USDA NRCS

United States Department of Agriculture
Natural Resources Conservation Service

Part 651
Agricultural Waste Management
Field Handbook

Chapter 5 Role of Soils in Manure Management

Issued August 2012

Acknowledgments

Chapter 5 was originally prepared and printed in 1992 under the direction of by **James N. Krider** (retired)**,** national environmental engineer; Soil Conservation Service (SCS), now Natural Resources Conservation Service (NRCS). **James D. Rickman** (retired), environmental engineer, NRCS, Fort Worth, Texas, provided day-to-day coordination in the development of the handbook. Authors and those who made major contributions to chapter 3 included **Michael F. Walter**, Cornell University, Ithaca, New York; **Victor W.E. Payne** (retired)**,** environmental engineer, NRCS, Auburn, Alabama; and **Timothy Powers** (retired)**,** environmental engineer, NRCS, Nashville, Tennessee.

This version was prepared under the direction of **Noller Herbert,** Director, Conservation Engineering Division, Washington, DC. Revisions to the chapter were provided by **William Boyd,** Leader of the National Manure Management Team, Greensboro, North Carolina, with review from the National Soil Health and Sustainability Team, Greensboro, North Carolina. It was finalized under the guidance of **Darren Hickman**, national environmental engineer, Conservation Engineering Division, Washington, DC.

Editorial and illustrative assistance was provided by **Lynn Owens**, editor; **Wendy Pierce**, illustrator; and **Suzi Self**, editorial assistant, National Geospatial Management Center, Fort Worth, Texas.

Chapter 5 Role of Soils in Manure Management

Contents

Tables

Figures

651.0500 Introduction

Most manures and other by-products of domestic animal production are applied to the land. Soil, properly managed, can serve as an effective buffer between potential pollutants in manure and air and water resources. The manure, properly applied, can also be used to improve soil health and recycle nutrients for plant growth. A well-planned agricultural waste management system (AWMS) that uses manure as a land-improving resource considers landscape features and the physical, chemical, and biological properties of soils. This chapter describes soil properties and characteristics that affect soil suitability and limitations for land application of manure.

Soil suitability for site-specific manure storage or treatment practices, such as a waste storage pond, waste treatment lagoon, or waste storage structure, are not described in this section. Soil variability within soil map delineations and mapping scale generally prevent using soil maps for evaluation of these site-specific AWMS 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, infiltration rates observed/inferred soil properties, and the soil limitations or hazards for the site-specific components. See chapter 7 of this handbook for site-specific considerations.

Soil data should be collected and evaluated early in the planning process. An AWMS should not be implemented without adequate and complete soil maps and soil interpretive information. The NRCS Web Soil Survey (WSS) (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm) is a good place to begin. The aerial photos available at the WSS can be used to estimate the size of fields in acres and to make a preliminary identification of surrounding features such as public roadways and surface water resources, and estimate distance to neighboring houses, schools, or businesses. The Soil Map feature superimposes a map of the soils on the aerial photo and provides a map legend. The map legend provides access to a detailed soil description for the soil map units in the area of interest. The Soil Data Explorer feature provides suitability and limitation ratings for various soil uses. Of particular interest for an AWMS is information under the Manure and Food Processing tab under Waste Management. This gives a rating description for this use with the reasons and numeric values of the ratings for each soil map unit.

Contact the local Natural Resources Conservation Service (NRCS) field office staff for additional information concerning these soil interpretations. They will be able to discuss actual experience with these soils, and, if necessary, they can make a field visit to verify that the mapping units shown by the WSS adequately represent the soil features in a particular field. For a Comprehensive Nutrient Management Plan (CNMP), an onsite investigation is essential to ensure the status of features on maps and photos.

Soil information and maps may be inadequate for planning AWMS components. If soil data or maps are inadequate or unavailable, onsite soil survey information must be obtained before completing an AWMS plan. This information includes a soil map of the area, a description of soil properties, soil variability, and soil interpretive data. It may be advisable to dig soil pits. Soil pits are especially important if the soils information is critical to the function of a component of the AWMS. Soil suitability and limitation information can also be obtained from published soil surveys, section II of the NRCS Field Office Technical Guide (FOTG), the NRCS field office automated conservation planning software/program, Soil Data Mart, tables and soil data sets, Soil Interpretation Records (SIR), and National Soil Handbook soil interpretation guides, part 603.

651.0501 Soil phases

Soil is a heterogeneous material made up of solids, liquids, and gases that come together in a matrix for living organisms. These three phases and the organisms associated with them influence the supply of nutrients to plant roots.

The **solid phase** consists of both minerals and organics. The minerals are classified by their size as gravel, sand, silt, and clay. The organics are the humus and the plant and animal residues that are decomposing at various rates into the more stable humus. The amount of plant available nutrients held by a soil depends upon its unique biological, chemical, and physical makeup. This makeup can be ascertained by the types of soil organisms present, soil's cation exchange capacity (CEC), pH, organic matter content, clay mineralogy, and water holding capacity. When farming practices impoverish the organic fraction of the solid phase, the soil's ability to hold and cycle plant nutrients is drastically reduced. However, the addition of organic materials, such as compost and manure, high biomass cover crops and mixtures in the rotation, and diverse crop rotations with high biomass plants, including perennials and other plants with extensive root systems, can work together to enhance the organic fraction.

The clay and organic fractions of soil are important for plant nutrients because of their high level of chemical activity. The clay/organic fraction of soil can hold ammonium nitrogen, potassium, sodium, calcium, magnesium, iron, manganese, zinc, and cobalt. These elements are called cations (positively charged ions) that are held on negatively charged clay and organic colloidal particles. Nitrate nitrogen, phosphorus, sulfur, boron, and molybdenum are anions (negatively charged ions) that are largely held by the organic fraction or mineral complexes. Compared to nitrogen, phosphorus has a strong attraction 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. Nitrate is an anion that is held very loosely to the soil exchange site, if at all, and moves readily with percolating soil water.

The **liquid phase** of the soil is called the soil solution and consists of water with small quantities of numerous minerals and nutrients in the solute form. The liquid phase is responsible for the transport of nutrients in the soil. Oxygen and carbon dioxide can also be dissolved in the soil solution and transported to and from the system. A large percentage of manure waste is water. Depending on the type, timing, and method of delivery of waste, agricultural waste water can be used to supply part of the plant's moisture as well as nutrient requirements.

The **gaseous phase** occupies the pore space that is not filled with water. 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. Plant roots typically require oxygen and give off carbon dioxide. For this reason, there is usually more carbon dioxide in the soil gas mixture than in the atmosphere. Oxygen from the atmosphere must continuously replenish the soil either through soil pores or, in some instances, through the plants themselves. Gas exchange affects denitrification, mineralization of organic material, and soil micro-organism's population and growth rate.

When thinking of soil as solids, liquids, and gasses, we must not lose sight of the critically important **biotic components**. Large animals affect the soil at its surface, some digging into the soil. The plant canopy, residue, and roots all affect soil characteristics and development. The soil is also host for fungi and millions of microbes that are important for the aggregation of soil particles, the formation of soil structure, and the support of plants. Manure can be a valuable food source for soil organisms. Agricultural soils are also heavily influenced by human management. The judicious use of manure to help develop and maintain a hospitable environment for living things is an important task of the manure manager.

651.0502 Soil-manure interaction

The many complex interactions between soil and manure are functions of the soil environment, microbial populations, chemical interactions, and physical properties of the soil and of the characteristics of the manure applied to the land. The following describes some of these relationships.

(a) Filtration

Filtration is the capture and subsequent degradation of manure solids in the soil matrix. Soil filtering systems are used to reduce biological oxygen demand (BOD), consume or remove such biostimulants as phosphates and nitrates, provide long-term storage of heavy metals, suppress pathogens, and degrade pesticides. Soils suitable for filtering systems must have permeability rates slow enough to allow adequate retention time for water purification but allow 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.

A poorly designed or poorly managed filtration system can overload the soil ecosystem with high amounts of suspended solids from the wastewater and will clog soil pores and reduce soil hydraulic conductivity. Computing adequate soil porosity and managing timely wastewater applications are essential to maintaining soil filtration. Climate, total suspended solids (TSS) in the wastewater, soil types, landscape features, type of irrigation systems, manure transport systems tillage systems, and cropping systems must be considered to maintain soil porosity and hydraulic conductivity.

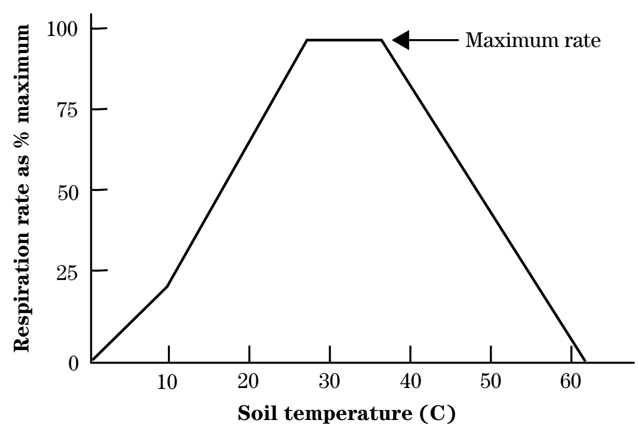
The wastewater application rate should not exceed the ability of the soil to assimilate the waste into the soil ecosystem. This assimilative capacity of the soil is dependent on the rates at which various types of waste and organic amendments can decompose in the soil environment. This decomposition rate is dependent on soil temperature, soil-moisture content, and the diversity and health of the soil ecosystem. Periods of wetting and drying not only increase microbial decomposition and by-product uptake by the crop, but also decrease potential clogging of soil pores. In areas where the temperature is warm for long periods, the increased microbial activity and longer crop uptake periods can allow for the application rates to be increased.

Crop management systems that maintain a living crop on the land where manure is applied through the use of cover crops and diverse crop rotations improve and sustain soil health, which in turn helps maintain soil permeability, infiltration, and aeration, all of which enhance filtration and the associated biological decomposition processes. Reducing tillage can limit degradation of soil tilth and reduce the tendency for soil compaction and crusting.

(b) Biological degradation

The decomposition rate of organic material in the soil is primarily controlled by the chemical and biological composition of the soil and of the organic material itself. Soil factors include temperature (figs. 5–1 and 5–2), moisture, oxygen supply, pH, available nutrients

Figure 5–1 Relationship between microbial respiration rate and temperature



(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. These factors interact and determine the environment for microbial growth and metabolism. The physical and chemical nature of soil ecosystems and the management that influence that nature determine the specific types and numbers of the soil microorganisms available to decompose organic material.

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 organic amendments must take into account the chemical reactions that occur between the soil and the organic 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.

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.

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

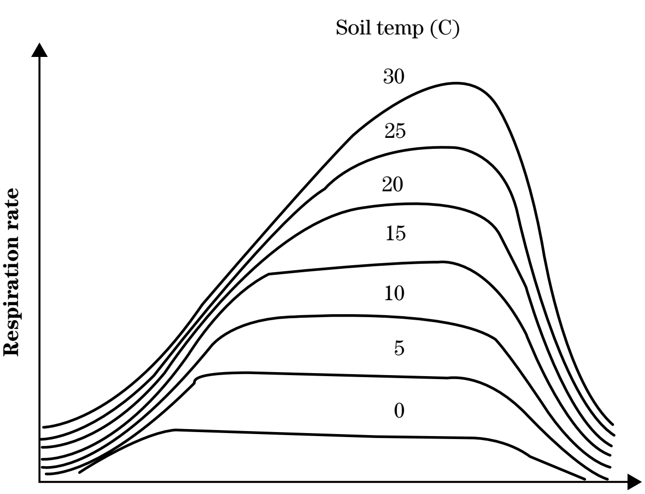


Table 5–1 Common exchangeable soil cations and anions

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}	

Plants obtain many of their nutrients from soil by an electrochemical process called cation exchange. This process is the key to understanding soil fertility. Cation exchange requires very small particles with a large surface area to hold electrically charged ions. Humus colloids are ideal; clay colloids also have a good CEC, but sand particles are too big. The finely divided platelets of the humus and clay colloids produce a large surface area—1 gram of the clay mineral bentonite has been estimated to have a surface area of 800 square meters. The surfaces are coated with a thin film of water, which contains dissolved nutrients. Each platelet has an extra electron, which gives it a negative charge. This negative charge attracts positively charged nutrient ions from the nutrient solution such as ammonium (NH_4+), calcium ($Ca++$), magnesium ($Mg++$) and potassium ($K+$). These nutrient ions can be absorbed by the plant root, by exchanging them for other ions such as hydrogen ($H+$). Many soil micro-organisms carry a negative charge, which enables them to attract nutrients and to move freely about the humus and clay colloids.

CEC measures the quantity of potentially available cation nutrients that are in a stable, accessible form. It is measured in milliequivalents (me) per 100 grams of soil. Typical values are 6.3 me/100g for sand and 27.2 me/100g for clay/loam. The higher the CEC, the greater the potential fertility of the soil. This is why clay soils tend to be more fertile than sandy soils and why the fertility of sandy soils can be improved by the addition of clay and humus. The cation-exchange process can, however, only store and release positively charged nutrients; the availability of nutrients in anion form, such as phosphorus and sulfur, is not affected by CEC. Soil organisms play a key role in conserving and releasing these nutrients. Cation exchange is the adsorption and exchange of both nonmetal and metal cations to negatively charged sites on soil particles and soil organic materials. 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.

The by-products of mineralization 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.

651.0503 Soil-manure mineralization relationship

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 nutrients (N, P, K), macronutrients and micronutrients, salts, and heavy metals. The mineralization of agricultural waste material is governed by the biological, chemical, and physical properties of soil and organic waste, soil moisture, and soil temperature.

(a) Microbial activity

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 and 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 degrees Fahrenheit (0 °C) to more than 72 degrees Fahrenheit (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 degrees Fahrenheit (5 °C) or more below the mean summer soil temperature. Microbial activity and organic waste mineralization in soil 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 soil moisture. 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 of this handbook, 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. The mineralization and pool of available nutrients is dependent on the C:N ratio of the manure, residual nutrients (particularly nitrates) in the soil, and other organic material present such as crop residues.

Ammonium nitrogen (NH_4^+) is the initial by-product of organic nitrogen mineralization. Ammonium is adsorbed to soil particles through cation exchange. It can be used by plants or micro-organisms. Ammonium nitrogen is further oxidized to nitrate (NO_3^-) by nitrifying bacteria. 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 groundwater. 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. The maintenance of vegetation with living roots in a field can help capture and cycle nitrates and other nutrients reducing their loss through leaching and runoff.

(c) Phosphate mineralization

Organic phosphorus in manure 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 moderate 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 surface 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.

(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. Particularly potassium, but also to a lesser extent calcium and magnesium, does typically leach from the surface layer, which usually has courser textures than the subsoil, but it is attracted by the clay in the subsoil and usually does not leach beyond the top few inches of the subsoil. Thus, leaching losses of potassium are not significant and have little potential to contaminate groundwater. Though calcium and magnesium can leach into groundwater or aquifers, 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 groundwater supplies and aquifers. This immobilization is strongest in soils that have high organic matter content, 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 groundwater or aquifer contamination. See chapter 6 of this handbook for the impact of heavy metals on plants.

Sandy soils with low organic matter content 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 groundwater. 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 imply that agricultural wastes cannot be used. It does, however, indicate 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 manure 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.

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.

Soil suitability ratings for nonsite-specific manure 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 manure management system are important considerations when evaluating agricultural waste suitability ratings for soils. A soil scientist should be consulted when assessing the effects of soil variability on design and function of a manure management system.

At the end of this section, table 5–3 provides a list of restricting soil characteristics with associated recommendations for the land application of agricultural waste.

(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 a third or a tenth bar tension (commonly called the field capacity) and 15 bar tension (commonly called the permanent wilting point). While 15 bar tension is commonly used as the permanent wilting point for calculating available soil moisture, the actual permeate wilting point of a plant is species specific. 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.

Limitations for agricultural waste applications are slight if the available water capacity is more than 6.0 inches per 5 feet 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 groundwater 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 groundwater. 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 groundwater contamination.

Available water holding capacity can be enhanced through the application of manure and other organic agricultural waste. Other practices, such as a winter cover crop, crop rotations, and reduced tillage, can be used in conjunction with manure applications to increase soil organic matter content, help stabilize soil structure, and enhance available water capacity. Although manure adds organic material to the soil, incorporating the manure can result in a release of soil carbon and destruction of soil structure that greatly reduces or reverses the benefits of the manure application.

(b) Bulk density

Bulk density, or soil mass per unit volume, is expressed in grams per cubic centimeter (g/cm^3). 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 grams per cubic centimeter 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 grams per cubic centimeter 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. Controlled traffic farming systems that include manure and wastewater spreading will minimize the areas and overall impacts of compaction associated with land application.

Agricultural wastes can be surface applied to medium- to fine-textured soils that have bulk density less than 1.7 grams per cubic centimeter. 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 per cubic centimeter. Injection application and reduced application rates on these soils help to prevent liquid waste runoff and compensate for slow infiltration. 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 groundwater contamination. (See sections 651.0503(h) and 651.0503(i).)

The soil disturbance that occurs when incorporating wastes may result in an increase in bulk density to the detriment of soil infiltration and surface permeability. An alternative to incorporation is to manage for increased crop residue on the surface, follow fall manure applications with cover crops, and allow soil organisms and weather cycles to move the manure into the soil. Other alternatives include rotations that include perennials and annuals with deep and extensive root systems that return high amounts of biomass to the soil and applying manure on cover crops and green manure crop with a diverse mix of vegetation. Allowing the soil to retain and improve its structure will result in improved infiltration and permeability over time.

(c) 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 of potassium, magnesium, and calcium (K, Mg, Ca) 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 and anions released by manure mineralization processes. Conversely, soils in which the CEC is low have low potential for exchanging and retaining these agricultural waste materials. Reduced tillage helps increase the CEC and the associated aggregate stability that is vital for nutrient adsorption and desorption. While the potential for nitrate contamination of underlying groundwater and aquifers is highest for soils that have low CEC and lowest for those with high CEC, this may not have to do directly with the CEC itself. The attraction of the ammonium ion to the negative charges on the soil colloid is quite weak compared to the attraction of the potassium, magnesium and calcium ions; thus, most of the sites are occupied by these other ions. The conversion of the ammonium ion to nitrate commonly occurs over a relatively short period of time, and the nitrates tend to slip through the system. When it comes to nitrates, a high CEC may be an indicator of the presence of high soil organic matter (SOM), and the resulting attenuation of nitrate may be because the greater soil microbial activity associated with the SOM are taking up the nitrogen in their functions, cycling it among themselves until it is taken up by the crop.

The limitations for solid and liquid waste applications are slight for soils that have a CEC 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 groundwater 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 groundwater contamination.

The application of organic material, management of crop residue, rotations, cover crops, reduced tillage, and applications of lime to raise the pH of the soil are practices that can raise the CEC. Some manures, like those from a laying operation or manure that has been treated with a buffering agent, can have a buffering effect on the soil, as well.

(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 manure 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 the soil-plant 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 groundwater and aquifer contamination is high. Reducing waste application rates on soils that have a moderate limitation diminishes groundwater 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 the components of agricultural wastes and 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 waste adsorptive capacity.

Limitations for application of manure 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 manure is 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 application rates on these soils helps to alleviate overloading and lessens the potential for groundwater contamination.

The potential for contamination of shallow groundwater is high if manure is applied to soils that have severe limitations. Careful application and management of manure applied to these soils are recommended. Frequent applications at low rates is a management alternative that may work on these soils.

(f) Flooding

As a soil use limitation, 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 in this context. 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 (greater than 50 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. Solid agricultural waste can be incorporated immediately after application. Incorporating agricultural wastes and applying wastes when the probability of flooding is low reduces the hazard to surface water. Liquids can be injected, and equipment is developing for the injection of solids. Maintaining vegetation on the surface is another practice that reduces the risk due to flooding.

(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 5.

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, or 5 (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 or 10 percent by volume of the soil.
- Stones and boulders more than 10 inches in diameter make up more than 5 percent by weight or 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 impedes 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 of manure to soils that have slow water intake potential can increase soil structure and porosity, thus improving the potential water intake rate; however, 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 manure. Soils in hydrologic group D have a slow intake potential, high runoff potential, and generally have moderate limitations for the applications of manure. Incorporating manure applied to hydrologic group D soils may initially help prevent the removal and transport of wastes by runoff and water erosion; but, the longer term effects of soil disturbance may offset this temporary gain. 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 manures 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 groundwater supplies. Aquifer contamination potential can be reduced by reducing application rates, using split applications, and applying the manure 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 solids has the potential to contaminate underlying high water table and groundwater supplies. Water table depth, type, time of year, and duration data should be collected if manure is 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 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 manures that are applied to or incorporated in the surface layer. Application and incorporation of manure can improve soil surface intake and permeability; however, frequent applications at high rates can clog soil pores and reduce soil surface permeability and intake.

Manure can be applied to soils that have only slight limitations because of permeability. Manure applied to soils that have permeability of less than 0.2 inch per hour should be injected, applied at reduced rates, and applied when potential runoff and erosion events are not eminent. 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, organic 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 manures 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. Low pH has a direct impact on soil microbial activity and the growth of many plants, resulting in less uptake of nutrients. Continuous, high application rates of manure reduce soil pH depending on soil and organic amendment types. If large amounts of manure 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 areas subject to ponding have a very high potential for con-

Table 5–2 Agricultural waste-soil permeability rate limitations

Waste	Limitations		
	Slight	**Moderate**	**Severe**
	in/h		
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

taminating the ponded surface water. Application on these soils should be avoided during times of the year when ponding is common, if possible. Manure applied to ponding prone areas other times of the year may be able to increase the percolation rate in some soils, especially if followed by deep-rooted cover crops or grasses in rotation.

(l) Salinity

Salinity is the concentration of dissolved salts in the soil solution and is related to electrical conductivity. Electrical conductivity is the standard measure of soil salinity and is recorded as millimhos per centimeter (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 of this handbook. Salinity ratings are for the electrical conductivity of the soil surface. Limitations for the application of agricultural wastes are very slight if salinity is measured as less than 4 millimhos per centimeter, slight if it is 4 to 8 millimhos per centimeter, moderate if 8 to 16 millimhos per centimeter, and severe if more than 16 millimhos per centimeter.

Soils that have moderate limitations affect the choice of crops that can be grown and cause reduced germination. Agricultural wastes that have high salt content 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.

Manures that have low salt content and a high C:N ratio can be applied and will have a beneficial effect on soils that have a moderate or severe salinity rating. Application of manure and bedding with low salt and high C:N ratios to these soils can improve intake, permeability, available water capacity, and soil structure. It can also reduce 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, application 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 manure 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 and severe limitations should be to reduce the potential for runoff and subsequent surface water contamination. Conservation practices that reduce potential water erosion and runoff help prevent the erosion and transport of agricultural wastes and should be applied on these slopes.

(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. A 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 is 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.

Manure and bedding that has low sodium content and a high C:N ratio can be applied and will have a beneficial effect on soils that have a moderate or severe SAR rating. Application of manure that has low salt content 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. All manure application should be to living diverse cover crops. High salt tolerant crops should utilized if necessary.

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 or apply to a living cover crop.	Improves available water capacity. Contaminants can flow into groundwater.
	< 3.0	Severe	(Very low available water capacity and very low capacity. Reduce application rates and use split applications or apply to a living cover crop.	Improves available water capacity. Contaminants can flow into groundwater and enter surface water.
Dense layer (bulk density)	(grams/cc)			
Soil texture: Medium and fine Coarse	 <1.7 All	Slight	Apply when soil moisture content is such that the field is in tillable condition.	Reduces bulk density and minimizes compaction.
Medium and fine	>1.7	Moderate	(Compaction and runoff.) Apply when soil moisture content is such that the field is in tillable condition. Reduce application rate and inject liquid waste.	Reduces bulk density and minimizes compaction.
Low adsorption				
(cation-exchange (meq/100g of soil) capacity))	> 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 groundwater.
	< 5	Severe	(Very low adsorption and exchange of cations; heavy metals.) Reduce application rates.	Contaminants can flow into groundwater.

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 groundwater. 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 groundwater. 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 groundwater.
	< 2	Severe	(Shallow soil depth and root zone.) Application of agricultural wastes not recommended.	Contaminants can flow into groundwater.
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 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 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; tock fragments, 3–10 inches in diameter; stones and boulders, >10 inches in diameter):	% by weight (volume)			
(rock fragments) (stones and boulders)	<15 (<10) <5 (<3)	Slight	Apply waste.	None
(rock fragments) (stones and boulders)	15–35 (10–25) 5–15 (3–10)	Moderate	(Restricted equipment operation.) Apply waste at reduced rates.	Contaminants can enter surface water.
(rock fragments) (stones and 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 operation.) Apply waste at reduced rates.	Contaminants can enter surface water.
	3, 4, 5	Severe	(Restricted equipment trafficability and operation.) Apply waste at reduced rates.	Contaminants can enter surface water.
Intake (hydrologic soil group) Liquid and 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 infiltration.
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 groundwater.
Liquid and solid waste	D	Moderate	(Slow infiltration and potential runoff.) Inject agricultural wastes.	Improves infiltration and surface soil permeability. Contaminants can flow into groundwater.
Liquid and high solid waste	A/D, B/D, C/D	Severe	(Water table near the soil surface.) Reduce application rates.	Contaminants can flow into groundwater.

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
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 and high solids waste	2.0–6.0	Moderate	(Leaching vulnerability.) Inject liquid waste.	Contaminants can flow into groundwater.
Liquid waste	<0.2	Severe	(Slow to very slow permeability and potential runoff contamination of surface water.) Inject liquid waste.	Contaminants can enter surface water.
Liquid and high solids waste	>6.0	Severe	(Rapid permeability and leaching vulnerability.) Inject liquid waste and reduce application rate.	Contaminants can flow into groundwater. 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.
	4.5–6.0	Moderate	(Increased availability of heavy metals and reduced plant growth potential.) Reduce application rates and apply lime..	Heavy metal contaminants can flow into groundwater.
	<4.5	Severe	(Increased availability of heavy metals, reduced plant growth, and limited crop selection.) Reduce application rates and, apply lime.	Heavy metal contaminants can flow into groundwater.
Ponding (ponding)	All	Severe	(Ponded water.) Application of agricultural wastes not recommended during times when ponding in likely.	Contaminants can 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
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 and 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 and low salt wastes:** Improve soil infiltration, permeability, and structure; reduce plant toxicity. **Saline wastes:** May increase soil salinity if applied at continuous high rates.
Slope (slope)	(percent)			
	<8	Slight	Apply waste.	None
	8–15	Moderate	(Moderately steep slopes, potential water erosion.)Install conservation practices that control and reduce runoff and erosion.	Contaminants can enter surface water.
	>15	Severe	(Steep slopes, water erosion, and limited cropping potential.) Install conservation practices that control and reduce runoff and erosion.	Contaminants can 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
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 and 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 and low sodium wastes:** Improve soil infiltration, permeability, and structure; reduce plant toxicity. **Sodic wastes:** May increase soil sodicity if applied at continuous high rates.

651.0505 References

Albrecht, W. 1975. The Albrecht Papers, Vol. I and II, In Acres. Raytown, MO.

Balfour, E. 1975. The living soil and the Haughley experiment. Faber and Faber, London, England. 382 pp.

Belanger, J. 1977. Soil fertility. In Countryside Press, Waterloo, WN. 160 pp.

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

Doram, D. 1991. Measuring crop quality with the refractometer. In Synergy, vol. 3, No. 2, pp. 32–34.

Gershuny G., and J. Smillie. 1986. The soul of soil, a guide to ecological soil management, Gaia Services. Erle, Que. 109 pp.

Kohnke, H., and D.P. Franzmeier. 1995. Soil science simplified (4th edition). Waveland Press, Inc. Grove, IL.

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

U.S. Department of Agriculture. 1974. Factors involved in land application of agricultural and municipal wastes. Agric. Res. Serv. Washington, DC.

U.S. Department of Agriculture. 1951 (rev. March 1989). Soil survey manual. Soil Conserv. Serv., chapter 3. Washington, DC.

U.S. 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. Washington, DC.

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

U.S. Department of Agriculture. 1983 (rev. draft, 1989). National soils handbook, part 603.03–6. Soil Conserv. Serv. Washington, DC.

U.S. Department of Agriculture. 1987. Principles of groundwater for resource management systems. Soil Conserv. Serv., Field level training manual, pp 98–99. Washington, DC.

Waksman, S. 1948. Humus. Wiley & Sons, New York, NY.

Waksman, S. 1952. Soil Microbiology, Wiley & Sons, New York, NY.

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.