BASIC SOIL PROPERTIES

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Introduction

This is the first module within the Soil and Water (SW) Management series provided by the Montana State University Extension Service and Rocky Mountain Certified Crop Adviser (CCA) program. Used in conjunction with the Nutrient Management (NM) modules, this series is designed to provide useful, applicable information for Extension agents, CCAs, consultants, and producers within Montana and Wyoming on practices used to effectively manage soil and water resources. To enhance the learning objective and provide CCAs with continuing education units (CEUs) in Soil and Water Management, a quiz accompanies this module. Also, realizing there are many other sources of information pertaining to soil erosion, we have included an appendix at the end of the module listing additional resources and contacts. This module covers the following Rocky Mountain CCA Soil and Water Management Competency Areas: basic soil properties, water and solute movement and plant/water relations.

Objectives

After reading this module, the reader should be able to:

- List basic soil properties and understand the relationships between properties
- Understand how soil texture affects water and plant relations
- Recognize how management practices influence soil structure, porosity and soil organisms
- Understand relationships between soil chemical properties to exchange capacity, pH and salt-affected soils
- Describe the relationship between soil organic matter and basic soil properties

Background

As the first module within the *Soil and Water Management (SW)* series, this module introduces basic physical, chemical and biological properties that affect agricultural soils. Processes such as fertility, water and solute movement and retention, and organic matter accumulation and decomposition are all affected by soil properties. Some of the properties presented in this module have already been discussed in *Nutrient Management (NM) Modules 1–15* (see Appendix), and many will be expanded upon in subsequent *SW* modules.

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Soil Physical Properties

Soil is comprised of minerals, soil organic matter (SOM), water, and air (Figure 1). The composition and proportion of these components greatly influence soil physical properties, including texture, structure, and porosity, the fraction of pore space in a soil. In turn, these properties affect air and water movement in the soil, and thus the soil's ability to function. Although SOM comprises a relatively small portion of soil, typically only 1–4% in Montana and Wyoming agricultural soils, it plays a key role in many soil processes (*NM 8*) and will be discussed throughout the module.

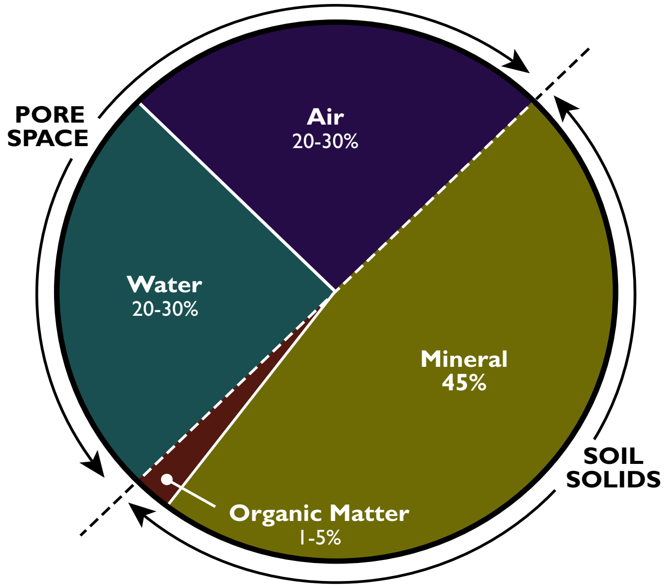


Figure 1. The four components of soil. Minerals and SOM make up the solid fraction, whereas air and water comprise the pore space fraction. A typical agricultural soil is usually around 50% solid particles and 50% pores. (Adapted from Brady and Weil, 2002)

Soil Development and Horizons

Soil development is caused by climate and living matter acting upon parent material (weathered mineral or organic matter from which the soil develops), as conditioned by topography, over time (Brady and Weil, 2002). The result of these processes is a soil profile of varying layers, or 'horizons,' each with distinct texture, structure, color and other properties. Most agricultural soils are grouped into four main 'master' horizons: O, A, B, and C (Figure 2). Various subcategories may occur within these horizons and are designated by a lower case letter following the master horizon capital letter (e.g., Ap or Bt). The O horizon is an organic layer above the mineral soil that consists of fresh or partially decomposed organic material and is most common in forested soils. The A horizon is the mineral soil surface layer and is the horizon most impacted by biological and human activity. It usually has the highest percentage of SOM, which often results in it being darker in color than the rest of the profile (*NM 8*). Below the A horizon will be either an E horizon, usually not present in grassland/agricultural soils, or a B horizon, the horizon of accumulation. Material from the A (or E) horizon, such as clay and carbonates, leach downward and accumulate in the B horizon. The C horizon represents the weathered parent material. Bedrock (designated by R) or a deep accumulation of materials deposited by wind, water, glaciers or gravity often lies below the C horizon. Not all soils will have every horizon or subhorizon present. For instance, a poorly developed soil may lack a strongly defined B horizon or highly eroded lands may have a thin, or nonexistent, A horizon.

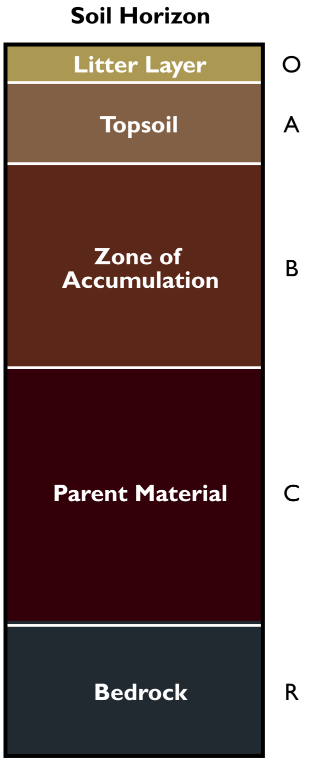


Figure 2. A general soil profile.

Soil Texture

Soil texture can have a profound effect on many other properties and is considered among the most important physical properties. Texture is the proportion of three mineral particles, *sand*, *silt* and *clay*, in a soil. These particles are distinguished by size, and make up the fine mineral fraction (Table 1). Particles over 2 mm in diameter

Table 1. Diameter and approximate size of four soil particles.

Soil Particle	Diameter (mm)	Approximate Size
Gravel	>2.0	●
Sand	0.05-2.0	•
Silt	0.002-0.05	·
Clay	<0.002	Invisible to naked eye

(the ‘coarse mineral fraction’) are not considered in texture, though in certain cases they may affect water retention and other properties. The relative amount of various particle sizes in a soil defines its texture, i.e., whether it is a clay, loam, sandy loam or other textural category (Figure 3).

Texture is the result of ‘weathering,’ the physical and chemical breakdown of rocks and minerals. Because of differences in composition and structure, materials will weather at different rates, affecting a soil’s texture. For example, shale, an easily weathered rock, forms clay-rich soils, whereas granite, a slow weathering rock, usually forms sandy, coarse soils. Since weathering is a relatively slow process, texture remains fairly constant and is not altered by management practices.

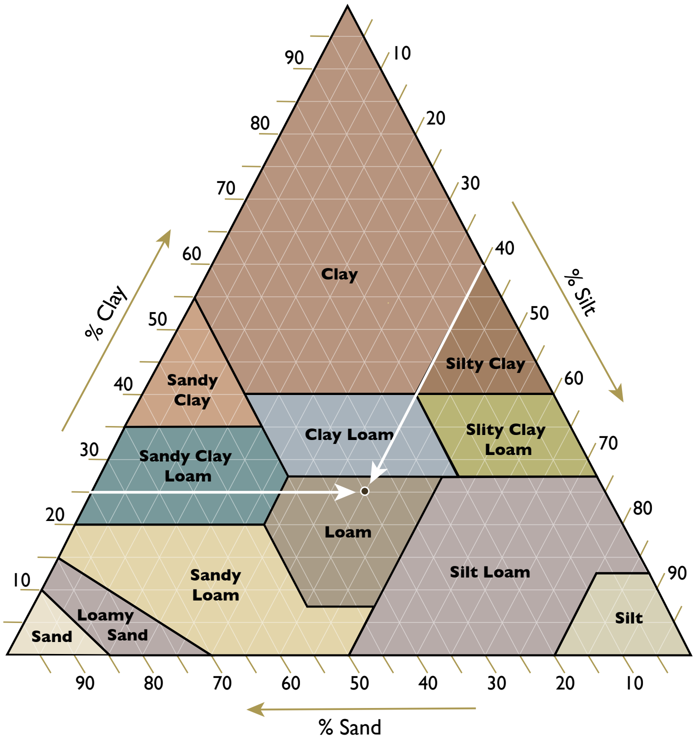


Figure 3. Textural triangle showing a soil’s textural class according to the percentage of sand, silt and clay it contains. Note that a solid with 25% clay and 40% silt is loam.

Soil Colloids

‘Soil colloids’ refer to the finest clay and SOM particles in a soil. Colloids are an important soil fraction due to properties that make them the location of most physical and chemical activity in the soil. One such property is their large surface area. Smaller particles have more surface area for a given volume or mass of particles than larger particles (Figure 4). Thus, there is increased contact with other colloids and with the soil solution. This results in the formation of strong friction and cohesive bonds between colloid particles and soil water, and is why a clay soil holds together better than a sandy soil when wet. Chemical colloidal properties will be discussed further in the module.

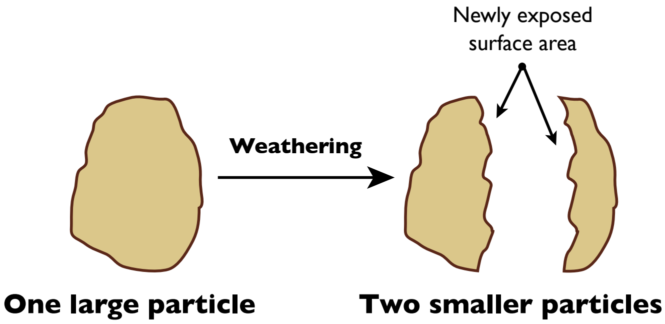
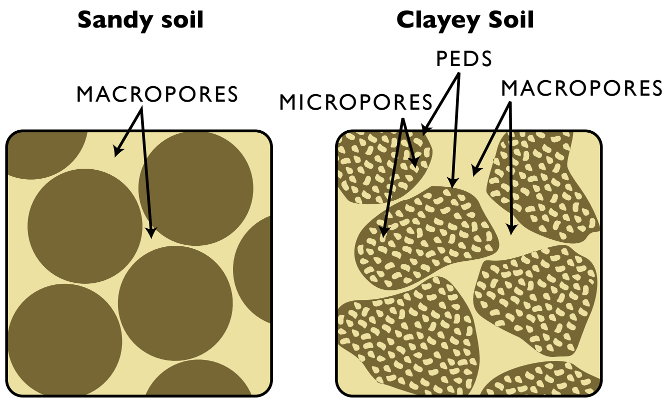


Figure 4. Illustration of surface area. The smaller particles have a greater total surface area than the one larger particle.

Soil Structure

Soil structure is the arrangement and binding together of soil particles into larger clusters, called aggregates or ‘peds.’ Aggregation is important for increasing stability against erosion, for maintaining porosity and soil water movement, and for improving fertility and carbon sequestration in the soil (Nichols et al., 2004). ‘Granular’ structure consists of loosely packed spheroidal peds that are glued together mostly by organic substances (Figure 5). Granular structure is characteristic of many A horizons, particularly those with high SOM content and biological activity. Larger peds, in the form of plates, blocks, or prisms, are commonly associated with the B horizon and are formed via shrink-swell processes and adhesive substances (Gardiner and Miller, 2004). As soil swells (wets or freezes) and then shrinks (dries or thaws), cracks form around soil masses, creating peds. Peds are held together and in place through the adhesion of organic substances, iron oxides, clays or carbonates. Cracks

Figure 5. Topsoil exhibiting granular structure.



Loosely structured sand particles

Aggregated clay particles

Figure 6. Generalized porosity in sandy and clayey soils.

and channels between peds are important for water, air, and solute transport and deep water drainage. Finer soils usually have a stronger, more defined structure than coarser soils due to shrink/swell processes predominating in clay-rich soils and more cohesive strength between particles.

Soil Porosity

Many important soil processes take place in soil pores (the air or water-filled spaces between particles). Soil texture and structure influence porosity by determining the size, number and interconnection of pores. Coarse-textured soils have many large (macro) pores because of the loose arrangement of larger particles with one another. Fine-textured soils are more tightly arranged and have more small (micro) pores (Figure 6). Macropores in fine-textured soils exist between aggregates. Because fine-textured soils have both macro- and micropores, they generally have a greater total porosity, or sum of all pores, than coarse-textured soils.

Unlike texture, porosity and structure are not constant and can be altered by management, water and chemical processes. Long-term cultivation tends to lower total porosity because of a decrease in SOM and large peds (Brady and Weil, 2002). Surface crusting and compaction decrease porosity and inhibit water entry into the soil, possibly increasing surface runoff and erosion (*SW 3* and *4*). Calcareous and salt-affected soils can also alter porosity and structure (discussed later). In general, increasing SOM levels, reducing the extent of soil disturbance, and minimizing compaction and erosion will increase soil porosity and improve structure.

Water and Plant Relations

Soil texture, and the properties it influences, such as porosity, directly affects water and air movement in the soil with subsequent effects on plant water use and growth. The proportion of pores filled with air or water varies, and changes as the soil wets and dries. When all pores are filled with water, the soil is 'saturated' and water within macropores will drain freely from the soil via gravity. 'Field capacity' (FC) is the amount of water remaining in the soil after all gravitational water has drained. Remaining water is held in micropores via attractive 'capillary' forces or surface tension between water and solids. Unlike gravitational water, capillary water is retained in the soil and can only be removed by plant uptake or evaporation. The amount of capillary water that is available to plants is the soil's 'water holding capacity' (WHC) or 'plant available water' (PAW). This water is available for plant uptake until the 'permanent wilting point' (PWP) is reached, a point at which water is held too tightly by the soil for plants to extract it. These concepts are illustrated in Figure 7 and will be expanded upon in *SW 5*.

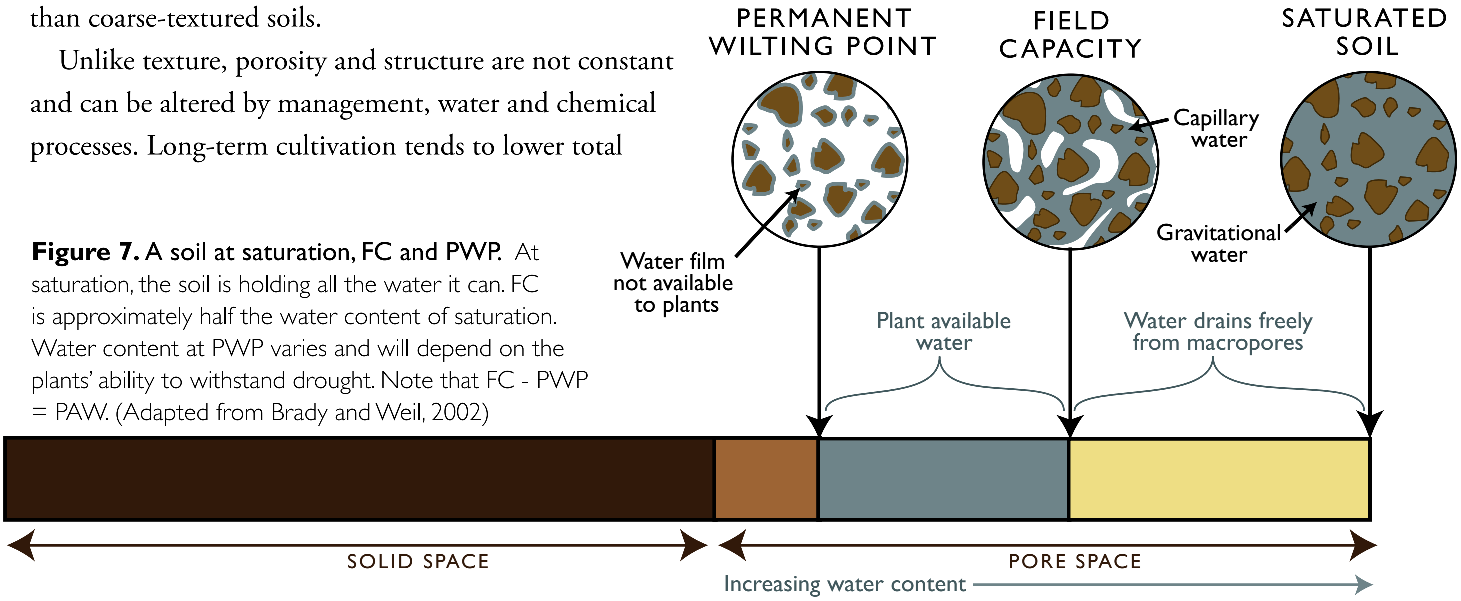


Figure 7. A soil at saturation, FC and PWP. At saturation, the soil is holding all the water it can. FC is approximately half the water content of saturation. Water content at PWP varies and will depend on the plants' ability to withstand drought. Note that FC - PWP = PAW. (Adapted from Brady and Weil, 2002)

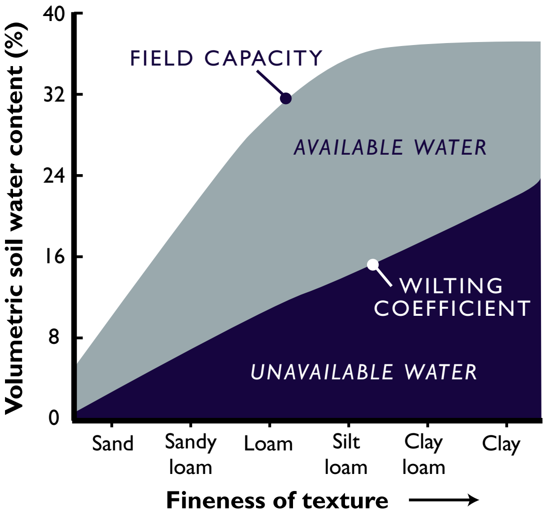


Figure 8. Relationship of soil texture with soil water content. (From Gurevitch et al., 2002)

A soil's ability to provide plants with adequate water is based primarily on its texture (Figure 8). If a soil contains many macropores, like a coarse sand, it loses a lot of water through gravitational drainage. Consequently, many pores are open for aeration, and little water remains for plant use before PWP is reached. This can cause drought stress to occur during dry periods. Conversely, a fine-textured soil, such as a clay loam, has mainly micropores which hold water tightly and don't release it under gravity. Though such soils generally have greater PAW than coarser soils, they are prone to poor aeration and anaerobic (without oxygen) conditions, which can negatively affect plant growth. Well-aggregated, loamy soils are best suited for supplying plants with water because they have enough macropores to provide drainage and aeration during wet periods, but also have adequate amounts of micropores to provide water to plants and organisms between precipitation or irrigation events.

Similar to clay, SOM is able to hold and retain large quantities of water. SOM aggregates have been shown to increase WHC, infiltration, and porosity, and reduce compactibility (Carter, 2002). Increasing residue returns and adding organic amendments may be an economically feasible method for improving a soil's WHC, among other benefits.

Chemical Properties

Exchange Capacity

Most chemical interactions in the soil occur on colloid surfaces because of their charged surfaces. Due to their chemical make-up and large surface area, colloids have charged surfaces that are able to sorb, or attract, 'ions' (charged particles) within the soil solution. Depending on the ion's charge, size and concentration in the soil, it can be sorbed and held to the colloid surface or exchanged with other ions and released to the soil solution. The soil's ability to sorb and exchange ions is its 'exchange capacity' (Figure 9; covered in *NM 2*). Although both positive and negative charges are present on colloid surfaces, soils of this region are dominated by negative charges and have an overall (net) negative charge. Therefore, more cations (positive ions) are attracted to exchange sites than anions (negative ions), and soils tend to have greater cation exchange capacities (CEC) than anion exchange capacities (AEC). Fine-textured soils usually have a greater exchange capacity than coarse soils because of a higher proportion of colloids (*NM 2*, Table 4).

Soil pH

Soil pH refers to a soil's acidity or alkalinity and is the measure of hydrogen ions (H^+) in the soil (addressed in *NM 8*). A high amount of H^+ corresponds to a low pH value and vice versa. The pH scale ranges from approximately 0 to 14 with 7 being neutral, below 7 acidic, and above 7 alkaline (basic). Soil pH can affect CEC and AEC by altering the surface charge of colloids. A higher concentration of H^+ (lower pH) will neutralize the negative charge on colloids,

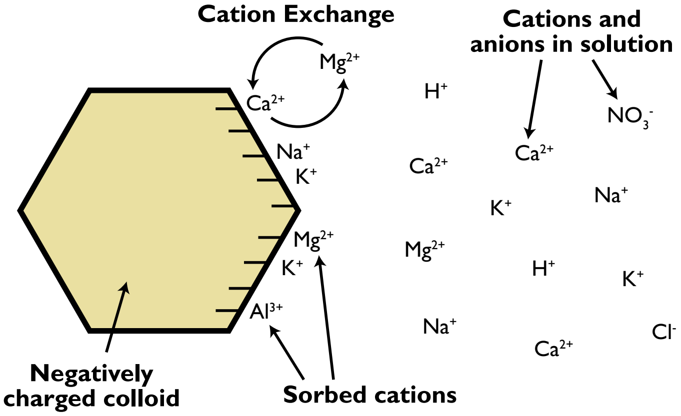


Figure 9. Simplified representation of exchange capacity. Because the colloid is primarily negatively charged, cations dominate the exchange sites. (Adapted from Brady and Weil, 2002)

Q & A #1

I've heard the terms "alkali" soils and "alkalinization." Are these referring to high pH (alkaline) soils?

No, not entirely. Alkali and alkalinization are somewhat obsolete terms today, but were used in the past to describe sodic (sodium) and saline (salt) soils, respectively. While many saline and sodic soils have a high pH (alkaline), these terms do not directly indicate this.

thereby decreasing CEC and increasing AEC. The opposite occurs when pH increases (*NM 2*, Figure 6). Discussion and management of acid and alkaline soils is presented in *NM 8*.

Salt-Affected Soils

The presence and concentration of salts in soil can have adverse effects on soil function and management. Salt-affected soils are most common in arid and semiarid regions where evaporation exceeds precipitation and dissolved salts are left behind to accumulate, or in areas where vegetation or irrigation changes have caused salts to leach and accumulate in low-lying places (saline seeps). The three main types of salt-affected soils are saline, sodic and saline-sodic (Q&A #1). Saline soils contain a high amount of soluble salts, primarily calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+), whereas sodic soils are dominated by sodium (Na^+). Saline-sodic soils have both high salt and Na^+ content. Salts in soil can affect structure, porosity and plant/water relations that can ultimately lead to decreased productivity. Salt-affected soils and their management are detailed in *SW 2*.

Calcareous Soils

Many soils in the northern Great Plains are dominated by calcium and magnesium carbonates and are referred to as 'calcareous' soils. The most common carbonate found in calcareous soils of Montana and Wyoming is lime ($CaCO_3$). Calcareous soils often form from the weathering of carbonate-rich parent material, such as limestone or lime-enriched glacial till, and generally occur in areas where precipitation is too low to leach the minerals from the soil. Carbonates can be found throughout a soil profile or concentrated in the lower horizons due to downward leaching. The subhorizon letter 'k' denotes a calcareous horizon layer (e.g., Bk). Calcareous soils can be distinguished in the field by an effervescence (fizz) reaction that occurs when a drop of dilute acid (10% hydrochloric acid or strong vinegar) is applied (Brady and Weil, 2002).

The presence of carbonates in soil can affect soil productivity by influencing soil pH, structure, WHC and water flow. Calcareous soils have a high 'buffering capacity,' or resistance to changes in pH. This is due to free carbonates being able to effectively neutralize acids in the soil. Thus, the pH of calcareous soils changes very little and is maintained near 8. Because calcareous soils are so well-buffered, reducing the pH with acidifying amendments (*NM 10*) is often difficult and costly.

Carbonates can alter soil structure by affecting texture and promoting aggregation. Carbonate deposits can be of varying size, ranging from very fine clay-like powder to coarser, silt-like deposits, which can impact texture. If carbonates are not removed prior to analysis, soils may be incorrectly classified. For instance, a soil analyzed for texture without the removal of $CaCO_3$ may classify as a clay loam, however after removing carbonates it may classify as a sandy loam. Thus, it is important to consider the presence of carbonates when analyzing the texture of calcareous soils, both in the field and laboratory. Additionally, Ca^{2+} and Mg^{2+} in soil causes soil particles to 'flocculate,' or clump together, thus increasing the formation of stable aggregates (*SW 2*).

The influence of carbonates on soil structure can cause calcareous soils to have different water relation properties than non-calcareous soils. WHC can be affected by the size and concentration of carbonates. Very fine carbonate particles can coat clay and silt particles and reduce their surface tension with water, and when a large percentage of $CaCO_3$ is present in the clay fraction (30% or higher), the soil's WHC can be reduced (Massoud, 1972). Diffusivity, a measure of how well water moves through soil, may also be affected by carbonates. Comparing calcareous with non-calcareous soils having a similar particle size distribution, it has been observed that the calcareous soils have a higher diffusivity, likely due to greater aggregation (Massoud, 1972). However, effects will differ depending on the total content and size distribution of $CaCO_3$. For instance, the presence of the carbonate in the clay fraction tends to decrease diffusivity.

$CaCO_3$ tends to have a cementing effect, and in some soils, surface crusts or sub-surface hardpans, layers of deposits held by $CaCO_3$, can form. These calcareous features can cause water infiltration and aeration to be restricted, and may inhibit seedling emergence and establishment. Crust conditions may be ameliorated with tillage and increased SOM content. Additionally, high concentrations of carbonates can be toxic to plants and soil organisms.

Another molecule common to semi-arid soils is gypsum ($CaSO_4 \bullet 2H_2O$). Gypsum accumulates in soil in a process similar to carbonate accumulation. However, since $CaSO_4 \bullet 2H_2O$ is more soluble than $CaCO_3$ and sulfate (SO_4^{2-}) is not as abundant as carbonate, gypsum deposits are less common and generally found in drier climates where very little leaching occurs (Lindsay, 1979). Soils dominated by gypsum are buffered, but not to the extent of carbonate-dominated soils, and typically have a pH between 7 and 8.

Biological Properties

Soil Biota

The soil environment is teeming with biological life and is one of the most abundant and diverse ecosystems on earth. Soil biota, including flora (plants), fauna (animals) and microorganisms, perform functions that contribute to the soil's development, structure and productivity. General characteristics and functions of these groups are presented below.

Soil Flora

Plants act on the soil environment by aiding in structure and porosity, and in supplying SOM via shoot and root residue. Root channels can remain open for some time after the root decomposes, allowing an avenue for water and air movement. Roots also act to stabilize soil through aggregation and intact root systems can decrease soil loss. The 'rhizosphere,' the narrow zone of soil directly surrounding plant roots, is the most biologically active region of the soil. It contains sloughed root cells and secreted chemicals (i.e., sugars, organic acids) that provide organisms with food.

Soil Fauna

Soil fauna work as soil engineers, initiating the breakdown of dead plant and animal material, ingesting and processing large amounts of soil, burrowing 'biopores' for water and air movement, mixing soil layers, and increasing aggregation. Important soil fauna include earthworms, insects, nematodes, arthropods and rodents. Earthworms are considered one of the most important soil fauna. Through the process of burrowing, they provide channels that increase a soil's porosity, WHC, and water infiltration (Lee, 1985; Figure 10). They also increase further biotic activity by breaking down large amounts of SOM through digestion and supplying nutrient-rich secretions in their casts (Savin et al., 1994). Furthermore, earthworms are able to build soil by moving between 1 to 100 tons of subsoil per acre per year to the surface, possibly helping offset losses by erosion (Magdoff and van Es, 2000).

Figure 10. Vertical earthworm burrow. Such burrows allow water and air to move deep into the soil, offering greater resource movement for deep-rooted plants and adequate water drainage. (Photograph from USDA-ARS, Coshocton, OH)

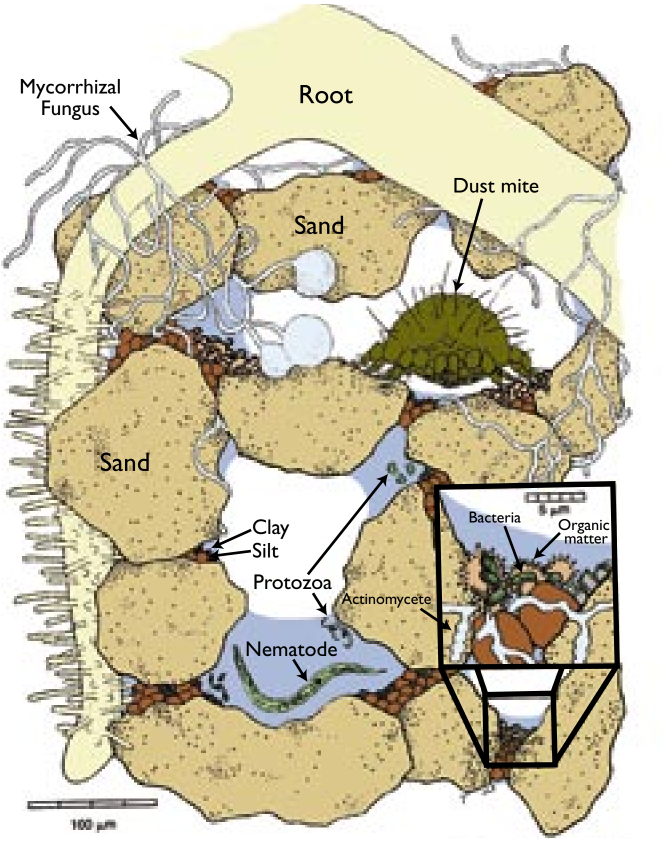


Figure 11. Soil organisms and their environment. (From Sylvia et. al., 1998)

Soil Microorganisms

Microorganisms (microbes) are invisible to the naked eye. However, their effect on numerous soil properties are far-ranging. Microorganisms represent the largest and most diverse biotic group in soil, with an estimated one million to one billion microorganisms per one gram of agricultural top soil (Tugel and Lewandowski, 1999). Microbes aid soil structure by physically surrounding particles and 'gluing' them together through the secretion of organic compounds, mainly sugars. This contributes to the formation of granular structure in the A horizon where microbial populations are greatest.

Soil microbes include bacteria, protozoa, algae, fungi and actinomycetes (Figure 11). Bacteria are the smallest and most diverse soil microbes. Bacteria are important in SOM decomposition, nutrient transformations and small clay aggregation. Some bacteria carry out very special roles in the soil, such as *Rhizobia*, the nitrogen-fixing bacteria associated with legume roots. Protozoa (e.g., amoebas, ciliates, flagellates) are mobile organisms that feed on other microbes and SOM. Algae, like plants, photosynthesize and are found near the soil surface. Fungi are a diverse group of microbes that are extremely important in the breakdown of SOM and large aggregate stability. Many fungi have long 'hyphae' or 'mycelia' (thin thread-like extensions) that can extend yards to miles underneath the soil surface and physically bind soil particles (Figure 12). Actinomycetes are a microbial group that are classified as bacteria, but have hyphae similar to fungi. They are important for SOM breakdown, particularly the more resistant fractions, and give soil much of its 'earthy' odor. Bacteria dominate in agricultural and grassland soils, whereas fungi are more prevalent in forest and acid soils (Tugel and Lewandowski, 1999).

An important relationship found in almost all soils and plants, including many crop species, are mycorrhizae. Mycorrhizae are a plant-fungal symbiosis (a relationship between two interacting species) in which fungi infect and live in, or on, a plant root. The fungus depends on the plant for energy, and in return, the fungus and its hyphae can take up nutrients for the plant, and possibly improve plant growing conditions. For instance, mycorrhizae associations have been shown to increase plant-water relations and reduce severity of some plant diseases (Smith and Read, 1997), as well as improve soil aggregate stability due to the binding actions of hyphae and glomalin, a mycorrhizal secreted chemical (Nichols et al., 2004). Ultimately, however, the full benefit of mycorrhizae to a plant will depend on the individual plant's needs and soil conditions. Commercial mycorrhizal inoculants are available. However, research regarding their effectiveness on yield are

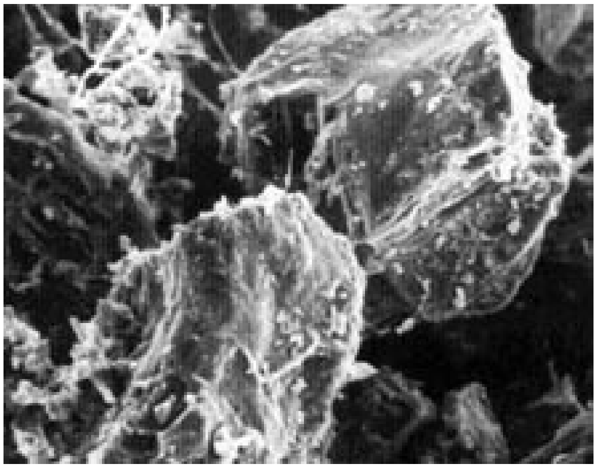


Figure 12. Fungal mycelia wrapped around and binding soil particles. (Photo from Brady and Weil, 2002)

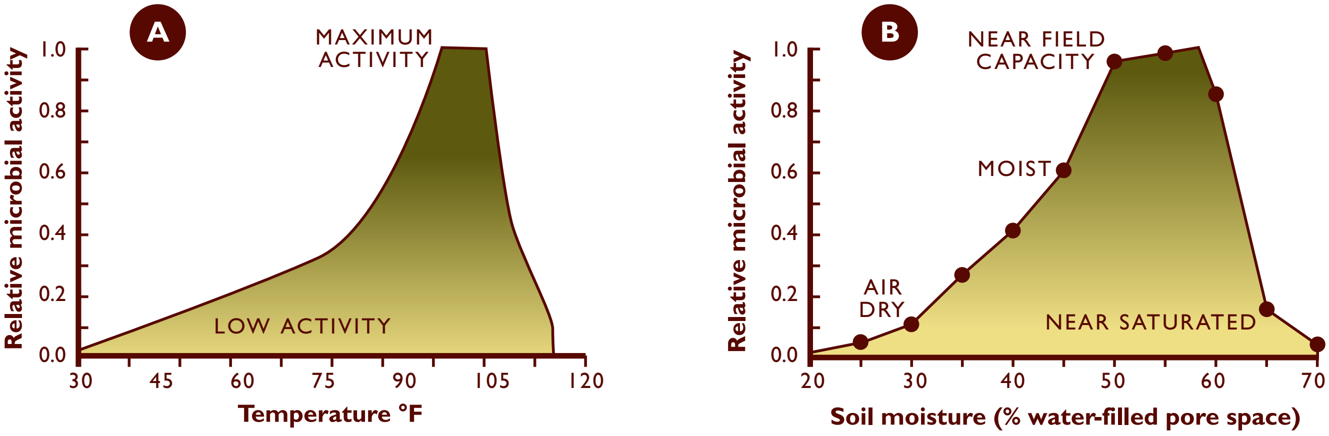


Figure 13. Soil temperature (A) and moisture (B) effects on relative microbial activity. (From Vigil and Sparks, 2003)

variable, and they may only be economical for small-scale, high-value crops (Smith and Read, 1997). Therefore, improving and maintaining existing mycorrhizal populations by increasing SOM content, reducing tillage and other soil disturbances, and eliminating long fallow periods may work best for encouraging mycorrhizal symbioses in agricultural.

Biological Activity

Soil biological activity is controlled by many factors in the soil. Residue and SOM quantity and quality, primarily nitrogen (N) content, are major limiting factors for soil organism activity (*NM 3* & *8*). Other soil factors that promote activity are adequate levels of oxygen, near-neutral pH, temperatures between 85-95°F, and 50-60% moisture (Brady and Weil, 2002; Figure 13). Combinations of these factors will result in maximum activity (Figure 14). Although some organisms have adapted to extreme environmental conditions, overall activity generally diminishes when conditions fall outside of these ideal ranges. For example, if a soil becomes too wet, oxygen diffusion is impeded and overall activity slows since oxygen is required by most organisms.

Management practices can affect soil organism activity through changes in aeration and structure, cropping systems, and inputs. Tillage typically accelerates short-term bacteria and protozoa activity by increasing aeration and breaking up residue into smaller particles that are more exposed to microbial attack (Vigil and Sparks, 2003). Conversely, fungal biomass has been shown to increase in conservation tillage systems, possibly as a result of less tillage disrupting fungal hyphal networks and/or increases in SOM levels (Frey et al., 1999). Earthworm populations also tend to increase with practices that increase SOM levels and minimize soil disturbances. Crop rotation systems may support more organism diversity and activity than monoculture systems due to increased and more diverse residues and specific interactions occurring between certain plants and organisms (Olfert et al., 2002).

Fertilizer applications can also influence soil organism populations and activity. Biotic activity in soils with low fertility or SOM content will likely increase with the addition of fertilizers, particularly those containing N; populations will eventually stabilize as N is consumed. In addition, certain fertilizer applications, such as the injection of anhydrous ammonia, can temporarily harm some soil organisms at the injection site (Tugel and Lewandowski, 1999). However, most organism populations will rebound with time.

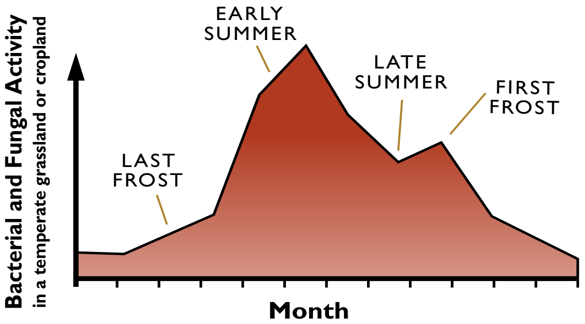


Figure 14. Seasonal effects on microbial activity in the northern Great Plains. (Tugel and Lewandowski, 1999)

Summary

Soil physical, chemical and biological properties affect many processes in the soil that make it suitable for agricultural practices and other purposes. Texture, structure, and porosity influence the movement and retention of water, air and solutes in the soil, which subsequently affect plant growth and organism activity. Most soil chemical properties are associated with the colloid fraction and affect nutrient availability, biota growing conditions, and, in some cases, soil physical properties. Biological properties in soil contribute to soil aggregation, structure and porosity, as well as SOM decomposition and mineralization. Organism activity is controlled by various soil conditions and may be altered by management practices. Since many soil properties are interrelated with one another, it is difficult to draw distinct lines of division where one type of property dominates the behavior of the soil. Therefore, understanding and recognizing soil properties and their connections with one another is important for making sound decisions regarding soil use and management.

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Appendix

Books

The Nature and Properties of Soils, 13th edition. N.C. Brady and R.R. Weil. 2002. Prentice Hall. Upper Saddle River, New Jersey. 960 p. Approximately $115.

Soils In Our Environment, 10th edition. D.T. Gardiner and R.W. Miller. 2004. Pearson Education, Inc. Upper Saddle River, New Jersey. 641 p. Approximately $120.

Soil and Water Conservation for Productivity and Environmental Protection, 4th edition. Troeh, F.R., J.A. Hobbs, and R.L. Donahue. 2004. Prentice Hall. Upper Saddle River, New Jersey. 656 p. Approximately $120.

Extension Materials

The following Extension materials are available and can be obtained at the address below. (Shipping rate varies depending on quantity, see http://www.montana.edu/publications/)

MSU Extension Publications
P.O. Box 172040
Bozeman, MT 59717-2040

Geologic Parent Materials of Montana Soils. 1980. This bulletin can help you understand the properties, potentials and limitations of Montana soils by understanding the physical and chemical properties of their geological parents. Includes 11 illustrated map units, glossary and appendices. 1B721. 188 p. $5.00

Soils of Montana. 1982. This bulletin gives a broad perspective on the soils and landscapes in Montana, with background on geologic, topographic, climactic and vegetative factors. Includes detailed descriptions of regional soil types and 29" x 45" general soil map. 1B744. 1982. 96 p. $5.00

Montana Soil Surveys—Understanding the Land. 1982. 2F225. Free

Nutrient Management Modules (1–15). 4449- (1 to 15). Can be obtained from Extension Publications or on-line in PDF format at http://www.montana.edu/wwwpb/pubs/. Free

Soil and Water Management Modules (1-3). 4481-1, 4481-2 and 4481-3 can be obtained from Extension Publications or on-line in PDF format at www.montana.edu/wwwpb/pubs/4481.html/. Free

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Web Resources

NRCS web link to on-line version of Soil Biology Primer.
http://soils.usda.gov/sqi/soil_quality/soil_biology/soil_biology_primer.html

Montana and Wyoming NRCS Home Pages with links to Soils page
www.mt.nrcs.usda.gov and www.wy.nrcs.usda.gov

Soil Science Education Home Page
http://ltpwww.gsfc.nasa.gov/globe/index.htm

University of Nebraska NebGuide on soil physical properties and water relations. http://ianrpubs.unl.edu/fieldcrops/g964.htm

Montana State University Publications ordering information for Extension Service Publications. http://www.montana.edu/publications

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