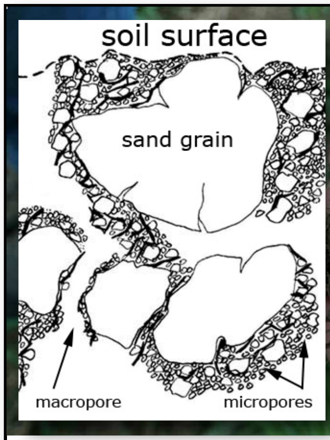
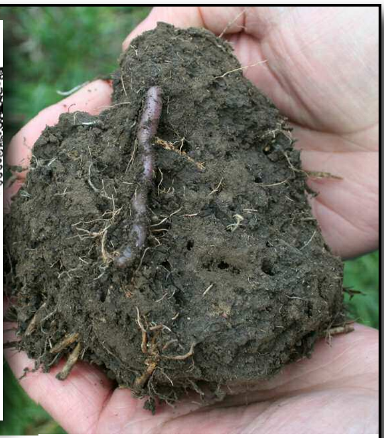
Soil Quality Indicators

Soil Structure & Macropores

Sand, silt and clay particles are the primary mineral building blocks of soil. Soil structure is the combination or arrangement of primary soil particles into aggregates. Using aggregate size, shape and distinctness as the basis for classes, types and grades, respectively, soil structure describes the manner in which soil particles are aggregated. Soil structure affects water and air movement through soil, greatly influencing soil's ability to sustain life and perform other vital soil functions.

Soil pores exist between and within aggregates and are occupied by water and air. Macropores are large soil pores, usually between aggregates, that are generally greater than 0.08 mm in diameter. Macropores drain freely by gravity and allow easy movement of water and air. They provide habitat for soil organisms and plant roots can grow into them. With diameters less than 0.08 mm, micropores are small soil pores usually found within structural aggregates. Suction is required to remove water from micropores.





High residue and cover crops contribute organic matter to soil, while no-till management helps protect organic matter and allow accumulation. Organic matter provides food for earthworms and other soil biota. All play a role in developing or protecting soil structure and macropores to help soil function at a high level. Inset shows relationship of macro- and micropores to soil aggregates.

Factors Affecting

Inherent - Aggregation of soil particles to develop soil structure is affected by clay particles and shrinking and swelling of clay masses. Clay particles carry a negative charge on their surface that can cause them to repel each other, but that attracts and adsorbs cations present in the soil. Stacks of clay particles can form when their negative surface charge is neutralized by tightly adsorbed polyvalent cations, such as Ca^{2+} and Al^{3+}. Further, Ca^{2+}, Fe^{2+} and Al^{3+} flocculate (clump together) stacks of clay particles, and with humus (negatively charged, highly decomposed, stable organic matter), bind to form small, stable soil aggregates.

In contrast, sodium ions (Na^{+}) are associated with soil dispersion. They are monovalent, relatively large and they are the prominent cation adsorbed to clay particles in some soils in arid and semi-arid regions. Because of their relatively weak charge and large size, sodium ions are ineffective at promoting clay stacking and aggregate formation. Dispersed clay causes the soil to be almost structureless, impervious to water and air, and undesirable for plant growth.

When soil dries out and water is removed, clay stacks move closer together, the soil shrinks in volume, and cracks develop in weakly bonded areas. As soil wetting and drying cycles are repeated with rainfall (or irrigation) and removal by plants, an extensive network of cracks develops and soil aggregates become more defined. Freezing and thawing cycles have a similar shrinking and swelling effect since freezing of soil water to form ice crystals withdraws water from clay structures. Shrinking and swelling breaks apart and compresses soil particles into defined structural aggregates. Certain types of clay particles have shrink-swell properties of their own.

Dynamic - While chemical and physical factors play a prominent role in small aggregate formation in clay soils, biological processes are important for development of large aggregates and macropores, and they are the primary factor for aggregation of sandy soils. Important biological processes include: earthworms burrowing in soil and ingesting soil particles to form casts, development of sticky networks of roots and fungal hyphae, and production of organic glues by fungi and bacteria. Plant roots also contribute to aggregation and development of macropores as they push through the soil while they are growing or by leaving channels when they die. Mycorrhizae, or thread-like fungi, secrete a gooey protein called glomalin that is an effective cementing agent for providing short-term stability of large aggregates. Organic glues are produced by fungi and bacteria as they decompose plant residues. Water-resistant substances produced by roots and microorganisms provide long-term stability of months to a few years of soil aggregates.

Organic matter is the major contributing factor for aggregate formation that can be directly affected by human management. It provides energy for microbial processes that release organic products. The organic products chemically interact with soil particles and iron and aluminum oxides to bind soil particles together into aggregates. Tillage can have favorable and unfavorable effects on aggregation and soil structure. Short-term, tillage breaks clods apart, incorporates organic matter into the soil, and loosens it to increase porosity; however, long-term, tillage increases decomposition of organic matter, prevents accumulation, and reduces its aggregating effects. Tillage of wet soil generally destroys surface soil structure.

Relationship to Soil Function

Important soil functions related to soil structure are: sustaining biological productivity, regulating and partitioning water and solute flow, and cycling and storing nutrients. Soil structure and macropores are vital to each of these functions based on their influence on water and air exchange, plant root exploration and habitat for soil organisms. Granular structure is typically associated with surface soils, particularly those with high organic matter. Granular structure is characterized by loosely packed, crumbly soil aggregates and an interconnected network of macropores that allow rapid infiltration and promote biological productivity. Structure and pore space of subsurface layers affects drainage, aeration, and root penetration. Platy structure is often indicative of compaction.

Problems with Poor Function

Clay soils with poor structure and reduced infiltration may experience runoff, erosion, and surface crusting. On-site impacts include erosion-induced nutrient and soil loss and poor germination and seedling emergence due to crusted soil. Off-site impacts include reduced quality of receiving waters due to turbidity, sedimentation and nutrient enrichment. Water entry into a sandy soil can be rapid, but subsurface drainage of sandy soils with poor structure can also be rapid such that the soil cannot hold water needed for plant growth or biological habitat.

Practices that lead to poor soil structure include:

- Disturbance that exposes soil to the adverse effects of higher than normal soil drying, raindrop and rill erosion, and wind erosion
- Conventional tillage and soil disturbance that accelerates organic matter decomposition
- Residue harvest, burning or other removal methods that prevent accumulation of soil organic matter
- Overgrazing that weakens range and forage plants and leads to declining root systems, poor growth and bare soil
- Equipment or livestock traffic on wet soils
- Production and irrigation methods that lead to salt or sodium accumulation in surface soils

Crumbly structure of surface soil is associated with adequate organic matter content.

Improving Soil Structure & Macropores

Practices that provide soil cover, protect or result in accumulation of organic matter, maintain healthy plants, and avoid compaction improve soil structure and increase macropores.

Practices resulting in improved soil structure and greater occurrence of macropores favorable to soil function include:

- Cover Crop
- Conservation Crop Rotation
- Irrigation Water Management
- Prescribed Grazing
- Residue and Tillage Management
- Salinity and Sodic Soil Management

Evaluating Soil Structure & Macropores

Schoeneberger, PJ, Wysocki, DA, Benham, EC, and Broderson, WD (editors). 2002. Field Book for Describing and Sampling Soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Soil structure is described in the Soil Quality Test Kit Guide, Section I, Chapter 11, pp. 23 – 27. See Section II, Chapter 10, p. 76 for interpretation of observations.

Reference: Brady, NC and Weil, RR. 2002. The Nature and Properties of Soils, 13th Edition. Prentice Hall, NJ.

Time needed: 60 minutes