu, Ni and Cd. Obtain from Table 1 in Publication AY-240 the maximum amount of metal allowed for the CEC of soil used.**

   Max. amt. metal allowed (Table 1, AY-240) ÷ [conc. in sludge (Sec.A) x 0.002] = max. tons sludge/acre

   a. Our example: Pb __880__ ÷ (__500__ x 0.002) = __880__ tons sludge/acre

      Zn __440__ ÷ (__3000__ x 0.002) = __73__ tons sludge/acre

      Cu __220__ ÷ (__1000__ x 0.002) = __110__ tons sludge/acre

      Ni __220__ ÷ (__50__ x 0.002) = __2200__ tons sludge/acre

      Cd __8.8__ ÷ (__20__ x 0.002) = __220__ tons sludge/acre

   Your sludge: Pb _____ ÷ (_____ x 0.002) = _____ tons sludge/acre

      Zn _____ ÷ (_____ x 0.002) = _____ tons sludge/acre

      Cu _____ ÷ (_____ x 0.002) = _____ tons sludge/acre

      Ni _____ ÷ (_____ x 0.002) = _____ tons sludge/acre

      Cd _____ ÷ (_____ x 0.002) = _____ tons sludge/acre

   NOTE: Maximum amount of sludge allowed is the lowest tonnage figure calculated.

2. **Calculate number years that sludge can be applied.**

   Max. tons sludge allowed/acre (1.a) ÷ tons sludge applied/acre/year (Sec.C, 6.a or 6.b) = No. years

   a. Incorporated application

      Our example: __73__ ÷ __3.3__ = __22__ years

      Your sludge: _____ ÷ _____ = _____ years

   b. Surface application

      Our example: __73__ ÷ __5.5__ = __14__ years

      Your sludge: _____ ÷ _____ = _____ years