Soil Physical Properties

Soil Color

Used to distinguish adjacent horizons, in soil classification and as an indicator of internal water drainage. Color is measured in reference to a standard set of color chips (*Munsell Color Book*). There are three color parameters:

Hue	Dominant spectral color
Value	Relative blackness or whiteness
Chroma	Amount of pigment mixed with gray value

Typical interpretation of soil color:

Brown / black	Organic matter
Red	*Hematite*, good drainage and aeration
Yellow	*Goethite*, moderate drainage and aeration
Gray	Fe^{2+} , poor drainage and aeration
Green / blue	*Gley*, extremely poor
White	Calcium carbonate, $CaCO_3$
Mottling	Varied colors of peds
No mottles	Good drainage and aeration
Yellow / gray	Moderate
Gray / bluish	Very poor

Soil Texture

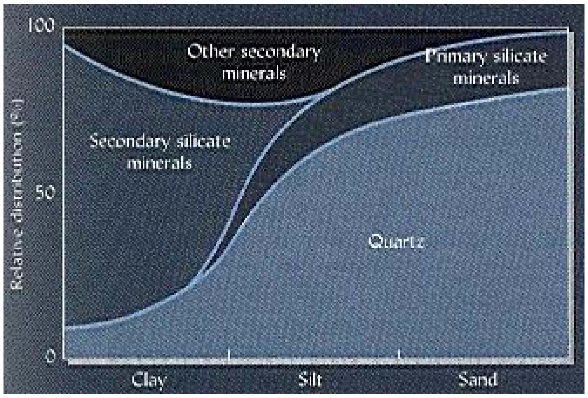
Proportion of different size particles in a soil. USDA classification system:

< 1.00 mm	very coarse	**sand**	2.000
< 0.50	coarse		1.000
< 0.25	medium		0.500
< 0.10	fine		0.250
< 0.05	very fine		0.100
< 0.002		**silt**	0.050
		clay	0.002

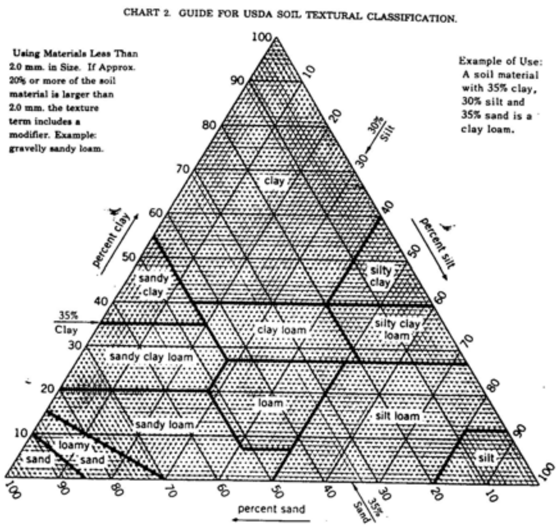
Coarse fragments are > 2 mm.

Surface area of soil separates per unit mass (or volume) increases with decreasing size. As surface area increases water holding capacity, organic matter content, adsorption of nutrients, rate of mineral weathering, coherence of particles and microbial activity all tend to increase. However, drainage, aeration and ease of tillage decrease.

Composition of Soil Separates



Textural Classes



Textural triangle defines the ranges of sand, silt and clay for all 12 textural classes.

Determination of Textural Class

Soil texture can be estimated by the *feel method* and precisely determined in the laboratory by a *mechanical analysis*. The latter may be by the hydrometer or pipette method. In either case, a mechanical analysis is based on Stokes' law for the settling of spherical particles in a viscous fluid,

$$v = g(D_s - D_l)d^2/18\eta$$

which shows that velocity, v, of particle settling is proportional to the square of the particle diameter, d, where g is acceleration due to gravity, η is viscosity of the liquid medium, and D_s and D_l are the densities of the particle and liquid, respectively. So that if v is expressed in terms of distance per time,

$$t = 18\eta z/[g(D_s - D_l)d^2]$$

one can determine the time, t, required for particles of diameter d to settle distance z.

In the pipette method, therefore, a known mass of soil is suspended in known volume of solution and an aliquot above depth z removed after prescribed times. These aliquots contain only particles of diameter less than d. For a settling depth of 10 cm,

Separate	Size	Time to Settle
Sand	d > 0.05 mm	< 1 minute
Silt	d >.002mm	8 hours

Complete particle size distribution (not just textural class) can be determined by series of such measurements, supplemented by sieve data for sand.

Since adsorbed cations such as Al^{3+}, Ca^{2+}, and H^+ tend to *flocculate* small soil particles, these must be displaced by addition of an excess of Na^+ which tends to *disperse* aggregates into discrete particles.

Soil texture may be considered a permanent property of a soil since it is only slowly altered over long periods of time by erosion, deposition, *eluviation / illuviation*, and weathering.

Soil Structure

Structure refers to the grouping of soil particles into secondary bodies called aggregates or *peds*. Some soils, however, are *structureless*, either *single grain*, as with sands, or *massive*, as in some clays.

Types of structural units:

Spherical	*Crumb*	(high porosity)
	Granular	(low porosity)

Common at surface in soils with high organic matter.

Platy

Occurs in surface and subsurface horizons.

Prism — *Columnar* (tops rounded)
Prismatic (tops angular)

Subsurface

Blocky — *Angular* (edges distinct)
Subangular (edges rounded)

Subsurface

The field description of soil structure also includes relative size (*class*) and strength of cohesion (*grade*).

Structure affects water movement, aeration and heat transfer. For example, infiltration decreases along the sequence single grain, spherical > blocky, prismlike > platy, massive.

Development of Soil Structure

In the surface soil is related to the shrink-swell behavior of certain clays and the adhesive effect of organic materials from roots and soil microorganisms. The translocation of silicate clays, oxides and salts affects structure development in the subsurface soil.

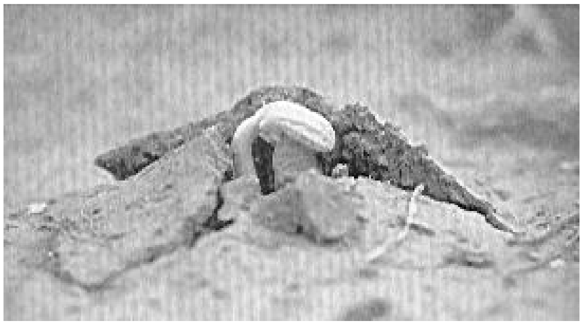
Soil Consistence

Term applied to resistance of soil to mechanical stresses or manipulation. It is judged at different moisture contents.

Surface Aggregate Formation and Stability

Rainfall is conserved if the soil surface is well-aggregated because most water will infiltrate the surface rather than run off it. In turn, soil erosion is reduced and surface water quality preserved. Several factors are responsible for aggregate formation and stability. The adhesive action of organic matter and a dominance of flocculating cations favor aggregate formation and stability. Crop residues on the soil surface also protect aggregates from the disruptive effect of raindrop impact.

Destruction of surface aggregates, whether slaked by rain or broken, destabilized or crushed by tillage and traffic, tends to lead to the formation of a surface *crust*. Infiltration is slow and runoff fast when a crust covers the soil.



Soil crust.

Management of Soil Structure

Minimize tillage
Till under optimum moisture to avoid more drastic impact, especially puddling
Keep residues on the soil to add organic matter and protect the surface
Cover crops also add organic matter and protect the surface

Puddled soil to left.

Particle Density

PD = mass soil solids / volume of soil solids

Units are g cm^{-3}

Depends on the mineralogical composition of soil but typically varies little (2.60 to 2.75 g cm^{-3}) because the range in density of common soil minerals is narrow. When particle density is unknown, an average is 2.65 g cm^{-3} is assumed. The particle density of organic matter is lower (0.9 to 1.3 g cm^{-3}).

Bulk Density

BD = mass soil solids / total volume occupied by solids

Therefore, BD < PD. Methods for determining BD include removing a core of known volume or measuring the volume of a small excavation. In either case, the mass of solids is determined by weighing after soil water is evaporated (105 ^oC).

Bulk density varies with texture, depth and management. From the standpoint of plant growth, high BD is not good because it restricts water flow and root penetration.

Higher in coarse textured soils because clay soils are generally aggregated. Therefore, clay soils exhibit not only *macropores* between aggregates but also *micropores* within aggregates.

Higher lower in the profile than at surface due to lower organic matter and greater compaction.

Higher in cultivated soils because cropping tends to lower organic matter and decrease aggregation.

HFS and AFS

Hectare-furrow slice (HFS) is the assumed mass of a hectare to depth of 15 cm, 2200 Mg (metric ton, 1000 kg. *Acre-furrow slice* (AFS) is the assumed mass of an acre to depth of 6 in, 1000 tons (2000 lbs).

Pore Space

Can be calculated from known PD and BD.

$V_p = V_t - V_s$

And since $V_s = m_s / PD$ and $m_s = BD\ V_t$

$V_p = V_t (1 - BD/ PD)$

Or expressed as a fraction of total volume

$V_p / V_t = 1 - BD/ PD$

Clearly, pore space and bulk density are inversely related.

Not only is total porosity important for soil aeration and water movement, so too is pore size distribution. Macropores allow good aeration and rapid water flow but micropores do not. Approximately defined, macropores are 0.06 mm and larger and micropores are < 0.06 mm in diameter. The distribution of pore sizes is affected by texture, structure and management.

Sandy soils largely contain macropores. Clay soils also have intraaggregate macro-pores and interaggregate micropores. Cropping and tillage reduce organic matter and pore space, especially macropores. Conservation tillage limits or reverses this effect.

Water Content

Gravimetric

mass of water / mass of soil solids

Volumetric

volume of water / volume of soil

Calculated using mass of water and density of water

$(m_w / D_w) / V_{soil}$

Air-dry moisture content

$(m_{air\text{-}dry\ soil} - m_{oven\text{-}dry\ soil}) / m_{oven\text{-}dry\ soil}$

Expressed air-dry moisture as a fraction of the mass of soil solids.