In one course we wanted a very large area of sand hazard. We required an elevation of at least 4 feet to provide proper visibility. There was at this point a large bunker about 7 feet high and about 20 feet long. This mound was all top soil, so we carted it to the compost pile to be used for topdressing, and then we dug up enough of the surrounding area to make a round mound about 6 feet in diameter and about 4 feet high. The crown of this was made fairly flat and sodded. The sides were sloped enough so that sand could be kept up to the edge of the sod. An area around this mound to the extent of about 2,000 square feet was dug just deep enough to retain a fairly thick layer of sand. Scattered over this area we made numerous small mounds which were completely covered by sand. The drainage from this hazard was entirely a surface matter and, fortunately, one side was a little lower than the other and we have had no trouble at all with it. It has also turned out well from the viewpoint of play.

This brief communication is given from one inexperienced person to those of you who are equally inexperienced with the hope that you may profit by our mistakes as well as our successes.

Physical Soil Factors Affecting Turf Growth

By O. J. Noer

Neglect to investigate thoroughly physical soil relationships preliminary to improving poor turf by fertilizer or other means may lead to failure. Unfavorable soil conditions frequently overshadow everything else, and until corrected defeat any program of improvement. Several years ago an otherwise excellent course possessed two very poor greens. When fertilizer failed to effect improvement, excessive shade was held responsible. Investigation, however, revealed faulty construction to be the major cause. The seed bed consisted of a 2-inch layer of peat superimposed upon 4 inches of beach sand. Fortunately the underlying soil was excellent, so deep plowing to thoroughly incorporate the sand and peat with the deeper soil corrected the difficulty and, today, these greens are the equal of any on the course. While this is admittedly an extreme case, there is great need for more careful consideration of physical soil characteristics, particularly on greens. The use of too heavy top soil during construction often retards and, occasionally, prevents the establishment of good turf. Consolidation takes place and prevents the free entrance of air and water into the soil.

Besides a multitude of small mineral particles and organic matter, soil contains water and air, all of which are essential to normal turf growth. Each cubic foot of good surface soil consists of approximately 50 per cent solid matter, 25 per cent air and 25 per cent moisture or water. The organic matter rarely constitutes more than 5 per cent of the solid soil substance. Turf plants anchor themselves to the soil by means of an extensive root system, and depend upon it for water and mineral food elements. Insoluble plant food elements dissolve in the soil water and both are then imbibed by the minute root hairs. Without energy life is impossible, a rule to which roots are no exception. They breathe to obtain oxygen and release energy. The process is one of slow combustion, and is similar to the respiratory process of animals.

The water-holding capacity of the soil and the amount of air space depend upon the size and arrangement of the individual soil particles. Differences in the amount of surface depend upon size and determine the capacity to hold available water and affect the rate at which solution of plant food takes place. Careful selection of soil for use on greens with these facts in mind minimizes subsequent maintenance problems.

The general term "texture" refers to the size of the soil particles. Thus, sands, loams or clay soils are said to be coarse, medium or fine textured. For practical purposes the individual particles are arbitrarily grouped into seven classes; namely, fine gravel, coarse sand, medium sand, fine sand, very fine sand, silt and clay. The limits of the various classes are determined by their relative value in affecting the physical properties and crop-producing powers of the soil.

The extreme variation in size is striking. Approximately 25 grains of coarse sand placed end to end span an inch, whereas more than 5,000 clay particles are required to span the same distance. Differences in size also account for the enormous differences in the numbers of particles in a given volume. In one grain (less than a teaspoonful) there are approximately 45 billion clay particles, 65 million silt, 2 million very fine sand and only 2,000 coarse sand particles. Is there any wonder that comparatively small differences in amounts of a particular class of particles often profoundly influence soil properties?

Soils never contain particles of only one size although uniform particles may predominate. Based on texture a soil may be a sand, sandy loam, silt loam, clay loam or clay. Sands contain 80 per cent or more of sand, and the larger the individual particles, the coarser the sand. Only 30 per cent of clay is sufficient to make a soil a clay. The loam soils are intermediate in composition.

Clay is more effective in modifying the texture of a soil than the same amount of sand due to the unusual properties possessed by it.

When clay is puddled, or worked when wet, the minute particles pack so closely that even their layers prevent the passage of water. Moist clay is plastic and can be worked into shapes which it still retains upon drying, and the mass becomes very hard and tenacious. If clay is suspended in water, the small particles remain in suspension almost indefinitely, but by the addition of small amounts of certain substances such as lime, gypsum, etc., the minute particles clot to form larger aggregates which rapidly settle to the bottom of the container. This power to clot occurs in the soil and plays a very important part in the management of soils high in clay. When the clay clots it is in a state of aggregation and the soil behaves as though it were composed of coarser particles. Just as the potter works clay to break the aggregates down into the ultimate particles to make it more plastic, so working clay soils when too wet destroys the aggregates and makes the soil more clayey than before. The soil then becomes more impervious to the passage of water and air, and dries into tenacious hard lumps. To make it tractable is difficult and requires considerable time. This may be accomplished by alternate freezing and thawing, incorporation of organic matter, and is furthered by the action of such substances as lime, gypsum, etc.

While texture is of great importance and determines the ultimate producing power, the arrangement of the individual grains is almost equally important. Texture refers to the size of the particles, but their arrangement determines soil structure. The structural condition influences the circulation of air and water in the soil, both very essential when turf is growing actively. In clean sand each individual particle is an individual unit and has but a chance arrangement in relation to the surrounding grains. In highly fertile soils the particles are bunched and held in groups, granules or crumbs. This arrangement is especially essential in fine-textured soils (clays, clay loams, etc.). Granulation with the formation of crumb structure enables these soils to function as though they were more or less coarse grained.

The spaces existing between the individual particles constitute the air space, more commonly called pore space. Theoretically, in a soil made up of equal sized spheres in contact with one another, the amount of pore space depends solely upon arrangement and not on the relative size. Thus a cubic foot of marbles contains as much pore space as a cubic foot of shot. In columnar order the pore space is about 47 per cent and in oblique order, 26 per cent. If small spheres exist within large ones, the pore space is materially increased and theoretically may reach 75 per cent. This is the condition approximated in well-granulated soils. When there are spheres of several sizes, the smaller ones may so completely fill the spaces between the larger ones that the pore space is almost completely eliminated. This is the condition in puddled clay soils. Working clay soils when too wet forces small particles into the spaces between the larger ones, and the granular structure is destroyed. This frequently happens during construction in wet seasons. The bad effect of several days plowing on heavy soils may be noticeable for several years.

Soil grains are unequal in size and irregular in shape, so the ideal conditions mentioned are only approximated. In the fine-textured soils the small particles do not settle so closely in proportion to their size as do the sands and consequently contain relatively more pore space. The relation of texture to pore space for some soils under field conditions is as follows:

	Per Cent Pore Space
Clean Sand	33.50
Fine Sand	44.00
Sandy Loam	50.00
Silt Loam	53.00
Clay Loam	56.00

Turf grasses, in common with other plants, draw enormous quantities of water from the soil. Most of the water is evaporated from the leaves. Investigation shows that from 200 to 500 pounds of water are evaporated for every pound of dry matter produced. It is safe to say that 5,000 barrels of water are evaporated during the production of 1½ tons of grass, an amount frequently produced on each acre.

Turf roots draw only upon the water which surrounds the individual soil particles. The water exists in the form of a film and is called capillary water. Soils made up of small particles hold the most water because of the extensive internal surfaces. Loams contain from two to three times as much film water as sands. Soil structure also affects the water-holding capacity. Loosening the structure of sands often lowers its moisture-holding capacity. The individual soil particles are so far apart that formation of a continuous film is prevented. Crumb structure in clays increases the supply. Water is held around the individual particles within the granules and also surrounds the compound granule.

The roots can not acquire all the capillary water held by the soil. Water is most easily taken when the films are thick, and as the thickness of the film is reduced it becomes increasingly difficult to obtain water until a point is reached where the water is held so firmly to the soil grain that the turf begins to wilt. Sands contain only about 3 per cent capillary water when wilting begins, whereas clay loams may still contain 15 to 20 per cent capillary water, but the total amount of water held by sandy soils is so much smaller that the amount available for plant use is small. While light rains following periods of drought have relative high efficiency on sands, due to the small amount of internal surface, they may be wholly ineffective on the heavy soils with thin, tremendous internal surfaces.

The diminishing supply of capillary water in the surface soil is frequently partially replenished by capillary rise. Fine-textured soils have the greatest capacity and can move water to greater heights than the coarser soils, but the rate of movement is often so slow for clay soils that plants perish before water can be brought up from the subsoil to meet the demand. The friction is so great that the actual movement is very inefficient. All things considered, it is the intermediate loam soils which most readily meet the needs of the growing turf for water, provided the water need be moved only over moderate distances.

When soils become dry the water movement is greatly retarded because dry soils resist wetting. Movement is also slower when the films become very thin due to the friction offered by the particles.

Any discussion of physical soil properties is hardly complete without at least some mention of the important rôle played by organic matter or humus. Aside from the fact that it is the great natural source of nitrogen, it exerts pronounced effects upon soil structure and increases the water-holding capacity. Humus acts as a weak cement and holds the soil particles together, thus it serves to bind the coarse-grained sandy soils, and by forming aggregates of the finest clay particles tends to make the heavy clay soils more open. The presence of only small amounts of humus are needed to produce marked changes.

Humus has a tremendous water-holding capacity, but much of the water is held so tenaciously that turf roots can not utilize it; yet it is a well-known fact that soils well supplied with humus resist drought better than those low in humus. The difference is probably not so much in the greater amount of water held as in that the humus soil absorbs a large amount of water temporarily during a heavy rain and then lets it work more slowly down into the soil. Water is thereby retained within reach of the plant roots for a longer time.

It is doubtful if humus should be used as the only soil modifier on sandy soils, particularly in the warmer sections of the country. Under these conditions it rapidly disappears, being utilized by the soil bacteria. If fine-textured soil is available and used with the humus material, the beneficial effects of the minute mineral particles will persist after the humus disappears.

Soils for use on greens should be selected on a basis of texture and not color. Black color is an indication of humus, but if clay is the predominating mineral constituent, a light-colored loam is much more suitable. Everything considered, the best soils are those of intermediate texture—the sandy loams, loams and silt loams. These require a minimum of supplementary material such as sand or organic matter to make them suitable for topdressing material. They have a large water-holding capacity, are provided with ample pore space, move water rapidly, and quickly develop a desirable soil structure. Sands have too low water-holding capacity and clay soils, even under the best management, are apt to become hard.

Clay soils require relatively large amounts of sand to effect material change in their structure and reasonably coarse sand must be used. Relatively less clay effectively modifies sandy soils. These are the same principles which underlie the grouping of soils into different classes.

It is almost hopeless for the average club to modify the texture of fairway soils by the addition of sand or clay, due to the great expense involved. Soils should be placed in the best possible condition prior to seeding. Heavy soils should be plowed only when moisture conditions are favorable, even at the expense of a few days' delay. If time permits plowing in the year preceding seeding, the structure will be materially improved by alternate freezing and thawing during the winter. A green manure crop, preferably a legume, plowed under, will add beneficial organic matter. If the soil is acid, the acid legumes should be used. When turf is once established and maintained in thrifty condition, it will materially improve structure on heavy soils. As new roots form the older ones die. Decay of the dead roots augments the humus supply, and as the mass of new roots push forward, granulation and development of desirable crumb structure takes place.

Experiences with and Opinions on *Poa annua* in Putting Greens

During this season the subject of *Poa annua* has attracted more attention and caused more discussion than usual. The fact that the putting greens at Oakmont, where the Open Championship was played, are largely composed of this grass and that the weather this summer, particularly in the North, was unusually favorable to its long continued growth probably accounts for the unusual interest shown. Its value as a putting green turf seems to be governed by local conditions, by the kind of turf invaded by it, and by personal opinion as to its own particular merits, concerning which there is by no means lack of controversy.

In the Metropolitan District, Mr. Robert White believes that it not only makes a good putting turf but that from 75 percent to 90 percent of the turf in old greens is composed of *Poa annua* until the middle of