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AERIFICATION OR CULTIVATION OF ESTABLISHED TURFGRASSES

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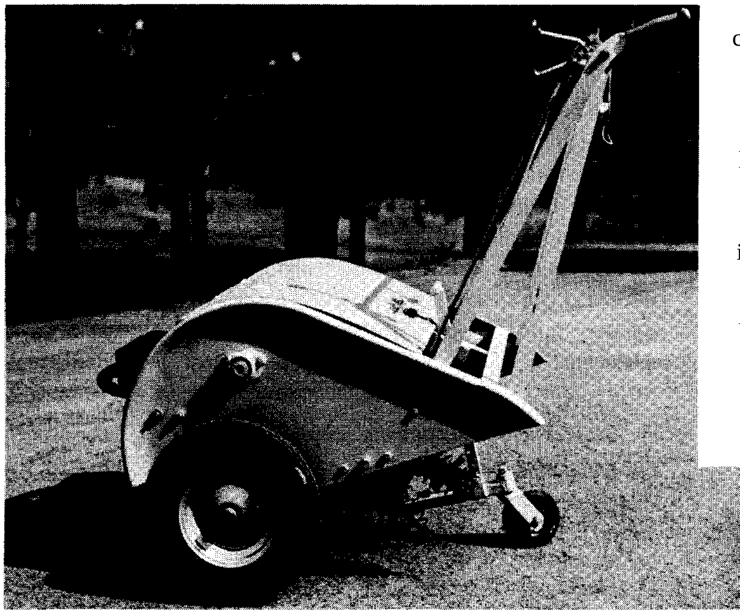
The practice of Turfgrass aerification or cultivation has become an accepted and regular practice on many golf courses and other turfgrass areas in the United States. While the benefit from aerification have been demonstrated and described numerous times a review of our present knowledge of this practice may be worthwhile.



Turfgrass cultivation is the mechanical breaking of compacted surface soil and matted turf without excessive disturbance of the grass plants. This can be accomplished by a variety of tools which remove numerous small, uniformly-spaced cores of soil to a depth of several inches or by spikers which merely punch, cut or tear these openings. There is no experimental evidence of the superiority of one type of turfgrass cultivator over another. Perhaps rightfully so however, the use of the core-removing types is finding increasing favor among the men in the turfgrass industry. Simple reasoning leads to the belief that greater and longer lasting benefits should be derived from the actual removal of soil cores to the surface compared with the simple punching of holes which may even, in the end, increase soil compaction.

All turfed areas may not necessarily show equal benefit from aerification. It is doubtful, however, that any harm would ever result from a properly conducted

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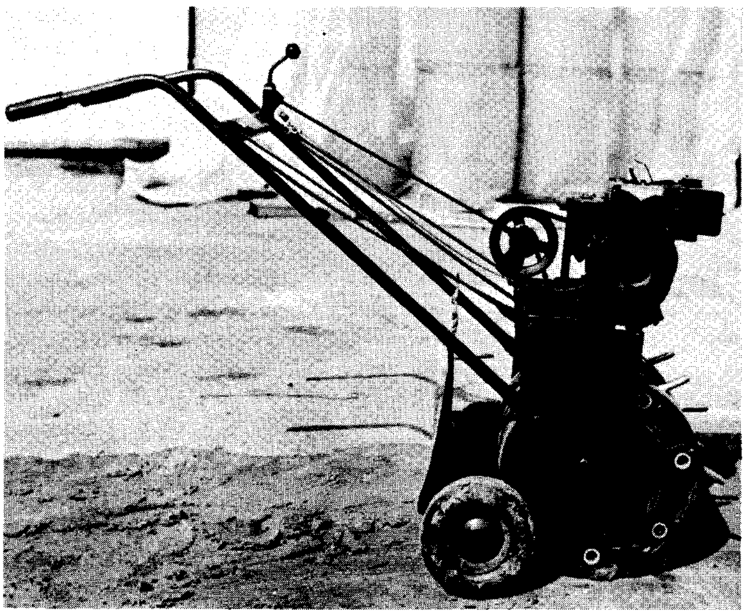

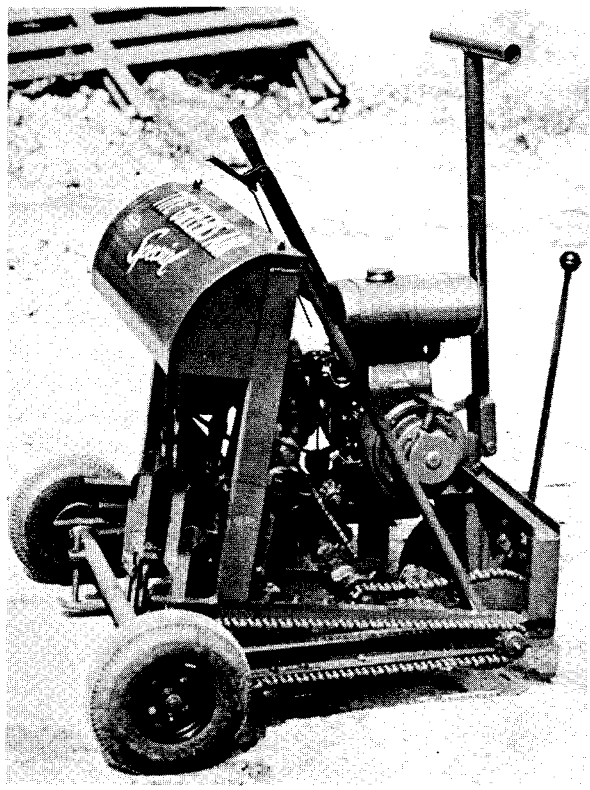

FIGURE 1 - THREE POPULAR TYPES OF POWER OPERATED TURFGRASS CULTIVATORS

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aerification program. Many undesirable conditions resulting from poor soils, mismanagement, or overly-vigorous grasses may be improved by regular turf cultivation.

Soil compaction resulting from foot traffic is usually confined to the top 2 to 3 inches of soil. Most aerification tools will penetrate to a depth of 4 inches, thus they are capable of breaking through the average compacted soil layer.

Soil compaction reduces the oxygen supply in the soil, thus restricting root development. Soil compaction also lowers the water infiltration rate, causing ponding or excessive run-off. Efficient utilization of fertilizer materials is impaired in compacted soils. Any of these conditions leads to difficult management and weak unhealthy turf.

It is not unusual to find masses of roots growing in the holes a short time after aerification. The grass roots often will grow into the non-compacted soil at the bottom of the holes, thus reaching a depth several times greater than previously possible. In badly compacted soils the location of each hole made by the machine sometimes can be seen from a distance as dark-green tufts of grass indicating that soil compaction was severely retarding grass growth.

If the soil is of good texture the cores brought to the surface need not be removed but should be crumbled before becoming too dry and distributed evenly over the area with a drag mat. In this case, it is not necessary to use a top dressing, The holes will be partially filled with crumbled soil from the cores and the grass roots will soon grow into them.

Where the turf is growing on heavy soils the soil can be gradually improved by removing the soil cores and top dressing with sand and organic matter. A good top dressing material is the soil mixture proposed by Lunt* consisting of 10 parts of sand, 2 parts of Krillium-treated sandy clay loam, and three parts of loose peat. Sawdust may often be substituted for the peat. The same top dressing material should be used following every aerification. Pure sand, such as washed plaster sand, may also be used.

Layers of soil of different textures often develop on older turf areas. This condition is particularly common on putting greens, bowling greens and other specialized turf where top dressing is a common practice. These layers may be caused by changes in the type of top dressing or simply by alternate layers of top dressing and a partially decomposed mat of grass leaves. Whatever the cause, the result is the same, a restriction of the downward movement of water. This restriction of water movement produces a dry subsoil and a wet surface soil lacking oxygen. A consistent aerification program will perforate these layers and gradually destroy them, permitting good water drainage and air movement through the soil.

FIGURE 2 -
MASS OF SEASIDE BENTGRASS ROOTS GROWING IN AN AERIFICATION HOLE.
NOTE THICK SAND LAYER AT A.

Many vigorous grasses, especially stoloniferous grasses such as the bermudas and bentgrasses, will quickly build up an excessively thick mat or thatch of dead but undecomposed grass leaves and stems. This mat or thatch will prevent irrigation water or rain from reaching the soil, especially on slopes where it will behave much like a thatched roof. Here again, regular aerification will perforate this thatch permitting the water to reach the soil.

Aerification preceding applications of dry fertilizer, especially phosphates, is a good practice. More of the fertilizer will be placed where it will be directly available to the grass roots. When thin spots in the turf are to be reseeded or where cool-season grasses are to be overseeded on bermuda, a thorough aerification will help prepare an excellent seedbed. The holes will often serve as excellent spots for planting sprigs of improved bents and bermudas in an old turf without renovation.

When and how often should a turf be cultivated? This will depend largely upon the conditions and requirements of each individual turfgrass area. Some turf may benefit from monthly aerifications, others may require treatments once or twice a year, while some may not need a regular aerification program. Spring, early summer, and fall are the best times for aerification of cool-season grass turf as these grasses are then making their most rapid growth. The bermudas and other warm-season grasses may be given aerifications any time through the summer and early fall.

Lunt, 0. R. A Method for Minimizing Compaction in Putting Greens. Sou. Calif. Turfgrass Culture 6 (3): 1-4, 1956.

WATER MEASURING AND CONTROL EQUIPMENT

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The art of irrigation has been practiced for about 7000 years, making it one of the oldest arts. Yet scientific research in irrigation is only 60 or 70 years old and we are just beginning to use scientific methods for irrigating. The use of water measuring and control equipment is contributing much to the transition from art to science of irrigation.

I want to present this topic in three parts. The first will be measuring the irrigation water you apply to the soils. The second will be the measurement of the moisture in the soil between irrigations. The third part will consider automatic control systems.

Measuring Irrigation Applications

There are two types of water measurement which are very simple and with which you are all familiar. One is a water meter in a pipe line such as you have in your home by means of which the city bills you for water consumed. More and more are meters of this type used for measuring and charging for irrigation water. The operation of the meter is positive, accurate, and totalizing so that the total flow between any *two* reading times is obtained whether or not the flow rate is constant.

Meters are calibrated in various units such as gallons, cubic feet, cubic meters, acre inches, and acre feet depending on the requirements of the buyer.

While the meters themselves are accurate, their use for estimating the amount of irrigation water applied to a given area is no better than the distribution of water by the irrigation system used. And irrigation systems for lawns and turf frequently leave much to be desired in the uniformity of water distribution. However, an average application over the area covered can be calculated rather easily.

The simplest case would be where a known area of turf was irrigated and the meter was calibrated in acre inches. If the area was 100 by 150 feet and used 0.5 acre inches of water, the application would be

$$\frac{0.5 \times 43560}{100 \times 150} = 1.45 \text{ inches.}$$

If the area is large and irrigated by several sets, the calculation could be made for each set using the length of the sprinkler line times the distance between sets as the area. Not all meters are conveniently calibrated in acre inches but may be in gallons or cubic feet. The problem is to convert these units to acre inches, rhen proceed as above. The following formulas can be used for the conversion or to prepare a conversion table if there is to be much use for it.

$$\frac{\text{Gallons}}{27200} = \text{acre inches}$$

$$\frac{\text{Cubic feet}}{3630} = \text{acre inches}$$

The second type of water measurement we want to consider is the precipitation gage, more commonly known as a rain gage. Though certain specific requirements and specifications must be met by official rain gages, any cylindrical vessel with reasonably sharp edges, tall enough to prevent splash, and set so that its opening is parallel to the plane of the earth's surface will serve for irrigation application measurements. Used food cans make good gages if the top is carefully cut out. With these cans we can measure the amount of water actually received by a certain parcel of ground under sprinkler irrigation.

Because water distribution from sprinklers is never uniform no one gage will accurately measure how much water is received by the whole area or the various parts of it. It takes several gages scattered over the area in a random or systematic pattern. From these the overall average for the area can be computed as well as some estimate of the quality of the distribution. Some very revealing figures may be obtained such as a ten fold variation between the high and low cans and a can number requirement, based on statistical analysis, of 20 or more to estimate a satisfactory mean.

The techniques for good measurement are simple but important. As mentioned before, the cans must be set straight. Wind should be less than 5 mph. Can contents should be measured as soon as possible after the irrigation is completed to avoid evaporation; and it is best to measure the contents by pouring into a graduated vessel and measuring the volume of water collected. The diameter of the can opening should be measured at 2 or 3 different places and averaged. When the area of the opening,

$$\frac{\pi D^2}{4}$$

is divided into the volume collected, the depth of irrigation is obtained.

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Moisture Measuring Instruments

Except for an occasional leaching to control salinity, the reason we apply water is to obtain a favorable soil moisture condition for plant growth. Thus a measurement of our soil moisture condition is about the most important measurement we can make.

Soil moisture measuring instruments now available for general use come in two classes. One class operates on a hydraulic principle and the instruments are called tensiometers. The other class operates on an electrical principle and are called electrical resistance blocks.

Though these instruments operate on slightly different principles, both classes measure the same thing, the relative wetness of soil, the availability of soil moisture, soil moisture tension, or soil suction, whichever term you prefer to use. They do not measure the total quantity of water in soil. An analogy between moisture measuring instruments and a thermometer, suggested by S. J. Richards, is useful to illustrate this point.

A thermometer measures temperature but not the total quantity of heat in a room. Human comfort is dependent on the temperature, not the total quantity of heat present, just as plant well-being is based on soil moisture tension as measured by moisture measuring instruments, not on the total quantity of water in the soil. You can maintain room comfort by adding heat when the thermometer calls for it without knowing the amount of heat added. Similarly you can maintain suitable soil moisture conditions by adding water when the instrument calls for it without necessarily knowing the amount of water added.

Each class of instruments has certain advantages and limitations. They measure different ranges of soil moisture though there is considerable overlap. Tensiometers are effective in the wet end of the moisture scale from saturation to partial dryness. They are capable of measuring excessive wetness, a not uncommon detrimental condition, as well as the approach to a condition of dryness at which many plants should be irrigated including turf grass. Tensiometers are usually recommended for sandy soils because most of the available water in such soils is held at tensions within the measuring range of the tensiometer. Resistance blocks are generally effective from partial to extreme dryness. They are not sensitive to changes in very wet soils and therefore not so capable of detecting dangerous saturated or near-saturated conditions. Resistance blocks are usually suggested for use in medium to fine textured soils where a large part of the available water is held at tensions within the measuring range of the blocks. Electrical resistance blocks should be avoided in saline soils because the electrolytic effect causes erroneous readings.

Some degree of protection is needed for each type. Tensiometers have breakable parts which protrude above ground level to varying heights and must be protected from animals and machinery. Resistance blocks have only wires protruding and need less protection. Also the wire leads from resistance blocks can be buried in a shallow trench and emerge at a protected position many feet from the block installation. Freezing will damage tensiometers but has no effect on resistance blocks. However, resistance blocks made of gypsum will dissolve away with continued exposure to saturated soil conditions while tensiometers are virtually unaffected.

Precise cost comparisons cannot be made. Tensiometers are more expensive, initially, than resistance blocks but have a longer life expectancy. The life expectancy of gypsum blocks varies depending on soil and moisture conditions from one to three or four years. Unless damaged, tensiometers should last five to ten years.

To obtain maximum benefit from moisture measuring instruments they should be read frequently and systematically and the readings plotted on a chart. It is best to take readings early in the morning and once daily is a desirable frequency. From your plotting you may see that there are times when changes from one day to the next are insufficient to warrant daily readings. A study of your plotting will suggest the needed frequency. A study of the plotting reveals the adequacy of the previous irrigation as well as an advance prediction of time to irrigate by extrapolating the lines. Instruments placed at two or more depths are recommended to detect either a failure to adequately wet the lower part of the root zone or an excessively wet subsoil from overirrigating.

Automatic Control Systems

Using the heat analogy again, we can say that our irrigation controls are in about the same relative position that home heating was 40 or 50 years ago. At that time we were using some thermometers to guide our heating but almost no thermostats. Today we are using some moisture instruments to guide our irrigating but only very recently have there been attempts to connect them to apparatus for automatically controlling irrigation. Initial attempts have now been made but there are problems yet to be solved.

Good thermostatic control became possible only after engineers discovered where to install the thermostat and how to design a controllable heat source and good distribution system. Successful automatic irrigation will require above all a good distribution system. It will also require dependable controls and correct location of the moisture sensing element.

When these have been accomplished there is good reason to believe that automatic irrigation will expand greatly, that it will improve vegetative growth and plant condition and improve efficiency of irrigation by reducing excessive losses and untimely irrigations. The ability to accomplish much of the irrigation during night hours will aid efficiency by operating at a time of mini-

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mum wind and evaporation losses. It will also aid in the management of turf areas heavily used for recreation.

Three types of automatic controls have come to my attention. One type is activated by a moisture sensing element similar to a tensiometer installed near the first lateral. Each lateral operates in sequence after the first lateral has been started and is controlled by hydraulically operated diaphragm valves. Shutoff is by timer which can be set individually for each lateral, or any lateral can be bypassed if desired. Various features of flexibility are built into the control box such as selected time of day for the irrigation to start, several short timer controlled irrigations a day for new seedings, adjustment for degree of dryness before irrigations are initiated, intermittent operation for low intake areas, and complete manual operation if desired.

Another type uses a moisture sensing element similar to an electrical resistance block. Instead of one element starting a series of irrigations for all laterals, each lateral has its own separate moisture sensing element. In this type of irrigation control the sensing element also gives the signal to shut off the water. It depends on irrigation water penetrating the soil and reaching the sensing element. Electrically operated solenoid valves control the lateral lines. Various flexibility features are incorporated in the control box such as selection of time of day for irrigations to commence, manual operation or by-pass for individual lines and adjustment for degree of dryness before irrigations are initiated.

The third type operates entirely from a time clock control box. The laterals are turned on in sequence, at a selected time of day and operate for a preselected length of time. Water control is by electric solenoid valves. Two different control boxes are available, one of which has individual length of time adjustments for each lateral while the other has a single length of time adjustment for all laterals. Both boxes have manual control or off switches for individual laterals and are equipped with an automatic rain switch. When 1/4 inch or more rain falls an exposed electrical resistance element is activated and causes the control box to bypass all laterals for a 24 hour period.

I think the future holds much promise and opportunity for improvement in measurement, distribution, and control of irrigation water and will approach the point where we can say "this is the science of irrigation."

A paper presented at tbe Southern California** Turf-**grass Institute at the University of California at Los Angeles, October 15, 1957.

SOIL TYPES FOR PUTTING GREENS

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According to the National Golf Foundation (5) more than 700 new golf courses are currently being planned or considered in the United States. In building these courses, more than 9,000 greens will be constructed. While the cost of greens varies greatly, one to two thousand dollars are often spent in constructing high quality greens. Thus, it is probable that 5 to 10 million dollars will be spent on the construction of new greens in the next several years. Money spent on constructing these greens so that subsequent maintenance costs will be minimized will be well invested.

A putting green soil should have the chemical and physical properties which will permit the growth of turf having a good playing surface. The soil itself should have a satisfactory resiliency. The chemical properties of the soil are relatively easily controlled with fertilizers and amendments, but physical properties are not easily altered except in the surface inch or two once a green is constructed. The most important physical properties in putting greens are those which relate to drainage and water retention, and as Kunze et al. (2) have pointed out, since few natural soils have the requirements of a good putting green mixture, it is usually desirable to prepare special soil mixes for putting greens.

The soil must supply the plant with water, fertilizer elements and oxygen and be free of toxic concentrations or constituents. In the case of putting greens, it must do this in spite of the compactive forces which will come through use. Even if the soil environment is favorable grass growth may be unsatisfactory because of pests, diseases, climatic conditions, or for other reasons. The extreme shallow rooting, one to two inches, which is frequently observed in putting greens undoubtedly reflects an unfavorable soil condition for the growth of roots.

The basic cause for the shallow rooting seems to be the lack of sufficient oxygen, or perhaps the accumulation of too much carbon dioxide, below shallow depths to premit root growth (4). Compaction, of course, contributes to the poor aeration in fine-textured soils by destroying the relatively large diameter pores in the soil which are normally filled with air. Discrete sand layers

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in a green also contribute to poor aeration because the soil above such a sand layer will remain saturated with water after every irrigation. Rapid and sufficient drainage is required to improve aeration. The requirement for sufficient drainage is discussed below.

Several investigators (1, 2, 4) have proposed that greens be constructed using a relatively high percentage of sand -- 80 to 90 per cent. It has been shown that sand mixes properly prepared will maintain high infiltration rates in spite of compaction such as would be received on a green (1, 2, 4). High infiltration rates are associated with the rapid removal of excess water from the soil. Gorman (1) has suggested that the infiltration rate serve as an index of suitability of a putting green mixture. This seems to be a very logical suggestion. Infiltration rates measured on a number of greens in Los Angeles very often fell in the range from 0.04 to 0.10 inch per hour. When infiltration rates are this low, it is difficult to introduce more than fractions of an inch of water into the soil at a time and runoff which may accumulate in depressions in the greens easily occurs.

The importance of relatively high infiltration rates on greens will increase in the future as the trend towards automation in irrigation increases. To effectively take advantage of these labor-saving techniques, it will be necessary that infiltration rates on greens be good. Gorman (1) suggested 0.8 of an inch per hour as a satisfactory rate. Probably rates this high or higher can be indefinitely maintained on properly constructed sandy greens.

In regard to the amount of air space required in soils for the growth of grass, Kunze and his associates (2) have presented evidence that 10 to 15 per cent non-capillary porosity is sufficient for good grass growth. This figure is in the range reported for other plants (3).

In summary, the physical properties required in the putting green soil appear to be a free porosity* of 10 to 15 per cent developing after irrigation, a relatively high infiltration rate so that this amount of free porosity is developed soon and a retention of about 10 per cent or more available water on a volume basis. This last figure is quite arbitrary -- lower values of available wafer may necessitate too frequent watering for convenience. As has been stated, a high sand content mix of the proper grade of sand can be made to meet these requirements and, as will be pointed out below, it is also possible to have a high water holding capacitywith sand under shallow soil conditions. Sandy soil mixes do not have high retentive capacities for many plant nutrients. Fortunately, however, there are available many special purpose fertilizers** which should make the fertility management of sandy greens relatively easy.

The use of calcined (structurally stable) clay aggregates offers an alternative approach to the use of sand in putting greens. Theoretically, calcined clay aggregates could be prepared which would have a high water-holding capacity, an adequate free porosity, high infiltration rates, and high retentive capacity for plant nutrients. The feasibility of such materials undoubtedly merits evaluation.

The selection of the proper grade of sand is all important if sand is to be the skeletal material in a putting green. The author supports the view that the best way of properly selecting and preparing a putting green mix is with the aid of laboratory tests. Highway engineers have long since taken guesswork out of foundation specifications through laboratory tests. Indeed, quality control by laboratory testing is a characteristic of American industry. Greenskeepers would be saved much grief if greens were constructed to specifications. Perhaps the time has come for some organization such as the Golf Course Superintendents of America to consider retaining the services of a laboratory to aid in selecting materials and evaluating mixes for putting greens. The type of tests necessary are not difficult to perform.

If sand is to form the framework of the soil mix and constitute approximately 85 per cent of the mix, the water and air relations of the mix will be strongly influenced by the texture of the sand. Figure 1 summarizes the water retention of various grades of sand. If columns of sand were placed in a pan and then wetted thoroughly at the surface so that water passed all the way through, and the bottom of the column were standing in water, the curves trace out the equilibrium moisture content of the sand at various distances from the water surface. The air space in the soil is the difference between the moisture content at the water level and the moisture content at any particular distance above the water level. Thus, in a sand of .5 to .4 mm diameter range at about 7 to 9 inches above the water level, the moisture content suddenly decreases and the percentage air space suddenly increases. Sand in the range .1 to .05 remains practically saturated with water even 40 inches above the water table.

**Free porosity as used here refers to the air space in the soil as a percentage of the bulk volume.*

***Some fertilizer materials which are resistant to leaching and persist for a month or more are the following:*

1. *Nitrogen is available as activated sewage sludge and other organic sources as well as urea-formaldehyde.*
2. *Phosphorus as single superpbospbate.*
3. *Potassium is available as a long lasting glass "Dura-K." This material is available* **only** *from Glostex Chemical Company, 3056 Bandini Boulevard, Los Angeles 23, California.*
4. *Calcium is long lasting in the form of limestone and gypsum (the latter is present in single superphosphate).*
5. *Magnesium is long lasting in the form of dolomitic limestone.*
6. *Sulfate is long lasting in the form of gypsite and gypsum (present in single superpbospbate).*

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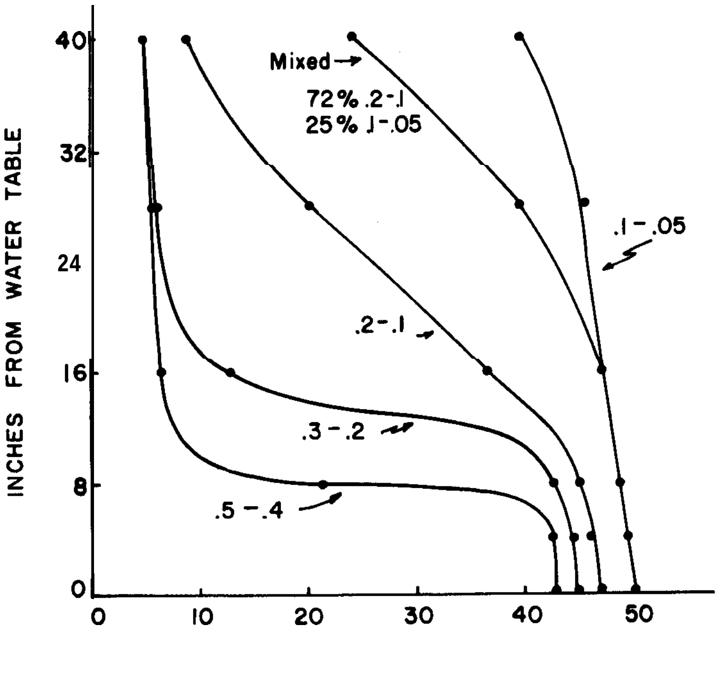

Figure 1: Volume per cent moisture retained by various grades of sand as determined by the height above a water table.

If sand is placed on top of a soil in which internal drainage is good, the moisture content will drain to approximately that value obtaining at 40 inches from the water table after one or two days. (The mixed sand curve and the .1 to .05 would drain considerably more than is indicated at 40 inches in Figure 1.)

If, however, the soil underlying the sand were impervious and the excess water had to be removed by tile drainage, the moisture content of the sand, after drainage ceased, would be very different than in the case where drainage occurred through the soil. Table 1 summarizes two cases which illustrate the point.

TABLE 1

Moisture retention by a given sand as influenced by depth of sand and underlying drainage

DEPTH FROM SOIL SURFACE	MOISTURE CONTENT IN VOLUME PER CENT UNDER CONDITIONS: A	B
0	5	8
4	5	12.5
8	5	35
12	5	42.5
16	5	44.5
20	5	45

Note: It is assumed that the moisture retention curve is that of the 0.3 - 0.2 mm sand in Figure 1. In both cases A and B it is assumed that 20 inches of the sand overlie a soil. In case A the soil has good drainage and the moisture content (somewbat idealized) of the sand at various depths is shown after drainage essentially ceases following a thorough wetting. About a day or two is required to reach equilibrium. In case B the underlying soil is impervious and excess water must be removed by tile drainage. The moisture contents in case B are those prevailing in the sand when drainage ceases from the tile.

These important facts emerge from the data:

The water and air proportions in sands will depend very much on whether the soil drains well or poorly under the sand. If tile drainage must be depended upon, and the depth of the sand layer is about 20 inches or less, then shallow soil conditions exist and the water retention of the sand is greatly increased. If shallow soil conditions prevail, the water and air relations which exist following an irrigation (when drainage ceases) depend on the texture of the sand and the distance above the water table which is at the tile depth.

It is apparent from the foregoing that the proper size of sand to be used in a putting green mix will be dependent on the depth of sand, drainage in the soil underlying the sand as well as other considerations not discussed, such as frequency of rainfall or irrigation.

The practice of purposely making the subsoil underlying a green impermeable and depending upon tile drainage for excess water removal has considerable appeal. This technique would greatly increase the water-holding capacity of the sand. The equilibrium water and air relations in the mix would be those prevailing in the suction range corresponding to the depth of the sand. If the sand depth were 15 to 20 inches it would not be difficult to prepare mixes having 10 or more inches of favorable air and watet relations.

Figure 2 shows that the incorporation of a coarse organic material such as horticultural grade peat affects soil structure principally in the range of pore sizes which drain in the range of about 0 to 10 inches from

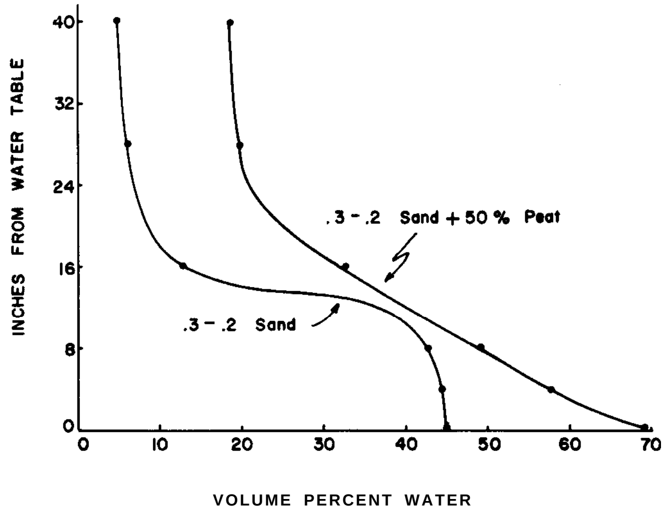

Figure 2: The moisture content of 0.3-0.2 mm diameter sand and sand plus 50 per cent by volume of course spagnum peat as determined by the height above a water table.

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the water level. Thus, Figure 2 shows that an).3-0.2 mm sand would have about 5 per cent air space 10 inches from a water table. If 50 per cent peat by volume had been incorporated, the air space at 10 inches from the water table would be about 24 per cent.

The incorporation of moderate amounts of clay in sand-soil mixes will increase somewhat the capacity of the mix to retain most fertilizer elements and will increase the water-holding capacity of the soil somewhat, especially if deep soil conditions exist (drainage is satisfactory underneath the sand). This can be done by blending in well aggregated, structurally stable clay soil in the proper amount. The use of krilium to stabilize clay aggregates is a good practice. Kunze et al. (2) consider clay contents in excess of about 4 per cent to be undesirable. In laboratory tests Lunt (4) reported infiltration rates could be maintained in excess of one inch per hour after compaction treatments, even if as much as 7.5 per cent krilium treated clay were present. Probably one of the principal reasons for the unsatisfactory performance of some high sand content greens has been the inclusion of too much silt or clay, particularly when these fine fractions are not aggregated.

Kunze et al. (2) reported good success with putting green mixtures composed of 8-l-l or 8 1/2-1/2-1 sand-soil-peat mixtures. The soil used was Houston black clay. Clay contents by weight exceeding about 4 per cent appeared to be undesirable. This is in reasonably close agreement with other proposals (1, 4). Kunze et al. (2) also reported best growth of grass when the sand-soil-mix was composed of particles in the range of 1 to .05 mm. It is the opinion of the writer that under most conditions slightly finer grades of sand would be more desirable. The data in Figure 1 show that if the subsoil is impermeable, a sand layer 16 to 20 inches deep will provide 6 to 10 inches of soil well aerified if sand is in the range of 0.4-0.2. If the sand layer is shallower (subsoil drainage poor, tile drained), the sand should be coarser. If subsoil drainage is good, then an increase in the sand fraction from 0.2 - 0.1 mm would be desirable. The precaution previously urged (4), that the sand mix not contain more than about 6 to 10 per cent sand, silt, or unaggregated clay in the range smaller than 0.1 mm, still applies.

An illustration of how data were obtained for the construction of a putting green may be of interest. First, the soil was excavated to a depth of 20 inches on the green site. The subsoil was high in clay and infiltration rate was determined to be less than 0.1 inch per hour. It was decided tile drainage would be required. Next, several sources of sand were considered and one finally selected which seemed satisfactory. A screen analysis provided the particle size distribution and other laboratory tests determined the water and air proportions which would prevail at various heights above a water table. (Near the tile the sand would be saturated following an irrigation.) The data obtained were the following:

Sand size (diameter)	Percentage
0.59 mm	20.1
.59 - .50	14.8
.50 - .25	57.2
.25 - .10	6.7
.10	1.1
	99.9

Equilibrium air and water percentages in the sand following a thorough irrigation as a function of depth

Sand depth	Vol. % Water	Vol. % Air
1 inch	11	29
4 "	12.5	27.5
8 "	15	25
12 "	20	20
20 " (depth of tile drainage)	40	0

Laboratory tests showed that the infiltration rate of a mixture composed of about 85 per cent sand, about 7 1/2 per cent redwood sawdust, and about 7 I/2 per cent clay plus silt derived from a clay loam soil which had been treated with krilium had an infiltration rate in excess of 5 inches per hour after a compaction treatment. In calculating the amount of sand in a mix, the contribution of sand from a soil which may be blended into the principal sand source should be included.

Twelve inches of the sand were placed above the tile drains and then a mix of the sand with krilium-treated clay loam and redwood sawdust composed the surface 8 inches. The sand composed about 85 per cent of the mix and the silt plus clay from the clay loam soil and redwood sawdust approximately 7 1/2 per cent by volume each. The green was compacted while moist with roller, and wet down thoroughly several times to prevent subsequent uneven settling. The cost of materials for a 6500 square foot green was about $1,300.

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