Soil Physics

FACT SHEET 9

The characteristics associated with soil physical features include soil structure, porosity, water infiltration and bulk density. Soil structure is strongly influenced by soil texture. It is also influenced by management. Management induced compaction is in many cases the primary limiting factor to soil health and productivity.

Soil structure

Soil structure describes the way the sand, silt and clay particles are arranged and held together. A well structured soil is referred to as friable and crumbles readily when handled. As well as texture, soil structure is also influenced by the presence of organic matter and soil macro and micro biota.

Soil breaks up into units called aggregates, also known as peds, which contain organic matter and spaces known as soil pores. Pores may range in size from the large spaces between aggregates (macropores) down to the very small spaces (micropores) within or between soil particles. The size and arrangement of aggregates result in the soil structure. Compaction is essentially a reduction in the number and continuity of soil macropores.

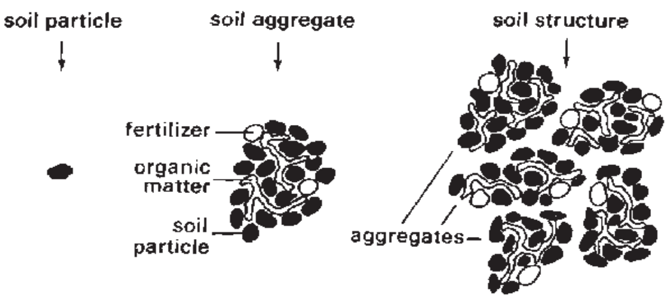

Figure 1: The relationship between soil particles, aggregates and soil structure.

An introduction to aspects of soil structure and relationship to soil texture is provided in Factsheet 1 of this series.

Figure 2: A well structured, friable soil breaks easily into aggregates.

Soil aggregates are bound together by a number of agents. Processes which enhance the aggregation of soil particles include;

- the sticky mucilage produced by soil biota and root exudates
- the physical binding forces of fungal hyphae
- substances released by organic matter
- electro-static forces such as the charges on clay minerals.

In well structured soil, large aggregates break into smaller aggregates and will have a low density and high porosity (air space). Alternatively, poorly structured soil may collapse into dust or remain as a solid clod and will have a very dense structure and low porosity. Well structured soil with high porosity will also have a higher water holding capacity.

Soil structure is strongly influenced by management actions

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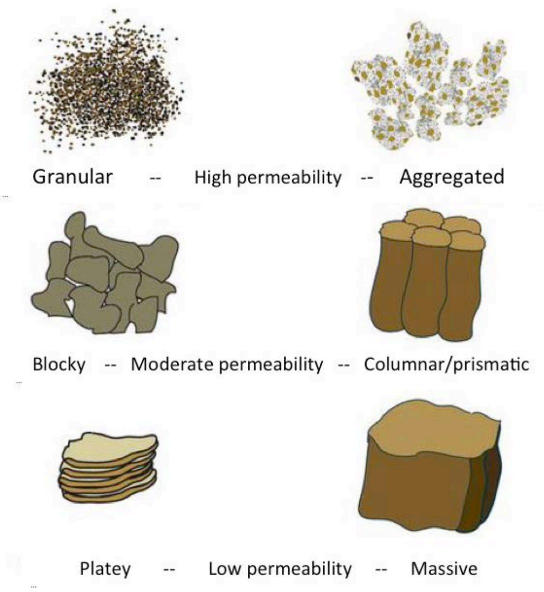

Figure 3: Depending on texture, different types of structure, or ped shapes, influences water movement through soil.

Aggregate stability

Aggregate stability describes the ability of the soil aggregates to retain their structure when placed under stress. Stress can be in the form of mechanical pressure, raindrops or cultivation. Stable aggregates will resist deformation under pressure. Unstable aggregates may either slake, where they disintegrate into smaller crumbs or disperse where they dissolve into individual particles. Organic matter aids soil structure and reduces slaking.

Dispersion is an indicator of soil sodicity, where relative to other cations, excessive exchangeable sodium is present in the clay minerals of the soil. Sodium ions are relatively large and decrease the attractive forces between clay particles encouraging dispersion. When dispersive soils are wet the soil structure collapses and soil pores are filled by clay particles resulting in reduced pore space.

Figure 4: Examples of degrees of dispersion of soil aggregates after 24 hours in water.

Soil porosity

Soil porosity refers to the spaces within and between aggregates and soil particles. The amount of pore space determines the amount of water a given volume of soil can hold. In a well structured soil the porosity of the top 10-15cm will be 50%. That is, for a given volume of dry soil the mineral and organic matter component occupies half the space and the remainder is air. When wet, these air filled spaces can potentially hold water. Porosity may range from 30-60%, sandy soils have lower porosity and clay soils tend to have higher porosity.

The soil profile is composed of a range of pore sizes of differing origin which have different functions.

Macropores (>0.08mm diameter) are most important for soil water infiltration and air movement in soil. They may originate from channels left by decaying roots, channels made by soil animals, aggregation of soil particles or soil cracks. Functionally, the level and continuity of macropores determines the rate at which water can infiltrate and drain through the soil (this process is refered to as hydraulic conductivity). Macropores provide habitat for many soil organisms and plant roots can grow easily into them.

Mesopores (0.08-0.03mm diameter) known as storage pores are the largest pores filled at field capacity and represent the largest store of soil water readily available for plant use.

Micropores (<0.03mm diameter) are most commonly found within soil aggregates. Also an important source of storage, water within soil aggregates is held by capillary forces and suction is required to remove water from micropores. Much of the soil water within micropores is unavailable for uptake by plant roots.

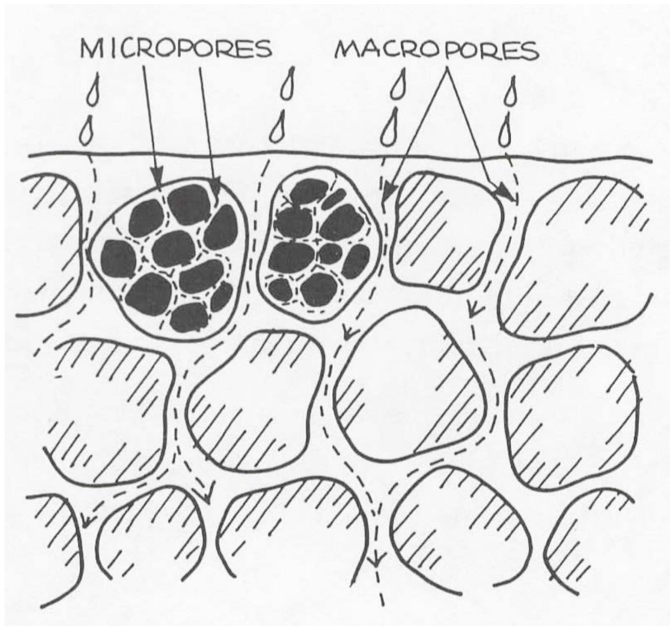

Figure 5: Macropores act as transmission pores and micropores are more important for water storage in soil.

A good balance of pore size distribution in a soil is critical to allow air and water movement as well as water retention and storage of water for plant roots to access for growth.

Optimal porosity enhances soil water infiltration and potential water holding capacity of soil. It also enhances potential root growth and biological activity in the soil.

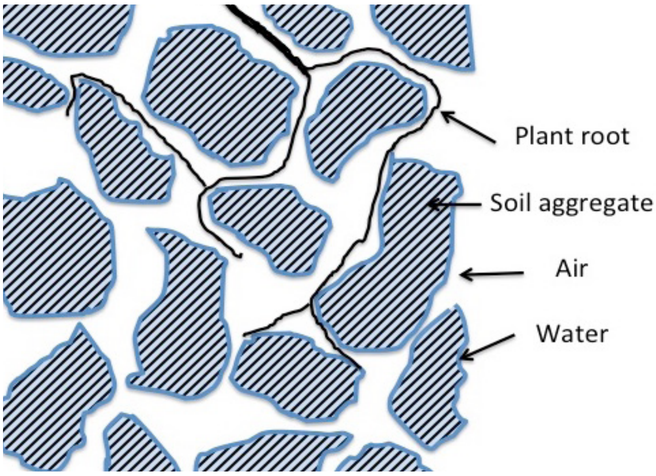

Figure 6: Well structured soil with high porosity enhances water infiltration, root growth and biological activity.

A reduction in porosity, particularly the number and continuity of macropores equates to soil compaction, an increase in the bulk density of soil.

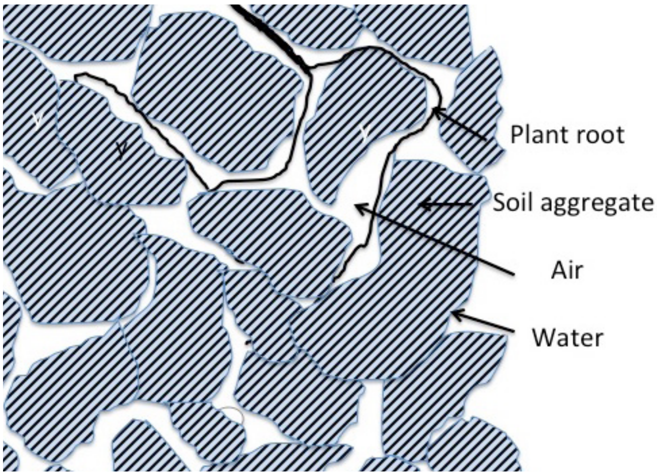

Figure 7: Compacted soil has reduced air space, poor soil water infiltration and plant root growth is limited.

Pore size and pore size distribution can change regularly within a soil. Natural wetting and drying of soil, biological activity and artificial (mechanical) soil processes create and destroy pores and change other attributes of soil aggregates. Table 1 lists some common effects of soil processes on pore size distribution.

Table 1: Some possible effects of soil processes on pore size distribution

PROCESS	POSSIBLE EFFECTS
Shrinkage	- can enlarge macropores - can create new macropores - within an aggregate, can cause intra-aggregate porespace to decrease in size or increase if clay particles are shrinking
Swelling	- can decrease size of macropores - can close macropores - within an aggregate can cause intra-aggregate porespace to increase in size or decrease if clay particles are expanding
Mechanical compression	- can decrease size of macropores - can close macropores - can break up aggregates, reducing the number of intra-aggregate pores and reduce the proportion of pore space represented by micropores
Cultivation	- can destroy macropores - can create interclod macropores - can break up aggregates, reducing the number of intra-aggregate pores and reduce the proportion of pore space represented by micropores
Biological activity	- can create new macropores - burrowing organisms can enlarge macropores - can decrease size of macropores if affected by compression from expansion of a nearby root - can increase aggregation promoting the creation of inter-aggregate micropores
Chemical activity	- formation of precipitates can constrict or obstruct pores - dissolving precipitates can enlarge pores - can increase or decrease inter-particle cohesion with effects on pore size and structure

Source: JR Nimmo (2004)

Bulk density

The bulk density of a soil describes how heavy or dense a soil is. It is a measure of the weight of soil in a given volume. Porosity is inversely related to bulk density. Together the bulk density and porosity of a soil give an indication of the size, shape and arrangement of soil particles – the soil structure. Optimal values of both are vital for plant growth, biological activity and soil water infiltration.

Ideally a bulk density of around 1g/cm3 will provide optimal air and water movement through soil. Bulk density >1.6 g/cm^3 is reported to restrict root growth and soil with bulk density of 1.5 g/cm^3 is considered acceptable for agricultural soils. The latter figure is used in routine chemical analyses to convert mg/kg of an element (as reported in your soil test) to kg/ha for practical application rates.

Since sandy soils tend to have larger but fewer pore spaces they also tend to have relatively higher bulk densities, commonly between 1.3-1.7 g/cm^3. Well structured clay soils have a much higher amount of pore space within and between very small particles. The bulk density of these and fine silt soils will generally range between 1.1-1.6 g/cm^3.

Bulk density increases with compaction. Compaction is caused as soil aggregates are compressed together, forcing air out of the soil. Soils are most vulnerable to compaction when they have high moisture content. Applying excessive pressure when soil is wet causes it to deform by damaging aggregate stability therefore degrading soil structure.

As bulk density or compaction increases the amount of plant available water decreases and the energy required to be exerted by roots to penetrate the soil increases, effectively limiting root growth. In the absence of plant roots, soil biota cannot be effectively sustained and porosity decreases.

As soil compaction (or bulk density) increases the limited soil moisture also restricts nutrient availability and cycling since most plant nutrients are taken up from the soil solution.

Soil strength

Another related concept is that of soil strength which is affected by moisture content. Dry, high strength soils resist deformation but also restrict root growth. When wet, clay particles separate. As moisture content increases the cohesion of clay particles decreases and as a result soil strength decreases and the risk of soil compaction under pressure increases. Wet soil is far more susceptible to severe compaction than dry soil because of the relationship to soil strength.

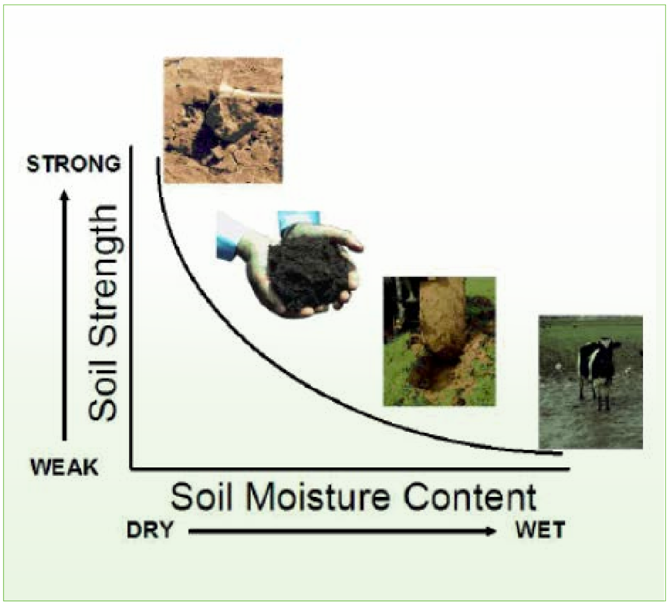

Figure 8. The relationship between soil moisture content and soil strength

This is number nine in a series of 12 Factsheets which cover a range of topics regarding soil health and effective function of soil processes.

More Information

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