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Waste Management
Field Handbook

Chapter 5 Role of Soils in Waste Management

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Chapter 5 Role of Soils in Waste Management

651.0500 Introduction

Agricultural waste management system (AWMS) planning, design, implementation, and function are dependent on soil physical and chemical properties and landscape features. The AWMS planner and designer must understand agricultural waste related soil suitabilities and limitations. This chapter describes soil agricultural waste interactions and those soil properties and characteristics that affect soil suitability and limitations for an AWMS.

Soil data should be collected early in the planning process. Essential soil data include soil maps and the physical and chemical properties that affect soil suitability and limitations for an AWMS. Soil maps are in published soil surveys or, if not published, are available at the local Natural Resources Conservation Service field office. Soil suitability and limitation information can be obtained from published soil surveys, section II of the Field Office Technical Guide (FOTG), Field Office Communication System (FOCS), tables and soil data sets, soil interpretation records (SIR's), and the National Soils Handbook interpretation guides, part 603.

Soil information and maps may be inadequate for planning AWMS components. Agricultural waste management systems should not be implemented without adequate and complete soil maps or soil interpretive information. If soil data or maps are inadequate or unavailable, soil survey information must be obtained before completing an agricultural waste management system plan. This information will include a soil map of the area, a description of soil properties and their variability, and soil interpretive data.

651.0501 Soil phases

Soil is heterogeneous material made up of three major components: a solid phase, a liquid phase, and a gaseous phase. All three phases influence the supply of plant nutrients to the plant root.

The **solid phase** is the main nutrient reservoir. It holds nutrients in the cation form (positive charged ions), such as potassium, nitrogen (as ammonium), sodium, calcium, magnesium, iron, manganese, zinc, and cobalt on negatively charged clay and organic colloidal particles. Anionic (negatively charge ions) nutrients, such as nitrogen (as nitrate), phosphorus, sulfur, boron, and molybdenum, are largely held by the organic fraction or mineral complexes.

Nitrate is held very loosely to the anion exchange sites of the soil and move readily with percolating soil water. As the organic fraction is impoverished because of poor farming practices, the soil's ability to hold these elements is drastically reduced.

Phosphorus is often fixed to the mineral soil fraction containing iron, aluminum, and carbonates. It can be attached to hydrous aluminum, iron oxides, carbonates, and clays, particularly the kaolinitic type.

The amount of plant available nutrients held by a soil depends upon its unique chemical and physical makeup. This makeup can be ascertained by a soil's cation-exchange capacity, pH, organic matter content, clay minerology, and water holding capacity.

The **liquid phase** of the soil, the soil solution, is responsible for the transport of nutrients in the soil. Nutrients transported in the liquid phase are present in the solute form of the nutrient element. Oxygen and carbon dioxide can be dissolved in the soil solution and transported to and from the system. A large percentage of agricultural waste material is composed of water. Depending on the type, timing, and method of delivery of waste, this water can be used to supply part of the plant's moisture as well as nutrient requirements.

The **gaseous phase** mediates the exchange of gases that occurs among the numerous living organisms in the soil. Nitrogen, oxygen, water vapor, and carbon dioxide are the primary gaseous by-products of the soil and plant system. Gas exchange affects denitrification, mineralization of organic material, and soil micro-organism growth rate.

651.0502 Soil-agricultural waste interaction

Soil-agricultural waste interactions are a complex set of relationships that are dependent on the soil environment, microbial populations, and the chemical and physical properties of the soil and waste material. The following discussion describes some of these relationships.

(a) Filtration

Soil filtering systems are used to deplete Biological Oxygen Demand (BOD), consume or remove such biostimulants as phosphates and nitrates, provide long term storage of heavy metals, and deactivate pathogens and pesticides. Soils suitable for use as filtering systems have permeability slow enough to allow adequate time for purification of water percolating through the soil system.

A balance of air, water, and nutritive substances at a favorable temperature is important to a healthy microbial population and an effective filtration system.

Figure 5–1 Relationship between microbial respiration rate and temperature

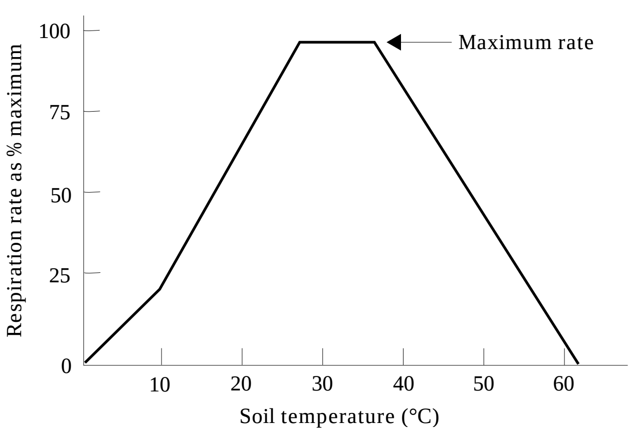
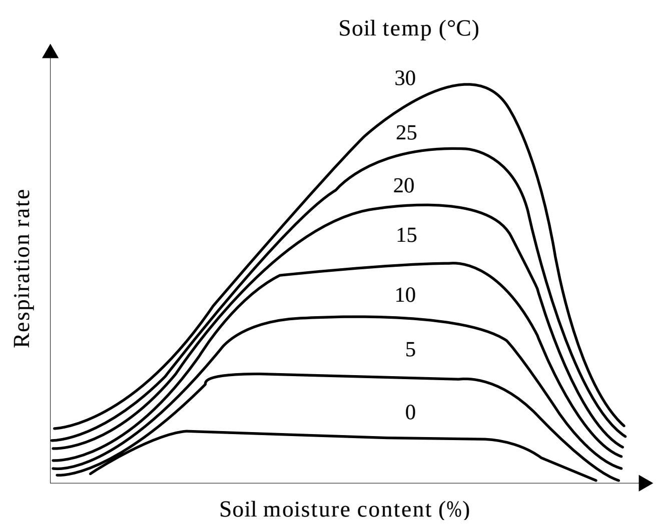


Figure 5–2 Relationship of microbial respiration rate to temperature and moisture



For example, overloading the filtration system with wastewater that has high amounts of suspended solids causes clogging of soil pores and a reduction of soil hydraulic conductivity. Management and timing of wastewater application are essential to maintaining soil filter systems. Climate, suspended solids in the wastewater, and cropping systems must be considered to maintain soil porosity and hydraulic conductivity.

The wastewater application rate should not exceed the waste decomposition rate, which is dependent on soil temperature and moisture content. Periods of wetting and drying increase microbial decomposition and by-product uptake by the crop and decrease potential soil pore clogging. In areas where the temperature is warm for long periods, the application rates may be higher if crops or other means of using the by-products of waste decomposition are available.

Tillage practices that maintain or improve soil tilth and reduce soil compaction and crusting should be included in the land application part of agricultural waste management systems. These practices help to maintain soil permeability, infiltration, and aeration, which enhances the biological decomposition processes.

(b) Biological degradation

Several factors affect biological degradation of various agricultural waste organics when the waste is applied to soil. These factors interact during the biological degradation process and can be partitioned into soil and organic factors.

Soil factors that affect biological degradation are temperature, moisture, oxygen supply, pH, available nutrients (N, P, K, and micronutrients), porosity, permeability, microbial population, and bulk density. Organic factors are carbon to nitrogen ratio (C:N), lignin content, and BOD.

The soil and organic factors interact and determine the environment for microbial growth and metabolism. The physical and chemical nature of this environment determines the specific types and numbers of soil micro-organisms available to decompose organic material.

The decomposition rate of organic material is primarily controlled by the chemical and biological composition of the waste material, soil moisture and temperature (figs. 5–1 & 5–2), and available oxygen supply. Rapid decomposition of organic wastes and mineralization of organic nitrogen and phosphorus by soil micro-organisms are dependent on an adequate supply of oxygen and soil moisture.

High loading rates or high BOD waste may consume most of the available oxygen and create an anaerobic environment. This process can cause significant shifts in microbial populations, microbial metabolisms, and mineralization by-products. Under anaerobic conditions, the by-products may be toxic and can be in sufficient concentrations to inhibit seed germination and retard plant growth, even after aerobic conditions have been restored. See section 651.0503(a).

(c) Chemical reactions

Management for utilization of organic waste material must take into account the chemical reactions that occur between the soil and the waste components. These reactions are broadly grouped as ion exchange, adsorption, precipitation, and complexation. The mechanisms and rates of these reactions are dependent upon physical, chemical, and biological properties of the soil and organic waste material.

Organic waste mineralization by-products consist of macro- and micro-plant nutrients, soluble salts, gases, and heavy metals. These by-products dissolve and enter soil water solutions as precipitation or irrigation water infiltrates the soil surface and percolates through the soil profile. The dissolved by-products are subject to the interactions of ionic exchange, adsorption, precipitation, or complexation. These processes store and exchange the macro- and micro-plant nutrient by-products of organic waste mineralization. They also intercept and attenuate heavy metals, salts, and other detrimental mineralization by-products that can adversely affect plant growth and crop production.

Ion exchange reactions involve both cations and anions (table 5–1). Ionic exchange and adsorption is the replacement or interchange of ions bonded electrostatically to exchange sites on soil particles and soil organic materials with similarly charged ions in the soil solution. This ionic interchange occurs with little or no alteration to exchanging ions.

Cation exchange is the adsorption and exchange of nonmetal and metal cations to negatively charged sites on soil particles and soil organic materials. Cation-exchange capacity (CEC) is the measure of a soil's potential to exchange cations and is related to soil mineralogy, pH, and organic matter content.

Anion exchange is the exchange and replacement of negatively charged ions to positively charged sites on soil particles. Anion exchange capacity is relatively low in most soils when compared to cation exchange; however, anion exchange is important because the anion exchange potential of the soil is related to its ability to retain and exchange nitrate nitrogen (NO_3–N), sulfate, chloride, boron, molybdenum, and phosphorus.

Adsorption and precipitation are processes that remove an ion from the soil solution. Sorption occurs as ions attach to the solid soil surface through weak chemical and molecular bonds or as strong chemical bonds. Precipitation is the deposition of soluble compounds in soil voids. It occurs when the amount of the dissolved compounds in the soil solution exceeds the solubility of those compounds.

Complexation is the interaction of metals with soil organic matter and some oxides and carbonates, resulting in the formation of large, stable molecules. This process extracts phosphorus and heavy metals from the soil solution. These stable complexes act as sinks for phosphorus, heavy metals, and some soil micronutrients.

651.0503 Soil-agricultural waste mineralization relationship

The mineralization of agricultural waste material is governed by the biological, chemical, and physical properties of soil and organic waste; the soil moisture; and the soil temperature. Organic waste mineralization is a process where microbes digest organic waste, reduce the waste material to inorganic constituents, and convert it to more stable organic materials. Inorganic materials released during this process are the essential plant nutrient (N, P, K), macronutrients and micronutrients, salts, and heavy metals.

(a) Microbial activity

Soil-agricultural waste material microbial composition and microbial activity greatly influence the rate of organic waste mineralization. Soil moisture, temperature, and aeration regulate soil microbial activity and thus are factors that influence the rate of waste mineralization.

Table 5–1 Common exchangeable soil cations and anions

Elements	Cations	Anions
Aluminum	Al^{+3}	
Boron		BO_3^{-3}
Calcium	Ca^{+2}	
Carbon		CO_3^{-2}, HCO_3^-
Chlorine		Cl^-
Copper	Cu^+, Cu^{+2}	
Hydrogen	H^+	OH^-
Iron	Fe^{+2}, Fe^{+3}	
Magnesium	Mg^{+2}	
Manganese	Mn^{+2}, Mn^{+3}	
Molybdenum		MoO_4^{-2}
Nitrogen	NH_4^+	NO_2^-, NO_3^-
Phosphorus		HPO_4^{-2}, $H_2PO_4^-$
Potassium	K^+	
Sulfur		SO_3^{-2}, SO_4^{-2}
Zinc	Zn^{+2}	

Soils that are warm, moist, and well aerated have the highest potential microbial activity and the highest potential rate of organic waste mineralization. Lower potential rates should be expected when soils are dry, cold, or saturated with water. (See figs. 5–1 & 5–2.)

Average annual soil surface temperature and seasonal temperature variations have a significant impact on the duration and rate of soil microbial activity. Average annual soil temperatures in the conterminous United States range from less than 32 °F (0 °C) to more than 72 °F (22 °C). Microbial activity is highest in soils that have high average annual soil temperature and lowest in soils that have low temperature.

In many areas, the mean winter soil temperature is 9 °F (5 °C) or more below the mean summer soil temperature. Microbial activity and organic waste mineralization in the soils in these areas are greatest during the summer months and least during the winter months. Thus, microbial activity decreases or increases as mean monthly soil temperature changes throughout the year.

Agricultural wastes applied to cold or frozen soils mineralize very slowly, are difficult or impossible to incorporate, and are vulnerable to surface runoff and erosion. Potential agricultural waste contamination of surface water is highest when agricultural wastes are applied under these conditions.

Microbial activity is also highly dependent on the soil moisture content. Soils that are dry throughout most of the growing season have a low organic matter mineralization rate. Microbial activity in these soils is greatest immediately after rainfall or irrigation events and decreases as soil moisture decreases. Conversely, soils that are moist throughout most of the growing season have higher microbial activity and more capacity to mineralize organic waste. Wet soils or soils that are saturated with water during the growing season have potentially lower microbial activity than moist soils. This is not caused by a lack of soil moisture, but is the result of low soil aeration when the soils are saturated.

(b) Nitrogen mineralization

Organic nitrogen is converted to inorganic nitrogen and made available for plant growth during the waste mineralization process. This conversion process is a two way reaction that not only releases nitrogen, but also consumes nitrogen.

Agricultural waste materials, especially livestock manure that has C:N ratios shown in chapter 4, increase the energy or food supplies available to the soil microbial population. This high energy stimulates soil microbial activity, which consumes more available nitrogen than the mineralization processes release. Thus, high microbial activity during initial waste mineralization can cause a reduction of available nitrogen below that needed for plant growth. Nitrogen deficiency also occurs if the waste mineralization cannot supply sufficient quantities of nitrogen to the plants during periods of rapid growth. This is most apparent in spring as the soil warms and crops exhibit a short period of nitrogen deficiency.

Ammonium nitrogen (NH_4^+) is the initial by-product of organic nitrogen mineralization. Ammonium is adsorbed to soil particles through the cation exchange. It can be used by plants or micro-organisms. Ammonium nitrogen is further oxidized by nitrifying bacteria to nitrate (NO_3^-). This form of nitrogen is not strongly adsorbed to soil particles nor easily exchanged by anion exchange.

Nitrate forms of soil nitrogen are susceptible to leaching and can leach out of the plant root zone before they can be used for plant growth. Nitrate can contaminate if leached below the soil root zone or transported off the field by runoff to surface water. Soils that have high permeability and intake rates, coarse texture, or shallow depth to a water table are the most susceptible to nitrate contamination of ground water. Those that have low permeability and intake rates, fine texture, or steep slopes have a high runoff potential and are the most susceptible to nitrogen runoff and erosional losses.

(c) Phosphate mineralization

Organic phosphorus in agricultural wastes is made available for plant growth through the mineralization process. Phosphorus is removed from the soil solution by adsorption to the surface of clay particles or complexation with carbonates, iron, aluminum, or more stable organic compounds.

Phosphorus mobility is dependent on the phosphorus adsorption and complexation capacity of a soil. Soils that have slow permeability and high pH, lime, Fe or Al oxides, amorphous materials, and organic matter content have the highest phosphorus adsorption capacity. Adsorbed phosphorus is considered unavailable for plant growth. Soil erosion and runoff can transport the sorbed and complexed phosphorus offsite and contaminate surface water. Adsorbed phosphorus in suface water may become available by changes in the water pH or redox potential. Conversely, soils that have rapid permeability, low pH, and low organic matter have low phosphorus adsorption capacity allowing phosphorus to leach below the root zone. However, this seldom occurs.

(d) Potassium, calcium, and magnesium mineralization

Potassium, calcium, and magnesium converted from organic to inorganic compounds during mineralization have similar reactions in the soil. Upon dissolution, they become cations that are attracted to negatively charged soil particles and soil organic matter. These minerals are made available for plant growth through the cation exchange process. Potassium is less mobile than nitrogen and more mobile than phosphorus. Leaching losses of potassium are not significant and have little potential to contaminate ground water. Calcium and magnesium can leach into ground water or aquifers, but they do not constitute a hazard to water quality.

(e) Heavy metal and trace element mineralization

Heavy metals and trace elements are by-products of the organic mineralization process. Municipal sludge applied on the land is often a source of heavy metals. They are strongly adsorbed to clay particles or complexed (chelated) with soil organic matter and have very little potential to contaminate ground water supplies and aquifers. This immobilization is strongest in soils that have a high content of organic matter, pH greater than 6.0, and CEC of more than 5. However, application of organic waste containing high amounts of heavy metals can exceed the adsorptive capability of the soil and increase the potential for ground water or aquifer contamination. See chapter 6 for the impact of heavy metals on plants.

Sandy soils that have low content of organic matter and low pH have a low potential for retention of heavy metals. These soils have the highest potential for heavy metals and trace element contamination of aquifers and ground water. Surface water contamination from heavy metals and trace elements is a potential hazard if agricultural wastes are applied to areas subject to a high rate of runoff or erosion.

651.0504 Soil characteristics

Soil suitabilities and limitations for agricultural waste application are based on the most severely rated soil property or properties. A severe suitability rating does not necessarily infer that agricultural wastes cannot be used. It does, however, infer a need for careful planning and design to overcome the severe limitation or hazard associated with one or more soil properties. Care must be taken in planning and designing agricultural waste management systems that are developed for soils that have a moderate limitation or hazard suitability rating. In general, moderate limitations or suitability ratings require less management or capital cost to mitigate than do the severe ratings.

Slight is the rating given soils that have properties favorable for the use of agricultural wastes. The degree of limitation is minor and can be overcome easily. Good performance and low maintenance can be expected.

Soil suitability for site specific agricultural waste storage or treatment practices, such as a waste storage pond, waste treatment lagoon, or waste storage structure, are not discussed in this section. Soil variability within soil map delineations and mapping scale generally prevent using soil maps for evaluation of these site specific agricultural waste management system components. Soil investigations conducted by a soil scientist or other qualified person are needed to determine and document site specific soil information, such as soil type, observed and inferred soil properties, and the soil limitations or hazards for the site specific components. See chapter 7 for site specific considerations.

Nonsite specific agricultural waste utilization practices are those that apply agricultural wastes to fields or other land areas by spreading, injection, or irrigation. The suitability, limitations, or hazards associated with these practices are dependent upon and influenced by the geographical variability of the soil and soil properties within the area of application. They are discussed in this chapter.

Soil suitability ratings for nonsite specific agricultural waste management system components and practices are determined from soil survey maps and FOTG interpretive tables, SIR, or National Soils Handbook interpretive guides. Soil variability within fields or geographical areas may require the collective assessment of soil suitability and limitation ratings for the application of agricultural wastes in the area under consideration. Soil features and their combined effect on the agricultural waste management system are important considerations when evaluating soil-agricultural waste suitability ratings for soils. A soil scientist should be consulted when assessing the effects of soil variability on design and function of an agricultural waste management system.

(a) Available water capacity

Available water capacity is a measure of the soil's capacity to hold water in a form available to plants. It is a function of soil porosity, texture, structure, organic matter content, and salinity. Available soil water is estimated as the difference between soil water content at 1/3 or 1/10 bar tension (field capacity) and 15 bar tension (permanent wilting point). The available water capacity is generally expressed as the sum of available water in inches to a specified soil depth. Generally, this depth is 5 feet or the depth to a root-restricting layer, whichever is less. Available water capacity infers the capacity of a soil to store or retain soil water, liquid agricultural wastes, or mineralized agricultural waste solids in the soil solution. Applying agricultural wastes increases soil organic matter content, helps to stabilize soil structure, and enhances available water capacity.

Limitations for agricultural waste applications are slight if the available water capacity is more than 6.0 inches per 5 foot of soil depth, moderate if it is 3.0 to 6.0 inches, and severe if it is less than 3.0 inches. Soils for which the limitations are moderate have reduced plant growth potential, limited microbial activity, and low potential for retaining liquid and mineralized agricultural waste solids. Lower waste application rates diminish the potential for ground water contamination and help to alleviate agricultural waste overloading.

Soils that have severe limitations because of the available water capacity have low plant growth potential, very low potential for retaining liquid or mineralized agricultural waste solids, low microbial activity, and high potential for agricultural waste contamination of surface and ground water. Reducing waste application rates, splitting applications, and applying waste only during the growing season diminish potential for ground and surface water contamination and help prevent agricultural waste overloading.

The volume of liquid agricultural waste application should not exceed the available water capacity of the root zone or the soil moisture deficit at the time of application. Low rates and frequent applications of liquid agricultural wastes on soil that has low available water capacity or during periods of high soil moisture deficit can reduce potential for ground water contamination.

(b) Bulk density

Bulk density, soil mass per unit volume, is expressed in grams per cubic centimeter. It affects infiltration, permeability, and available water capacity. Coarse textured soils have only a slight limitation because of bulk density. Medium to fine textured soils in which the bulk density in the surface layer and subsoil is less than 1.7 g/cm^3 have slight limitations for application of agricultural wastes. Medium to fine textured soils in which the bulk density in these layers is more than 1.7 g/cm^3 have moderate limitations.

Agricultural waste application equipment may compact the soil when the waste is applied to soil by spreading or injecting and soil moisture content is at or near field capacity. Agricultural wastes should be applied when soil moisture content is significantly less then field capacity to prevent compaction.

Agricultural wastes can be surface applied to medium to fine textured soils that have bulk density less than 1.7 g/cm^3. Liquid waste should be injected and application rates reduced when the bulk density of medium to fine textured soil is equal to or greater than 1.7 g/cm^3. Injection application and reduced application rates on these soils help to prevent liquid waste runoff and compensate for slow infiltration.

Incorporating wastes that have a high solids content with high levels of organic carbon reduces the soil surface bulk density and improves soil infiltration and surface permeability. The high bulk density associated with coarse textured soils does not impede or affect the application of agricultural wastes. The high permeability rate of coarse textured soils may affect the application rate because of the potential for ground water contamination. (See sections 651.0503(h) and 651.0503(i).)

(c) Cation-exchange capacity

Cation-exchange capacity (CEC) is an index of the soil's capacity to exchange cations with the soil solution. It affects the ability of the soil to adsorb and retain cations and heavy metals. Cations are held to the soil particles by adsorption and can be returned to the soil solution for plant use by the exchange process.

Soils that have high CEC and organic soils can exchange and retain large amounts of cations released by agricultural waste mineralization processes. Conversely, soils in which the CEC is low have low potential for exchanging and retaining these agricultural waste materials. The potential for agricultural waste contamination of underlying ground water and aquifers is highest for soils that have low CEC and lowest for those with high CEC.

The limitations for solid and liquid waste applications are slight for soils that have a cation-exchange capacity of more than 15, moderate for those with a capacity of 5 to 15, and severe for those for which it is less than 5. Underlying ground water supplies and aquifers can become contaminated when agricultural wastes are applied at high rates to soils that have moderate or severe limitations because of their CEC. Reducing agricultural waste application rates can reduce the hazard for ground water contamination.

(d) Depth to bedrock or cemented pan

The depth to bedrock or a cemented pan is the depth from the soil surface to soft or hard consolidated rock or a continuous indurated or strongly cemented pan. A shallow depth to bedrock or cemented pan often does not allow for sufficient filtration or retention of agricultural wastes or agricultural waste mineralization by-products. Bedrock or a cemented pan at a shallow depth, less than 40 inches, limits plant growth and root penetration and reduces soil agricultural waste adsorptive capacity. Limitations for application of agricultural wastes are slight if bedrock or a cemented pan is at a depth of more than 40 inches, moderate if it is at a depth of 20 to 40 inches, and severe at a depth of less than 20 inches.

Agricultural wastes continually applied to soils that have moderate or severe limitations because of bedrock or a cemented pan can overload the soil retention capacity. This allows waste and mineralization by-products to accumulate at the bedrock or cemented pan soil interface. When this accumulation occurs over fractured bedrock or a fractured cemented pan, the potential for ground water and aquifer contamination is high. Reducing waste application rates on soils that have a moderate limitation diminishes ground water contamination and helps to alleviate the potential for agricultural waste overloading. If the limitations are severe, reducing waste application rates and split applications will lessen overloading and the potential for contamination.

(e) Depth to high water table

Depth to high water table is the highest average depth from the soil surface to the zone of saturation during the wettest period of the year. This saturated zone must be more than 6 inches thick and persist for more than a few weeks. A shallow depth to high water table may not allow for sufficient filtration or retention of agricultural wastes or agricultural waste mineralization by-products. A high water table at a depth of less than 4 feet can limit plant and root growth and reduce the soil's agricultural waste adsorptive capacity.

Limitations for application of agricultural wastes are slight if the water table is at a depth of more than 4 feet, moderate at a depth of 2 to 4 feet, and severe if it is at a depth of less than 2 feet. Depth and type of water table, time of year, and duration data should be collected if agricultural wastes are to be applied to soils suspected of having a water table within 4 feet of the soil surface.

Agricultural wastes applied to soils that have moderate limitations because of the water table can overload the soil's retention capacity and percolate through the soil profile contaminating the water table. Reducing waste application rates on these soils helps to alleviate agricultural waste overloading and lessens the potential for ground water contamination.

The potential for contamination of shallow ground water is very high if agricultural wastes are applied to soils that have severe limitations. Careful application and management of agricultural wastes applied to these soils are recommended. Management should include frequent applications at very low rates.

(f) Flooding

Flooding is the temporary covering of the soil surface by flowing water. Ponded and standing water or flowing water during and shortly after rain or snowmelt are not considered flooding. Flooding events transport surface-applied agricultural wastes off the application site or field and deposit these materials in streams, rivers, lakes, and other surface water bodies.

Soils that have none or rare flooding potential (5 times or less in 100 years) have slight limitations for the application of agricultural waste. Occasional flooding (5 to 50 times in 100 years) is a moderate limitation for the application of agricultural waste, and frequent flooding (50 to 100 times in 100 years) is a severe limitation.

Agricultural wastes should be applied during periods of the year when the probability of flooding is low. Liquid agricultural waste should be injected, and solid agricultural waste should be incorporated immediately after application. Incorporating agricultural wastes and applying wastes when the probability of flooding is low reduce the hazard to surface water.

(g) Fraction greater than 3 inches in diameter—Rock fragments, stones, and boulders

Rock fragments, stones, and boulders are the soil fractions greater than 3 inches and are measured as a weight percent or estimated as a volume percentage of the whole soil. The upper size limit is undefined, but for practical purposes is about 40 inches. Stoniness is a soil surface feature that is defined as the percent of stones and boulders (rock fragments greater than 10 inches in diameter) that cover the soil surface. It is represented as classes 1 through 6.

Limitations for agricultural waste application are slight if stoniness is class 1 (less than 0.1 percent of the surface covered with stones and boulders), moderate if it is class 2 (0.1 to 3.0 percent of the surface covered with stones and boulders), and severe if it is classes 3, 4, 5, or 6 (more than 3 percent of the soil surface is covered with stones and boulders).

Rock fragments, stones, and boulders can restrict application equipment operations and trafficability and affect the incorporation of agricultural wastes. Incorporating agricultural wastes that have high solids content may be difficult or impractical where:

- Rock fragments between 3 and 10 inches in diameter make up more than 15 percent, by weight, (10 percent, by volume) of the soil
- Stones and boulders more than 10 inches in diameter make up more than 5 percent, by weight, (3 percent, by volume) of the soil
- The soil is in stoniness class 2 or higher

Because of this, agricultural wastes applied to these areas may be transported offsite by runoff and have the potential to contaminate the adjacent surface water. Local evaluation of the site is required to determine if the size, shape, or distribution of the rock fragments, stones, and/or boulders will impede application or incorporation of agricultural wastes.

(h) Intake rate

The intake rate is the rate at which water enters the soil surface. Initial water intake is influenced by soil porosity, bulk density, moisture content, texture, structure, and permeability of the surface layer. Continued water intake rate is controlled by the permeability of underlying layers. Water intake potential is inferred from hydrologic soil groups and inversely related to the hydrologic group runoff potential. If agricultural wastes that have large quantities of suspended solids are applied at high rates on soils that have high or moderate intake potential, soil macropore space can clog and the soil intake rate is reduced. Conversely, application and incorporation of agricultural wastes to soils that have slow water intake potential can increase soil structure and porosity, thus improving the potential water intake rate. The short-term effect may be pore clogging and resulting runoff if application rates are high on soils that have a slow intake rate.

Soils in hydrologic groups B and C have moderate intake potential and slight limitations for application of agricultural wastes. Soils in hydrologic group D have a slow intake potential, high runoff potential, and generally have moderate limitations for the applications of agricultural wastes. Incorporating agricultural wastes applied to hydrologic group D soils helps to prevent the removal and transport of wastes by runoff and water erosion and can reduce the potential for surface water contamination. Liquid waste application rates should not exceed irrigation intake rates for soils in hydrologic groups B, C, or D. Application rates that exceed the irrigation intake rate may result in runoff of agricultural wastes, which have the potential to contaminate adjacent surface water.

Soils in hydrologic group A generally have moderate limitations for the application of agricultural wastes that have high solids content, and severe limitations for liquid wastes. Rapid intake of liquid and mineralized waste solids has the potential to contaminate underlying aquifers and ground water supplies. Aquifer contamination potential can be reduced by reducing application rates, using split applications, and applying the waste only during periods of the year when evapotranspiration exceeds precipitation.

Soils in dual hydrologic groups, such as A/D, B/D, or C/D, have severe limitations for the application of agricultural wastes. Rapid and moderate infiltration of liquid and mineralized waste solids have the potential to contaminate underlying high water table and ground water supplies. Water table depth, type, time of year, and duration data should be collected if agricultural wastes are to be applied to soils in dual hydrologic groups. Aquifer and water table contamination can be lessened by reducing application rates, using split applications, and applying only during periods of the year when evapotranspiration exceeds precipitation.

(i) Permeability rate

Permeability (hydraulic conductivity) is the quality of soil that enables water to move downward through the soil profile. It generally is inferred from the permeability of the most slowly permeable horizons in the profile. Permeability is estimated from soil physical properties and is expressed in inches per hour. Permeability rates affect runoff, leaching, and decomposition rates of agricultural wastes that are applied to or incorporated in the surface layer. Application and incorporation of agricultural wastes improve soil surface intake and permeability; however, frequent applications at high rates can clog soil pores and reduce soil surface permeability and intake.

Agricultural wastes can be applied to soils that have only slight limitations because of permeability. Agricultural wastes applied to soils that have permeability of less than 0.2 inch per hour should be incorporated (solids) or injected (liquids) into the soil to reduce potential surface water contamination from erosion and runoff. Split rate applications of liquid wastes applied to soils that have permeability of more than 2 inches per hour reduce the potential for contamination of shallow aquifers. Reducing the rate of application and using split applications of waste solids on soils that have severe limitations for this use can reduce the potential for contamination of shallow aquifers. Table 5–2 shows the limitation ratings for solid and liquid wastes.

(j) Soil pH

Soil pH affects plant nutrient availability, agricultural waste decomposition rates, and adsorption of heavy metals. Soils in which the surface pH is less than 6.5 have lower potential for plant growth and low heavy metal adsorption.

Limitations and recommendations are based on the lowest pH value of the surface layer. Limitations for the application of agricultural wastes are slight if the pH in the surface layer is more than 6.5, moderate if it is 3.5 to 6.5, and severe if it is less than 3.5. Continuous, high application rates of agricultural wastes reduce soil pH. If large amounts of agricultural wastes are applied to small fields or land tracts, the soil pH should be monitored to prevent its reduction to levels that affect soil ratings and limitations for plant growth.

(k) Ponding

Ponding is standing water in a closed depression that is removed only by percolation, transpiration, or evaporation. Agricultural wastes applied to soils that are ponded have a very high potential for contaminating the ponded surface water. Application on these soils should be avoided if possible.

(l) Salinity

Salinity is the concentration of dissolved salts in the soil solution and is related to electric conductivity. Electrical conductivity is the standard measure of soil salinity and is recorded as Mmhos/cm. High soil salinity interferes with the ability of the plant to absorb water from the soil and to exchange plant nutrients. This interference reduces plant growth and seed germination and limits the choice of crops that can be successfully grown. If soil salinity is a potential hazard or limitation, crops that have a high tolerance to salinity should be used in the agricultural waste management system. For further information on the use of these crops, see chapters 6 and 11.

Table 5–2 Agricultural waste–soil permeability rate limitations

Waste	- - - - - - Limitations - - - - - -		
	Slight	Moderate	Severe
	- - - - - - - - in/hr - - - - - - - -		
Solids	< 2.0	2.0 – 6.0	> 6.0
Liquid	0.2 – 2.0	0.06 – 0.2 or 2.0 – 6.0	< 0.06 or > 6.0

Salinity ratings are for the electric conductivity of the soil surface. Limitations for the application of agricultural wastes are very slight if salinity is measured as less than 4 mmhos/cm, slight if it is 4 to 8 mmhos/cm, moderate if 8 to 16 mmhos/cm, and severe if more than 16 mmhos/cm.

Soils that have moderate limitations affect the choice of crops that can be grown and cause reduced germination. Agricultural wastes that have a high content of salt can be applied to moderately rated soils, but applications should be rotated among fields and rates should be reduced to prevent an increase in soil salinity and further degradation of plant growth.

Applying agricultural wastes that are high in salt to soils that have a severe rating should be avoided to prevent increasing soil salinity and further inhibiting plant growth and organic matter decomposition. However, limited amounts of agricultural wastes can be applied if applications are rotated among fields and soil salinity is monitored.

Agricultural wastes that have low salt content and a high C:N ratio can be applied and will have a beneficial impact on soils that have a moderate or severe salinity rating. Application of low salt, high C:N ratio agricultural wastes to these soils improves intake, permeability, available water capacity, and structure. It also reduces salt toxicity to plants.

(m) Slope

Slope is the inclination of the soil surface from the horizontal expressed as a percentage. The slope influences runoff velocity, erosion, and the ease with which machinery can be used. Steep slopes limit application methods and rates and machinery choices. Runoff velocity, soil carrying capacity of runoff, and potential water erosion increase as slopes become steeper.

Limitations for the application of agricultural wastes are slight if the slope is less than 8 percent, moderate if it is 8 to 15 percent, and severe if it is more than 15 percent. Agricultural wastes applied to soils that have moderate limitations should be incorporated. This minimizes erosion and transport of waste materials by runoff, thus reducing the potential for surface water contamination.

Soils that have severe slope limitations have limited cropping potential and are subject to excessive runoff and erosion. Agricultural wastes should be incorporated into these soils as soon as possible to reduce the potential for surface water contamination. Conservation practices that reduce potential water erosion and runoff help prevent the erosion and transport of agricultural wastes and should be incorporated in the agricultural waste management system.

(n) Sodium adsorption

Sodium adsorption is represented by the Sodium Adsorption Ratio (SAR), which is the measured amount of sodium relative to calcium and magnesium in a water extract from a saturated soil paste. A high and moderate SAR, more than 4, interferes with the ability of the plant to absorb water from the soil and to exchange plant nutrients. This interference reduces plant growth and seed germination and limits the choice of crops that can be successfully grown. An SAR of more than 13 has a detrimental effect on soil intake, permeability, and structure.

Limitations for the application of agricultural wastes are slight if SAR less than 4, moderate if it is 4 to 13, and severe if it is greater than 13. Soils that have moderate limitations affect the choice of crops that can be grown and reduce germination. To prevent increasing soil SAR and further degradation of soil properties, agricultural wastes that are high in sodium should not be applied to soils that have a moderate or severe rating. Agricultural wastes that have low sodium content and a high C:N ratio can be applied and will have a beneficial impact on soils that have a moderate or severe SAR rating. Application of agricultural wastes that have low salt conent and a high C:N ratio to these soils improves soil intake, permeability, and structure. It also reduces the plant toxicity effect of soil sodium.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Droughty	(inches)			
(Available water capacity)	> 6.0	Slight	Apply waste.	Improves available water capacity.
	3.0– 6.0	Moderate	(Low available water capacity and low retention). Reduce application rates.	Improves available water capacity. Contaminants can flow into ground water.
	< 3.0	Severe	(Very low available water capacity and very low retention). Reduce application rates and use split applications.	Improves available water capacity. Contaminants can flow into ground water and enter surface water.
Dense layer				
(Bulk density)	(grams/cc)			
Soil texture:				
Medium & fine	<1.7	Slight	Apply when soil moisture content is such that the field is in tillable condition.	Reduces bulk density and minimizes compaction.
Coarse	All			
Medium & fine	≥1.7	Moderate	(Compaction and runoff.) Apply when soil moisture content is such that the field is in tillable condition. Incorporate high solids content waste. Reduce application rate and inject liquid waste.	Reduces bulk density and minimizes compaction.
Low adsorption				
(Cation-exchange capacity)	(meq/100g of soil)			
	> 15	Slight	Apply waste.	Increases cation-exchange capacity and organic matter content.
	5–15	Moderate	(Low adsorption and exchange of cations, and heavy metals.) Reduce application rates.	Contaminants can flow into ground water.
	< 5	Severe	(Very low adsorption and exchange of cations; heavy metals.) Reduce application rates.	Contaminants can flow into ground water.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste—Continued

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Thin layer/ cemented pan (Depth to bedrock or cemented pan)	(inches) > 40	Slight	Apply waste.	None.
	20 – 40	Moderate	(Moderate soil depth and limited root zone.) Reduce application rates.	Contaminants can flow into ground water. Potential waste overloading of the soil if applied at high rates.
	< 20	Severe	(Shallow soil depth and root zone.) Reduce application rates and use split applications.	Contaminants can flow into ground water. Potential waste overloading of the soil if applied in a single application at high rates.
Wetness (Depth to high water table)	(feet) > 4	Slight	Apply waste.	None.
	2 – 4	Moderate	(Moderate soil depth and limited root zone.) Reduce application rates.	Contaminants can flow into ground water.
	< 2	Severe	(Shallow soil depth and root zone.) Application of agricultural wastes not recommended.	Contaminants can flow into ground water.
Flooding (Flooding frequency)	None, rare (5 times or less in 100 years.)	Slight	Apply waste.	None.
	Occasional (5 to 50 times in 100 years.)	Moderate	(Flooding and transport of waste offsite.) Apply and incorporate waste during periods when flooding is unlikely.	Contaminants can enter surface water.
	Frequent (50 to 100 times in 100 years.)	Severe	(Flooding and transport of waste offsite.) Apply and incorporate waste during periods when flooding is unlikely.	Contaminants will most likely enter surface water.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste—Continued

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Too stoney or too cobbly (Fraction, > 3 inches in diameter; Rock fragments, 3 – 10 inches in diameter; Stones and boulders, >10 inches in diameter):				
	% by weight (volume)			
(Rock fragments) (Stones & boulders)	< 15 (< 10) < 5 (< 3)	Slight	Apply waste.	None.
(Rock fragments) (Stones & boulders)	15–35 (10–25) 5–15 (3–10)	Moderate	(Restricted equipment opera tion.) Apply waste at reduced rates.	Contaminants can enter surface water.
(Rock fragments) (Stones & boulders)	> 35 (> 25) > 15 (> 10)	Severe	(Restricted equipment trafficability and operation.) Apply waste at reduced rates.	Contaminants can enter surface water.
(Stoniness)	Stoniness class			
	1	Slight	Apply waste.	None.
	2	Moderate	(Restricted equipment oper- ation.) Apply waste at reduced rates.	Contaminants can enter surface water.
	3, 4, 5	Severe	(Restricted equipment traffic- ability and operation.) Apply waste at reduced rates.	Contaminants can enter surface water.
Intake (hydrologic soil group)				
Liquid & solid wastes	B and C	Slight	Apply solid waste. Do not exceed irrigation intake rates of liquid waste.	High application rates may cause clogged surface pores and reduced infiltra tion.
Solid wastes	A	Moderate	(Leaching of mineralized waste.) Reduce rate of application.	Application may clog surface pores and reduce infiltration.
Liquid wastes		Severe	(Rapid infiltration and leaching vulnerability.) Split applications and reduce application rates.	Contaminants can flow into ground water.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste—Continued

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Intake (cont)				
Liquid & high solids waste	D	Moderate	(Slow infiltration and potential runoff.) Inject or incorporate agricultural wastes.	Improves infiltration and surface soil permeability. Contaminants can enter surface water.
Liquid & high solids waste	A/D, B/D, C/D	Severe	(Water table near the soil surface.) Reduce application rates.	Contaminants can flow into ground water.
Poor filter or percs slowly				
(Permeability)	(inches/hour)			
High solids waste	< 2.0	Slight	Apply waste.	Improves soil surface infiltration and permeability.
Liquid waste	0.6 – 2.0	Slight	Apply waste.	Improves soil surface infiltration and permeability.
Liquid waste	0.2 – 0.6	Moderate	(Slow permeability and potential runoff vulnerability.)	Contaminants can enter surface water.
Liquid & high solids waste	2.0 – 6.0	Moderate	(Leaching vulnerability.) Inject liquid waste and incorporate high solids content waste.	Contaminants can flow into ground water.
Liquid waste	< 0.2	Severe	(Slow to very slow permeability and potential runoff contamination of surface water.) Inject liquid waste and incorporate high solids content waste.	Contaminants can enter surface water.
Liquid & high solids waste	> 6.0	Severe	(Rapid permeability and leaching vulnerability.) Split applications of liquid waste and reduce application rates of liquid and high solids content waste.	Contaminants can flow intoground water. Reduced permeability from organic matter accumulation in pores.
Too acid				
(pH)	> 6.0	Slight	Apply waste.	Very high application rates of wastes may lower soil pH.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste—Continued

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Too acid (cont.)				
	4.5 – 6.0	Moderate	(Increased availability of heavy metals and reduced plant growth potential.) Reduce application rates, apply lime, and incorporate.	Heavy metal contaminants can flow into ground water.
	< 4.5	Severe	(Increased availability of heavy metals, reduced plant growth, and limited crop selection.) Reduce application rates, apply lime, and incorporate.	Heavy metals contaminants can flow into ground water.
Ponding (Ponding)	All	Severe	(Ponded water.) Application of agricultural wastes not recommended.	Contaminants can enter surface water.
Excess salt (Salinity)	(mmhos/cm)			
	< 4	Slight	Apply waste.	None.
	4 – 8	Moderate	(Slight salinity—choice of crops and germination restricted.) Apply high C:N, low salt wastes. **Saline wastes:** Rotate application fields and reduce rates.	**High C:N & low salt wastes:** Improve soil infiltration, permeability, and structure; reduce plant toxicity. **Saline wastes:** May increase soil salinity if applied at continuous high rates.
	> 8	Severe	(Salinity, crops limited to salt-tolerant grasses.) Apply high C:N, low salt wastes. **Saline wastes:** Rotate application fields and reduce rates.	**High C:N & low salt wastes:** Improve soil infiltration, permeability, and structure; reduce plant toxicity. **Saline wastes:** May increase soil salinity if applied at continuous high rates.

Table 5–3 Soil characteristics and recommendations and limitations for land application of agricultural waste—Continued

Restricting feature (Soil characteristics)	Site condition	Degree of limitation	(Limitation or hazard) Recommendations	Impact
Slope				
(Slope)	(percent)			
	< 8	Slight	Apply waste.	None.
	8 – 15	Moderate	(Moderately steep slopes, potential water erosion.) Incorporate liquid and high solids waste and control runoff.	Contaminants can enter surface water.
	> 15	Severe	(Steep slopes, water erosion, and limited cropping potential) Incorporate liquid and high solids waste and control runoff.	Contaminants can enter surface water.
Excessive sodium				
(Sodium adsorption)	(SAR)			
	< 4	Slight	Apply waste.	None.
	4 – 13	Moderate	(Slight sodicity, choice of crops and germination restricted.) Apply high C:N, low sodium wastes. Rotate application fields and reduce rates for sodic wastes.	**High C:N & low sodium wastes:** Improve soil infiltration, permeability, and structure; reduce plant toxicity. **Sodic wastes:** May increase soil sodicity if applied at continuous high rates.
	> 13	Severe	(Sodicity, limited to sodium-tolerant grasses.) Apply high C:N, low sodium wastes. Rotate applications of sodium wastes. Rotate application fields and reduce rates for sodic wastes.	**High C:N & low sodium wastes:** Improve soil infiltration, permeability, and structure; reduce plant toxicity. **Sodic wastes:** May increase soil sodicity if applied at continuous high rates.

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Biswas, T.D., B.M. Ingole, and K.K. Jha. 1969. Changes in the physical properties of the soil by fertilizer and manure application. Fertilizer news, vol. 14, no. 7, pp. 23–26.

Lance, J.C. 1975. Fate of nitrogen in sewage effluent applied to soil. J. Irrigation and Drainage Div.

United States Department of Agriculture. 1974. Factors involved in land application of agricultural and municipal wastes. Agric. Res. Serv.

United States Department of Agriculture. 1951 (rev. March 1989). Soil survey manual. Soil Conserv. Serv., chapter 3.

United States Department of Agriculture. 1979. Animal waste utilization on cropland and pastureland. A manual for evaluating agronomic and environmental effects. Sci. and Educ. Adm. Util. Res. Rep. 6.

United States Department of Agriculture. 1982. Measuring hydraulic conductivity for use in soil survey. Soil Conserv. Serv., Soil Surv. Invest. Rep. 38, pp 9–11.

United States Department of Agriculture. 1983 (rev. draft, 1989). National soils handbook, part 603.03–6. Soil Conserv. Serv.

United States Department of Agriculture. 1987. Principles of ground water for resource management systems. Soil Conserv. Serv., Field level training manual, pp 98–99.

Witty, J.E., and K.W. Flach. 1977. Site selection as related to utilization and disposal of organic wastes. Amer. Soc. Agron., Soils for management of organic wastes and wastewaters, chapter 13.