UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
Region 8
Albuquerque, New Mexico

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PHYSICAL PROPERTIES OF SOILS

Regional Bulletin No. 54
Soil Series No. 6 (Inter-Section Education)
February 1939

INTRODUCTION

This bulletin is the second of the series of technical bulletins being prepared by the Regional Section of Conservation Surveys in the interests of assisting other technicians to acquaint themselves with fundamental and practical principles of soil science and practice. The response to the first bulletin, entitled "The Soil in Relation to Its Parent Material and Environment", was such as to justify the continuation of the series. The attempt has been made to present the information in simple terms and to limit the discussion to simple fundamental considerations. Sources of information for more exhaustive technical consideration of any particular subject discussed will be given by the Soils staff, on request.

PHYSICAL PROPERTIES OF SOILS

by

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In the first bulletin of this series, entitled "The Soil in Relation to Its Parent Material and Environment", the significance of these two factors in relation to the development of a soil was pointed out. The physical properties of a soil, discussed in this second bulletin, bear a close relationship to both parent material and environment, as they are to a great extent dependent upon them. In fact, the physical properties which characterize a given soil indicate to the field man the general nature and degree of development of that soil.

The term "physical properties" as applied to soils refers to those natural recognizable characteristics which express physical conditions. However, in the field of soils, chemical and physical properties are so closely interrelated that it is not possible to make a hard and fast separation between the two. Some of the physical properties of a soil, such as color, compactness, depth of soil profile and thickness of horizons, can be readily determined in the field, while others, such as texture, amount of colloids, pore space and volume weight are more properly and accurately determined in a laboratory.

In order to make clear the meaning of physical properties of a soil, some of the more important ones may be listed. It should be kept in mind that these refer to those properties which are ordinarily considered as purely physical rather than chemical. Chemical properties will be discussed in a later bulletin.

The following list gives the physical properties of soils that are considered the more outstanding and important:

1. Texture
2. Structure
3. Color
4. Consistency
5. Specific gravity, volume weight, and porosity
6. Soil moisture relationships
7. Expansion and shrinkage of soils under varying amounts of moisture.

Each of these will be discussed briefly in order to point out its importance in soils and its relationship to each of the others.

1. Texture. This, perhaps, is the most important of all properties exhibited by a soil since so many other characteristics are directly related to or dependent on soil texture. Texture refers to the size of

mineral grains. There are all gradations in these sizes, from those easily discernable by the naked eye to those beyond the range of a powerful microscope. General terms, such as coarse, medium, fine, or very fine, as applied to a soil indicate the relative size of the predominant grains. Also "heavy", "medium", and "light" are terms used to indicate texture. Heavy and fine or very fine are used synonymously and refer to clay loams and clays, while coarse and light are applied to sands and sandy loams.

A "mechanical analysis" of a soil means the separation of a soil into grain sizes or "separates". Eight grain sizes or separates are usually recognized. They are:

1.	Fine gravel	--	2	-	1	mm.
2.	Coarse sand	--	1	-	0.5	"
3.	Medium sand	--	0.50	-	0.25	"
4.	Fine sand	--	0.25	-	0.10	"
5.	Very fine sand	--	0.10	-	0.05	"
6.	Silt	--	0.05	-	0.005	"
7.	Clay	--	0.005	-	0.002	"
8.	Ultra clay	--	0.002	-	?	"

This percentage distribution of soil separates or grain sizes is known in engineering interpretation as soil grading. Soils containing a wide range of separates are considered to be well graded, while those containing a dominant amount of one or two separates are considered to be poorly graded. Grading has marked influence on volume weight and permeability, which in turn determine the suitability of soils for construction purposes.

According to the official system of textural soil classification used in the United States, definite classes or "textural grades" have been established, based on varying percentage of these separates or sizes of unit soil particles. A total of twenty textural grades have been established on this basis. These are all listed and defined in the table of textures given on the next page. However, for most practical needs not more than about ten of these classes are commonly mapped in any one survey.

If an appreciable quantity of stones occur on the surface, or throughout the profile, any of the classes would be modified by the word "stony", as stony sandy loam, stony clay, etc. If an appreciable amount of gravel occurs, then sandy loam would become "gravelly sandy loam", etc.

The following table shows the proportions of the grain-sizes found in the major textural grades when the mechanical analysis is made by the "Centrifuge Method", using ammonia as a dispersant. (When the method followed involves the use of sodium oxalate or hydroxide as dispersants, with or without pretreatment with peroxide and hydrochloric acid, the increased yield of clay invalidates these proportions: From U.S.D.A. Circular 419.)

1. Soils containing less than 20 per cent clay:

<u>Sands</u> - Less than 15 per cent silt and clay -

Coarse sand (35 per cent or more fine gravel and coarse sand, and less than 50 per cent fine or very fine sand).

Sand (35 per cent or more fine gravel, coarse and medium sands, and less than 50 per cent fine or very fine sand).

Fine sand (50 per cent or more fine and very fine sands).

Very fine sand (50 per cent or more very fine sand).

<u>Loamy Sands</u> - From 15 to 20 per cent silt and clay -

Loamy coarse sand (35 per cent or more fine gravel and coarse sand, and less than 35 per cent fine and very fine sand).

Loamy sand (35 per cent or more fine gravel, coarse, and medium sands, and less than 35 per cent fine and very fine sand).

Loamy fine sandy (35 per cent or more fine and very fine sands).

Loamy very fine sand (35 per cent or more very fine sand).

<u>Sandy loams</u> - From 20 to 50 per cent silt and clay -

Coarse sandy loam (45 per cent or more fine gravel and coarse sand).

Sandy loam (25 per cent or more fine gravel, coarse and medium sands, and less than 35 per cent very fine sand).

Fine sandy loam (50 per cent or more fine sand, or less than 25 per cent fine gravel, coarse and medium sand).

Very fine sandy loam (35 per cent or more very fine sand).

<u>Loams and Silt Loams</u> - With 50 per cent or more silt and clay -

Loam (less than 20 per cent clay, from 30 to 50 per cent silt, and from 30 to 50 per cent sand).

Silt loam (less than 20 per cent clay, 50 per cent or more silt, and less than 50 per cent sand).

2. Soils containing from 20 to 30 per cent clay:

<u>Clay loams</u>

Sandy clay loam (less than 30 per cent silt, and from 50 to 80 per cent sand).

Clay loam (from 20 to 50 per cent silt, and from 20 to 50 per cent sand).

Silty clay loam (from 50 to 80 per cent silt, and less than 30 per cent sand).

3. Soils containing 30 per cent or more clay:

Clays

Sandy clay (from 30 to 50 per cent clay, less than 20 per cent silt, and from 50 to 70 per cent sand).

Clay (30 per cent or more clay, less than 50 per cent silt, and less than 50 per cent sand).

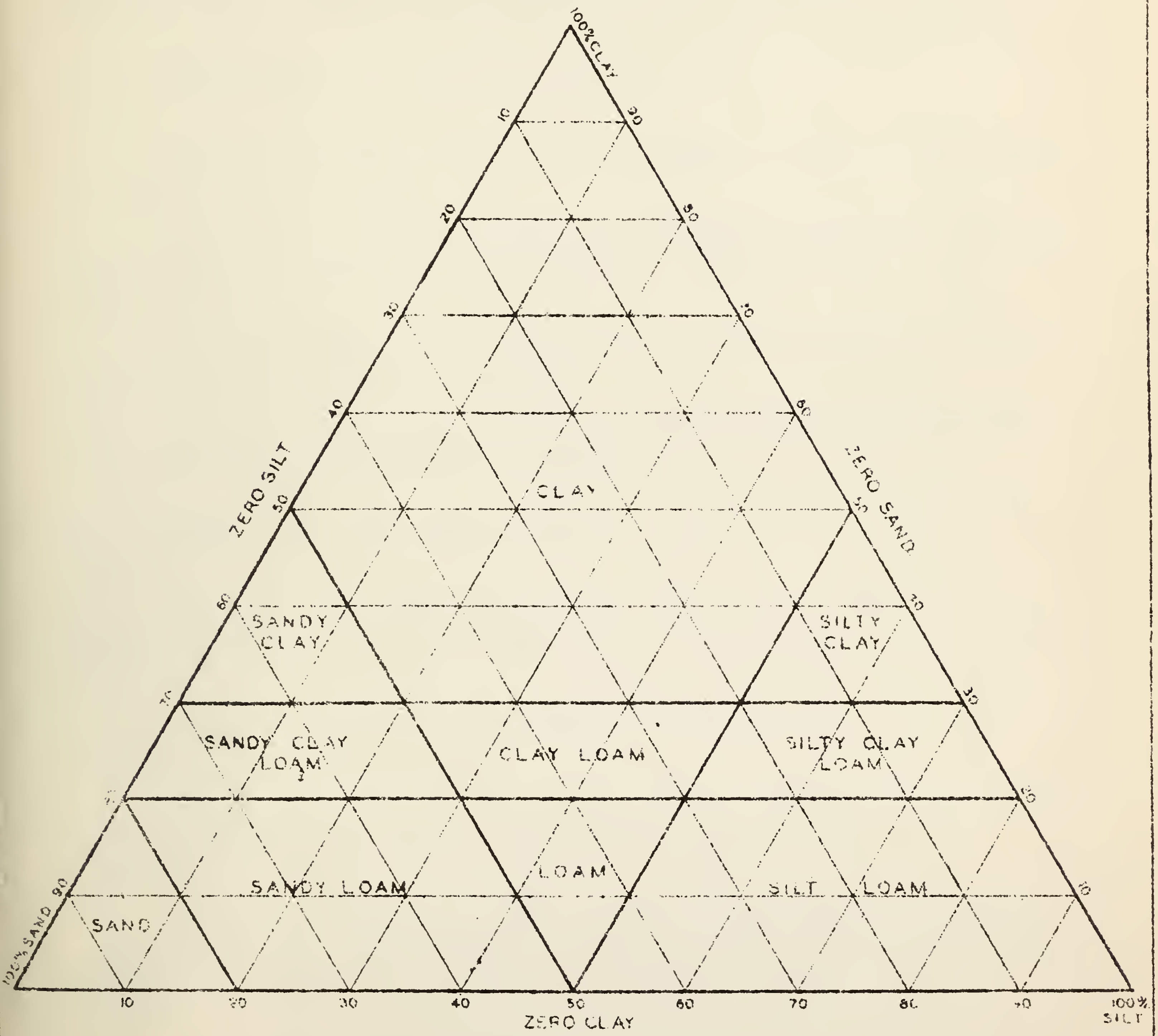
Silty clay (from 30 to 50 per cent clay, from 50 to 70 per cent silt, and less than 20 per cent sand).

The diagram included in this bulletin shows ten of the major soils classes and how the textural name of a soil may be determined after a mechanical analysis has been made of the soil.

To use the diagram, locate the points that correspond to the percentages of silt and clay of the soil in question on the silt and clay lines. From these points draw lines inward paralleling the left side and base of the triangle respectively for silt and clay. The name of the division of the triangle in which the lines intersect gives the class name. This diagram also shows graphically that some soils have a very wide range in percentage of soil separates while others have a very narrow range.

The texture of a soil is determined in the field by rubbing the soil between the fingers. This requires skill and practice and the soils technician should frequently check his ability by "feeling" soils whose textures have been determined in the laboratory. Care must be taken not to confuse soil aggregates with individual soil grains. Very frequently a soil is found in which the very fine soil particles adhere very closely and compactly in granules or aggregates, which gives the impression that the soil has a much coarser texture than that which actually exists. This is especially true of some soils of high lime content found in Region 8. The lime acts as a cementing agent and "binds" the soil particles into aggregates. Before the texture in such soils can be determined the soil should be moistened to the extent that the aggregates are broken down when the soil is rubbed between the fingers. In fact, many soils men always make it a point to judge textures with moist samples rather than dry.

2. Soil Structure. Soil structure refers to the arrangement of


100% CLAY
ZERO SILT
ZERO SAND
CLAY
SANDY CLAY
SILTY CLAY
SANDY CLAY LOAM
CLAY LOAM
SILTY CLAY LOAM
LOAM
SANDY LOAM
SILT LOAM
SAND
100% SAND
ZERO CLAY
100% SILT
10
20
30
40
50
60
70
80
90

the individual soil grains; whereas, texture refers to the size of the individual soil grains. Man's influence over texture is extremely slight, but he may materially alter the structure of a soil by the addition of organic matter, the application of lime, cultivation under different degrees of moisture , etc.

Some of the more common terms used to describe structure are: single grain, massive, fragmental, granular, crumb, platy, columnar, nutlike, and prismatic. Brief definitions of the above terms follow:

Single Grain - Each grain by itself. Particles are not arranged into aggregates, as in dune sand (structureless).

Massive - A soil mass showing no evidence of any distinct arrangement of particles, structureless. May be found in soils of any texture.

Fragmental - Irregular aggregates, angular or rounded, soft or hard, but firm. Commonly found in alluvial (water-deposited) silty or clayey soils.

Granular - Firm, small, angular or rounded aggregates of about two centimeters or less in diameter.

Crumb - Generally soft, small porous aggregates, irregular in shape, two centimeters or more in diameter.

Platy - Thin horizontal plates. If plates are very thin, the structure is sometimes termed laminated.

Columnar - An arrangement of the soil mass into more or less regular columns, separated by long vertical cleavage planes and shorter horizontal cleavage planes. Generally the columns have rounded tops.

Nutlike - Compact, hard aggregates somewhat rounded in shape, usually from one-half to four centimeters in diameter.

Prismatic - Columns broken into sections, quite regular in size, parallel faced, with vertical axes longer than horizontal axes, usually pentagonal or hexagonal in shape.

There are a number of other terms used to describe structure, but these are the more common ones. For complete list of definitions see C. F. Shaw's GLOSSARY OF SOIL TERMS, or Charles E. Kellog's SOIL SURVEY MANUAL.

One of the most important factors which regulate or produce different soil structures is the presence of soil colloids.

One of the principal physical properties which colloids impart to a soil is their cohesive or binding effect of soil particles into aggregates. Some colloids have a much stronger binding power than others, depending upon their chemical nature . Sodium carbonate, commonly called black alkali, greatly reduces the binding power while lime increases

it. These effects have a marked influence on soils through their influence on its structure.

The degree to which colloids can bind the soil into aggregates determines the degree of aggregation of that soil. When these aggregates are bound together strongly enough to resist slaking in quiet water, they are said to be water-stable granules. When they do slake in quiet water, the amount of slaking that takes place is called the degree of dispersion. Therefore, a highly aggregated soil shows only a slight amount of dispersion and, conversely, a highly dispersed soil can show only a slight amount of aggregation.

In clay soils which contain considerable colloids, all of the soil grains or separates may be bound into aggregates. In sandy soils having a low per cent of colloid this may not be true. The colloid may be all used in binding together the finer separates such as silt and coarse clay, leaving a significant portion of the sand grains free as individual grains. Such a soil is still considered to be aggregated if little of the colloid or coarse clay slakes free. Such soils exist in a heterogeneous state in which aggregates are intermingled with single unit sand grains. If the colloid has very little binding power, it does not form aggregates of the fine textured material, and the soil is considered to be dispersed. A small amount of fine material can do much more toward rendering a soil tight and impermeable to water if evenly distributed in the pores between the coarser separates, as in the dispersed soil, than if localized into the granules as in the aggregated soil. For this reason impermeable so-called "slick spots" in dispersed alkali soils of high sand content are common, while aggregated sandy soils are highly permeable.

The degree of aggregation or dispersion of a soil is of vital importance in determining its erodibility, permeability, and suitability for construction. Dispersed soils are highly impermeable, erode much faster under small flows and are treacherous to use in dry construction or where shrinkage may open cracks into a fill or foundation.

So it is evident that the presence or absence and the kind of soil colloids are very important to soil structure which directly affects many other characteristics of the soil.

The particular structure which a soil assumes is a practical consideration from a number of points of view. It influences moisture movement, root penetration, plant nutrition, soil aeration, the movement and distribution of salts and other important conditions. These influences will be discussed at various points in this series of papers in connection with other pertinent subjects which are to be presented.

3. Color. The color of soil is seldom of great importance in itself, except in connection with soil classification. Its greatest importance usually lies in the fact that it frequently acts as an indicator of some other more important characteristic or condition of the soil that is reflected by the color.

For instance, the content of organic matter, which, in turn, is

one of the measures of soil fertility, is indicated by color. A dark color is generally indicative of a soil high in organic matter, and usually, under favorable drainage and climatic conditions, a dark soil is a "rich" or productive soil. The gray colors of the desert and semi-desert soils of Region 8 are due partly to the very low organic content and partly to the high content of lime. In general, it can be said that the lighter colored soils are low in organic matter and the darker colored soils have a high orgaic content. However, certain soils sometimes derive their dark color from high contents of minerals such as manganese or magnetite.

Another important soil characteristic which color may indicate is the condition or adequacy of the drainage of a soil. The red or reddish-brown colors in a soil are usually due to the presence of unhydrated iron oxide. Unhydrated iron oxides exist to a very small degree in excess moisture, such as in poorly drained soils, and when they become hydrated the red color may change to a rusty mottled or bluish gray. In some cases a yellow color also indicates poor drainage. Consequently, a red color generally indicates a well-drained and well-aerated soil, while rusty mottled or blusih gray colors most frequently indicate poor drainage.

Frequently a soil inherits its color from the parent rock from which it was derived and thus is an indicator of the particular geologic material forming the soil.

4. <u>Consistence.</u> As previously discussed, soil structure refers to the arrangement of soil particles within particular soil aggregates. Soil consistence, on the other hand, refers to the degree of attraction or cohesion of the particles for each other in the whole soil mass. When soil particles cohere tightly, they may produce a soil mass that is hard when dry or very plastic when wet. Consistence refers in particular to the varying degrees of looseness or compactness. To describe these characteristics, the following terms are used: Loose, open, mellow, friable, crumbly, plastic, sticky, hard, moderately compact, very compact, and cemented. However, it must be kept in mind that the consistence of a soil changes with changes in moisture content. For example, a soil when dry may be very hard, but with a high moisture content it might be very sticky; also a soil when dry may be quite friable but when wet it may lose its friability. Consequently, when consistence is described it is necessary to describe the moisture conditions also.

Structure and consistence are very closely related. The structure of a soil may be changed, thus resulting in a change of the whole soil mass into a different consistence. For example, a soil with a friable granular structure, and a mellow consistence may be changed by the trampling of many stock or by plowing when too wet, into a puddled, compact condition. Thus, the natural structural condition changes into a structureless mass which has a hard, compact consistence when the soil becomes dry.

5. <u>Specific gravity, volume weight, and porosity.</u> These physical

properties are considered together here because they are very closely related, and the latter two are more or less dependent upon each other. Volume weight and porosity are largely determined by texture and structure, which have already been discussed. Specific gravity of a soil is the weight of the soil particles themselves as compared to the weight of pure water. The specific gravity of a particular soil remains the same whether that soil is loose or compact, since it does not take into consideration the pore space in the soil mass. The purely mineral soils have a very narrow range in specific gravity, 2.6 and 2.7.

One condition may materially vary the specific gravity of a soil; that is the content of organic matter. Thus it may be expected that the surface or A horizon of a soil high in organic matter would have a lower specific gravity than the B horizon or subsoil.

An organic soil, such as a peat, may have a specific gravity well below 1.

The actual weight of a dry soil in any given volume is expressed by volume weight, that is, the number of times heavier the dry soil is than an equal volume of water. For example, a cubic foot of water weighs 62.42 pounds. If it is found that a cubic foot of soil weighs 106.1 pounds, which is about the average weight for sand, the volume weight would be 106.1 divided by 62.42 or 1.70. Volume weight of a soil is often referred to in soils literature as apparent specific gravity. The terms are synonymous. Engineers ordinarily consider volume weight as the weight of one cubic foot of soil.

Volume weight depends on the texture, structure and organic content of a soil. Sandy particles tend to lie in close contact, thus increasing the weight of the soil. Finer textured soils, silt loams, clay loams, and clay have smaller and lighter particles which do not lie so closely together; hence, the volume weight is less.

Volume weight is also closely related to porosity, or the pore spaces in a soil (discussed below). When a soil is compacted, its volume weight increases because of the increase in the volume occupied by the soil particles and the decrease of the pore space.

If it were possible to compact a soil to the extent that all the pore space (or voids, as they are sometimes called) was completely eliminated, the volume weight would approach very closely the specific gravity.

Porosity is a term which refers to the pores or voids between the individual particles and between the aggregates that make up the soil. The pore space of a soil is dependent upon texture, structure, organic content, and degree of compaction. As already mentioned, the coarse-textured soils are heavy (i.e., in weight) because the coarse particles tend to lie in close contact. The fine-textured soils are lighter in weight because the particles are smaller and, because such soils tend to resist compaction. Consequently, the sands and sandy loams generally have less pore space than the finer-textured silt loams, clay loams, and clays. The finer-textured soils have a greater aggregate amount of voids, but the individual voids are much smaller than those of the sandy soils. This explains why water penetrates more rapidly into sands and sandy loams than into clay loams and clays and, as a result, internal circulation of both air and water is greater in the coarse-textured

soils. The proportions of air and water which fill the pore space in a soil are constantly changing as the content of soil moisture changes.

Specific gravity, volume weight and porosity, especially the latter two, are important factors to the farmer, the rancher, and the soil conservationist. For instance, the farmer or rancher should not increase the volume weight of his soils by improper cultivation, or by over-trampling, to such an extent that he would destroy or greatly impair the porosity of the soil.

The conservationist can deal more easily with open, porous soils than with heavy, impervious soils because the former absorb rainfall more readily, conserve moisture and, therefore, are less susceptible to water erosion. But, on the other hand, open porous soils may be more susceptible to wind erosion than heavier soils.

However, in the construction of a dam it is often necessary to increase the volume weight and decrease the porosity by compaction to make the dam resistant to the force of a head of water and to prevent or retard penetration of water into and through the dam.

6. Soil-moisture relationships. The amount of moisture which a soil can hold and the availability of that moisture to vegetation are of extreme importance. Again, practically all the properties which have been mentioned influence the amount and availability of moisture of the soil.

Three forms of soil moisture are recognized: (a) hygroscopic moisture, (b) capillary moisture, and (c) gravitational moisture.

The hygroscopic moisture in a soil is held so strongly by the soil particles that it is non-available or only very slightly so to plants. The amount of hygroscopic moisture is largely determined by the amount of colloids in the soil. It may be very low in a sandy soil or may run as high as 18 or 20 per cent in a clay soil. Hygroscopic moisture is non-liquid and is not capable of movement.

The moisture beyond the hygroscopic water which is capable of only a sluggish movement is referred to as inner-capillary water. It is very closely related to hygroscopic moisture but exists in a liquid condition. The inner-capillary water may be considered as transitional between hygroscopic and true capillary or film water.

The outer-capillary water exists in large pore spaces and as a film over the particles and colloidal material. It is loosely held by the soil though sufficiently strong to resist gravitation.

This form of water moves through the soil, largely by film adjustment. For instance, when the feeder roots of a plant absorb the moisture with which they are in contact, an unstable condition is created near the feeder roots and by film adjustment water from surrounding areas starts moving toward the plant roots to replace the water which has been removed. This will continue until the available moisture supply is used up and then, unless more moisture is added, the plant is forced to go into

a rest period or wilting occurs, or even death may result to the plant. This is called the critical moisture point and this corresponds approximately to what is called the wilting coefficient. It is approximately though not exactly true that the critical moisture point, or the wilting coefficient, is reached when all the outer-capillary moisture has been used up. Thus the wilting point may be reached, in case of a heavy clay soil, when that soil still has as much as 20% moisture, because that moisture is not readily available to the plant roots. Therefore, not only is the amount of moisture a soil can hold an important factor; the availability of that moisture is of prime importance.

By capillary action, moisture may move upward, downward, or laterally in a soil. This is important in irrigation. However, there is often a mistaken idea as to the distance which moisture will move laterally or horizontally from an irrigation furrow for instance. It is often much less than is expected. The distance and rate of this movement depend largely on the texture and structure of a soil. If the crops to be irrigated are dependent for their moisture supply on the lateral movement of moisture from furrows, frequent checks of the soil should be made to determine how far the lateral movement is for a given soil. From this knowledge the irrigation furrows can be properly spaced.

The upward rise of moisture in soils by capillarity is important. Such a rise has been observed to reach a height of more than 10 feet in some soils. Generally the rise is most rapid in sandy soils, but the ultimate heights are much less than in medium heavy-textured soils (loams, silt loams, and clay loams), while the rise is much slower in the latter. Heavy soils high in colloids have a slow rise and the moisture does not reach the height that it does in the medium textured soils, due largely, it is thought, to the swelling of the colloids and the consequent blocking of pore spaces and minute channels in the soil column. Soils containing alkali salts and a small amount of clay have the most rapid rise and reach the greatest height.

Two important effects of capillaryrise are: (1) crops, growing on soils which are in contact with water-table near the surface, may be sub-irrigated; (2) an injurious effect is often a result when the capillary water has dissolved alkali salts which would otherwise be well distributed throughout many feet of soil. As the moisture carrying these salts in solution rises to the surface, the moisture is evaporated, leaving a deposit of alkali on the surface, and within the surface soil.

As soon as the maximum capillary capacity of a soil has been satisfied, any additional water added to the soil will form free water in the pore spaces. This water may be so loosely held by the soil that it will respond to the pull of gravity and move on downward into the soil. This is called gravitational water.

When sufficient water is applied to the soil to replace the air from the pore spaces, it is then in a saturated condition. Unless a soil has good sub-surface drainage, saturation is likely to result in a water-logged condition unfavorable to plant growth. However, if good

drainage is provided, gravitational water becomes a very important means of leaching harmful quantities of alkali from the soil.

7. Expansion and Shrinkage of Soils under Varying Degrees of Moisture. No doubt everyone has observed that clay soils are subject to cracking and checking as the moisture is dried out of them. On the other hand, but perhaps less noticeable, these soils will puff up or expand in volume when water is added. Soils which expand the most are those which, in general, contain the highest amount of colloids. Expansion in soils is due largely to the attraction of water by the soil colloid, thereby making their effective diameters much greater and actually moving them apart. Some colloids expand to a much greater degree than others. Certain pure colloids when in contact with free water have been observed to expand several hundred times their volume. Obviously, the presence of such colloids in a soil will cause a decided expansion of the soil mass when the soil is wetted.

Inevitably, as such soils dry out there will be a reduction in volume, or a shrinkage of the soil mass, which results in settling and cracking as noted above.

Expansion and shrinkage are important, and laboratory methods have been worked out by which they can be measured. One important result of shrinkage is that when cracks and checks are formed, aeration of the soil is improved, the rate and amount of water penetration are increased, organic matter is carried deeper into the soil. As a result, a more favorable structural condition of the soil may be obtained. On the other hand, the results of expansion and shrinkage are not always favorable. Highway departments often have to spend large sums of money to eliminate or minimize these factors in the construction and maintenance of hard-surfaced highways. Also, in the construction of an earthen dam, the engineer often has to plan, at increased expense, against the forces of expansion and shrinkage of the soil material.

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