THE PHYSICAL PROPERTIES OF SOIL

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As an introduction to the discussion of soil, it might be well to ask, "What is soil?" The answer to this question depends largely on who is doing the asking. To the mother it is the dirt that gets on the child's clothing; while to the gravel quarry operator it is the overburden which must be removed to get at the gravel. A soil scientist working for the conservation service considers soil as a naturally occurring body on the landscape consisting of genetically related layers formed by the combined efforts of climate and vegetation acting on a particular parent material over a long period of time. To anyone in production agriculture, like the farmer, gardener or turf manager, the soil is that material (organic or mineral, synthetic or naturally occurring) which serves as the support medium for the growth of plants.

Regardless of the way people look at it, however, each soil possesses certain chemical and physical properties; and an understanding of these characteristics is essential if the soil is to be used wisely no matter what the purpose. The chemical properties of soil will be discussed by Drs. Kussow and Schulte. In this article, the emphasis will be on the physical properties of soil. By physical properties we mean those which can be sensed by the user, that is, felt or measured (like weight, depth, temperature, etc.). *It should be noted that it is quite common to find soils in which the physical properties are more limiting to plant growth than the chemical conditions of the same soil.*

Physically all soils are composed of solids (or particles) and spaces (voids or pores) between them. The first part of this discussion will deal with those physical properties related to the solid phase of soils, while the second part concerns those physical properties which are related more to the pore spaces in the soil.

Part 1. Physical Properties Associated With Solid Phase of Soil

A) Composition of soil solids. The solid portion of soil consists of organic and inorganic material having the following composition:

1. Soil organic matter can be dead or alive animal or plant material and may range in size from macroscopic to microscopic. Thus, it includes such diverse things as earthworms to bacteria and from roots to humus particles so small they can be seen only with the aid of an electron microscope. Humus is the colloidal and very active fraction of organic matter manufactured in the soil by many of these same organisms. Soils consisting largely of fibrous organic matter are termed Peats, while those composed mainly of non-fibrous organic matter are called Mucks. About 8% of Wisconsin's land surface (or approximately 2.8 million acres) are classified as organic soils. Peats are named according to the plant material from which they formed. Thus, there are woody, mossy (sphagnum and hypnum), reed-sedge peats, etc. In turf management peats are often used to condition soils and are applied at the rate of 10-20% by volume (foot printing generally occurs as values exceed 20%).
2. Soil inorganic matter consists of mineral particles derived from the weathering of parent rock. These particles are classified on the basis of size into one of three groups, called soil separates.[1/]

B) Soil separates. The three soil separates and their size limits are:

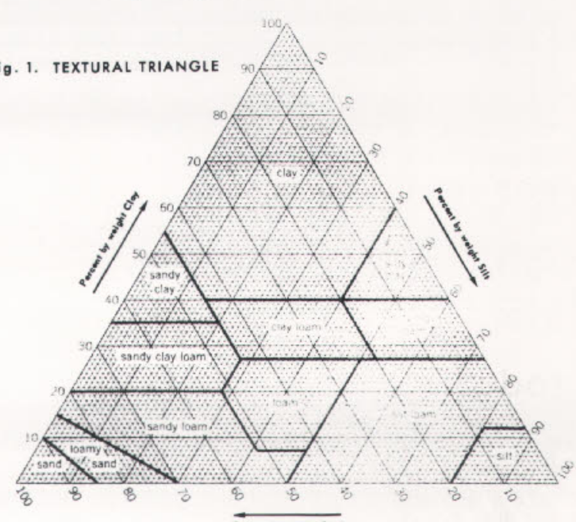
1. Sand (2 to 0.05 mm in diameter). In the metric system, 25 millimeters are approximately equal to 1 inch.
2. Silt (0.05 to 0.002 mm in diameter)
3. Clay (less than 0.002 mm in diameter)

Note: Particle size is important because it determines the surface area exposed by the various soil separates, which in turn determines their physical and chemical activity. Thus, clay is more active than silt which is more active than sand, and the degree of activity is related inversely to particle size. For example, 4 lbs. of a typical sand will expose approximately 40 sq. ft. of surface area. For the same weight of silt the area increases to 4,000 sq. ft., whereas, 4 lbs. of clay exposes about 40,000 sq. ft. (nearly 1 acre), and in the case of colloidal clay the value is approximately 10 times this or 10 acres of area.

C) Soil texture. The relative proportion of the three soil separates impart to each mineral soil its distinctive feel or texture. There are 12 mineral soil classes as seen in the textural triangle in Fig. 1. Depending on their texture, these 12 classes can be arranged into three groups: coarse, medium and fine, as given below:

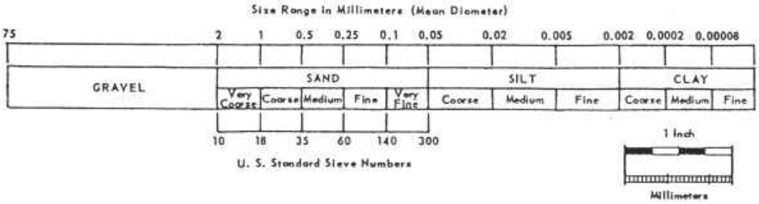
1. Coarse textured soils (CTS) are sand, loamy sand and sandy loam.
2. Medium textured soils (MTS) are loam, silt loam and silt.
3. Fine textured soils (FTS) are clay, sandy clay, silty clay, clay loam, sandy clay loam and silty clay loam.

Fig. 1. TEXTURAL TRIANGLE



[1/] Mineral particles greater than 2 mm in diameter (gravel, pebbles, etc.) are not considered unless they exceed 20% by volume of the soil. Then the soil's name reflects the modification, for example, gravelly loam.

COMPARISON OF PARTICLE SIZES IN USDA SYSTEM



Note: In Wisconsin approximately 33% of the surface mineral soils are CTS (of which sands and loamy sands predominate), while about 50% are MTS (with silt loams dominating) and the remaining 17% are FTS (of which clays, clay loams and silty clay loams dominate). The distribution of these soils in Wisconsin is given in the accompanying map and shows that in the southern part of the state silt loam soils are the most common textural class, while in central Wisconsin sands predominate. Clayey soils are found along the coastal areas of both Lake Michigan and Lake Superior.

Fig. 2. Textural distribution of surface soils in Wisconsin.

D) Soil structure. If soil texture is defined as the feel imparted to the soil by the relative proportions of the soil separates, soil structure refers to the arrangement of these same separates in the soil. Structure is classified according to grade, type and class.

1. Grade of soil structure refers to the degree that the soil separates are aggregated (that is, clumped together) and varies from strongly through weakly aggregated to no aggregation or structureless.
   a) Aggregated grade. The aggregation process involves two steps. First, the soil particles must be brought together. This is done chemically by flocculation and physically by drying, root growth, tillage, earthworm activity, etc. Secondly, the clumped particles are then cemented together to form an aggregate or ped, which is characterized by lines of weakness (called cleavage) between adjoining surfaces and by many different pore sizes within and between the peds. Humus, iron oxides, clay materials and carbonates are excellent materials that serve as cementing agents in soils.
   b) Non-aggregated or structureless grade. Two kinds exist, they are:
      i — Single grained. This is seen in CTS which do not contain sufficient cementing agents to bind the soil particles together and, as such, they occur as non-coherent, single grains. Loose sand is an excellent example of this grade.
      ii — Massive. This is seen in medium to fine textured soils (M-FTS) in which the aggregated structure has been ruined either physically by puddling or chemically by defocculation. The latter occurs in soils high in exchangeable sodium, such as coastal regions along oceans or other bodies of salt water. The physical abuse or puddling of soil is by far the more common, especially in Wisconsin, and occurs when the soil is worked or walked on when it is too wet (in the plastic form of soil consistence, to be discussed shortly). In the massive state the soil particles adhere to one another in masses, which upon drying are referred to as clods. These differ from peds in that they have no cleavage lines of weakness and exhibit few if any large or medium size pores. Soils in the puddled condition have been likened to concrete. This is an apt comparison because plant roots, tillage implements, air and water have a difficult time penetrating them, which makes growing plants in these soils something less than enjoyable.
2. Type of soil structure refers to the shape of the individual soil aggregate. Some of the more common structural types and their relative shapes are:
   a) Granular and crumb (spheroidal shapes). This is the ideal type of structure to have in the surface layer of M-FTS.
   b) Blocky and nuciform (cubic shapes). Typical structure seen in the subsoil of M-FTS.
   c) Platy (plate-like shape). Some M-FTS will have this type in their subsoil which causes internal drainage problems, since plates behave like shingles and impede downward movement of water in these soils.
3. Class of soil structure refers to the size of the aggregate or ped. It is an important consideration when planting seed. Small seeds (like bentgrass) require a finer seedbed than do large seeds, like ryegrass.

E) **Soil consistence.** To have a well aggregated soil is one thing; to maintain it is another. Soil consistence is the ability of an aggregated soil to withstand deformation and it varies with the texture, moisture and organic matter content of each soil. Some of the more common forms of soil consistence are:2/

1. Dry state. M-FTS are most resistant to deformation when soil is dry.
2. Friable state. The soil is moist. This is the most desirable form of soil consistence in M-FTS for tillage, root penetration, walking on the soil and improving its aggregation through aerification.
3. Plastic state. In this form, M-FTS are most susceptible to deformation. Working or walking on an aggregated soil in this state (water content between moist and wet) results in the destruction or puddling of the aggregates, leaving the soil in a massive (cloddy) condition upon drying. M-FTS in the plastic state of consistence should not be worked or walked on but rather should be allowed to dry out until the friable state of consistence is reached. An exception to this rule is when the intent is to puddle the soil, as in the construction of seepage barriers in earthen dams or to seal the bottom of man-made lakes, ponds or land-fill sites.
4. Liquid state. In this condition the soil is wet and behaves like a liquid. That is, it will tend to flow under an applied force. It is in this state that soil on a slope is subject to landslides. Also, it is at this form of soil consistence that cave-ins occur in tunnels or ditches.

F) **Soil conditioning agents.** These are mineral or organic materials which are used to improve the physical condition of soils. *It is interesting that these materials are equally as effective in CTS as they are in M-FTS, although for entirely different reasons.* In CTS the soil conditioning agent contributes the medium to small size pores these soils (as we'll see shortly in Part 2), are lacking, whereas, in puddled M-FTS the conditioning agent supplies the large pores which these soils need. Some common examples of these materials are:

1. Mineral conditioning agents. Calcined (fired) clay, diatomaceous earth, perlite and expanded vermiculite.

Note: Do not use the latter two materials on soils subject to traffic. Their best use is for flower beds and potting mixtures.

2. Organic conditioning agents. Rotted sawdust, compost, rotted manure and peat. With regard to the latter, it should be noted that experts prefer woody to mossy peats (and hypnum over sphagnum), with reed-sedge a poor third for conditioning turf soils. *In no case should one use sedimentary peat for this purpose due to its high content of fine mineral material.*

Table 1. Sand sizes by turf use.*

SAND PARTICLE SIZE CLASSIFICATION TABLE

	*ASTM Mesh		Sieve Opening Millimeter	Sieve Opening Inches		
	4		4.76	0.187		
	5		4.00	0.157		
	6		3.36	0.132		
	7		2.83	0.111		
	8		2.38	0.0937		
	9		2.00	0.0797		
	10		1.68	0.0661		
	12		1.41	0.0555		
	14		1.19	0.0469		
	16		1.00	0.0394		
	20		.84	0.0331		
RANGE	24		.71	0.0278	COARSE	
FOR	28		.59	0.0234		
BUNKER	32		.50	0.0197		
USE	35	RANGE	.42	0.0165		IDEALLY –
	42	FOR	.35	0.0139	MEDIUM	MINIMUM
	48	SOIL	.30	0.0117		OF 75%
	60	MIXES	.25	0.0098		MEDIUM
	65		.21	0.0083		SAND
	80		.18	0.0070		
	100		.15	0.0059	FINE	
	115		.13	0.0049		
	150		.11	0.0041		
	170		.09	0.0035		
	200		.07	0.0029		
	250		.06	0.0025		
	270		0.5	0.0021		
	325		.04	0.0017		

*Quality Sand Bunkers, Stanley J. Zontek, Vol. 2, May 1984 The Grass Roots.

Part 2. Physical Properties of Soil Associated With Pore Spaces of Soil

A) **Soil porosity.** Two aspects of this physical property are most important to plant growth, namely, the amount and size distribution of soil pores.

1. Amount of soil porosity determines the storage capacity of the soil for air and water, in addition to serving as the space through which roots penetrate the soil. Contrary to popular belief, CTS generally have the least amount of pore volume of all soils (about 80% as much as M-FTS). The reason they give the appearance of being "light" soils is due to their lack of aggregation, which gives them a loose, single-grained effect. On the other hand, M-FTS have about 25% more pore volume than CTS, yet they are commonly referred to as "heavy" soils, due to the fact that they contain sufficient fine material to cause the soil particles to adhere to one

2/It will be noted that these forms of soil consistence apply essentially to M-FTS. Soils like sands do not contain enough fine material to be aggregated and hence have a single grained structure. Now this can be both good and bad. The latter occurs, as we'll see in Part 2, due to the sand's limited porosity (both in amount and size distribution) which makes these soils droughty. The beneficial effect of a single grained structure, however, lies in the fact that these soils, with their lack of aggregation, can't be ruined even under severe physical (or chemical) abuse. This explains why sand is used in the construction of USGA Spec Greens and why it's preferred for topdressing and in bunker or sand trap use. In this regard, it should be emphasized that a well sorted sand of medium to coarse size is recommended, as given in Table 1.

another (either as peds or clods, depending on the soil condition as we have seen) and this produces greater friction or drag.

Note: The terms "light" and "heavy" in connection with soil refers to the amount of draw bar pull required in tilling the soil. CTS require less power than M-FTS, hence they are referred to as "light" soils whereas M-FTS require more power and are called "heavy" soils. In terms of actual weight (or mass) per unit bulk volume, one can quickly see from Table 2 that the CTS typically have the greatest bulk density and the least amount of pore space of all the soils.

Table 2. Typical values for some soil physical properties.

Soil Texture	Bulk Density g/cm³	Bulk Density lbs/ft³	% Soil Porosity
Sand	1.6	99.8	40
Silt loam	1.3	81.8	50
Clay	1.2	74.9	55
Muck	0.4	24.9	65
Peat	0.2	12.4	85

2. Pore size distribution. In CTS the majority of pores are large, which also helps to give these soils their "light" appearance. Large pores are ideal for taking in water and draining away the excess. However, they do not hold water very well and, therefore, CTS tend to be droughty. On the other hand, M-FTS which are puddled tend to have mainly very small pores (like concrete), thus causing them to be poorly drained. In the aggregated state, however, M-FTS have the ideal pore size distribution. That is, they have all pore sizes. . .small to medium sizes within and between the smaller peds and large size pores between the medium to larger peds.

B) Soil water. From the standpoint of water efficiency, a good soil is one which takes in water easily, drains away the excess readily and stores sufficient water between rains or irrigation to supply the needs of plants growing in the soil.

1. Infiltration is the entry of water into the soil. It is important because water that doesn't enter the soil obviously is not much use to plants growing in the soil. Moreover, water that doesn't enter the soil may be ponded on the surface, where it induces toxic reactions in the soil by preventing air exchange and destroys soil aggregates by softening the cementing agents. Also, if soil is on a slope water may runoff the surface and unless controlled can cause erosion and pollution problems. As stated earlier, soils with large pores have good infiltration rates. Thus, the importance of maintaining a well aggregated condition in M-FTS.

Note: CTS like sands, with their preponderance of large pores, have excellent infiltration rates. For this reason coarse sand (or fine to medium gravel) is often recommended for use in the construction of slit trenches; however, it should be emphasized that the effectiveness of these materials will be severely impaired if one then covers them with a layer of M-FTS as a means of inducing grass to grow over the slit.

2. Water storage. Water is held in soil by the forces of adhesion and cohesion. Water is attracted to the surfaces of soil particles by the force of adhesion (and the finer the particles the more surface area that will be exposed to this force as we've seen earlier). The force of cohesion is responsible for holding water in the pore spaces between these particles due to the attraction of one water molecule for another, creating a bridging effect in the water. Approximately half of the water stored in soil is available to plants growing in the soil (the other half is held so tightly to the soil particles and in the very fine pores as to make it unavailable for plant use). M-FTS generally have about twice the available water supply as CTS. In terms of plant use this means that in each foot of M-FTS, there exists about a two week or more supply of water, whereas, a foot of CTS holds about one week or less supply. The importance of soil depth favorable to plant roots becomes readily apparent, as does the rooting depth of plants. Thus, a soil may be deep and contain a good supply of available water but if the plant (like **Poa annua**) is shallow rooted, especially when cut at green height, it will soon be subject to desiccation.

Note: The construction of greens according to USGA specifications utilizes two physical properties of CTS which we have already mentioned and another basic principle of soil physics as we shall shortly see. For example, USGA spec greens are constructed out of sand because of their a) excellent infiltration rates and b) resistance to compaction, even when heavily trafficked under wet conditions. However, as with all sands, they tend to be droughty and it is in this regard that use is made of a fundamental law in soil physics, namely that the flow of water from a smaller to a larger pore space only occurs under conditions of saturated flow. That is, water cannot drain from a medium to coarse sandy topsoil that is underlain by fine gravel until the overlying layer of sand adjacent to the gravel is saturated. Only then can any free water be drained. In essence what this does is to create a perched water table above the gravel layer that increases the water storage capacity of the otherwise droughty sand. In short, it can make the sand hold as much water as some loamy soil but without the danger of becoming puddled when the golfers walk on it or maintenance equipment is driven over it. Truly, this is the best of all possible worlds for golf (or any athletic) turf.

3. Soil drainage. As discussed earlier, surface draining is necessary for good plant growth (certain plants like paddy rice are exceptions). Equally important is the drainage of excess water that has entered the soil, because unless this water is removed, good aeration is impossible and plants which are unable to respire cannot absorb nutients, including water. It may seem paradoxical that plants in a waterlogged soil could actually suffer from lack of water and wilt. Yet such a condition was observed a few years ago on national TV during the U.S. Open when play

had to be stopped so that the maintenance crew could cool the desiccating turfgrass by syringing it, in spite of the fact that prior to the tournament the course was deluged with rain. This so-called condition of "wet-wilt" arises whenever the plant is unable to respire properly, as in a wet, compacted soil. Poor aeration can also lead to deficiencies of nitrogen, potassium and iron, any one of which can produce the chlorotic discoloration often seen in turf trying to survive in poorly drained, compacted soils. Soil drainage affects plant growth in yet another important way, namely through its effect on soil temperature.

C) **Soil temperature.** The specific heat of water is about five times that of a dry mineral soil. That is, the heat required to raise the temperature of water 1°C is five times greater than that needed for an equal weight of soil. Thus, a wet, poorly drained soil is generally a cold soil and improving the drainage (either surface or subsurface) helps warm the soil. This also explains why plants growing in a CTS get off to a faster start in the spring than those in a M-FTS. Thus golf courses on sandy soils are the first to open in the spring, in northern climates, whereas, those on organic or clayey soils open later. Other ways of affecting soil temperature include irrigation or syringing, which produces a cooling effect when the water evaporates. In this regard it should be noted that a transpiring grass plant can be considerably cooler (as much as 10°F) than one that is not. Thus well cared for lawns and shade trees, whether they be in the yard or a home or on a golf course create a more pleasant environment even aside from their aesthetic attributes.

UW TURFGRASS RESEARCH RECEIVES CUSHMAN TRUCKSTER AND ACCESSORIES FROM OMC/LINCOLN AND WISCONSIN TURF

The departments of Plant Pathology, Soil Science, Horticulture and Entomology recently received the free use of a Cushman turf vehicle for turfgrass research. The award was made possible by OMC/Lincoln and Wisconsin Turf Equipment Corporation. Dr. Bob Newman and Dr. Gayle Worf accepted the keys from Curt Larson, General Manager of Wisconsin Turf, on May 29. The unit is provided at **no cost** to the UW—Madison and has a total package value of over $12,000. OMC/Lincoln started the program in 1982, and company executives feel the student exposure and training will be beneficial to them as they pursue their turf management careers after graduation. This is the first year the University of Wisconsin received this important support.

The award is from OMC/Lincoln and Wisconsin Turf.

The unit is fully equipped and available for use for all of 1985.

Curt Larson presents Bob Newman and Gayle Worf the Cushman keys.