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Agricultural Land Application of Biosolids in Virginia: Managing Biosolids for Agricultural Use

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Introduction

Although biosolids supply some of all of the essential plant nutrients and soil property-enhancing organic matter, land application programs are designed chiefly for their nitrogen-, phosphorus-, and (in the case of alkaline stabilized materials) lime-supplying capabilities. The general approach for determining biosolid application rates on agricultural land can be summarized as follows:

1) Determine nutrient needs for expected crop yield and soil test levels.
2) Calculate biosolids agronomic rates based on crop nitrogen (N) needs, soil test phosphorus (P) needs, or soil lime requirement.
3) Calculate supplemental fertilizer needs by subtracting the amount of plant-available N, P, and potassium (K) supplied by biosolids from the crop N, P, and K needs.

Determining nutrient needs

Fertilizer recommendations are based on the nutrient-supplying capability of the soil and the additional nutrients needed by crops to achieve their potential yield. The amounts of N, P, and K required by most crops to achieve long term economically feasible and environmentally sound yields for soils in Virginia have been established experimentally and are published in the Virginia Agronomic Land Use Evaluation System (VALUES; Simpson et al., 1993).

Soil testing is required prior to the application of biosolids to determine the suitability of soil pH and the availability of P and K. Soil testing can disclose whether limestone, P or K is required for optimum crop productivity. Nitrogen application rates are based on crop N needs for expected yields for a specific soil.

Determining agronomic rates

Biosolids are normally applied at rates to provide the nitrogen needed by the crop ("agronomic N rate"). Regulations require that bulk biosolids be applied at rates that supply no more than the agronomic N rate for the specific crop and soil type. The relative concentrations of nutrients in biosolids are rarely present in the proportions required by the target crop; thus, supplemental fertilization may be needed to promote optimum vegetative growth and yield.

The type of information presented in Table 1, which is adapted from VALUES, is used to estimate the amount of N that can be used by various crops grown on biosolid-amended soils. Fertilizer N is not normally applied to legumes, which can obtain N from the atmosphere; however, nitrogen uptake has been used to establish agronomic N rates for legumes because they will use biosolids-furnished soil nitrogen.

Why are biosolids' applications usually based on crop N needs?

Nitrogen is required by crops in greater amounts than any other nutrient; thus, the crop requirements for most other nutrients are normally met when the agronomic N rate is applied. In addition, N is the nutrient most likely to be lost to surface and ground water if applied at greater than agronomic rates.

Several cautions regarding the determination of agronomic N rates are in order. (1) The amount of plant-available N can be underestimated or overestimated because the N composition of biosolids that is used to establish the average N concentration can vary significantly during the period of time that samples are collected and analyzed to establish the agronomic N rate. (2) The equations used to calculate plant-available N are not site or source specific, and the actual amounts of plant-available N may vary from the target

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

What is PAN and how is it determined?

Only a portion of the total nitrogen present in biosolids is available for plant uptake. This "plant available nitrogen" or PAN is the actual amount of N in the biosolids that is available to crops during a specified period. Equations for calculating PAN are relatively simple; however, choosing reasonable input values is more challenging. "Suggested" values for all necessary parameters are provided in Tables 2 and 3, but site-specific data, when available, should always be used in preference to "typical" values.

How are the availabilities of the different forms of N in biosolids determined?

Nitrogen in biosolids may be found in the ammonium (NH_4) or nitrate (NO_3) forms found in commercial inorganic fertilizers, or in organically-bound forms found in materials such as manures and composts. The amount of nitrogen that will be available to plants varies for each form of nitrogen. Nitrate is readily plant-available but is not found in high concentrations in most biosolids. Ammonium is also available to plants, but it can be lost to the atmosphere (volatilization) as ammonia (NH_3) gas when biosolids are applied to land without prompt incorporation into the soil. The available (non-volatilizable) fraction of NH_4^-N may be estimated from the values in Table 2.

Organic nitrogen must be broken down to NH_4^+ and NO_3^- (mineralization) by soil microorganisms before this form of nitrogen is available for plants to use; therefore, organic nitrogen can be considered to be a slow release form of nitrogen. The amount of PAN from organic nitrogen is estimated by using factors established by research, such as those presented in Table 3. The largest portion of organic nitrogen in biosolids is converted to plant available N during the first year after application to the soil.

As an example, the amounts of organic N that will become available for plant uptake upon mineralization of an aerobically digested biosolid (Table 3) are: 30% during the first year after application, 15% of the remaining organic N during the second year, and 8% of the remaining organic N during the third year. No additional credit for residual N is calculated after year 3 because the amounts are so small. The values in Table 3 may not be the most appropriate for all biosolids applied to any soil, but they are normally used when site specific data are not available. The amounts of available ammonium (NH_4) plus the available portion of the organic N (from Table 2) are used to calculate the rate of biosolids needed to supply a given amount of plant available N.

Will agronomic N rates of biosolids meet crop needs of all nutrients?

Not necessarily. Potassium (K) is often recommended for agronomic crops grown in Virginia soils, but the nutrient is present in low concentrations in biosolids. Supplemental potassium fertilization based on soil testing may be required for optimum plant growth where biosolids are applied. Research is currently being conducted to stabilize biosolids with caustic potash. This could increase the value of biosolids by fortifying the material with potassium.

How are the plant availabilities of P and K from biosolids determined?

EPA estimates that 50% of the P and 100% of the K applied in biosolids are available for plant uptake in the year of application. These quantities can be credited against fertilizer recommendations. Any P and K in excess of plant needs will contribute to soil fertility levels that can regularly be monitored via soil testing and taken into account when determining fertilizer recommendations in succeeding years.

What problems may be caused by applying biosolids at agronomic N rates?

Many soils in Virginia contain very high levels of phosphorus (P) due to long term manure application or repeated fertilization with commercial P fertilizer. High concentrations of soil phosphorus may increase P runoff into surface water, which can cause algal blooms that subsequently deplete oxygen for plant and animal life. The potential for such contamination exists where biosolids are applied on soils whose P concentrations are very high.

Biosolids normally supply similar amounts of plant available nitrogen and phosphorus, but crops require one-fifth to one-half as much phosphorus as nitrogen. Applying biosolids at rates to supply the nitrogen needs of the crop can increase the potential for P contamination of surface water where soil P levels are already high. To alleviate the potential of phosphorus runoff in such cases, it may be advisable to apply the biosolids at rates to meet the P needs of the crop. This would probably require the farmer to purchase nitrogen to meet the crop needs.

Can the proper biosolids application rate be determined by other fertility parameters?

The lime potential of the alkaline-stabilized biosolids may be used to determine application rates. The pH of sandy soils can rise rapidly when limed. Deficiencies of manganese in wheat and soybean and zinc in corn have sometimes been caused by excessive liming (pH > 6.8) of sandy soils in the Virginia Coastal Plain (east of I-95). Application of lime-stabilized bio-

Table 1

Historical mean yields and potential biosolid N utilization of various crops grown on soils of different productivity groups (Excerpted from Virginia Biosolids Use Regulations - Table 11).

Crop	Soil Productivity Group IIA Mean yield	N use lb/ac	Soil Productivity Group IIIB Mean yield	N use lb/ac
Corn				
grain (yield=bu/ac)	140	140-160	110	110-130
silage (yield=tons/ac)	19	140-160	16	110-130
Soybean (yield=bu/ac)				
early season	40	140-160	35	110-130
late season	34	140-160	25	110-130
Wheat (yield=bu/ac)				
standard	56	90	48	80
intensive	70	90	60	80
Tallgrass hay (yield=tons/ac)	3.5-4	250	< 3	200
Pasture - fescue/orchardgrass	[a]	120	[a]	100
Alfalfa (tons/ac)	4-6	300	< 4	210

[a] Insufficient data to make a good estimate.

Table 2

Estimated plant-available percentage of ammonia from biosolids (adapted from Virginia BURs - Table 12).

Management practice	Biosolids pH<10	Biosolids pH>10
	Available portion (%)	
Injection below surface	100	100
Surface application with/		
— Incorporation within 24 hours	85	75
— Incorporation within 1-7 days	70	50
— Incorporation after 7 days	50	25

Table 3

Estimated percentage of organic N that becomes available for plant uptake at various times after application for different biosolids (adapted from Virginia BURs - Table 12).

Time after application	Lime stabilized	Aerobically digested	Anaerobically digested	Composted
Years		Plant available portion of organic N (%)		
0-1	30	30	20	10
1-2	15	15	10	5
2-3	7	8	5	3

solids at agronomic N rates onto such soils that already have high pH's can induce deficiencies of manganese and zinc. Crop yield reductions can result if the deficiency is not corrected, and the soil nitrogen not utilized by the crop can potentially leach into groundwater. Thus, alkaline-stabilized biosolids should not be applied at rates that raise the soil pH in Coastal Plain soils above 6.5 (and 6.8 for all other soils).

What other guidelines are important in maintaining optimum pH for soils amended with biosolids?

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

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

Determining annual biosolids rates

The agronomic N rate can be applied to provide N needs once every three years until any trace element limits are reached. Biosolids may be applied frequently at "less than agronomic rates," usually limited to about 60 percent of agronomic rates. It may be prudent to limit the biosolid application to a rate where biosolid P is equal to fertilizer P recommendations or the P removed by the crop in soils that already contain high amounts of plant available P. In these instances, N will probably be applied at less than the crop N need, and additional N will need to be supplemented. This P rate could be followed as long as it did not exceed the agronomic N rate or Part 503 pollutant loading limits for metals.

How is agronomic N rate calculated?

1 Determine the fertilizer N recommendation for the crop based on the expected yield level for the soil.

Use Table 11 in the Biosolids Use Regulations or justify alternative site specific loading rates by documenting historic crop yield records or by written verifications from Virginia Tech/Virginia Cooperative Extension personnel.

2 Subtract anticipated N credits (i.e., other sources of N) from the recommended fertilizer N rate, such as:
   a) Residual N from a previous legume crop (as estimated from Table 11C in the Biosolids Use Regulations)
   b) N that has already been applied or will be applied during the growth of the crop by fertilizer, manure, or other sources that will be readily available to plants
   c) Residual N remaining from previous waste (e.g., manure, biosolids)

3 Calculate the adjusted biosolids N rate by subtracting "total N available from existing, anticipated, and planned sources" from "total N requirement of crop."

4 Calculate the PAN/dry ton of biosolids for the first year of application using Equation 1:

$$PAN = NO_3\text{-}N + Kvol\ (NH_4\text{-}N) + Kmin\ (Org\text{-}N)$$

where:

PAN	=	lbs plant-available N/dry ton biosolids
NO_3-N	=	lbs nitrate N/dry ton biosolids
Kvol	=	volatilization factor, or plant-available fraction of NH_4-N (Table 2)
NH_4-N	=	lbs ammonium N/dry ton biosolids
Kmin	=	mineralization factor, or plant-available fraction of Org-N (Table 3)
Org-N	=	lbs organic N/dry ton biosolids (estimated by organic N = total Kjeldahl N - NH_4-N)

5 Calculate the amount of biosolids required to supply the crop N needs by:

Tons dry biosolids required/acre = adjusted biosolids N rate (in lbs/acre) divided by PAN/dry ton biosolids.

Divide the tons of dry biosolids by the percent solids to convert to wet weight.

How is agronomic P rate calculated?

Applying biosolids to meet the P, rather than the N, needs of the crop is a conservative approach for determining annual biosolid application rates. Supplemental N fertilization will be needed to optimize crop yields (except for N-fixing legumes) if biosolids application rates are based on a crop's P needs. The P in biosolids is estimated to be about half as available for plant uptake as the P normally applied to soils in commercial inorganic fertilizers. The agronomic P rate of biosolid for land application can be determined by Equation 2:

Agronomic P rate = Preq divided by Avail. P_2O_5/ dry ton where:

Preq	=	the P fertilizer recommendation for the harvested crop, or the quantity of P removed by the crop
Avail. P_2O_5	=	0.5 (total P_2O_5/dry ton biosolids)
Total P_2O_5/dry ton	=	%P in biosolid x 20[a] x 2.3[b]

[a]20 is the factor to convert % to lbs per ton
[b]2.3 is the factor to convert lbs P to lbs P2O5

How is agronomic lime requirement rate calculated?

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

Tons biosolids per acre = tons of CCE required/acre ÷ Biosolid's CCE/100

Example to determine N, P, and lime agronomic rates for a specific biosolid

A lime-stabilized biosolid has a pH>10, a CCE of 40%, a NO_3-N concentration of 1,000 ppm (0.1%), an NH_4-N concentration of 2,000 ppm (0.2%), a TKN concentration of 27,000 ppm (2.7%), and a total P concentration of 21,000 ppm (2.1%), all on a dry weight basis (percent dry solids is 17.6%). Corn for grain is to be grown on a Kempsville sandy loam soil that has a pH of 6.2, "high" Ca, Mg and K soil test ratings and a "low" P soil test rating. The biosolid will be surface-applied and disced into the soil within 24 hours. What should be the agronomic rate of the lime-stabilized biosolid?

The estimated yield potential of corn grown on a Kempsville soil is 120 bu/acre (Simpson et al., 1993) and the N rate permitted is 120-140 lbs/acre (Virginia Biosolids Use Regulations - Table 11).

The N-based agronomic rate is calculated from Equation 1 by:

a) Calculating the components of PAN in the biosolid
   NO_3-N = 1,000 ppm x 0.002 = 2 lbs/ton
   NH_4-N = 2,000 ppm x 0.002 = 4 lbs/ton
   TKN = 27,000 ppm x 0.002 = 54 lbs/ton
   Org-N = 54-(2 + 4) = 48 lbs/ton

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

c) Dividing the adjusted fertilizer N rate (140 lbs N/ dry ton) by the PAN/dry ton biosolid (19.4 lbs N/ dry ton) to obtain the agronomic N rate (7.2 dry tons/acre).

The P-based agronomic rate is determined from Equation 2 by:

a) Calculating the total amount of P_2O_5 in a ton of biosolids
   P_2O_5/dry ton = 2.1 x 20 x 2.3 = 96.6 lbs

b) Calculating the amount of plant available P_2O_5 in a ton of biosolids
   Plant available P_2O_5/dry ton = 0.5 x 96.6 = 48.3 lbs

c) Calculating the agronomic P rate
   The soil test rating of "medium" requires 120 lb P_2O_5/acre (Simpson et al., 1993); thus, the agronomic P rate = 120 lb P_2O_5/acre ÷ 48.3 lbs P_2O_5/ dry ton = 2.5 dry tons/acre (i.e., about 1/3 of the Agronomic N rate for the same biosolid).

The lime-based agronomic rate is determined from Equation 3 by:

a) The coarse-textured Kempsville soil is permitted 0.75 tons limestone/acre (Virginia Biosolids Use Regulations - Table 14); thus, the rate of lime-stabilized biosolids to provide 0.75 tons CCE/acre is given by:
   Tons biosolids per acre = tons of CCE required/acre ÷ Biosolid's CCE/100, or
   0.75 tons CCE/acre ÷ 40%/100 = 1.9 tons/acre

In summary, the N-based, P-based, and lime-based agronomic rates for the example above are 7.6, 2.5, and 1.9 dry tons/acre, respectively. The most limiting is the lime-based agronomic rate; thus, 1.9 dry tons or 10.8 wet tons (1.9 dry ton/acre divided by 0.176 dry ton/wet ton) should be the appropriate agronomic rate. Of course, the capability of the equipment to spread rates this low may prevent any biosolid application to the land in this example.

Determining supplemental fertilizer needs

The amounts of plant-available nitrogen, phosphorus, and potassium, and other nutrients added by the biosolid should be calculated once the application rate has been determined. Supplemental fertilizers should be applied if the amount of any nutrients in the biosolid is less than that recommended.

The amount of K applied in biosolids can be calculated from biosolid composition data (as done earlier for P). All of the K in biosolids can be assumed to be readily plant-available because K is a soluble element. The quantity of K_2O that can be credited against the fertilizer recommendation is calculated using the following equation:

Lbs K_2O/acre = dry tons biosolid/acre x lbs available K_2O/dry ton biosolids

where:

Available K_2O = %K in biosolid x 20^a x 1.2^b

a 20 is the factor to convert % to lbs per ton.

b 1.2 is the factor to convert lbs K to lbs K2O.

Example: The following calculation is used to determine the amount of K_2O added in a biosolid and supplemental K_2O required for a wheat field that has a K fertilizer recommendation of 100 lbs K_2O/acre and receives a biosolid containing 0.5% K at an agronomic N rate of 4 dry tons/acre:

Available K_2O = 0.5% x 20 x 1.2 = 12 lbs K_2O/dry ton

K_2O applied = 4 dry ton/acre x 12 lbs K_2O/dry ton = 48 lbs K_2O/acre

Additional K_2O needed = 100 lb K_2O/acre - 48 lb K_2O/acre = 52 lbs K_2O/acre

Selection of suitable crops for fertilization with biosolids

High N-use crops such as corn, soybean, small grains, and forages will minimize the amount of land needed for biosolid application and will benefit from the N supplying capability of bisolids. Crops grown for their flowering parts, such as cotton, can produce undesirable amounts of vegetative growth if they continue to accumulate N late in the season. Thus, slow release N sources such as biosolids and manures may impair the quality of such crops; however, biosolids can be used efficiently on other crops in rotation with cotton.

Biosolids can be applied to vegetable crops, but green leafy vegetables tend to accumulate higher concentrations of metals than the grain of agronomic crops. Some scientists have cautioned against using biosolids on vegetable crops because they provide a direct conduit of potentially harmful trace elements from the soil to humans. Therefore, grain and forage crops are better choices for biosolids application than vegetables. Tobacco accumulates heavy metals such as Cd in high concentrations, and the use of biosolids on tobacco land is not recommended.

Application methods

The most appropriate application method for agricultural land depends on the physical characteristics of the biosolids and the soil, as well as the types of crops grown. Biosolids are generally land applied using one of the following methods: 1) sprayed or spread on the soil surface and left on the surface for pastures, range and forest land; and 2) incorporated into the soil after being surface applied or injected directly below the surface for producing row crops or other vegetation. Both liquid and dewatered biosolids may be applied to land with or without subsequent soil incorporation.

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

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

Liquid biosolids can also be injected below the soil surface using tractor-drawn tank wagons with injection shanks and tank trucks fitted with flotation tires and injection shanks. Both types of equipment minimize odor problems and reduce ammonia volatilization by immediate mixing of soil and biosolids. Injection can be used either before planting or after harvesting

Liquid biosolids being applied to the surface of a pasture.

crops, but it is likely to be unacceptable for forages and sod production. Some injection shanks can damage the sod or forage stand and leave deep injection furrows in the field.

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

Dewatered biosolids can be applied to cropland by equipment similar to that used for applying limestone, animal manures or commercial fertilizer. Typically, dewatered biosolids will be surface-applied and incorporated by plowing or another form of tillage. Incorporation is not used when applying dewatered biosolids to forages. Biosolids application methods such as incorporation and injection can be used to meet Part 503 vector attraction reduction requirements.

Spreading of dewatered "cake" biosolids from a manure-type spreader in preparation for planting corn.

Timing of biosolids application

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

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

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

Biosolids storage

Storage facilities are required to hold biosolids during periods of inclement weather, equipment breakdown, frozen or snow-covered ground, or when land is unavailable due to growth of a crop. Liquid biosolids can be stored in digesters, tanks, lagoons, or drying beds; and dewatered biosolids can be stockpiled. The Biosolids Use Regulations specify that biosolids stored for more than 30 days must be placed into a specially designed, permitted, storage facility.

Further information can be found in the following Virginia Cooperative Extension fact sheets on agricultural land application of biosolids in Virginia: VCE Publication 452-301, Production and characteristics (Evanylo, 1999b); VCE Publication 452-302, Regulations (Evanylo, 1999c), and VCE Publication 452-304, Risks and concerns (Evanylo, 1999e).

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