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SOIL STRUCTURE - AGGREGATION

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SOIL STRUCTURE ---- AGGREGATION

It has been recongnized that the soil has capacity of providing water and nutrients to plant growth, One of most important reasons is attributed to its porous characteristic. Soil, as a porous medium for plant growth, has at least three functions. The first, the top part of plant can be supported by soil in which plant roots can penetrate and develop. The second, the water and nutrients neccesary for plant growing can be stored and transfered in pores of soil. And the third, the soil air surrounding roots, that is, the air in rhizosphere, can be exchanged with atmosphere above the soil through soil pores which bring about the renewal of the soil environment for plant . Therefore, the size, shape, continuty and stability of pore space in soil are most important for the biological nature of soils.

The major factor affecting soil porosity is the different spatial arrangement of particles including individual mineral particles, rock fragments, organo-mineral compounds and aggregates with different sizes in soil. The more attention has been paid to this problem in many publications and textbooks of Soil Physics. It is evident that the spatial arrangement of different particles in soil determines a lot of physical properties such as bulk density, porosity, permeability and penetrating force, etc., and consequently it affects water and nutrient storage, movement and their uptake by plant. A full understanding of the process in which the physical properties are found to influence the plant growth, which is of great significance for the increase in in production of agriculture, forestry and pasture.

I Definition of soil structure

Definition of soil structure varys more or less in different countries, or in different textbooks. The chinese farmers pay special attention to the shape of soil clods. The aggregate shape in soil like ant's eggs is considered as good structure, while it is like garlic clover as bad structure.

Slide 1, The description of aggregate shape
by chinese farmers

Most scientists from Eastern Europe[illegible] defines soil structure as a complex of soil aggregates with different sizes, shapes, porosities and their mechanical and water stabilities.

Slide 2.

While in many textbooks of Soil Physics definition of soil structure is described as a patten of spatial arrangement of particles including primary and secondary particles. For instance, in textbook of soil Physics edited by Baver (1972), it is shown that "the structure of a soil implies an arrangement of primary (such as individual sand, silt and clay) and secondary (such as aggregates or structural elements) particles into a certain structural pattens including the accompaning pore space".

Slide 3.

In Soil Physics written by Marshall et al., the authors define it as "the arrangement of the solid phase of the soil and of the pore space located between its constituent particles".

Slide 4.

In the new publication of the fundamentals of soil physics (1980), D. Hillel gives the definition as "the arrangement and organization of particles in soil".

Slide .

From mentioned above it seems that the term of soil structure generally denotes a qualitive concept, it is insufficient for description of the relation between soil structure and plant growth.

Belgium soil scientists De Leenheer and De Boodt point out that the definition of soil structure not only implies the spatial arrangement of soil particles, but also include the pore size distribution and other physical properties resulting from it, and their influence on plant growth. Based on this concept, it might be to able to determine soil structure quantitively and directly or indirectly to relate with plant growth under a certain conditions.

Slide .

Gardner, W.H. (1977) in his paper "Historical highlights in American soil physics (1776-1976)" shows that the current study on soil structure has entered into the stage in which it is paid more attention of spatial arrangement in soil profile and its influence on flux of water, heat and gases.

Slide .

Now the brief conclusion of this topic could be made as follows. Soil structure refers to the pattern of spatial arrangement of soil particles including pore space between them and its quantitive study includes other related physical properties, particularly, its influence on flux of water, heat, gases and plant roots growing. This is as same as the concept of general matter. Any matters have their inherent structure and function resulting from it. Soil is as same, it has inherent structure and function concerning flux of water, heat, gases, etc., but little attention has been paid on the latter in some textbooks.

II Genesis of soil structure

The genesis of soil structure refers to the causes and methods of formation of the structural units or aggregates. It has been shown that an aggregate consists of an intimate grouping of a number of primary particles into secondary unit. The mechanism of the formation of these aggregates is one of the most important phases of the structure problem.

On the other hand, the primary particles, such as the individual sand, silt and clay, are very stable existent in soil, but the aggregates are relatively instable, their quantity or quality are changeable and dependent on climatic and cultivation conditions, especially, on the agricultural operations such as cropping system, tillage, fertilizers, irrigation, drainage, etc.. Therefore, the study on the formation and destruction of soil aggregates and their stability in soils has evident agricultural significances.

Slide . Sandy particles are more stable and aggregates are relative instable

1. The importance of aggregation

The soil aggregation implies the capacity of soil to form aggregate. In evaluating the soil aggregation the size distribution, quantity and stability of aggregates have been stressed. These parameters of aggregation are important in determining a lot of physical processes in soil. It is well known that the different arrangement of soil particles can produce various characteristics of pore space. If we take the sphere as an ideal individual soil particle, the different porosities are produced between the hexahedron and dodecahedron arrangement of particles.

Slide . Hexahedron arrangement of particles

Slide . Dodecahedron arrangement of particles

Hexahedron arrangement of spheres is loose. In this system, each sphere touches six neighbors. If we combine and line [redacted] each eight spheres

from their centre to centre, a [redacted] cube is formed. Taking the radius as r, the volume of the cubic unit is equal to $(2r)^3$. In the cubic unit the occupied parts of 8 spheres just equal the volume of one entire sphere, $\frac{4}{3}\pi r^3$. Therefore, the porosity of one cubic unit is equal to

$(2r)^3 - \frac{4}{3}\pi r^3$, and the percentage of porosity in this system is

$$P = \frac{(2r)^3 - \frac{4}{3}\pi r^3}{(2r)^3} \times 100 = 47,64\%$$

The dodecahedron arrangement of sphere is very tight. In this system each sphere touches 12 neighbors spheres. If we combine and line [redacted] each eight spheres from their centre to centre, [redacted] an inclined cubes [redacted] is formed. In one unit, the lenth of its side is equal to 2r, one angle is equal to 60° and another is 120°. The occupied parts of 8 spheres in this unit is just equal to one sphere volume, $\frac{4}{3}\pi r^3$. The lenth of the bottom side of this unit is $2r \times \sqrt{3}r$, height is $\sqrt{\frac{9}{3}}\ r$. Therefore, the volume of this unit is equal to

$2\sqrt{3}\ r^2 \times \frac{\sqrt{3}}{\sqrt{3}}\ r$. The porosity of this unit equals

$2\sqrt{3}\ r^2 \times \sqrt{\frac{3}{3}}\ r - \frac{4}{3}\pi r^3$. Therefore, the percentage of porosity of dodecahedron system equals

$$P = \frac{2\sqrt{3}\, r^2 \times \sqrt{\frac{8}{3}}\, r - \frac{4}{3}\pi r^3}{2\sqrt{3}\, r^2 \times \sqrt{\frac{8}{3}}\, r} \times 100 = 25,95\%$$

It is evident that the difference of porosity between two arranging systems is very remarkably.

If the aggregate status is taken into consideration, the porosity resulting from various arrangement can be summed as following three kinds.

a, Maximum loose arrangement of particles and aggregates. There are both the hexahedron arrangement within the individual spheres in aggregate and among the aggregates. In that case,

$$P = 47,64 + \frac{52,36 \times 47,64}{100} = 72,58\%$$

b, Intermediate. There are hexahedron arrangement among the aggregates and dodecahedron arrangement within the individual spheres in aggregate. Then

$$P = 47,64 + \frac{52,36 \times 25,95}{100} = 61,23\%$$

c, Maximum tight arrangement of particles and aggregates. There are dodecahedron arrangement both among the aggregates and within the individual spheres in aggregate. Then

$$P = 25,95 + \frac{74,05 \times 25,95}{100} = 45,16\%$$

It is, of course, much complex in the field condition.

If the aggregates are destroyed due to some reasons, they are dispersed. In a certain compressive condition the arrangement of particles becomes tight. As a result, a lot of unfavorable properties of soil can be produced. For instance, if the red soil with good structure is ground for simulating structural destruction, the water and nutrient retention and movement are liable to become unfavorable for plant growth. From Slides , , , , we can see that

a, Slide , the infiltration rate of red soil with poor structure is lower than that of red soil with good structure. The measured results are obtained from field condition.

b, Slide , the evaporation rate is increased remarkably along with the destruction of soil structure.

c, Slide , the fixation capacity of phosphorus in poor structural soil is increased remarkably.

d, Slide , the retention capacity of NH_4-N in poor structural soil is decreased remarkably.

For the paddy soils, the aggregates can regulate the water-air regime in a good condition, as the soil be dehydrated after harvest of rice crop for preparation of seeding the dry-farming crops. The strong shrinkage of clayey paddy soil is present without sufficient aggregates after dehydration, which influences the preparation of seed-bed. And the time of seeding dry-farming crops is delayed as usual, because the cultivated horizon is still stick without aggregates resulted by poor drainage. Slides , , , show the effect of aggregates on some physical properties.

Slide . Variation in bulk density under different soil suctions of two structural soils.

Slide . Change of specific water capacity under different suctions of two soils.

Slide . The air-filled porosity under different suctions of two soils.

From slide , it has shown that the bulk density of soil consisted from particles with diameter $<$ 0,25 m is rapidly increased with the increase of soil suction, but in the soil with aggregates, the influence of soil suction on bulk density is not so much as above mentioned. The specific water capacity and air-filled porosity in soil with aggregates are also changed in a less extent along with the increase of soil suction. This is beneficial both for preparation of soil and crop growth after harvest of rice plant.

2. Formation of aggregate

The formation of soil aggregate may be caused by two ways. On the one hand, the individual soil particles are gethered together into the aggregates by several bonding actions. On the other hand, the massive soil mass is separated to aggregates by different stresses. In fact, two ways of aggregate formations

in the field condition are very difficultly distingueshed.

Slide . Two ways

In general, more attention has been paid on how the aggregates are gethered from individual particles in many publications of soil physics.

From Slide , we can see the model of aggregate described by Greenland (1981). This model can be formed by several forces.

Slide . Model of aggregate described by Greenland

(1) Flocculation of particles

a, Electrostatical attraction among the particles
mutual settlement of colloids

As it is well known, the soil is a polydisperse system, in which the colloids and ions with different charges, that is, positives and negtives, are existed. If in a system the particles have the same charges, they are stable, but in soils the particles including some ion groups have different charges. Some soil components, such as organic and silicic colloids, aluminum silicates and anions bear negtive charge. Other such as sesquioxides and cations have positive charges. As to clay mineral under acid condition, its edges produce positive charge and its faces have negtive charge. All these differnet charges can make them electrostatically neutral by their attraction and the colloids are flocculated. The floccules of colloids in early stage of flocculation is not neutral, because the positive and negtive charges of particles are unequal as usual, and the floccules still have residual charges positive or negtive. They can be attracted to form floccules continuously until they are neutralized.

Slide . The sketch of isoelectric flocculation from Kachinski, N.A.

b, Actions of electrolytes

It is well known that the colloid with a high eletro-kinetic potential (Zeta potential) repel each other in suspension. Once the Zeta potential declines about 20-30 mv, can the flocculation occur as a result of the atom and molecular attraction between the colloids overcoming their repellent force.

The decrease of Zeta potential may be induced by two ways. One is monovalent cations replaced by polyvalent cations. Other is increasing the concentration of electrolyte in suspension. In the former condition, the polyvalent cations are tightly adsorbed on the surface of colloid, they exhibit compressed the double layer of colloid. The compressed forces of cations are dependant upon their valences and hydrated radius of ions. The greater the compressed force, the stronger the flocculating force. The flocculating forces of different cations are in the following orders:

$$Fe^{3+} > Al^{3+} > Ba^{2+} > Sr^{2+} > Ca^{2+} > Mg^{2+} > NH_4^{1+} > K^{1+} > Na^{1+} > Li^{1+}$$

The H ion is a special case due to its minor hydrated radius and high strength of electric field on its surface.

Slide . The orders of different kind of cations by flocculating forces

As for the increasing the concentration of electrolyte in suspension, the osmotic pressure of dispersed medium is increased along with the increase of concentration. As a result, the double layer of colloid is compressed, the Zeta potential is declined, which leads to flocculation. The concentration of electrolyte leading to the initial flocculation of colloid is called as a flocculating limit. Its values are dependant on the atomic quantity and valence of ions. The greter the atomic quantity and valence, the lower the limit value. It is shown in slide .

Slide . Flocculating limits of various electrolytes.

It is very important to know the flocculating power of various cations for the agricultural purposes. For example, the reclamation of alkali soil is by means of using calcium sulphate as usual.

Slide . Reclamation of alkali soils

Alkali soils:

$$\text{Clay}\Big)\begin{matrix} Na \\ Na \end{matrix} + \begin{matrix} NaOH \\ Na_2CO_3 \end{matrix} \text{ --- deflocculation and poor physical properties}$$

Reclamation of alkali soils

$$\text{Clay}\Big)\begin{matrix} Na \\ Na \end{matrix} + CaSO_4 \text{ --- Clay}\Big) Ca + Na_2SO_4 \text{ (leached)}$$

c, Brownian movement

The mutual impacts of particles in suspension by Brownian movement may lead to their flocculation owing to disappearence of energy of particles in that case. The stronger the kinetic of particles, the more the energy is disappeared and the stronger the flocculation of particles is. As compared with electrostatical neutralization and increase in concentration of electrolyte, the effect of Brownian movement on flocculation is relative weak.

From that mentioned above we can make the brief conclusion about the flocculation of particles in suspension:

(a) it can be caused by electrostatic attraction,
(b) by the action of electrolyte -- decrease of Zeta potential
(c) by Brownian movement.

Slide .

(2) Cementation of floccules

It is obvious that the theory of flocculation is built on dilute suspension, that is, the ratio between the dispersed medium and solution must be very wide, for instance, 1 : 100 or even more. However, this ratio in actual soil has never been found, even in the soil that is in water saturated condition. In addition, some investigations have shown that the maximum diameter of floccules in suspension can not be exceed 0,05 mm due to, in that case, their settling out from suspension under

gravity. Therefore, from the viewpoint of soil structure, the flocculation is only a fundation of floccule formation, in other words, it determines the formation of microaggregates, while the macroaggregate formation requires a cementing or binding action of flocculated particles.

There are main three kinds of cementing substances in soil as usual: Clay particles, inorganic colloids or iron and aluminium colloids, and organic colloids.

a, Clay particles

Usually the size of clay particles is less than 1μ in diameter. Thus, they have a high specific surface and a strong surface energy to adsorb the ions, moleculars and even soil particles. Many soil scientists have pointed that the clay particles at least exert following functions in cementing process of aggregates:

(a) Clay to clay particles gathering together caused by electrostatic and van der waals forces.
(b) Aggregate formed by cohesion between the oriented clay particles.
(c) Aggregate formed by hydrogen bonding between the the clay particles and polymers .
(d) Dehydration promotes the development of the antecedent actions. As the soil dehydrated, the distance between particles are shorter, especially, the cohesion and van der waals forces become stronger.

Slide . Actions of clay particles

In the field condition the action of clay particles in aggregate formation is dependant on the presence of organic matter ~~and~~, the type of clay mineral, and the kind of ion. As Baver denoted, there is a high correlation between clay content and aggregation in the condition of low level of organic matter in soils. In those soils rich in organic matter, the effect of clay on aggregate formation becomes insignificant. Warkentin, B.P. in his paper (1982) states that a graph of a soil physical property against clay content shows a break at 30-35% clay. Up to that clay content , properties such as plant avaiable water and compressibility increase with increasing clay content, beyond this value, they depend on the kind of clay mineral and can not be predicted from clay content.

The method of adding clay material into sandy soils is very effective for improvement of some properties of sandy soils and is widely used in China. For example, near the Beijing suburb after the reclamation of sandy soil by using the clay material in amount of 10-15 T. for several years, the capacity of water retention in soil is increased remarkably and the

Slide . Reclamation of sandy soil by clay material yield of winter wheat were increased in 2 to 4 times, as compared with that of check.

b, Inorganical cementing agents

Earlier, some scientists reported that the formation

of stable aggregate in laterite is related with presence of iron oxides (Lutz, 1934). Laterly, other scientists have considered that the effect of aluminium oxides on the formation of aggregate is greater than that of iron oxides. Recent study has indicated that the effect of both the iron and aluminium oxides depend upon the dispersity of soil particles and the form of sesquioxides.

The effect of iron, aluminium hydroxides on the aggregation may be dual. On the one hand, they may act in solution as a flocculating agent, and on the other hand, they may exert a cementing effect. Most of the iron can be precipitated as a hydrated gels. Dehydration of these gels forms a good cementing agent for binding the flocculated particles together. In addition, the aggregation can be completed by the sesquioxides and humus interaction.

Slide .

In Sorthern China, are wide spread the laterite and lateritic red soils. Though in some soils, the clay content is more than 50%, but a lot of physical properties, such as water characteristic curves, adhesions, modulus of rupture and Atterberg's limits are quite different from other clayey soils, and are similar to sandy soils. One of the important reasons is attributed to presence of large amount of stable microaggregates formed by the amorphous sesquioxides.

In paddy soils of China the iron hydroxides play an important role in aggregation. In delta of the Youngtz river of China, there double or triple cropping systems per year are widely applied. In double cropping system, the winter wheat and rice are planted. At the period of rice growing the surface soil is flooded by irrigated water and reduction process is predominant. Ferric hydroxide is reduced to the ferro hydroxide, that is, $Fe^{3+} \rightarrow Fe^{2+}$. In that case, the soil aggregate usually is easy to be disintegrated. However, in the period of dryfarming crops after harvest of rice, the paddy field is gradually to subject oxidation process and the ferrohydroxide is oxidated to the ferri hydroxide, $Fe^{2+} -- Fe^{3+}$. The dispersed particles are again gathered together by the cemention of ferri hydroxide. In that case , the aggregation of paddy soil is improved. A good condition of permeability is favorable for growth of dryfarming crops. However, for some paddy soils with poor structure, after harvest of rice the surface soil is still wetted for a no short time even though under drainage. Usually, in these paddy fields the oxidation process, particularly, in subsoils is relatively weak, the amount of amorphous iron is lower than that of paddy fields with good structure. Therefore, the variation of amorphous iron in paddy soils generally may be developed as an indirect parameter to assess the soil structure in paddy field.

In the base saturated soils the presence of calcium bicarbonate in solution also can cement soil particles into aggregates. For instance:

$$Ca(HCO_3)_2 \dashrightarrow \underset{\substack{\downarrow \\ \text{cement particles}}}{CaCO_3} + CO_2 + H_2O$$

or

$$Ca(HCO_3)_2 + CaO ---- \underset{\substack{\downarrow \\ \text{cementing particles}}}{2CaCO_3} + H_2O$$

In acid soils addition of CaO (limming) or phosphate can improved soil structure. Concerning this problem Indian and Chinese scientists have done a lot of studies.

c, Organic cementing agents

It has been reconngized for a long time that organic matter serves as cementing agent. Organic matter in soils includes humus, polysaccharides, protin, lignin and products of microbial activity. The humic substances are predominant, usually, amounting to 50-90% in soils. They cement soil particles by following ways:

(a) The form of organic colloid is changed from sol to gel.

(b) by electrostatic attraction.

(c) by hydrogen bonding.

(d) by cation bridge bonding.

(e) by van der waals force.

Polysaccharides are a intermediate product of microbial decomposition, amounting to about 5-20% in soils. Their cementing action depends on their molecular weight. General speaking, when the molecular weight of polysaccharide attains **higher** [illegible], it exhibits strong cementing action among the particles. Some studies have denoted that if the content of humus in soil is less than 4%, the effect of polysaccharides is more significant, over this value the effect is lower (Greenland, [illegible]).

In addition to mentioned above reasons of aggregation, the change of hydrothermal condition in soils, such as the alternated wetting and drying, shrinkage and expansion, freezing and thawing, and the biological activity, such as root pressure and earthworm, etc. all directly or indirectly influence the aggregate formation.

Slide .

In conclusion of this topic the probable cementing mechanisms of aggregate formation summed by Harris are as follows. He, first of all, devided them into three main types:

I. Domain - Domain

II. Domain - Organic polymer - Domain

III. Quartz - (Silt, Inorgano-organo colloids) - Quartz

In each type there are several kinds of binding forms to be summed.

Slide .

I. Domain - Domain

A. There are cation bridges between the negtive face of clay minerals

Face - Face $\text{Face}^- --- M^{n+} --- \text{Face}^-$

B. There are positive edge site to negtive face.

Edge - Face $\text{EdgeAl-OH}_2^+ --- \text{Face}^-$

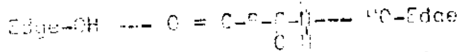
II. Domain --- Organic polymer --- Domain

A. Domain edge --- Organic polymer ---(Domain)

1, Anion exchange. Positive edge site to polymer corboxyl

$\text{EdgeAl-OH}_2^+ --- {}^-\text{OOC} - \text{R} - \text{COO}^- --- {}^+\text{H}_2\text{O-Al Edge}$

2, Hydrogen bonding between edge hydroxyl and polymer carbonyl or amide.



$\text{Edge-OH} --- \text{O} = \text{C-R-}\underset{\text{O}}{\text{C}}\text{-}\overset{\text{H}}{\underset{\text{H}}{\text{N}}} --- \text{HO-Edge}$

3, Cation bridge between negtive site and polymer carboxyl

$\text{Edge-O}^- --- M^{n+} --- {}^-\text{OOC-R-COO}^- --- \text{O}^-\text{-Edge}$

4, van der waals attraction between the edge and polymer.

B. Domain face - Organic polymer - (Domain)

1, Hydrogen bonding between polymer hydroxyl and external or internal (expending lattice mineral) face silicate oxygen.

$\text{Face Si-O} --- \text{HO-R-OH} --- \text{O-Si Face}$

2, cation bridge binding between domain external face and polymer carboxyl or other polarizable groups.

$\text{External face}^- --- M^{n+} --- {}^-\text{OOC-R-COO}^- --- M^{n+} --- \text{Ex.face}^-$

3, van der waals attraction between the domain face and organic polymer.

III. Quartz-(Silt, inorganic and organic colloids)-Quartz

A. Chemical bonds established between quartz surface gèls of hydrated aluminosilicates and active groups of other aggregate constituents.

B. Quartz grains held in a matrix of silt and clay stabilized primarily by:

1, oriented clay particles.

2, irreversibly dehydrated silicate, sesquioxides or humic sesquioxide complexes.

3, irreversible dehydrated humuc materials.

4, silt size microaggregates stabilized by humates.

5, organic colloids and clay domains bonded by mechanism cited under I and II.

***

Clay domain defined as a group of clay crystals oriented sufficiently close together by cations or hydrogen bonds between the crystal faces to have as a single unit.

M^{n+}--- free cation or positively charged metal oxide or hydroxide.

R -- organic polymer with axis horizontal or perpendicular to clay domain.

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The combinating energy of different bonds differs from each other. The chemical bond including atomic and ionic bonds gives 60-100 K.C./Grammol. Hydrogen bond energy --- 5-10 K.C./g.m.. And van der waals force -- 1-2 K.C./g.m.. Therefore, the aggregate formed by chemical bond is more stable than those formed by other ways.

III Aggregate stability

--- Some assessments of indices of soil structure

It is well known, the soil aggregates will be broken under the flooding condition as usual. In that case,

(1) The strength of soil decreases along with the increase of water content, because of reduced cohesion and the softening of cementing materials.

(2) If macroscopic swelling during adsorption, this will cause uneven strains throughout an aggregate so that its structure will be distorted and weakened. This effect of uneven wetting will be greatest when dry clay soil wets rapidly.

(3) Rapid wetting of dry soil can also cause damage by trapped air escaped from pore in aggregates. This behavior can be easyly observed when dry aggregates are immersed suddenly in water.

If the aggregates have been broken by mentioned above reasons, many physical properties of soil will be deteriolated. Such as due to loss of large pores and formation of surface crusting on drying, the water infiltration rate and emergence of seedling can be rapidly reduced, the rain-off and water erosion are increased sharply. Therefore, how to find that the aggregates in water are still stable, and how to measure them as an index for assessment of soil structure, this is very important problem not only for the theoritical, but also for many practical purposes.

Methods for finding how stable aggregates are in water are mostly the wet sieving method introduced early by A.F. Tiuliu (1928) and modified by Yoder and others. As for the assessment of indices of soil structure, there are a lot of recommendations introduced in many publications.

The content of water stable aggregates in diameter of 10–0,25 mm, mean weight diameter of aggregates obtained from wetting sieving method, and the change of mean weight diameters of aggregates obtained by dry and wet sieving methods in recent years are widely used in many countries. The content of 10–0,25 mm water stable aggregates is used as an index widely applied in China, Eastern European and India. The mean weight diameter of stable aggregates is widely used in America and other countries. The value is calculated by following formula.

$$MWD = \sum_{i=1}^{n} \bar{x}_i w_i$$

w_i -- weight of a given size fraction of aggregate

$\bar{x}_i$ -- meandiameter of that fraction.

The change of mean weight diameters of aggregates is widely used in West European.

In addition to mentioned above, some indirect indices of assessment on soil structure, such as the distribution of pore space in soil and air or water permeability of soil are also widely applied in many countries.

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