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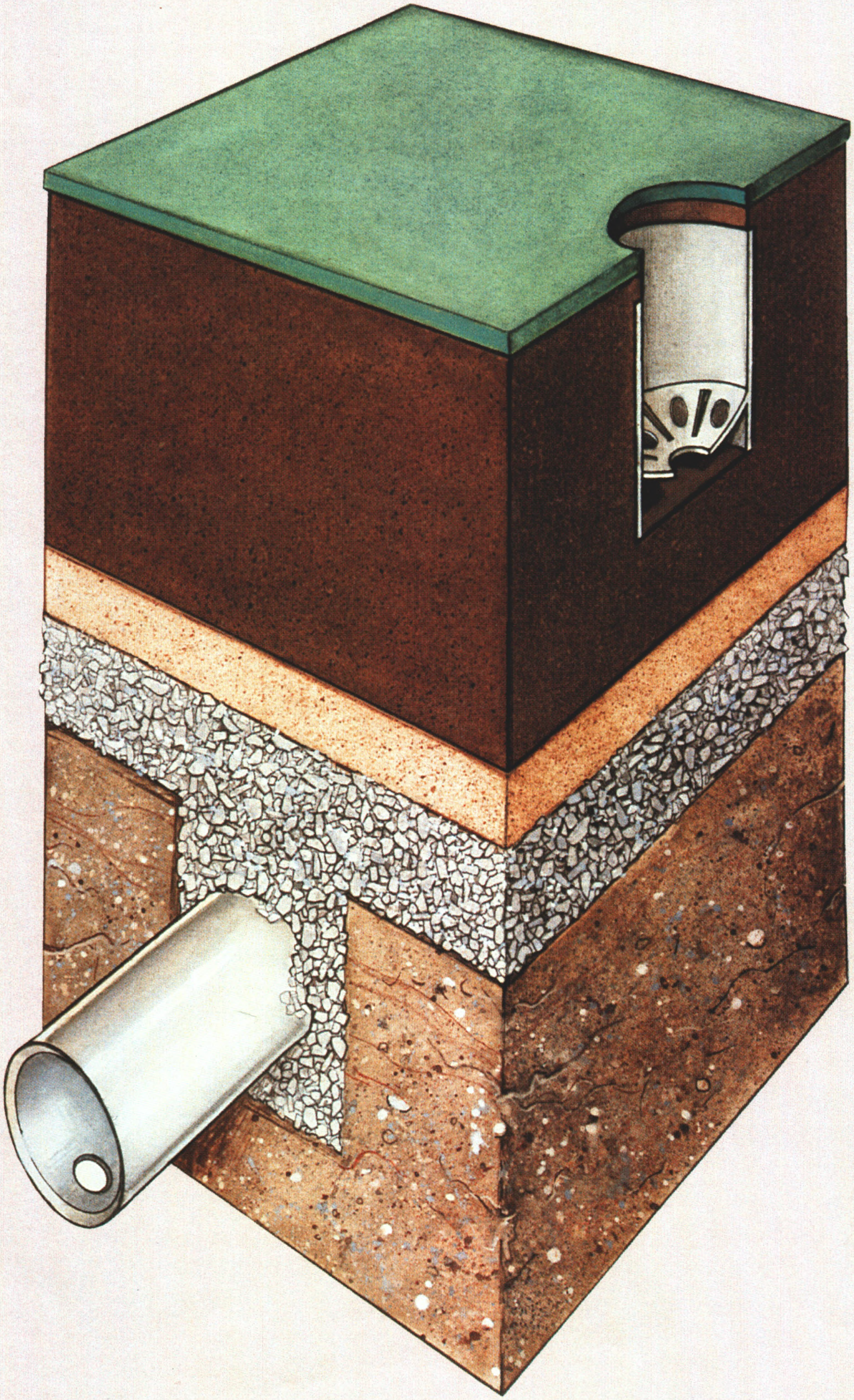

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The USGA extends warm thanks to the many people who gave freely of their expertise in the 1993 revision of the USGA Green Construction Recommendations.

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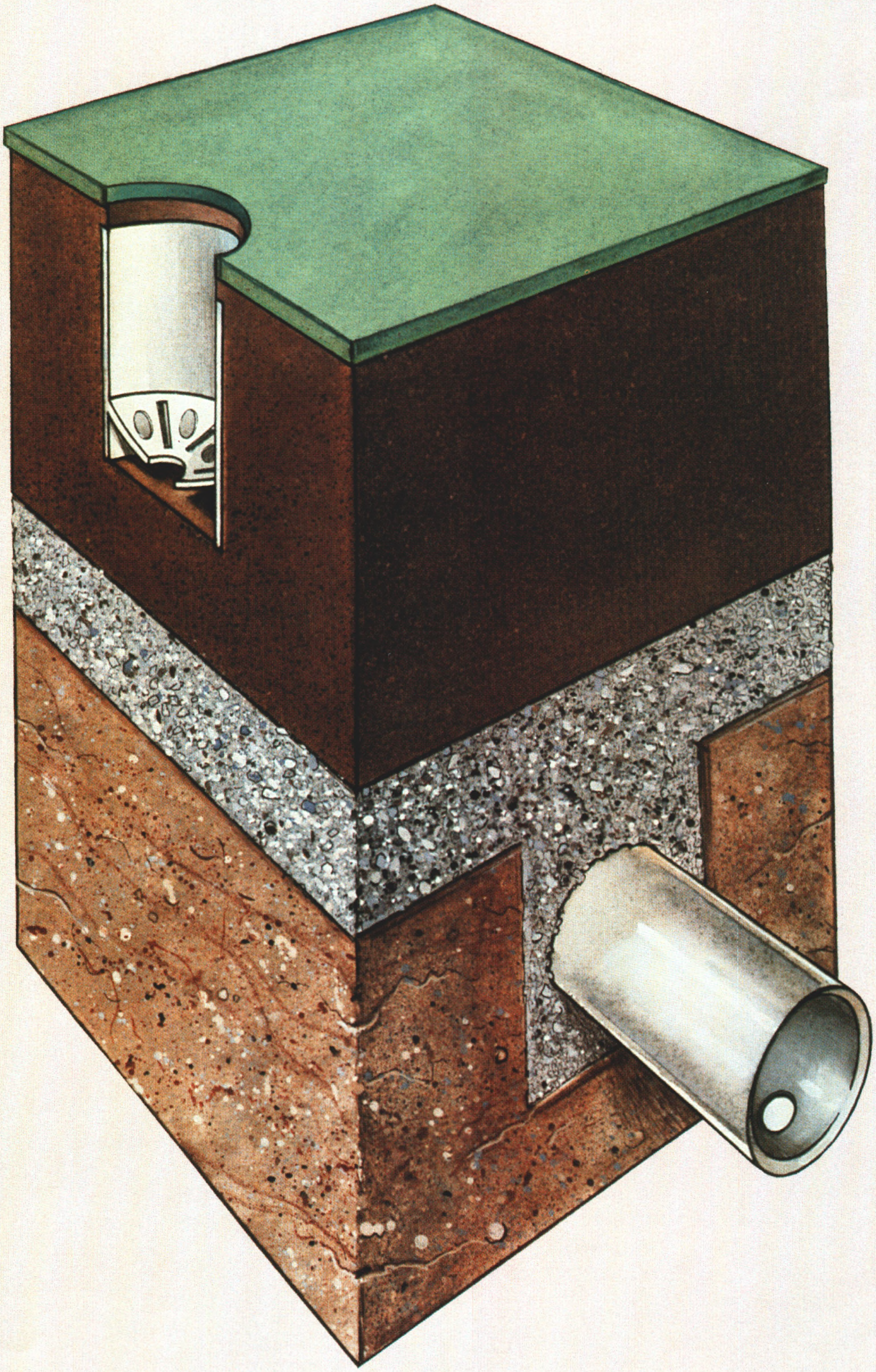
USGA Recommendations for Putting Green Construction

Profile of a green built to USGA Recommendations with the intermediate layer (cover). When the appropriate gravel is used, the intermediate layer can be eliminated (below).



THE
1993 REVISION

USGA RECOMMENDATIONS FOR A METHOD OF PUTTING GREEN CONSTRUCTION

by the
USGA GREEN SECTION STAFF

Following is the 1993 revision of the USGA Recommendations for a Method of Putting Green Construction. These recommendations are based on a review of the scientific literature prepared by Dr. Norman W. Hummel, Jr., and advice from the Advisory Committee and Review Panel (see inside front cover).

Step 1. The Subgrade

The slope of the subgrade should conform to the general slope of the finished grade. The subgrade should be established approximately 16 inches (400 mm) below the proposed surface grade — 18 to 20 inches (450 to 500 mm) when an intermediate layer is necessary — and should be thoroughly compacted to prevent further settling. Water collecting depressions should be avoided.

If the subsoil is unstable, such as with an expanding clay, sand, or muck soil, geotextile fabrics may be used as a barrier between the subsoil and the gravel blanket. Install the fabric as outlined in Step 2.

Construct collar areas around the green to the same standards as the putting surface itself.

Step 2. Drainage

A subsurface drainage system is required in USGA greens. A pattern of drainage pipes should be designed so that the main line(s), with a minimum diameter of 4 inches (100 mm), is placed along the line of maximum fall. Four-inch (100 mm) diameter laterals shall run up and across the slope of the subgrade, allowing a natural fall to the main line. Lateral lines shall be spaced not more than 15 feet (5 m) apart and extended to the perimeter of the green. Lateral lines should be placed in water-collecting depressions, should they exist. At the low end of the gradient, adjacent to the main line's exit from the green, drainage pipe should be placed along the perimeter of the green, extending to the ends of the first set of laterals. This will facilitate drainage of water that may accumulate at the low end of that drainage area.

Drainage design considerations should be given to disposal of drainage waters away from play areas, and to the laws regulating drainage water disposal.

PVC or corrugated plastic drainage pipe is preferred. Where such pipe is unavailable, clay or concrete tile is acceptable. Waffle drains or any tubing encased in a geotextile sleeve are not recommended.

Drainage trenches 6 inches (150 mm) wide and a minimum of 8 inches (200 mm) deep shall be cut into a thoroughly compacted subgrade so that drainage lines slope uniformly. Spoil from the trenches should be removed from the subgrade cavity, and the floor of the trench should be smooth and clean.

If a geotextile fabric is to be used as a barrier between an unstable subsoil and the gravel drainage blanket, it should be installed at this time. Under no circumstances should the fabric cover the drainage pipes or trenches.

A layer of gravel (see Step 3 for size recommendations) should be placed in the trench to a minimum depth of 1 inch (25 mm). It may be deeper, as necessary, to ensure a positive slope along the entire run of drainage lines. If cost is a consideration, gravel sized ¼ to 1 inch (6 to 25 mm) may be used for the drainage trench only.

All drainage pipe should be placed on the gravel bed in the trench, assuring a minimum positive slope of 0.5 percent. PVC drain pipe, if used, should be placed in the trench with the holes facing down. Backfill with additional gravel, taking care not to displace any of the drainage pipe.

Step 3. Gravel and Intermediate Layers

Place grade stakes at frequent intervals over the subgrade and mark them for the gravel drainage blanket layer, intermediate layer (if included), and root zone layer.

Table 1

PARTICLE SIZE DESCRIPTION OF GRAVEL AND INTERMEDIATE LAYER MATERIALS

Material	Description
Gravel: Intermediate layer is used	Not more than 10% of the particles greater than ½" (12 mm)
	At least 65% of the particles between ¼" (6 mm) and ⅜" (9 mm)
	Not more than 10% of the particles less than 2 mm
Intermediate Layer Material	At least 90% of the particles between 1 mm and 4 mm

Table 2

SIZE RECOMMENDATIONS FOR GRAVEL WHEN INTERMEDIATE LAYER IS NOT USED

Performance Factors	Recommendation
Bridging Factor	• $D_{15\ (gravel)} \leq 5 \times D_{85\ (root\ zone)}$
Permeability Factor	• $D_{15\ (gravel)} \geq 5 \times D_{15\ (root\ zone)}$
Uniformity Factors	• $D_{90\ (gravel)} / D_{15\ (gravel)} \leq 2.5$
	• No particles greater than 12 mm
	• Not more than 10% less than 2 mm
	• Not more than 5% less than 1 mm

The entire subgrade then shall be covered with a layer of clean, washed, crushed stone or pea gravel to a minimum thickness of four inches (100 mm), conforming to the proposed final surface grade to a tolerance of ±1 inch.

Soft limestones, sandstones, or shales are not acceptable. Questionable materials should be tested for weathering stability using the sulfate soundness test (ASTM C-88). A loss of material greater than a 12% by weight is unacceptable.

The LA Abrasion test (ASTM C-131) should be performed on any materials suspected of having insufficient mechanical stability to withstand ordinary construction traffic. The value obtained using this procedure should not exceed 40. Soil engineering laboratories can provide this information.

The need for an intermediate layer is based on the particle size distribution of the root zone mix relative to that of the gravel. When properly sized gravel (see Table 1) is available, the intermediate layer is not necessary. If the properly sized gravel cannot be found, **an intermediate layer must be used.**

A. Selection and Placement of Materials When the Intermediate Layer Is Used

Table 1 describes the particle size requirements of the gravel and the intermediate layer material when the intermediate layer is required.

The intermediate layer shall be spread to a uniform thickness of two to four inches (50 to 100 mm) over the gravel drainage blanket (e.g., if a 3-inch depth is selected, the material shall be kept at that depth across the entire area), and the surface shall conform to the contours of the proposed finished grade.

B. Selection of Gravel When the Intermediate Layer Is *Not* Used

If an appropriate gravel can be identified (see Table 2), the intermediate layer need not be included in the construction of the green. In some instances, this can save a considerable amount of time and money.

Selection of this gravel is based on the particle size distribution of the root zone material. The architect and/or construction superintendent must work closely with the soil testing laboratory in selecting the appropriate gravel. Either of the following two methods may be used:

1. Send samples of different gravel materials to the lab when submitting samples of components for the root zone mix. As a general guideline, look for gravel in the 2 mm to 6 mm range. The lab first will determine the best root zone mix, and then will test the gravel samples to determine if any meet the guidelines outlined below.
2. Submit samples of the components for the root zone mix, and ask the laboratory to provide a description, based on the root zone mix tests, of the particle size distribution required of the gravel. Use the description to locate one or more appropriate gravel materials, and submit them to the laboratory for confirmation.

Gravel meeting the criteria below will not require the intermediate layer. It is not necessary to understand the details of these recommendations; the key is to work closely with the soil testing laboratory in selecting the gravel. **Strict adherence to these criteria is imperative; failure to follow these guidelines could result in greens failure.**

The criteria are based on engineering principles which rely on the largest 15% of the root zone particles "bridging" with the smallest 15% of the gravel particles. Smaller voids are produced, and they prevent migration of root zone particles into the gravel yet maintain adequate permeability. The $D_{85\ (root\ zone)}$ is defined as the particle diameter below which 85% of the soil particles (by weight) are smaller. The $D_{15\ (gravel)}$ is defined as the particle diameter below which 15% of the gravel particles (by weight) are smaller.

• For **bridging** to occur, the $D_{15\ (gravel)}$ must be less than or equal to five times the $D_{85\ (root\ zone)}$.

• To maintain adequate **permeability** across the root zone/gravel interface, the $D_{15\ (gravel)}$ shall be greater than or equal to five times the $D_{15\ (root\ zone)}$.

• The gravel shall have a **uniformity coefficient** (Gravel D_{90}/Gravel D_{15}) of less than or equal to 2.5.

Furthermore, any gravel selected shall have 100% passing a ½" (12 mm) sieve and not more than 10% passing a No. 10 (2 mm) sieve, including not more than 5% passing a No. 18 (1 mm) sieve.

Step 4: The Root Zone Mixture

Sand Selection: The sand used in a USGA root zone mix shall be selected so that the particle size distribution of the **final root zone mixture** is as described in Table 3.

Soil Selection: If soil is used in the root zone mix, it shall have a minimum sand content of 60%, and a clay content of 5% to 20%. The final particle size distribution of the sand/soil/peat mix shall conform to that outlined in these recommendations, and meet the physical properties described herein.

Organic Matter Selection:

Peats — The most commonly used organic component is a peat. If selected, it shall have a minimum organic matter content of 85% by weight as determined by loss on ignition (ASTM D 2974-87 Method D).

Other organic sources — Organic sources such as rice hulls, finely ground bark, sawdust, or other organic waste products are acceptable if composted through a thermophilic stage, to a mesophilic stabilization phase, and with the approval of the soil physical testing laboratory. Composts shall be aged for at least one year. Furthermore, the root zone mix with compost as the organic amendment must meet the physical properties as defined in these recommendations.

Composts can vary not only with source, but also from batch to batch within a source. Extreme caution must be exercised when selecting a compost material. Unproven composts must be shown to be non-phytotoxic using a bentgrass or bermudagrass bioassay on the compost extract.

Inorganic and Other Amendments: Inorganic ammendments (other than sand), polyacrylamides, and reinforcement materials are not recommended at this time in USGA root zone mixes.

Physical Properties of the Root Zone Mix: The root zone mix shall have the properties summarized in Table 4, as tested by USGA protocol (proposed ASTM Standards).

Under the heading **Saturated Conductivity** in Table 4, **Normal range** refers to circumstances where normal conditions prevail for growing the desired turfgrass species. **Accelerated range** refers to conditions where water quality is poor, cool-season turfgrass species are being grown out of range of adaptation, or dust storms or high rainfall events are common.

Table 3

PARTICLE SIZE DISTRIBUTION OF USGA ROOT ZONE MIX

Name	Particle Diameter	Recommendation (by weight)	
Fine Gravel	2.0 - 3.4 mm	Not more than 10% of the total particles in this range, including a maximum of 3% fine gravel (preferably none)	
Very coarse sand	1.0 - 2.0 mm		
Coarse sand	0.5 - 1.0 mm	Minimum of 60% of the particles must fall in this range	
Medium sand	0.25 - 0.50 mm		
Fine sand	0.15 - 0.25 mm	Not more than 20% of the particles may fall within this range	
Very fine sand	0.05 - 0.15 mm	Not more than 5%	Total particles in this range shall not exceed 10%
Silt	0.002 - 0.05 mm	Not more than 5%	
Clay	Less than 0.002 mm	Not more than 3%	

Table 4

PHYSICAL PROPERTIES OF THE ROOT ZONE MIX

Physical Property	Recommended Range
Total Porosity	35% - 55%
Air-filled Porosity (at 40 cm tension)	15% - 30%
Capillary Porosity (at 40 cm tension)	15% - 25%
Saturated Conductivity	
Normal range:	6-12 inches/hr (15-30 cm/hr)
Accelerated range:	12-24 inches/hr (30-60 cm/hr)
Organic Matter Content (by weight)	1% - 5% (ideally 2% - 4%)

Related Concerns

IT IS ABSOLUTELY ESSENTIAL TO MIX ALL ROOT ZONE COMPONENTS OFF-SITE. No valid justification can be made for on-site mixing, since a homogeneous mixture is essential to success.

A QUALITY CONTROL PROGRAM DURING CONSTRUCTION IS STRONGLY RECOMMENDED. Arrangements should be made with a competent laboratory to routinely check gravel and/or root zone samples brought to the construction site. It is imperative that these materials conform to the recommendations approved by the laboratory in all respects. Some tests can be performed on site with the proper equipment, including sand particle size distribution.

Care should be taken to avoid over-shredding the peat, since it may influence performance of the mix in the field. Peat should be moist during the mixing stage to ensure uniform mixing and to minimize peat and sand separation.

Fertilizer should be blended into the root zone mix. Lime, phosphorus, and potassium should be added based on a soil test recommendation. In lieu of a soil test, mix about ½ pound of 0-20-10 or an equivalent fertilizer per cubic yard of mix.

Step 5. Top Mix Covering, Placement, Smoothing, and Firming

The thoroughly mixed root zone material shall be placed on the green site and firmed to a uniform depth of 12 inches (300 mm), with a tolerance of ± ½ inch. Be sure that the mix is moist when spread to discourage migration into the gravel and to assist in firming.

Step 6. Seed Bed Preparation

Sterilization: Sterilization of the root zone mix by fumigation should be decided on a case by case basis, depending on regional factors. Fumigation always should be performed:

1. In areas prone to severe nematode problems.
2. In areas with severe weedy grass or nutsedge problems.
3. When root zone mixes contain unsterilized soil.

Check with your regional office of the USGA Green Section for more information and advice specific to your area.

Fertilization

Contact your regional USGA Green Section office for establishment fertilizer recommendations and grow-in procedures.

The Whys and Hows of Revising the USGA Green Construction Recommendations

by JAMES T. SNOW
National Director, USGA Green Section

FOR MORE than 30 years the USGA recommendations for green construction have been the most widely used method for green construction throughout the United States and in other parts of the world. When built and maintained properly, USGA greens have provided consistently good results for golf courses over a period of many years.

In response to industry concerns about soil laboratory inconsistencies, the scientific validity of certain specifications, and other perceived problems, the USGA decided in 1991 to make a thorough scientific review of its specifications and, if needed, to publish an updated and revised version after the study was complete.

Plans for the project solidified when Dr. Norman Hummel, associate professor of turfgrass science at Cornell University and an expert in soils and soil testing, agreed to spend his year on sabbatical leave with the Green Section and lead a review of the green construction specifications. Among his objectives was to determine the reasons for laboratory inconsistencies and to update and standardize the recommended laboratory procedures. Also, he proposed to complete a thorough review of the scientific literature pertaining to green construction and sand-based root zone mixtures, recommend needed modifications to the current specifications, recommend quality control procedures for checking, sampling, and testing materials during construction, and identify needs for future research concerning green construction.

In following through with the review, the Green Section had several goals in mind:

1. To increase confidence in the specifications by providing a sound scientific rationale, establishing standardized lab procedures to help minimize the inconsistencies experienced in the past, and providing quality control guidelines to help ensure the best possible results during construction.

2. To reduce the cost of building USGA greens by taking whatever scientifically valid steps can be taken to provide greater flexibility, incorporate results of recent research and new technologies, and remove any unnecessary steps.

3. To provide the golf industry with the best possible green construction recommendations, given the current state of our scientific knowledge and experience, for the benefit of golfers who enjoy the game worldwide.

4. To identify weaknesses in our knowledge base and encourage scientists to pursue answers to the questions that could lead to even better quality, less costly, easier-to-maintain greens in the future.

To help ensure that a broad base of scientific knowledge was considered in revising the recommendations, an advisory committee (see inside front cover) was formed to serve as a sounding board for Dr. Hummel's work. The committee was very helpful in providing sources of information for the literature review, and in reviewing the proposed laboratory procedures and the new recommendations.

Dr. Hummel officially began his work on July 1, 1991, and his first order of business was to initiate the revision of the laboratory procedures. The original procedures were published by Dr. Marvin Ferguson in 1960, and no updating had been done by the USGA since then. For more than 20 years there had been little reason to modify the laboratory procedures, since there were just one or two laboratories providing testing services during most of that time. The golf boom of the 1980s, though, saw a large increase in the number of laboratories offering these services, and it wasn't long before inconsistencies began to appear. People who sent samples of the same material to several laboratories sometimes received greatly varying results.

It was clear from Dr. Hummel's survey of the laboratories that establishing new laboratory standards would greatly improve consistency from lab to lab (see "Why We Need Soil Testing Laboratory Standards for Root Zone Mixes" later in this issue). With the help of the Advisory Committee and with the cooperation of personnel at all of the soil testing laboratories, Dr. Hummel developed the new standards that were hoped for. These procedures have been submitted

USGA Recommendations — what most golf courses turn to the second time around.

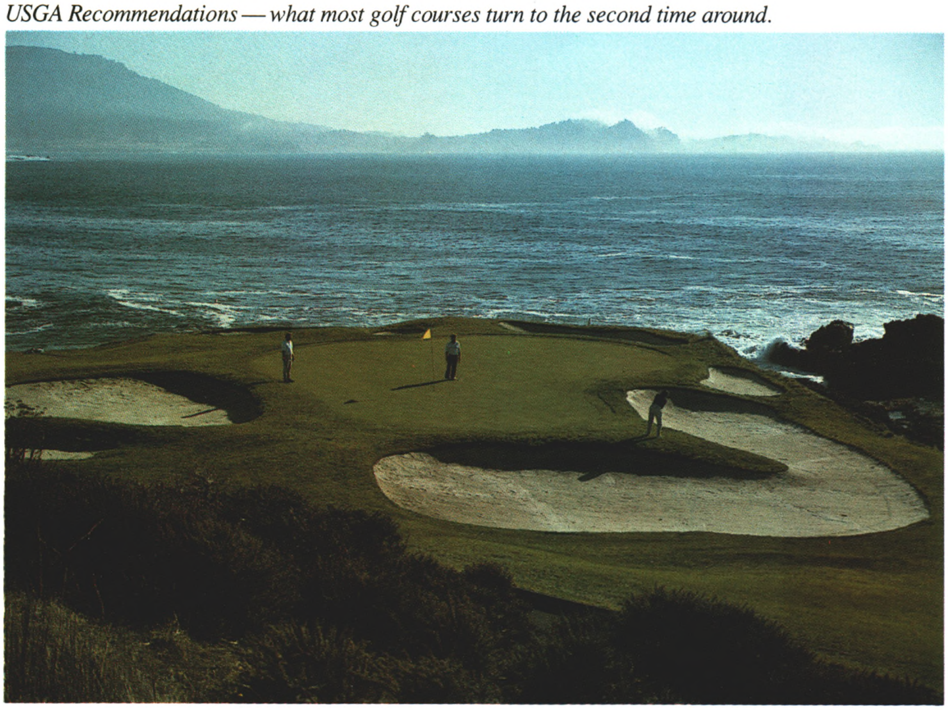


Table 1

SUMMARY OF CHANGES TO THE USGA GREEN CONSTRUCTION RECOMMENDATIONS

Subgrade

- The subgrade need not conform to the proposed finished grade; the purpose of the subgrade is to facilitate water movement to the drainage system. However, the surface of the gravel blanket layer must conform to the proposed finished grade.

Drainage

- Drainage trenches shall be a minimum of 8 inches (20 cm) deep.
- Drainage lines shall be not more than 15 feet (5 m) apart.
- A perimeter drain line (smile drain) shall be installed along the low end of the gradient, usually along the front of the green.

Gravel

- Both crushed stone and pea gravel are acceptable for use as the drainage blanket.
- Gravel materials suspected of lacking mechanical stability to withstand common construction traffic should be checked with the LA Abrasion test — ASTM procedure C-131 (value should not exceed 40).
- Gravel materials of questionable weathering stability should be tested using the sulfate soundness test — ASTM procedure C-88 (not more than 12% loss by weight).
- Slight change in particle size distribution for gravel where the intermediate layer is used. Previously, 100% required between ⅜" and ¼" (9mm and 6mm); now minimum 65% required between ⅜" and ¼", plus limits on percentages and sizes above and below this range.
- New recommendations developed for gravel particle size distribution for use with root zone mixture where intermediate layer is not used. Specific recommendations are based on the particle size distribution of the particular root zone mix.

Intermediate Layer

- The acceptable particle size range has been expanded. Now, 90% must fall between 1 mm and 4 mm (previously 1-2 mm).
- Need not be included if the properly sized gravel is used.

Root Zone Mixture

- The particle size range has been modified, allowing more fine sand (0.15 - 0.25 mm) but less very fine sand (0.05 - 0.15 mm).
- Provides guidelines for selection of peat materials (minimum of 85% organic matter by weight) and other organic composts (should be allowed to age for one year; must be shown to be non-phytotoxic; mix must meet physical properties).
- Provides guidelines for selection of soil component (if used). Soil component should have a minimum sand content of 60% and a clay content of between 5% and 20%.
- Some root zone physical properties have been modified:
  - Total porosity: 35-55% (previously 35-50%)
  - Air-filled porosity: 15-30% (previously 15-25%)
  - Saturated Conductivity (not included in 1989 version)
    Normal range: 6-12 inches/hr (15-30 cm/hr)
    Accelerated range: 12-24 inches/hr (30-60 cm/hr)
  - Organic matter content: 1-5% (ideally 2-4%) by weight

Seed Bed Preparation

- Sterilization required only 1) in areas prone to severe nematode problems, 2) in areas with severe weedy grass or nutsedge problems, or 3) when the root zone mix contains unsterilized soil.

Laboratory Procedures

- A revised and expanded set of laboratory procedures has been prepared and sent to all soil testing laboratories interested in testing materials for construction of USGA greens. Labs must agree to follow these protocols to be included on the list of soil testing laboratories sent out by the USGA with the green construction booklet.

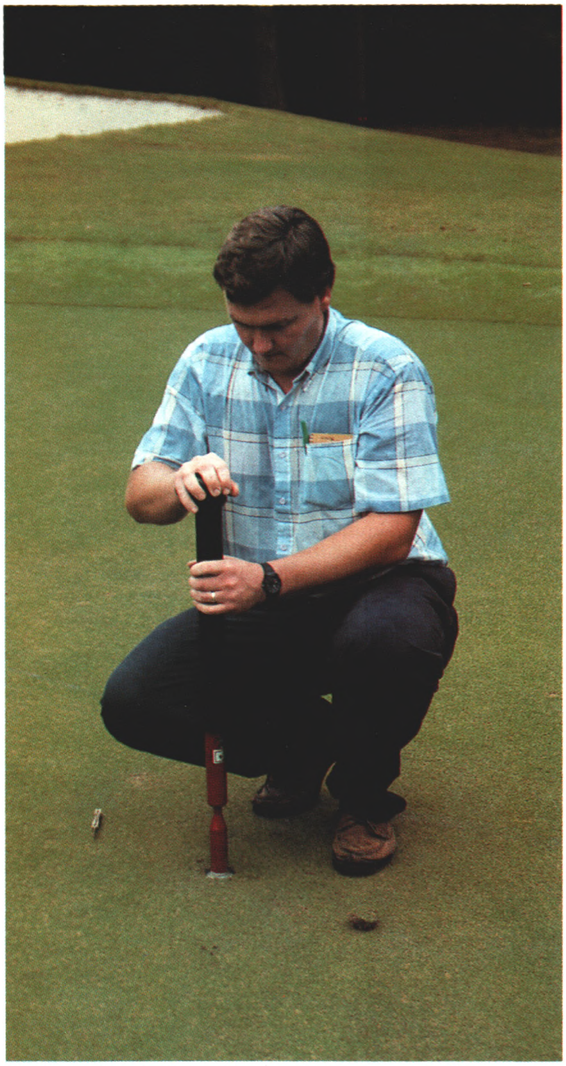
to the American Society of Testing and Materials (ASTM), and will undergo a thorough scientific review in hopes of having the procedures adopted by ASTM as national standards. In the future, only laboratories that agree to follow the new standards and to report the information called for in these procedures will be included on the list of laboratories that accompanies the USGA's green construction booklet.

Following the development of the new laboratory procedures, Dr. Hummel completed a thorough literature review to serve as a basis for prospective changes to the specifications. Upon completion of the review, and with input from the Advisory Committee and others, he recommended changes in adherance with the goals mentioned previously. After a thorough review of these recommendations by an international panel (see inside front cover) of knowledgeable scientists, architects, agronomists, industry personnel, and soil laboratory personnel, the 1993 version of the USGA Recommendations for a Method of Putting Green Construction was adopted by the Green Section staff.

As expected, there was some disagreement about some of the finer details of the proposed changes, but there was surprising agreement among the world's experts on the major points, and it is fair to say that the 1993 version of the USGA recommendations for green construction represents as much of a consensus as could ever be expected from such a broad-ranging group of experts.

Unquestionably the most prominent change is the option of eliminating the intermediate layer in the USGA green profile *if* the appropriate gravel can be found. Selection of the gravel is based on the particle size distribution of the root zone mix.

The use of the intermediate layer in a USGA green always has been one of the most contentious parts of the recommendations, and it simply has been left out by many contractors, architects, or superintendents for the sake of economy. Sometimes these greens worked very well, but in many other instances the lack of an intermediate layer resulted in disaster. In anticipating this revision of the recommendations, the Green Section staff decided that if a scientifically valid method could be identified to determine when the intermediate layer is not needed, it should be included in the recommendations. Doing so would save many courses tens of thousands of dollars in not having to purchase and install the intermediate layer material.



Dr. Norm Hummel checks cores from a green built many years ago according to USGA standards.

Good root zone physical properties equate to good roots and healthy turf.

Fortunately, from information supplied by two of our reviewers, an engineering textbook was located that described an extensively researched method for evaluating the need for filter materials in layered profiles. It fits our purpose very well, and is described in the following sections of this issue of the *Green Section Record*.

Another change that could save many thousands of dollars, depending on location, is the broadening of the particle size distribution for the intermediate layer, where the use of the layer is necessary. This change will make available many less-expensive materials for use as the intermediate layer, and there is no sacrifice in the way they function in the profile.

There are many other minor changes throughout the recommendations, including several to the physical properties of the root zone mix. The particle size range has been expanded to allow for more fine sand, but less very fine sand, allowing greater availability of acceptable sands in some parts of the country. Also, the test for saturated conductivity (infiltration rate) has been added, after having been left out of the recommendations in the 1989 version. See Table 1 for a summary of all the significant changes.

It should be emphasized that despite the changes that have been made, the underlying principles associated with USGA greens since 1960 have not been altered. They include the necessity of a drainage system to move excess water quickly away from the site, a gravel blanket to allow excess water to move quickly to the drainage system, a layered profile to create a perched water table for the conservation of moisture and nutrients in the root zone, and laboratory testing to ensure that the root zone mix and other components of the profile meet the required standards.

In the pages of this issue of the *Green Section Record* are the results of nearly two years of work by dozens of people. The USGA extends special thanks to Dr. Norm Hummel, who with patience and thoroughness steered the project to a successful end. Thanks also to members of the Advisory Committee and the Review Panel, and to countless others who offered constructive advice and moral support to those of us involved in the revision of the USGA's recommendations for putting green construction.

Rationale for the Revisions of the USGA Green Construction Specifications

by **DR. NORMAN W. HUMMEL, JR.**
Cornell University

The following review of the scientific literature pertaining to green construction served as a rationale for the changes made in the 1993 version of the USGA Recommendations for a Method of Putting Green Construction. Dr. Hummel's recommendations for each phase of green construction were based in part on previous versions of the USGA green construction specifications and in part on information gleaned from the literature. The green construction recommendations finally adopted by the Green Section staff (see previous section) were compiled with input from the Advisory Committee and the Review Panel.

MANY METHODS or systems of putting green construction have been proposed and used through the years, some more successfully than others. Since 1960, when they were first published (USGA Green Section Staff, 1960), the USGA Specifications for Green Construction have been the most widely recognized construction specifications in the industry. Two revisions of the specifications have been published since the original (USGA Green Section Staff, 1973, 1989). The purpose of this review article is to provide the scientific rationale behind the newest revision of the USGA Specifications.

Historical Perspective

The USGA Specifications are said to have evolved to their current form. Most of the changes since the original specifications have been in defining the root zone mix. Perhaps this is because most of the published research related to greens construction has concerned the root zone medium. To fully appreciate how the current specifications came to be, one must look at their origin.

Prior to World War II, golf course greens were usually constructed with soils native to the site of the green. Drawings from Donald Ross, however, show that as early as 1916 sand and manure were used as amendments to the soil (Hurdzan, 1985). At some point in the 1920s or 1930s, putting green root zone mixes had evolved into a standard 1-1-1 (sand-soil-organic) volume ratio. Much of the research on putting green root zone media prior to 1950 was on organic sources to substitute for the dwindling supplies of animal manure (Sprague and Marrero, 1931, 1932; Richer et al., 1949).

A tremendous growth in the popularity of golf followed the Second World War. It quickly became apparent that the construction methods of that time did not provide greens that could hold up to the greater demands expected of them. Thus, the 1950s became a decade of much research that ultimately led to the development of the USGA Green Construction Specifications.

R. R. Davis (1950, 1952) at Purdue University was the first to attempt to relate physical condition of putting green soils to their performance. He found that the better greens had greater total porosity than poor greens, probably due to differences in compaction. He also reported that all the greens he sampled were very wet, with moisture tensions typically around pF 2. On the basis of his work he proposed that soils should be modified with coarse sands to bring the total sand content up to 50%.

Preparing a firm foundation for a USGA green.

Garman (1952) was one of the first to research sand-soil-peat mixtures for root zones. He reported that the standard 1-1-1 mix did not possess adequate permeability under compacted conditions. He proposed a mix of sand, soil and peat that contained 8.2% clay by weight and 20% peat by volume. This mix had a permeability of 0.8 inches per hour; four times that of the 1-1-1 mix, and a rate then considered satisfactory for a root zone mix.

Later in the 1950s, the USGA funded research projects at Texas A&M and the University of California at Los Angeles on putting green root zone mixtures. Lunt (1956) reported that the most satisfactory sand for a root zone mix is that in the 0.2 to 0.4 mm range. Ideally, 75% or more of the sand particles should be in this range, with no more than 6% to 10% less than 0.1 mm. He concluded that a mix should be 85-90% sand, the remaining composed of fibrous peat and a well-aggregated clay.

At Texas A&M, Kunze (1956) looked at sand particle size and mixture ratios on soil physical properties and plant growth.

Highest bermudagrass yields were reported for mixes that had sand particles in the 0.5 to 1 mm range, 2% to 4% clay, and non-capillary porosities of 10% to 15%. Using an aggregated Houston black clay as the soil and a reed sedge peat as the organic source, he reported the highest yields with the 8-1-1 and 8.5-0.5-1 volume ratios. Grass rooting was strongly influenced by physical properties, the largest root mass produced in sand with a 0.25 to 0.5 mm particle size.

It should be noted that Kunze (1956) placed a layer of coarse sand between the root zone mixture and underlying gravel blanket. While this was simply a precaution to prevent migration of the root zone mixture into the gravel, it probably provided the pretense for including the coarse sand intermediate layer in the USGA Specifications. No other mention of it, or research supporting its use, can be found prior to the publication of the specifications.

In summarizing the work of Garman, Kunze, and himself, Lunt (1958) wrote that the physical properties required of a root zone mixture should be 10% to 15% non-capillary porosity, a high infiltration rate, and a minimum water retention of 10% by volume.

By now the USGA had recognized the importance of testing the physical properties of root zone mixes prior to green construction (Ferguson, 1955). Continuing with the work of Kunze, Howard (1959) looked at several root zone mixes and tried to relate laboratory-measured soil physical parameters to plant response; specifically yield and quality. He reported that non-capillary porosity and hydraulic conductivity were positively correlated to clipping yields and quality ratings.

Howard further reported that the sand that provided the highest yields and quality ratings was one in which 95% of the particles were less than 0.5 mm in diameter, in a ratio of 8.5-0.5-1 (sand-soil-peat), followed closely by the 8-1-1. Comparable yields and quality were obtained with a coarse sand (40% > 1 mm, poor sorting) in a 6-3-1 ratio, and with the medium sand (84% between 0.25 and 1 mm) in 7-2-1, 8.5-0.5-1 and 8-1-1 ratios.

While there was no statistical analysis to support it, the interaction of sand size (and sorting) and soil type was very apparent from the data. In all cases, it appears that available moisture is the limiting factor to both yield and quality. Physical properties of the highest performing sand for the different soil types were reported as: capillary porosities, 12% to 27%; non-capillary porosity, 19% to 27%; total porosity, 35% to 40%; and "hydraulic conductivity" of 0.33 to 6 in/hr (as measured on compacted cores in the lab). Again, the resulting physical properties of the mix varied greatly with soil and sand particle sizes.

On the basis of these studies, which were cited in the 1960 publication (USGA Green Section Staff, 1960), the USGA specified that a compacted root zone mix should have a minimum total porosity of 33%, of which non-capillary pores should range from 12% to 18%, and capillary pores from 15% to 21%. The permeability should be 1.27 - 3.81 cm/hr (0.5 to 1.5 in/hr).

It is interesting to note that despite all the studies identifying a desirable particle size range for sand, the 1960 Specifications did not specify a particular size distribution. Rather, it was stated that "the soil mixture should meet certain physical requirements," presumably referring to permeability and porosity.

Also, it should be mentioned that the "hydraulic conductivity" as determined by Howard and Kunze was measured as flux density at a hydraulic head of 6.4 mm (Howard, personal communication) and was calculated as:

$Jw = Q/At$

where:

Jw = flux density

Q = quantity of water passing through the core in time t

A = cross sectional area of the core

This equation does not take into account the driving force behind the water movement — the hydraulic potential gradient. Kunze (1956) noted that slight changes in hydraulic head resulted in large changes in permeability. Infiltration rates specified since the 1973 Specifications are measured as saturated hydraulic conductivity. Taking into account the hydraulic potential gradient used in both Howard's and Kunze's thesis, the actual saturated hydraulic conductivity would be about 12 times greater than the flux density. Thus, if the permeability of a root zone mix as specified in the 1960 USGA Specifications were expressed in terms used today, it would have specified a saturated conductivity rate of 6 to 18 in/hr (15 to 46 cm/hr).

Several years had passed before each of the following revisions of the USGA Specifications (USGA Green Section, 1973, 1989). Within each of those time periods several more studies were published that may have provided some of the rationale behind the revisions. The following is a review of the 1989 Specifications, along with a rationale for suggested changes.

Step 1. The Subgrade

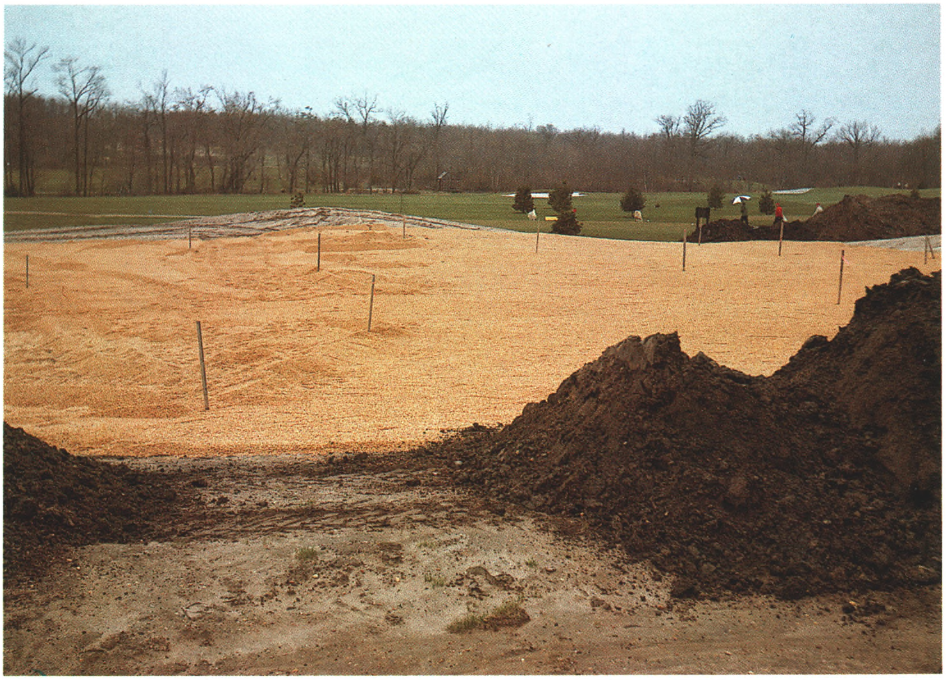
All three versions of the Specifications stress the need to contour the subgrade to that of the final grade, plus or minus one inch. Failure to do so "may cause wet spots in low areas, and droughty areas where the subgrade is substantially greater than the average." Contractors go to great pains to achieve this, unnecessarily so.

The purpose of the compacted subgrade with gravel blanket is to facilitate water movement to the drainage tubing. There-

Into the trenches for drainage installation.

fore, it is more critical that the subgrade follow the general slope of the green to move water to the drainage trenches. The gravel blanket then can be spread and shaped to the final contour of the green, varying the gravel depth if necessary. As shown by Dougrameji (1965), the depth of the underlying stratum will have no effect on moisture retention in the soil above.

In some situations, such as where the subsoil is an expanding clay, muck, or sandy soil, the subsoil may lack stability regardless of how much effort is made to compact it. Geotextiles would have an application to prevent the gravel layer from settling into the subsoil.



The gravel drainage blanket being laid to the depth indicated on the grade stakes.

Recommendation

The slope of the subgrade should conform to the general slope of the finished grade. The subgrade should be established approximately 16 to 18 inches (400 - 450 mm) below the proposed finished grade, and should be thoroughly compacted to prevent further settling. Abrupt changes in surface contours should be established in the subgrade. Water collecting hollows, however, should be avoided.

If the subsoil is unstable, such as with an expanding clay, sand, or muck soils, geotextile fabrics may be used as a barrier between the subsoil and the gravel blanket. Install the fabric as outlined in Step 2.

Step 2. Drainage

All three versions of the specifications have stated that any arrangement of tile placement may be used. To most effectively remove water accumulated in the gravel blanket, the main drain should be placed along the line of maximum fall, with laterals placed at an angle to this. This placement allows for the interception of water, maintains an adequate fall to the laterals, and a natural fall to the main drain(s) and green exit. The laterals should extend to the perimeter of the collar. Also, a perimeter tube should be placed at the low end of the gradient where water is likely to accumulate.

It is questionable if the tile spacing of ten feet is necessary, especially considering the storage capacity of the gravel. Placement every 15 feet should be more than adequate.

Recommendation

A subsurface drainage system is required in USGA greens. A pattern of drainage pipes should be designed so that main line(s) with a minimum diameter of 4 inches (100 mm) shall be placed along the line of maximum fall. Four-inch (100 mm) diameter laterals should be placed up and across the slope of the subgrade, allowing a natural fall in the laterals to the main drain. Lateral lines should be spaced no more than 15 feet (5 m) apart and extend to the perimeter of the green. Lateral lines should be placed in water-collecting depressions should they exist. At the low end of the gradient, adjacent to the main line(s) exit from the green, drainage pipes or tile should be placed along the perimeter of the green, extending to the ends of the first set of laterals to remove any water that may accumulate at this low end.

Main lines also should exit the green at the high end, extending several feet off the green. A clean-out box should be installed at this point.

Drainage design considerations also should be given to disposal of drainage waters, and laws regulating drainage disposal.

Drainage pipes preferably should be PVC or corrugated plastic. Where such pipe is unavailable, clay or concrete tile is acceptable. Waffle drains or any tubing encased in a geotextile sleeve are not acceptable. Fabrics should not be placed over the drainage pipes.

Cut trenches 6 inches (15 mm) wide into a thoroughly compacted subgrade so that drainage lines slope uniformly. Spoil from the trenches should be removed from the subgrade cavity.

If a geotextile fabric is to be used as a barrier between the subsoil and the gravel drainage blanket, it should be installed at this time. Check with the manufacturer for installation instructions. Under no circumstances should the fabric cover the drain lines.

A layer of gravel of a size as specified in Step 3 for the gravel blanket should be placed in the trench to a minimum depth of 1 inch. If cost is a consideration, gravel sized ¼ to 1 inch may be used for the drainage trench only. The depth of the gravel in the trench may be varied to ensure a positive slope along the entire run of drain lines.

All drainage pipe or tile should be placed on the gravel bed in the trench, assuring a minimum positive slope of 0.5 percent. PVC drain pipe should be placed in the trench with the holes faced down. Before covering the pipe with gravel, spot check with a carpenter's level or transit to ensure positive slope throughout the entire drainage system.

The trenches then should be backfilled with additional gravel, taking care not to displace any of the drain tubing.

Even with good subsurface drainage, the green design should provide surface drainage over the entire green in at least two directions.

Step 3. Gravel and Coarse Sand Layers

One of the most controversial issues surrounding the specifications is the inclusion of the coarse sand intermediate layer. Originally placed in the specifications as a precaution against migration of the topmix into the gravel, the intermediate layer has been a trademark of USGA greens.

Having coarse textured strata within the soil profile will result in a "perched water table" and increase the water retention of the entire profile (Miller and Bunger, 1963; Dougrameji, 1965; Unger, 1971). It has been widely misunderstood that the presence of the coarse sand layer is necessary in a green profile to have this effect. In fact, the 1989 specifications state that "it (the coarse sand layer) is an integral part of the perched water table concept."

Miller and Bunger (1963) showed increased moisture content whether soil was placed above sand or gravel. In fact, water content was actually higher in soil-above-gravel than soil-above-sand several days after irrigation. Greater water loss in the soil-above-sand was due to the greater unsaturated conductivity of the sand as compared to the gravel. Similar results were shown by Dougrameji (1965), but only with a fine sand above a coarser sand. Miller (1964) later proved that moisture retention characteristics of a soil could be predicted from the unsaturated conductivity of the underlying strata, a concept later proven applicable to greens mixes (Brown and Duble, 1975).

Having settled the argument for the necessity of the coarse sand layer for creating the perched water table, it must seriously be evaluated for its role in preventing particle migration. Migration of silt- and clay-sized particles is likely to be a natural phenomenon in sand as demonstrated by Wright and Foss (1968). The concept of the coarse sand layer was not to prevent this, but rather to prevent migration of the root zone mix into the underlying gravel.

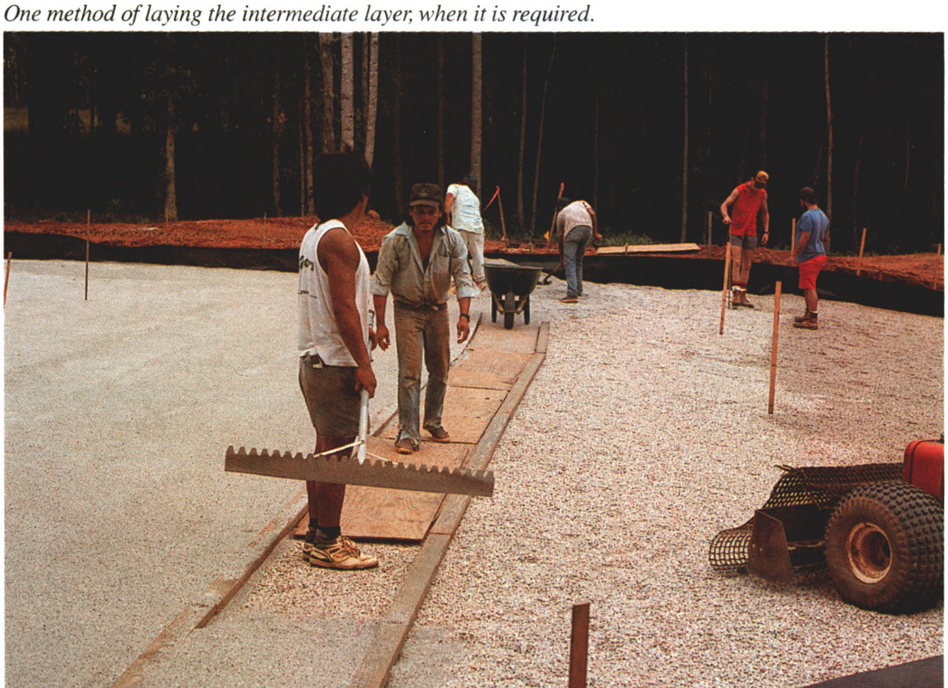
Brown and Duble (1975) assessed particle migration by placing two sands with different D_{50} values on three sizes of gravel. Both sands moved freely into the coarse gravel (D_{50} = 7 mm), but there were no differences in pore volume lost in the medium (D_{50} = 5 mm) or the fine (D_{50} = 4.25 mm) gravels with either sand, an 85-5-15, or a sandy loam soil.

It is interesting to note that the particle diameter ratio of the brick sand (D_{50} = 0.48 mm) over medium gravel (sand/gravel = 10.4) was nearly the same as the concrete sand (D_{50} = 0.64 mm) over the coarse gravel (sand/gravel = 10.9). Significant differences in migration occurred, however. Both exceed the 5 to 7 diameter limit set by the 1989 specifications. The Brown and Duble study raises some concern that the particle diameter ratio in itself may not be a suitable criterion for selecting gravel to underlie a root zone mix.

Brown et al. (1980) also reported minimal migration of root zone mix into gravel with 6-2-2 mixes with three sands. Johns (1976) also reported migration to be minimal.

Baker et al. (1991) reported that sand migration into gravel in sand slits was a function of particle size and gradation index. Finer sands and more uniform sands were more prone to movement. It should be mentioned that this study looked at straight sand that was dried to a low moisture content before it was placed on the gravel. Furthermore, the gravel had more than 60% of the particles greater than 7 mm in diameter.

One method of laying the intermediate layer, when it is required.



No doubt there are many factors that can influence migration besides particle size, including particle shape and the cohesiveness of the topmix. Idealistically, there is no question that greens can be built without the coarse sand layer if a properly sized gravel is available. How much compromising takes place in the field is another matter. It is common knowledge that hundreds, and perhaps thousands of greens have been successfully installed without the intermediate layer.

Civil engineers have within their discipline well established criteria for drainage system designs, including material selection in "layered" systems (Smedema and Rycroft, 1983). In fact, the U.S. Soil Conservation Service has published criteria for selecting underdrainage materials, based on the particle size distribution of the soil above.

Sowers (1970) describes the principles used to prevent seepage of soil particles into the underdrainage in an introductory soil mechanics textbook. In a layered system, extensive experiments have shown that the openings (voids) in the underlying material need screen out only the coarsest 15%, or the D_{85}, of the soil particles. These coarser particles collect and "bridge" over the openings, creating smaller openings which trap smaller particles. The effective diameter of the pores in between the gravel particles must be less than the D_{85} of the root zone. Since the diameter of the pores is about ⅕ the diameter of the finest 15% of the gravel ($D_{15\ Gravel}$), then

$$D_{15\ gravel} \leq 5D_{85\ root\ zone}.$$

It is also important that the "filter," or material under the root zone mix, be more pervious than the root zone. To assure that the ratio of permeabilities is greater than 20 to 1, the $D_{15\ gravel} \geq 5D_{15\ root\ zone}$.

Since the exclusion of the intermediate layer in greens is likely to continue despite what the USGA Specifications say, the USGA may better serve the industry by providing specifications for construction where the intermediate layer is not necessary. Where the layer is not used, very strict gravel specifications must be adhered to.

The recommended specifications redefine the particle size range allowed for the intermediate layer where it is necessary. The particle size range is better defined and was expanded to include fine gravel. The rationale behind this change was to make the specification much less restrictive than in the 1989 specs and also to better ensure that the perching forms above the intermediate layer. While this reduces the water storage capacity of the profile somewhat, it moves the water in closer proximity to the roots.

Recommendation

Grade stakes should be placed at frequent intervals over the subgrade and marked for gravel drainage blanket, intermediate layer (if included), and root zone.

With grade stakes in place, the entire putting subgrade should be covered with a layer of clean, washed, crushed stone or gravel to a minimum thickness of four inches. The gravel should be spread and shaped to conform to the contours of the proposed surface grade, plus or minus one inch.

The need for an intermediate layer is based on the particle size distribution of the root zone mix relative to that of the gravel. Where properly sized gravel is available, the intermediate layer is not necessary. Gravel meeting the criteria below will not require the intermediate layer. Strict adherence to this specification is imperative. FAILURE TO FOLLOW THESE SPECIFICATIONS COULD RESULT IN GREENS FAILURE.

The criteria for determining the need for an intermediate filter layer is based on engineering principles that rely on the coarsest 15% of the root zone particles "bridging" with the finest 15% of the gravel particles. Smaller voids are produced that prevent further migration of root zone particles into the gravel, but maintain adequate permeability. The $D_{85\ (\text{root zone})}$ is defined as the particle diameter in which 85% of the soil particles by weight are finer. The $D_{15\ (\text{gravel})}$ is defined as the particle diameter in which 15% of the gravel particles by weight are finer.

For the bridging to occur, the $D_{15\ (\text{gravel})}$ must be less than or equal to five times the $D_{85\ (\text{root zone})}$. It can be expressed as:

$D_{15\ (\text{gravel})} \leq 5 \times D_{85\ (\text{root zone})}$

To maintain adequate permeability, the $D_{15\ (\text{gravel})}$ should be greater than or equal to five times the $D_{15\ (\text{root zone})}$, written as:

$D_{15\ (\text{gravel})} \geq 5 \times D_{15\ (\text{root zone})}$

The gravel should have a uniformity coefficient (Gravel D_{90}/Gravel D_{15}) of less than or equal to 2.5, written as:

$D_{90\ (\text{gravel})}/D_{15\ (\text{gravel})} \leq 2.5$

Furthermore, any gravel selected should have 100% passing a ½" sieve and no more than 10% passing a No. 10 (2 mm), including no more than 5% passing a No. 18 (1 mm).

Tests should be performed on both the root zone mix and gravel by a competent laboratory to determine the need for an intermediate filter layer. The architect and/or the construction superintendent should work closely with the lab in selecting gravel and root zone materials.

If gravel cannot be found meeting this size specification, an intermediate layer is necessary. Table 1 provides the particle size specification for the gravel and intermediate layer materials.

Soft limestones, sandstones, or shales are not acceptable. Gravel materials should be tested for weathering stability using the sulfate soundness test (ASTM C-88). There should be no more than a 12% loss by weight of the material using this procedure. The LA Abrasion test (ASTM C-131) should be performed on any materials suspected of not having sufficient mechanical stability to withstand common construction traffic. The value should not exceed 40.

If an intermediate layer is included, it should be spread to a uniform thickness of two to four inches above the gravel base, and follow the contours of the proposed surface grade.

Collar areas around the green should be constructed to the same specification as the putting surface itself.

Table 1

PARTICLE SIZE DESCRIPTION OF GRAVEL AND INTERMEDIATE LAYER MATERIALS

Material	Description
Gravel: Intermediate layer is used	Not more than 10% of the particles greater than ½" (12 mm)
	At least 65% of the particles between ¼" (6 mm) and ⅜" (9 mm)
	Not more than 10% of the particles less than 2 mm
Intermediate Layer Material	At least 90% of the particles between 1 mm and 4 mm

Step 4. The Root Zone Mixture

Sand Selection

Particle Size

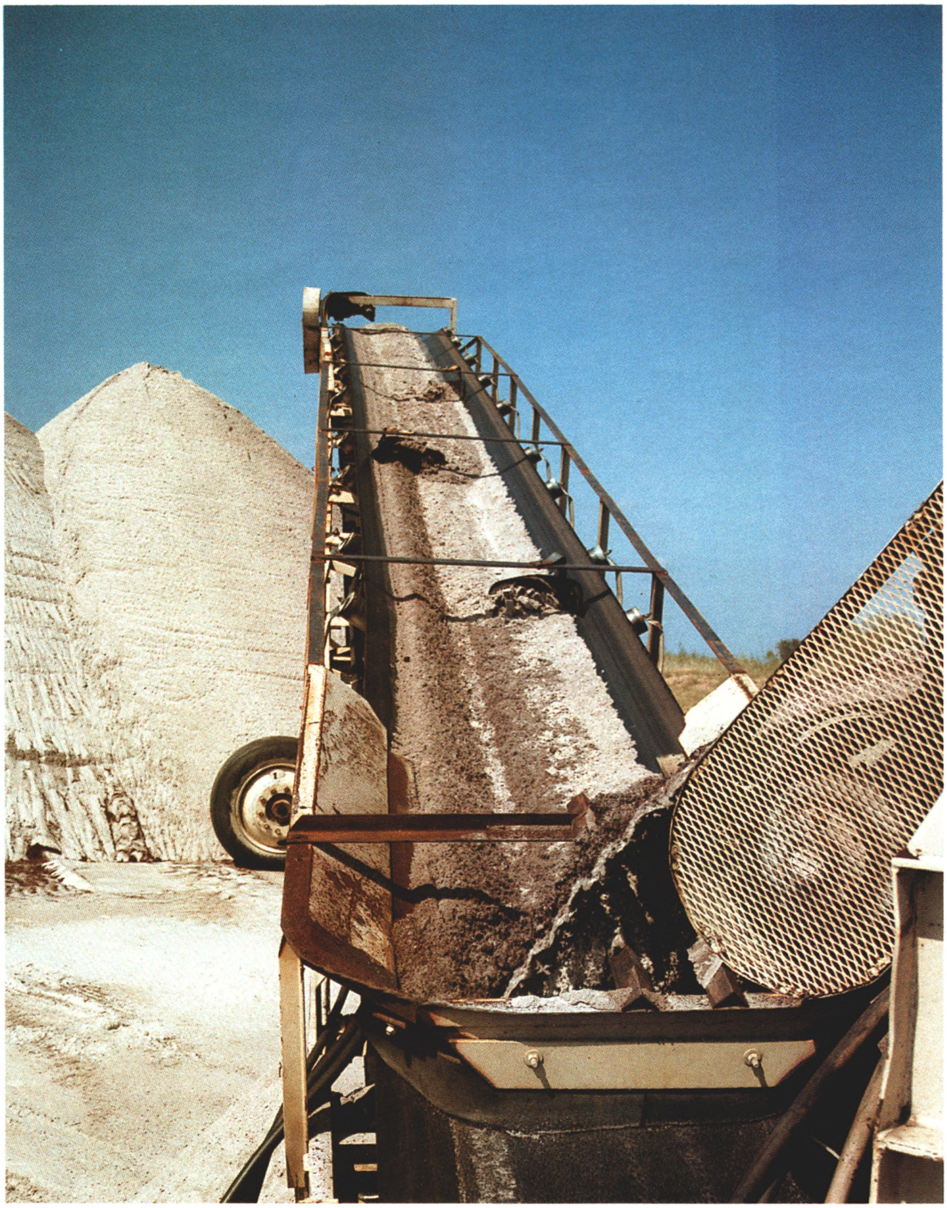
Sand is the primary component of a USGA putting green root zone mix. Back in the early 1950s, Garman (1952) proposed that root zone mixtures should be predominately sand, with 8.2% clay and 20% peat by volume. Lunt (1956) followed with a recommendation that a root zone mix should be composed of 85% to 90% sand mixed with a fibrous peat and well-aggregated clay. The best performing mixes reported by Kunze (1956) and Howard (1959) were those with medium/coarse sands in 80% to 85% by volume, the remainder being aggregated clay and peat. Brown and Duble (1975) also reported an optimum volume ratio of 85% sand, 5% clay, and 10% moss peat.

Since sand is the primary component of a root zone mix, the properties of a mix and the performance of the turf growing on it will be greatly influenced by the sand selected. Sand properties known to be important include sand grain size, uniformity, and, to a lesser extent, shape.

Baker (1990) provided a thorough overview of the properties of sands and of methods of characterizing them. Grain size has been shown to have a major influence on the physical properties of a mix (Davis et al., 1970; Adams et al., 1971; Waddington et al., 1974). Adams found that there was a linear relationship between the log K_{sat} and log particle size. On the basis of his work he concluded that a desirable sand should have 80% of its particles between 0.1 and 0.6 mm in diameter. Baker (1983) reported that K_{sat} was controlled primarily by grain size and sorting, while aeration porosity and moisture retention were influenced by grain size with weaker associations with grain sorting and shape.

The 1973 USGA Specifications (USGA Green Section Staff, 1973) was the first to provide an acceptable particle size range for the root zone mix. They specified that the mix (including soil and peat) contain no particles greater than 2 mm, not more than 10% greater than 1 mm, and not more than 25% less than 0.25 mm, including a maximum 3% clay and 5% silt.

These sand size specifications were in general agreement with Lunt (1956) who suggested that 75% of the particles fall between 0.2 and 0.4 mm in diameter. Kunze



Root zone mix in the final stages of preparation.

(1956) reported best physical properties with particles between 0.5 and 1 mm, followed by 0.25 and 0.5 mm. Howard (1959) concluded that 50% of the sand particles should be between 0.25 and 0.5 mm, but his data suggest that the other components of the mix should be considered when selecting the sand. Baker (1983) also concluded that the 0.25 to 0.5 mm range was most important for putting green root zones. Dahlsson (1987) recommended the sand for a root zone should have 92% of the particles between 0.1 and 1 mm in diameter.

The use of soil in root zone mixes has declined in recent years. When one currently speaks of a USGA root zone mix, soil is rarely considered. For soilless root zone mixes, Bingaman and Kohnke (1970) found that a medium-fine sand was suitable for athletic field turf. Davis et al. (1970) identified two sands that were suitable for soilless growth media, both with a majority of the particles in the 0.1 to 0.5 mm size range. In pure sand bowling greens, Davis (1977) recommended a sand having 85% to 95% of the grains between 0.1 and 1 mm, with 50% to 75% in the 0.25 to 0.5 mm range.

Sand Uniformity

Particle uniformity will influence the density to which a root zone mix will pack, as well as the physical nature of the pore space. In discussing the interpacking of sands, Adams et al. (1971) stated that a gradation index (D_{90}/D_{10}) of 2.5 would be the maximum that would preclude interpacking; the gradation index is defined as the ratio of the particles below which 90% of the particles fall, to the diameter to which 10% fall. As the gradation index increases from this, not only does total porosity decrease, but the tendency for particle migration increases. Adams (1982) later published an acceptable gradation index range of 6 to 12.

Bingaman and Kohnke (1970) recommended a gradation index (D_{95}/D_5) of 2 to 6. Standards for sand-soil-peat mixes were proposed by Blake (1980). He proposed that two parameters be used to define the quality of a sand for a root zone mix; a fineness modulus and a uniformity coefficient. The fineness modulus is an index of weighted mean particle size. The uniformity coefficient is a gradation index with a ratio of D_{60}/D_{10}. Based on his experience and the results of others' research, the author proposed a fineness modulus of 1.7 to 2.5 and a uniformity coefficient of < 4.

Blake (1980) reported uniformity coefficient, fineness modulus, and the percentage of particles between 0.25 - 1.0 mm in diameter for several sands. Of the 20 sands that met his proposed criteria, only 2 had 90% of the particles in the 0.25 to 1 mm range, 6 had 80%, and 14 had 70%. Therefore, while these standards may make it unnecessary to define limits, they may provide too much opportunity to have poor-quality sands accepted.

Chemical Properties

Sands used for root zone mixes in the U.S. are predominately quartz. Quartz sand is preferred for root zones because it is chemically inert and very resistant to further weathering. The availability of quartz sands, however, is limited in some parts of the country. As a result, sands containing calcium carbonate or other minerals often are used.

The use of calcareous sands, and some of the problems associated with them, were documented as far back as 1928 (Noer, 1928). While calcareous sands have been used for root zones for years, problems that might be associated with such sands are not well understood or documented.

In a discussion of sand-based root zone mixes, Daniels (1991) stated that softer sands such as feldspars and carbonates will weather faster than quartz. The weathering of such rock, however, would normally take decades. To what extent fertilization and irrigation enhance the weathering process is not understood.

A dozer carefully spreads root zone mix to a depth of 12 inches.

Particle Shape

Particle shape may have an influence on the physical properties of root zone mixes, although the impact of particle shape is thought to be small (Bingaman and Kohnke, 1970; Baker, 1990). Uniform, rounded sands may lack surface stability and could cause scalping and wheel tracking problems during grow-in. This problem usually amends itself after a few weeks as root growth develops, but in some cases the problem can last for years. There also has been speculation that very angular sands may cause some root shearing when the turf area is subjected to traffic.

It has been observed that sandy field soils compact to different bulk densities. Cruse et al. (1980) reported that particle smoothness had a fairly significant effect on compaction of these soils. More research is necessary to increase our understanding of this influence.

Summary

The literature very clearly defines the most desirable sand size range as 0.1 to 1 mm in diameter. The placement of the desired particle size distribution curve in this range should depend on the properties of the components to be mixed. Since most mixes designed today do not contain soil, allowances for more fine sands are in order, provided that certain physical parameters of the final mix are met.

Experience in placing a 100 mesh sieve (0.15) in a stack has shown that many sands with a uniform particle size distribution of 0.25 to 0.5 mm contain a substantial quantity of particles between 0.15 and 0.25 mm, with few passing the 100 sieve. Many sands have needlessly been rejected because they contain in excess of 10% less than 0.25 mm, as described in the 1989 Specifications. Placement of the No. 100 sieve in the stack assures that any fine sands included are in the upper ⅔ of the fine sand range.

The particle size distribution recommended for the USGA Specifications would have a maximum gradation index (D_{90}/D_{10}) of 6.67. This value falls well within the limits defined by Adams (1982), that being 6 to 12. The calculated maximum D_{60}/D_{10} using the equation published by Baker (1990) would be 2.65, falling within the range recommended by Blake (1980).

The effects of chemical makeup and particle shape on the performance of a sand are only speculative at this point. Allowing only quartz sands in a USGA root zone mix would be very inconvenient and nearly impossible in some parts of the country. Research on the stability of calcareous sands in root zones is needed.

Particle shape should be looked at by the labs so that extremely angular sands can be avoided.

Recommendation

Sand Selection: The sand used in a USGA root zone mix shall preferably be a naturally weathered, carbonate-free sand and shall be selected so that the particle size distribution of the **final root zone mixture** is as described in Table 2.

Soil Selection

While not nearly as popular as in the past, soil may still be used in a USGA Specification root zone mix. Guidelines for selection of soils suitable for a sand-based mix have not been provided in the past. Howard (1959) demonstrated the major influence soil texture may have on a root zone mix. Baker (1985a) amended medium-sized sand with 67 soil types to bring the total fines (<0.125 mm) to 20% by weight.

Table 2

PARTICLE SIZE DISTRIBUTION OF USGA ROOT ZONE MIX

Name	Particle Diameter	Specification	
Fine Gravel	2.0 - 3.4 mm	Not more than 10% of the total particles in this range, including a maximum of 3% fine gravel (preferably none)	
Very coarse sand	1.0 - 2.0 mm		
Coarse sand	0.5 - 1.0 mm	At least 60% of the particles must fall in this range	
Medium sand	0.25 - 0.50 mm		
Fine sand	0.15 - 0.25 mm	Not more than 20% of the particles may fall within this range	
Very fine sand	0.05 - 0.15 mm	Not more than 5%	Total particles in this range should not exceed 10%
Silt	0.002 - 0.05 mm	Not more than 5%	
Clay	Less than 0.002 mm	Not more than 3%	

Hydraulic conductivity ranged from 2.8 to 124.7 mm/hr, clearly showing that different soil types will have different influences on the properties of the resulting mix. The permeability and total porosity of the mix was most affected by aggregate size and stability. Organic content influenced total porosity as well, probably due to its influence on aggregate stability.

In an empirical survey of soils tested at the Sports Turf Research Institute (Bingley, England), Baker (1985b) reported that 70% of the soils they had rejected for use in sand/soil root zone mixes had unsatisfactory texture. With two exceptions, all acceptable soils had clay contents less than 22%, and silt contents less than 40%.

The influence of silt to clay ratio in root zone mixes on physical properties was investigated by Whitmyer and Blake (1989). They reported that in a mix with 92% sand, the air-filled porosity and saturated conductivity increased as the silt to clay ratio increased. Conductivity for a mix with a 1.67:1 silt to clay ratio (as per USGA) had a conductivity of 0.52 cm/min compared to 0.4 cm/min at lower ratios.

Recommendation

If a small quantity of soil is used in a USGA root zone mix, it shall have a minimum sand content of 60%, and a clay content of between 5% and 20%. The final particle size distribution of the sand/soil/peat mix shall conform to that outlined in these specifications, and meet the physical properties described herein.

Organic Matter Selection

The organic source is a very important component of a putting green root zone mix. The USGA Specifications only define that the root zone mix include "a fibrous organic amendment." Extreme variability can exist in peats and other organic sources that may influence the performance of a root zone mix. Waddington (1992) provides a review of peats for amending soils. The following review focuses on work relevant to high sand root zone mixes.

Peats

Peats have many applications for improving the physical and chemical properties of root zone media with and without soil (Lucas et al., 1965). The effect a peat has on the properties of a root zone can be influenced by the source of peat, degree of decomposition, pH, ash content, and moisture.

Studies have shown that the addition of peats to sand will decrease bulk density (Juncker and Madison, 1967; Paul et al., 1970; Waddington et al. 1974; Brown and Duble, 1975; Shepard, 1978; Brown et al. 1980; McCoy, 1992), and increase capillary porosity and/or available water (Horn, 1970; Davis et al., 1970; Waddington et al., 1974; Brown and Duble, 1975; Shepard, 1978; Brown et al. 1980; and McCoy, 1991 and 1992).

Effects of peat on permeability have varied with sand particle size and peat type. Fine peats such as reed sedge peats and peat humus will reduce the permeability of a sand to a much greater extent than a fibrous peat, such as sphagnum (Davis et al., 1970; Shepard, 1978; Brown et al., 1980; McCoy, 1992). Blake et al. (1981) found from experience that even small increments of reed sedge peat sharply reduced conductivity, suggesting that a small amount of sphagnum may be more suitable. Waddington et al. (1974) found, however, if reed sedge peat is added to a mixture at the expense of soil, the permeability will increase.

On fine sands, sphagnum peat has been shown to increase moisture retention with only a slight effect on permeability at volumes up to 20% (Paul et al., 1970). The authors point out that the interaction of organic source with sand necessitates testing of the mixes prior to their use as a root zone.

While sphagnum peats will increase the moisture retention of a sand root zone mix, McCoy (1991, 1992) reported that the amount of water available to the plant will vary with peat particle size. The author presented data showing the bimodal release of water from sphagnum sand mixes at various suctions. All peats had a primary peak that occurred as water was extracted from the pores between the sand grains and the peat particles. A coarse sphagnum peat with greater than 50% fiber had a second peak at much greater tensions as water was extracted from the pores within the peat particles. The secondary peak was much smaller for a medium sphagnum peat (33% fiber), followed by reed sedge peat (20%).

The stability of sphagnum peats in root zones has always been questioned without basis. While sphagnum peats are in a relatively undecomposed state as sold, the research does not bear out these concerns. Shepard (1978) found that the physical properties of a sand amended with 10% sphagnum peat were unchanged after one year with turf growing in it. Likewise, Maas and Adamson (1972) reported that sphagnum was stable after 36 months incubation.

While not technically peats (American Society of Testing and Materials, 1991), muck soils are often mistaken for peats and used in root zone mixes. McCoy (1992) reported that a muck soil with an organic matter content of 40% and a fiber content of 7% mixed with sand at 20% by volume had a saturated conductivity of 2.1 cm/hr and a very low compression index.

Other Organic Amendments

Other organic sources have been investigated for use in root zone mixes; most of them by-products of the forestry or agricultural industries. Sawdust and other wood products have been researched for modifying soils (Allison and Anderson, 1951; Lunt, 1955; Thurman and Pokorney, 1969; Maas and Adamson, 1972). Davis et al. (1970) and Paul et al. (1970) reported that redwood sawdust treated with nitrogen decreased saturated conductivity on a medium sand at 10% by volume. Additional increments increased saturated conductivity.

Addition of sawdust to sand increased air-filled porosity and slightly increased moisture retention, most of which was available to the plant.

Shepard (1978) added oak sawdust to sand at 10% by volume and found that it stunted growth and caused discoloration of bentgrass turf; this likely due to nitrogen (N) immobilization. Similar responses were reported on seed germination in soil amended with sawdust (Waddington et al., 1967). These results suggest that sawdusts must be thoroughly composted to be considered as the organic amendment in a root zone mix.

Bark products have also been looked at for use in root zone mixes. Uncomposted pine bark has been shown to decrease saturated conductivity (Davis et al., 1970; Paul et al., 1970), as well as increase it (Brown and Pokorney, 1975; Shepard, 1978; Brown et al., 1980), increase air-filled porosity (Davis et al., 1970; Shepard, 1978), and slightly increase moisture retention (Davis et al., 1970; Brown et al., 1980). Much of this additional water, however, was not plant available (Davis et al., 1970). Composted bark decreased saturated conductivity of a medium sand (Davis et al., 1970), and had very slight effects on aeration porosity or plant available water.

Shepard (1978) reported stunted growth and discoloration with the addition of pine bark to sand; again likely due to N immobilization. The stability of wood products in root zones has always been in question. Sawdusts will decompose faster than bark products (Allison and Murphy, 1962, 1963), and hardwoods faster than softwoods (Allison and Murphy, 1963). Mazur et al. (1975) reported that bark was not as stable as peat and deteriorated after a 13-month incubation period. The addition of soil to a mix may further enhance decomposition of wood products, as reported by Maas and Adamson (1972).

Davis et al. (1970) and Paul et al. (1970) looked at the physical properties of several organic sources mixed with 5 sands. Ammoniated rice hulls decreased the saturated conductivity of a medium sand (one similar to USGA specification), but increased it on a fine sand. While rice hulls produced little change in total water held, unavailable water increased (Davis et al., 1970). Brown et al. (1980) reported that rice hulls in a 7-1-2 mix decreased saturated conductivity of a sand, and increased moisture retention to levels similar to Michigan peat (8-0-2), and greater than the sphagnum in a 7-1-2 ratio.

It takes more than a quick look to determine if a root zone mixture meets acceptable standards; it takes thorough testing by an experienced laboratory.

Johns (1976) reported no differences in infiltration, water holding capacity, CEC, or root growth when rice hull amended sand was compared to sand amended with peat moss

Sludge composts have produced favorable plant responses when used as the organic amendment with sand (Shepard, 1978; Almodares et al., 1980). Shepard (1978) found that dried, ground sludge added to sand at 10% by volume increased saturated conductivity with little effect on total or aeration porosity. After a decrease in conductivity at 26 weeks, the author found that soil physical properties and organic matter content of the sewage sludge root zone mix were stable at 52 weeks. These results concur with Miller (1974), who reported that most sludge decomposition occurred in the first month. Brown et al. (1980) reported that sewage sludge in an 8-1-1 mix increased saturated conductivity and moisture retention. McCoy (1992) found that a composted sludge added to sand increased saturated conductivity and available water with increasing increments of sludge compost.

This literature review documents the major impact an organic source will have on the performance and physical properties of the root zone mix. Despite this, there has been little information on criteria to predict performance. Thus, recommendations for organic sources often have been left to the subjective evaluation of the person designing the mix (Gockel, 1986).

Guidelines for peat evaluation have been based primarily on percent organic matter. Minimum organic matter percentages as determined by loss on ignition range from 80% (McCoy, 1991), to 85% (Beard, 1982; Dixon, 1990), to 90% (Waddington et al., 1974; Daniels, 1991). The American Society of Testing and Materials (ASTM, 1991) classifies peat for ash content as follows: low ash, less than 5% ash; medium ash, 5 to 15% ash; and high ash, greater than 15% ash.

While we still don't know what that magical number is, the literature seems to support that native peats and high organic soils with organic matter percentages below 80% to 85% will result in excessive reductions in permeability and aeration porosities. On this basis, a minimum of 85% organic matter (maximum 15% ash) serves well as a safe specification in an area of study we have little information on.

Another means of evaluating peats is by the rubbed fiber content. While qualitative, it did provide some sense of the degree of decomposition. Kussow (1987) recommended that a peat have a rubbed fiber content of 50% to 75%.

Probably a better means of assessing peat quality is the fiber content as described by McCoy (1992). This value not only would identify peats with excessive fine particles, but also would sort organic sources for their value for water retention. McCoy (1991) suggests that fiber content range from 20% to 45%, modifying it to 50% (McCoy, personal communication). His study, however, included only a small sampling of peats. More research on this method and its interpretation is necessary before a fiber content range can be specified.

Recommendation

The preferred organic component shall be a peat with a minimum organic matter percentage of 85% by weight as determined by loss on ignition (ASTM D 2974-87 Method D).

Other organic sources such as finely ground bark, sawdust, rice hulls, or other organic waste products may be allowed if composted through a thermophilic stage, to a mesophilic stabilization phase. Composts should be aged for at least 1 year. Composts can vary not only with source, but also from batch to batch within a source. Extreme caution should be exercised when selecting a compost material. Composts must be proven to be non-phytotoxic using a bentgrass or bermudagrass bioassay on the compost extract. Furthermore, the root zone mix with compost as the organic amendment must meet the physical properties as defined in these specifications.

Inorganic and Other Amendments

Calcined Clay

Calcined clay materials have been marketed as soil amendments for many years. Very porous materials, calcined clays have been shown to increase capillary porosity and moisture retention. Much of this water, however, is held at high tensions and is unavailable for plant use (Hansen, 1962; Smalley et al., 1962; Letey et al., 1966;

Morgan et al., 1966; Valoras et al., 1966; Davis et al., 1970; Horn, 1970; Ralston et al., 1973; and Waddington et al., 1974). In fact, Smalley et al. (1962) reported decreased yields in clay amended plots, especially during drought periods. There have also been confirmed reports of particle degradation (USGA Green Section Staff, personal communication). While calcined clays may increase the exchange capacity of a root zone mix, its value in a root zone mix is highly questionable.

Vermiculite

Vermiculite is a very porous material with a high moisture-holding capacity and a low bulk density. Vermiculite has been reported to improve turfgrass yield and quality when compared to unamended sand or sandy loam soil (Smalley et al., 1962; Horn, 1970). Vermiculite has been reported to decrease permeability (Smalley et al., 1962; Paul et al., 1970; Davis et al., 1970), increase available water (Hagan and Stockton, 1952; Horn, 1970; Davis et al., 1970), and increase CEC (Horn, 1970). Smalley et al. (1962) noted a sharp decrease in permeability in vermiculite amended plots after the second year, perhaps due to compression of the particles.

There is inadequate field data on vermiculite in a sand based root zone mix to recommend its use at this time.

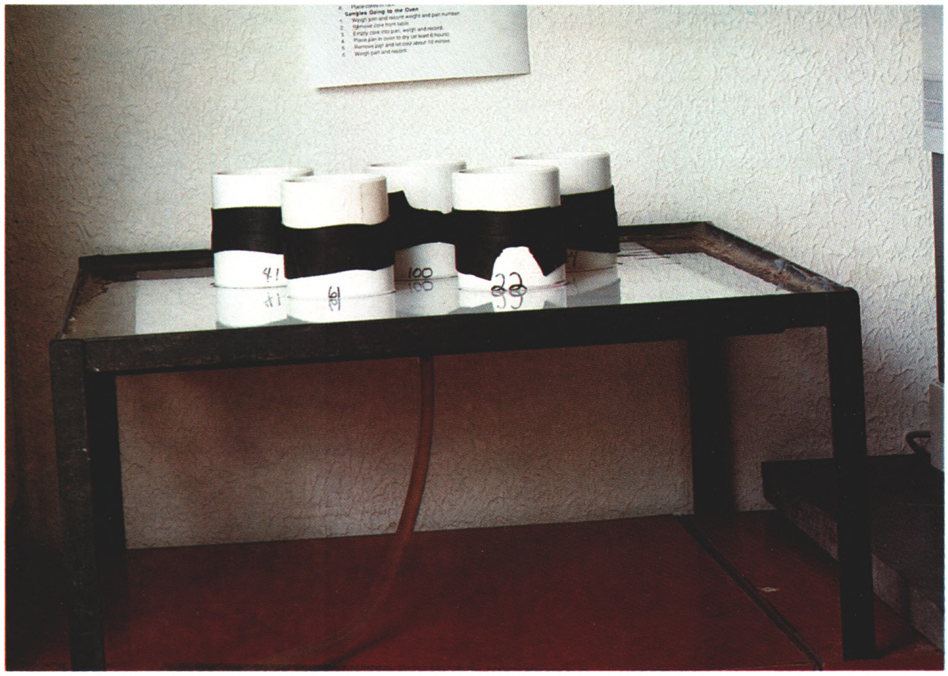
Perlite

Perlite is a very light, porous material commonly used for greenhouse and nursery media. When used to amend sands, perlite decreased permeability on a medium sand (Davis et al., 1970; Paul et al., 1970). Moore (1985) reported that 10% perlite added to a medium sand increased total porosity by 10% to 15% and moisture retention by 5%. Crawley and Zabcik (1985) found no effect at 10%, but at 20% by volume there was a slight increase in moisture retention, an increase in total and air filled porosity, and a decrease in saturated conductivity. These results are in some disagreement with Davis et al. (1970) and Hagan and Stockton (1952), who reported no increase in available water with perlite additions.

While perlite is resistant to weathering, it is very brittle and may be subject to breakage with compaction and cultivation. Again, there is insufficient field data or experience with perlite to recommend its use.

Calcined Diatomites

Calcined diatomites are naturally occurring minerals derived from diatoms, and processed to varying degrees. Dialoam is such a mineral that was looked at as an amendment in the 1970s. Davis et al. (1970) reported that dialoam had little influence on permeability of a medium-coarse sand. While the material increased moisture retention, much of the water was not available.



A tension table used to measure water retention.

Isolite is a lightweight, porous ceramic material available in two particle sizes. Laboratory data, corrected for particle density, indicate that isolite will increase capillary porosity at the expense of air-filled porosity (Innova Corporation, 1992). Nearly all of the additional water is available at tensions less than 0.1 bar. When added to sand at 10% by volume, isolite increased volumetric water content at 40 cm tension from 5.3% for unamended sand to 8.4%. Adding 10% reed sedge peat increased volumetric water content to 11.6% for the same sand.

Isolite is also brittle and may be subject to breakdown with cultivation practices. On the basis of the limited work available on this material, it would be imprudent to include it in the specifications at this time.

Clinoptilolite Zeolite

Clinoptilolite zeolite is a naturally occurring porous mineral of low bulk density and very high exchange capacity; about 230 cmol/kg (Mumpton and Fishman, 1977). Clinoptilolite is selective to potassium and ammonium (Ames, 1960). As an amendment to sand, clinoptilolite has been shown to increase moisture and nutrient retention (Ferguson et al., 1986; Ferguson and Pepper, 1987; Huang, 1992) and improve turfgrass quality when compared to sand alone (Ferguson et al., 1986). Huang (1992) reported that 5% and 10% additions of clinoptilolite in the 0.25 to 0.5 mm size range had no effect on saturated conductivity.

Compared to sawdust and sphagnum peat, clinoptilolite exhibited the highest volumetric exchange capacity and exchangeable K (Nus and Brauen, 1991). This high exchange capacity resulted in reduced nitrate and ammonium leaching losses, especially at higher N application rates (Huang, 1992).

Clinoptilolite zeolite appears to have potential as an inorganic amendment. The question of particle stability, however, has not yet been addressed in replicated trials. Also, there have not been any field trials in northern climates where freeze-thaw cycles may enhance weathering of the mineral.

Pumice

Pumice is a porous volcanic rock that has been shown to increase water retention, air porosity, and permeability of sand in laboratory experiments (Davis et al., 1970; Paul et al., 1970).

Polyacrylamides

Polyacrylamides (PAM) are water-absorbing polymers that hold many times their weight in water (Vlach, 1990). They are being promoted as amendments to sand root zone mixes to increase moisture retention. McGuire et al. (1978) reported that five PAMs tested did not alter the physical properties, CEC, or turf growth parameters when used to amend sand and sandy loam.

Baker (1991) reported increased moisture retention and an increase in ryegrass cover where PAMs were used. These benefits were observed for up to two years after incorporation. In greenhouse studies, Vlach (1991) reported beneficial effects of one PAM, but detrimental effects of other PAMs on seed germination and stand density. The polymers did not affect infiltration. There are confirmed reports, however, that the swelling of polymers in sand greens after irrigation or precipitation resulted in puddling and heaving of the green surface.

PAMs have not been adequately field tested to recommend their use in USGA greens.

Reinforcement Materials

Reinforcement materials have been used in sand-based sports fields to provide stability, especially in high-wear areas. Because of potential interference with cup cutting on greens, few, if any, would have an application in a putting green.

Fibresand is a product consisting of polypropylene fibers that are mixed with the root zone mix. Baker et al. (1988) reported only slight effects of Fibresand in sand construction, other than some improvement in surface stability and improved traction.

Beard and Sifers (1990) looked at 50 x 100 mm pieces of interlocking mesh elements (Netlon) incorporated into a root zone for sand stabilization. Netlon improved several properties of the root zone, most of which would be of little relevance in maintaining golf greens.

Recommendation

Inorganic amendments (other than sand), polyacrylamides, and reinforcement materials are not recommended at this time in USGA greens.

Physical Properties of the Root Zone Mix

Since their inception, the USGA Specifications for Green Construction have defined physical properties that a root zone mix must meet. In evaluating the Specifications, one must look at the required laboratory measurements and assess their usefulness in predicting the performance of a root zone mix. Table 3 reviews the physical parameters of the three previous specifications.

The value of measuring these physical parameters has been questioned. Taylor and Blake (1981) concluded that sand content provided a better measure of soil mixes than did packed laboratory samples. In comparing laboratory packed samples with undisturbed field samples, Blake et al. (1981) reported that only porosity at -100 mb water potential was correlated to the corresponding field property. Again, sand content was a better indicator of field properties, with a significant correlation to saturated conductivity, bulk density, and air porosity at -60 and -100 mb water potential.

In reviewing the research literature, the problem is compounded by the lack of consistency in methodology, and poorly described methodology in many cases. The need for standard test methods and the development of methods more predictive than correlative are sorely needed. Just the same, there has been sufficient work published to provide guidance to someone developing a root zone mix, guidelines that should be included in the USGA Specifications. Table 4 lists published measurements for root zone mixes that would be comparable to a USGA mix at that time, or for root zones identified as having been better performing mixes. Some data that was extracted from graphs may not be completely accurate.

The values discussed in this section are based on laboratory prepared samples, compacted with 3.027 J/cm^2 energy at a water potential of -40 mb. Standard methods for all these parameters have been prepared and will be submitted to the American Society of Testing and Materials for review and publication.

Bulk Density

The bulk density has been used as a parameter in assessing root zone mixes since the original specifications. Several studies, however, have found it an irrelevant number in predicting performance (Kunze, 1956; Smalley et al., 1962; Waddington et al., 1974; and Shepard, 1978). Most cite the influence of the density of other amendments, such as organic matter, and the mixing ratios as the major influence on bulk density measurements.

The 1989 USGA Specifications give a very wide acceptable range for bulk density, one that most mixes will meet regardless of their suitability as root zone mixes. It is a value that must be determined by the labs to calculate porosity and pore distribution. It is questionable, however, if it should be reported and that there be a required range that must be met. Thus, it has been proposed that the required bulk density range be dropped from the specifications.

Table 3

SUMMARY OF PHYSICAL PROPERTIES OF ROOT ZONES AS SPECIFIED BY THE USGA

USGA Specifications Version	Bulk Density g/cc	Saturated Conductivity in/hr	Total Porosity %	Air-Filled Porosity %	Capillary Porosity %	Moisture Retention %
1960	NS	0.5 - 1.5*	> 33	12 - 18	15 - 21	NS
1973	1.2 - 1.6	2.0 - 10.0	40 - 55	> 15	—	12 - 25
1989	1.2 - 1.6	NS	35 - 50	15 - 25	15 - 25	12 - 18

*Possibly referred to flux density at a hydraulic potential gradient of 6.35 cm

Table 4

PUBLISHED PHYSICAL PROPERTIES FOR VARIOUS ROOT ZONE MIXES

Reference	Volume Ratio	Saturated Conductivity (in/hr)	Total Porosity	Air-Filled Porosity	Capillary Porosity
Kunze (1956)	80-10-10	0.07 - 1.1	37 - 42%	13%	27%
	85-5-15	0.02 - 1.5	37 - 40%	14%	25%
Lunt (1958)				10 - 15%	> 10%
Howard (1958)	80-10-10	0.55 - 1.5		19 - 22%	15 - 27%
Junker & Madison (1967)	100% sand		44%	19%	
	75-0-25		57%	20%	
Paul et al. (1970)	90-0-10	5.9			
	80-0-20	5.1			
Waddington et al. (1974)	80-0-20	54		24%	27%
	80-10-10	28		15%	23%
Brown & Duble (1975)	85-5-15	37	46%	21%	
Brown et al. (1980)	80-0-20	7.3			18%
McCoy (1991)	85-0-15 sph	3.1	49%	22%	27%
	85-0-15 rs	2.4	47%	24%	23%

Moisture Retention

Moisture retention is currently the gravimetric expression of water content at a potential of -40 mb. The volumetric expression of moisture retention is referred to as capillary porosity. It is hard to decipher how this came to be in the specifications, first appearing in the 1973 version. It is a redundant value that may contribute to some of the confusion over lab results. Therefore, it is proposed that it be dropped as a required value in the specifications.

Of more practical vaue would be available water, that is, the water held between a potential of -40 mb and a lower potential. Some will determine available water as that between -40 mb and -15 bars, the hypothetical permanent wilting point. In sand peat mixes, however, Juncker and Madison (1967) reported that pole beans (*Phaseolis vulgaris*) wilted at about -200 mb for straight sand, and up to -400 mb for sand peat mixes. At this time we have little knowledge of what that wilting point is with grasses, or how we would interpret an available water value. It is an area, however, worthy of further research.

Porosity

Table 4 shows that published total porosity values fall within the ranges that have been recommended by the USGA in the past and perhaps have provided the basis for those recommendations. Of greater importance, however, is the distribution of pores at 40 cm tension.

Both Kunze (1956) and Howard (1959) reported a positive relationship of non-capillary porosity with yields and quality. Again, Table 4 shows that most values reported for air-filled porosity have been in line with the USGA Specifications. It is not uncommon with soilless mixes, however, to have air-filled porosity values greater than 25%, with the mix still providing adequate water retention.

The importance of water retention in these root zone mixes cannot be denied. Results from Howard (1959) suggest that water may be a limiting factor in maintaining greens, since higher yields were recorded on the finer sand, and because more soil was required to produce comparable yields in a coarse sand. Once again, Table 4 shows that USGA recommendations are in line with values obtained in research trials.

On the basis of this, it appears that only slight modifications are needed in the current recommendations for porosity.

Saturated Conductivity

The lack of a specified saturated conductivity range was another controversial aspect of the 1989 specifications. Howard (1959) reported that flux was correlated to yields and quality. Waddington et al. (1974) found a poor correlation between laboratory percolation rates and field infiltration rates in years 2 through 5. After 10 years, however, the relationships were much stronger. On the basis of this, the authors concluded that laboratory infiltration rates should be the primary criterion in selecting a mix.

In long-term studies, Schmidt (1980) found that infiltration rates dropped by an average of 46%. Likewise, Brown and Duble (1975) reported that turf cover decreased infiltration rates by half for mixes with 5% soil and 90% for mixes with 20% soil. Shepard (1978) reported similar reductions.

The difficulty in predicting field infiltration from compacted lab samples may explain why rates were not recommended in the 1989 version of the specifications. Leaving this parameter open-ended, however, has left much to the sometimes misguided interpretation of the laboratory. Saturated conductivity values of well over 50 in/hr have been acceptable to some labs. Despite the lack of consistent information to specifically define limits, acceptable saturated conductivity values would be of great service to the industry.

Recommendation

The root zone mix shall have the following properties as tested by USGA protocol (proposed ASTM Standards):

Total Porosity: 35-55%.

Air-filled Porosity at 40 cm tension: 15-30%.

Capillary Porosity at 40 cm tension: 15-25%.

Saturated Conductivity: Normal Range (where normal conditions for growing the desired grass species prevail): 6-12 inches/hr (15-30 cm/hr).

Accelerated Range: (where water quality is poor, or growing cool-season grasses out of range of adaption): 12-24 inches/hr (30-60 cm/hr).

Furthermore, the root zone mix shall have an organic matter content of between 1% and 5% (ideally 2-4%) by weight.

IT IS ABSOLUTELY ESSENTIAL TO MIX ALL ROOT ZONE COMPONENTS OFF-SITE. No valid justification can be made for on-site mixing, since a homogeneous mixture is essential to success.

A QUALITY-CONTROL PROGRAM DURING CONSTRUCTION IS STRONGLY RECOMMENDED. Arrangements should be made with a competent laboratory to routinely check gravel and/or root zone samples brought to the construction site. It is imperative that these materials conform to the mix or gravel approved by the lab in all respects. Some tests can be performed on site with the proper equipment, including sand particle size distribution.

Care should be taken to avoid over-shredding of the peat, since it may influence performance of the mix in the field. Peat should be moist during the mixing stage to ensure more uniform mixing and to minimize peat and sand separation.

Fertilizer should be blended into the root zone mix. Lime, phosphorus, and potassium should be added based on a soil test recommendation. In lieu of a soil test, mix about 1/2 pound of 0-20-10 or an equivalent fertilizer per cubic yard of mix.

Step 5. Topmix Covering, Placement, Smoothing and Firming

This section in the USGA's green construction booklet discusses the actual placement, including suggestions for spreading. Much of what is covered there may be better placed in "Tips for Success."

Recommendation

After the root zone mix materials have been thoroughly mixed off-site, the mix should be placed on the green and spread to a uniform, firmed thickness of 12 inches. Spreading the mix with small tracked equipment normally achieves final settled depth. Be sure that the mix is moist at spreading to prevent migration into the gravel and to assist in firming the mix. Repeated irrigation will help settling. Acceptable tolerance for the grading should be plus or minus ½ inch.

The surface should be firmed, smoothed, and contoured to the designed grade by wheel compaction from a mechanical sand rake or comparable machine. Wetting the surface will help facilitate final grading.

(Below) Almost finished — sowing the seed on a new USGA-standard green.
(Bottom) Firming and smoothing the surface prior to final seedbed preparation.

Step 6. Seedbed Preparation

Sterilization of the root zone mix by fumigation should be left to the discretion of the architect or consultant. Fumigation should always be performed:

1. In areas prone to severe nematode problems.
2. In areas with severe weedy grass or nutsedge problems.
3. When root zone mixes contain unsterilized soil.

Check with your regional office of the USGA Green Section for more information and advice specific to your area.

Research Needs

1. Development of laboratory methodology that better predicts the performance of a root zone mix in terms of actual field properties, especially in relating plant response to measurable soil physical properties.
2. Assessment of the properties of organic sources that can be quantified and used to predict performance in the field. This is most appropriate in view of the probability that native peats will become more scarce, while composts and other amendments become more available.
3. Evaluation of promising inorganic amendments.
4. Assessment of the influence of sand properties, including particle shape and chemical makeup, on root zone physical properties and their stability.

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Why We Need Laboratory Standards For Testing Root Zone Mixes

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LABORATORY standards are well established in the construction, medical, and many other industries. The American Society of Testing and Materials (ASTM), a national clearing house for such standards, has volumes full of standards for just about anything you can imagine. These consensus standards assure some degree of quality and continuity to their respective industries. Until now, no such standards have existed for testing USGA or other sand-based root zone mixes.

Many commercial laboratories perform physical tests on putting green root zone materials. In recent years, it has become common for golf course superintendents to split samples and send them off to different laboratories, only to receive very different results back from the labs. This has created much confusion in the industry, not to mention a lack of confidence in laboratories.

One important goal in the USGA's review of its green construction recommendations was to assess the current practices in the labs, and to develop scientifically sound standard test methods. Visits to the labs and discussions with lab personnel [by the author] revealed that no two were performing the tests in exactly the same manner. A split sample sent to all the labs confirmed what many already knew: evaluation of samples sent to different labs sometimes produces different results. Table 1 lists the particle size analysis of the sample as reported by nine labs. The results show that there was a fair amount of variation in the distribution of silt and clay and, to a lesser extend, sand. While it is not reported here, the labs did report very similar sand size distributions for the samples.

As part of the proposed new laboratory standards, a much more accurate method of measuring the silt and clay components of a mix has been established.

Results of the laboratory testing for the physical properties of the mix are shown in Table 2. The data show high levels of variability for infiltration, porosity, pore distribution, and moisture retention.

Much of the disparity in the results could be explained by differences in sample preparation, test procedures and, in at least two cases, mismeasurements or miscalculations. Standard methods have been developed that provide a "recipe" approach for determining these values. Most procedures have been adapted from those already published by the American Society of Agronomy or ASTM, and have been reviewed by several soil scientists.

In addition, guidelines have been established for quality assurance/quality control within the laboratories. This may be as simple as running duplicates or triplicates of samples, or running a known standard sample with each run.

While the USGA has seen to it that these standards have been developed, the industry must realize that 1) these standards are voluntary, and 2) they do not guarantee a minimum level of competence within the lab.

Any individual who obtains these procedures and follows them to the "T" should be able to produce good numbers. You should realize, however, that they may not have the agronomic experience or expertise to provide an appropriate interpretation, or to deal with follow-up questions you may have.

Nevertheless, the development of laboratory standards for root zone mixes were a long time in coming, and they should make a major difference in the quality and consistency of services received from the soil testing laboratories.

Table 1
RESULTS OF PARTICLE SIZE ANALYSIS

	Range	Mean	Std. Dev.
Sand	94.5% - 99.2%	96.6%	1.4
Silt	0 - 3.7%	1.8%	1.2
Clay	0.1% - 3.6%	1.6%	1.2

Table 2
RESULTS OF TESTING FOR PHYSICAL PROPERTIES

Physical Property	Range	Mean	Std. Dev.
Infiltration (in/hr)	7.7* - 18.8	11.4	3.8
Total porosity	40.1% - 50.9%	46.1%	2.9
Capillary porosity	14.5% - 29.7%	20.6%	4.9
Air-filled porosity	20.8% - 29.1%	25.4%	3.3
Bulk density (g/cc)	1.27 - 1.53	1.38	0.07
Moisture retention	9.9% - 22.8%	14.5%	4.1

*One lab reported a value of 0.52 in/hr. It later was determined they were reporting a value called flux density. The corrected value was 11.4 in/hr.

LABORATORY METHODS FOR EVALUATION OF PUTTING GREEN ROOT ZONE MIXES

Compiled by DR. NORMAN W. HUMMEL, JR.
Cornell University

The following laboratory procedures were put together by Dr. Norman W. Hummel, Jr., and were reviewed by members of the Advisory Committee and by personnel at soil testing laboratories currently testing materials for USGA-standard greens. Although few readers will be interested in the details of these procedures, they are published here to provide a widely distributed, readily available reference for future use.

Standard Test Methods for Saturated Hydraulic Conductivity, Water Retention, Porosity, and Bulk Density on Putting Green Root Zone Mixes

1. Scope

1.1 These test methods cover the measurements of saturated hydraulic conductivity, water retention, porosity (including distribution of capillary and air-filled porosity at 40 cm tension), and particle and bulk density on root zone mixes to be used for construction and topdressing of USGA recommendation greens or other highly trafficked turfgrass areas.

1.2 Water retention as described in this standard is a gravimetric expression of capillary porosity and is not a required measurement for USGA recommendation greens. Its inclusion in this standard is for the benefit of those who wish to continue to report it. Likewise, bulk density is no longer a specified measurement, but must be determined for calculation of total and capillary porosity.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to its use.*

2. Referenced Documents

2.1 Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. American Society of Agronomy Monograph No. 9, Part 1, Second Edition.

2.2 ASTM Standard D 854-83, Standard Test Method for Specific Gravity of Soils.

3. Summary of Methods

3.1 *Method A* — Saturated hydraulic conductivity is determined on compacted, saturated soil cores. Water flow through the core is maintained at a constant hydraulic head for four hours, or the point equilibrium is reached, at which time aliquots are collected.

3.2 *Method B* — Water retention at 40 cm tension is obtained by extracting the water from a prepared core by means of a tension table or other water extraction apparatus. When the weight reaches equilibrium, the weight is recorded. The core is oven dried at 105° C, until a constant weight is obtained. Water retention is calculated on an oven dried basis. Bulk density is calculated from the soil weight and volume.

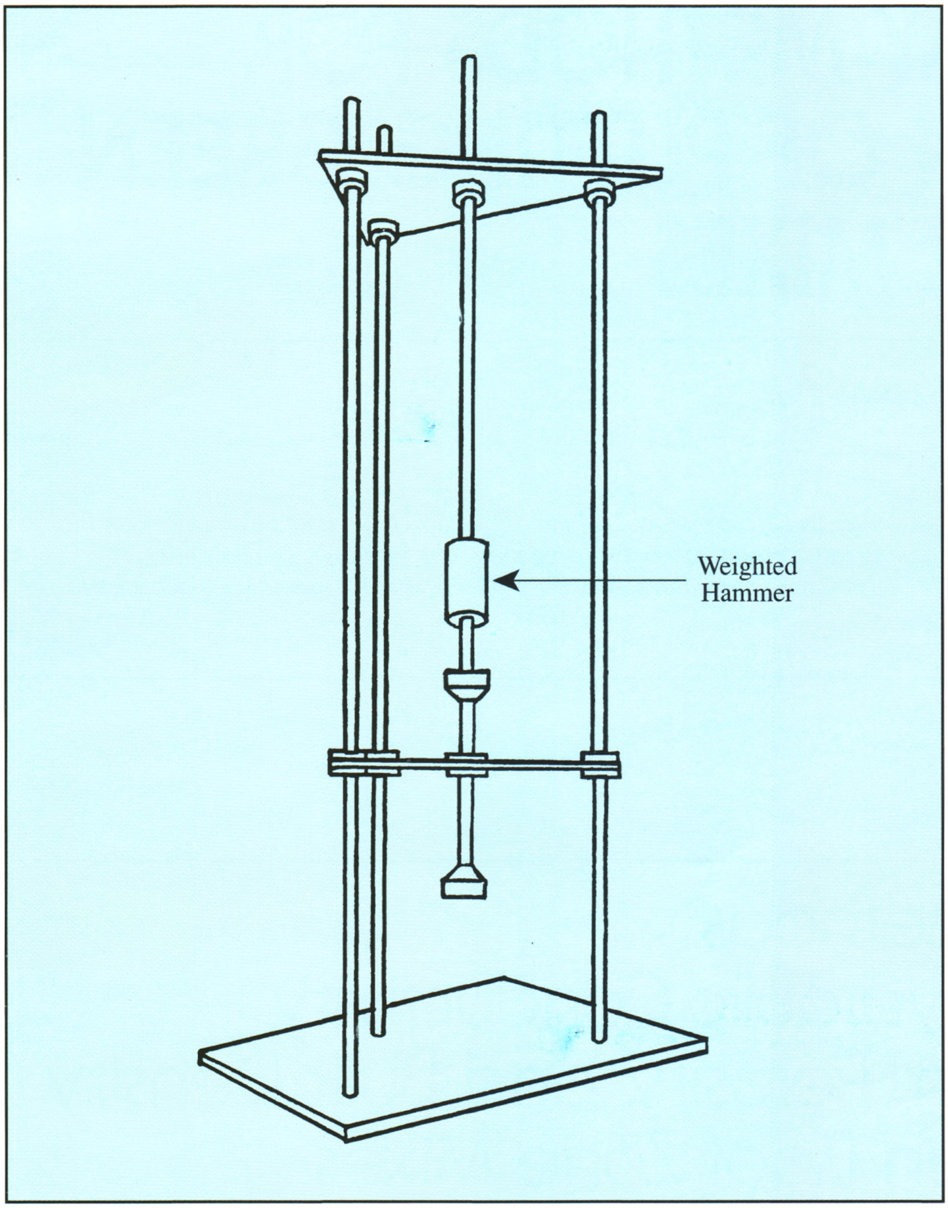


Figure 1. A suggested impact-type compactor to produce a total dynamic energy of 3.03 J/cm² across the surface cross-sectional area of the core. It has been found that 15 drops of the hammer from a height of 12 inches (as measured from the bottom of the weight to the top of the anvil) will produce a degree of compaction comparable to a severely compacted putting green, provided the soil contains moisture approximating field capacity.

3.3 *Method C* — Particle density is an average for all components of a rootzone mix and is used for calculating total porosity.

3.4 *Method D* — Total porosity is calculated from the bulk density and particle density.

3.5 *Method E* — Capillary porosity is calculated from the bulk density and water retention information. Air-filled or aeration porosity is calculated from the difference of total and capillary porosity.

4. Apparatus

4.1 *Cylinders*, made of metal, PVC, or similar durable materials shall have an inside diameter of 51 to 76 mm, and a minimum height of 76 mm.

4.2 *Compactor*, shall be such as to exert a total dynamic energy of 3.03 J/cm^2 (14.3 ft lbs/in^2) across the surface cross sectional area of the core. Figure 1 shows an example of such a device where a 3 lb weighted hammer is dropped 15 times from a height of 305 mm (12 inches).

4.3 *Permeameter,* capable of maintaining a constant hydraulic head for several hours.

4.4 *Tension or porous plate apparatus*, capable of extracting water out of the cores at a matric potential of - 40 mbars (40 cm tension). Figure 2 shows an example of a tension table.

4.5 *Oven*, capable of maintaining a constant temperature of 105° C.

4.6 *Pycnometer* — a small flask with a capacity of 50mL. The pycnometer should have a ground glass stopper with a small hole in it to allow the escape of air. A volumetric flask with a 100 mL capacity may also be used, but a larger sample size will have to be used to compensate for the decrease in precision of measuring the fluid volume.

4.7 *Balance* — A balance sensitive to 1 mg (0.001g) should be used with pycnometers. A balance with sensitivity to 10 mg may be used with volumetric flasks.

4.8 *Thermometer* — accurate to 0.5°C.

5. Preparation of Sample

5.1 *Premixed samples*

5.1.1 The cylinders should be prepared by attaching a double layer of cheesecloth or other suitable material with a rubber band onto the bottom of each cylinder. Weigh and record the weight of each cylinder.

5.1.2 Attach another cylinder of the same diameter to the top, securing with a 1" piece of bicycle inner tube or a water proof tape.

5.1.3 Screen the root zone mixture through a No. 4 sieve to remove peat clods and other debris. Peat clods should be broken up and returned to the sample.

5.1.4 Place moistened root zone mix into the cylinder, tapping gently on a firm surface as mix is added. Add sufficient quantities of mix to the cylinder so that the final level is 2-4mm above the top of the lower cylinder. The intent here is to have the surface of the soil as close as possible to the top, but not above the lip of the lower cylinder after compaction.

5.1.5 Place the cylinder in a pan of water and allow it to saturate from the bottom up. Be careful not to splash any water onto the soil surface. Allow the core to saturate for 30 to 60 minutes.

5.1.6 Place the cylinders on a tension table or other water extracting device, set to remove water at 40 cm of tension (see figure 2 for proper measurement). Leave sample cores on the table for at least 16 hours.

5.1.7 Place the cylinder onto the base of the compactor, and drop the weight 15 times from a height of 305 mm (12 inches).

5.1.8 Remove the upper cylinder. If the level of the mix is above the top of the lower cylinder, remove the mix, repack the cylinder, and recompact the sample. **Do not shave off the top of the soil.** If the level of the mix is

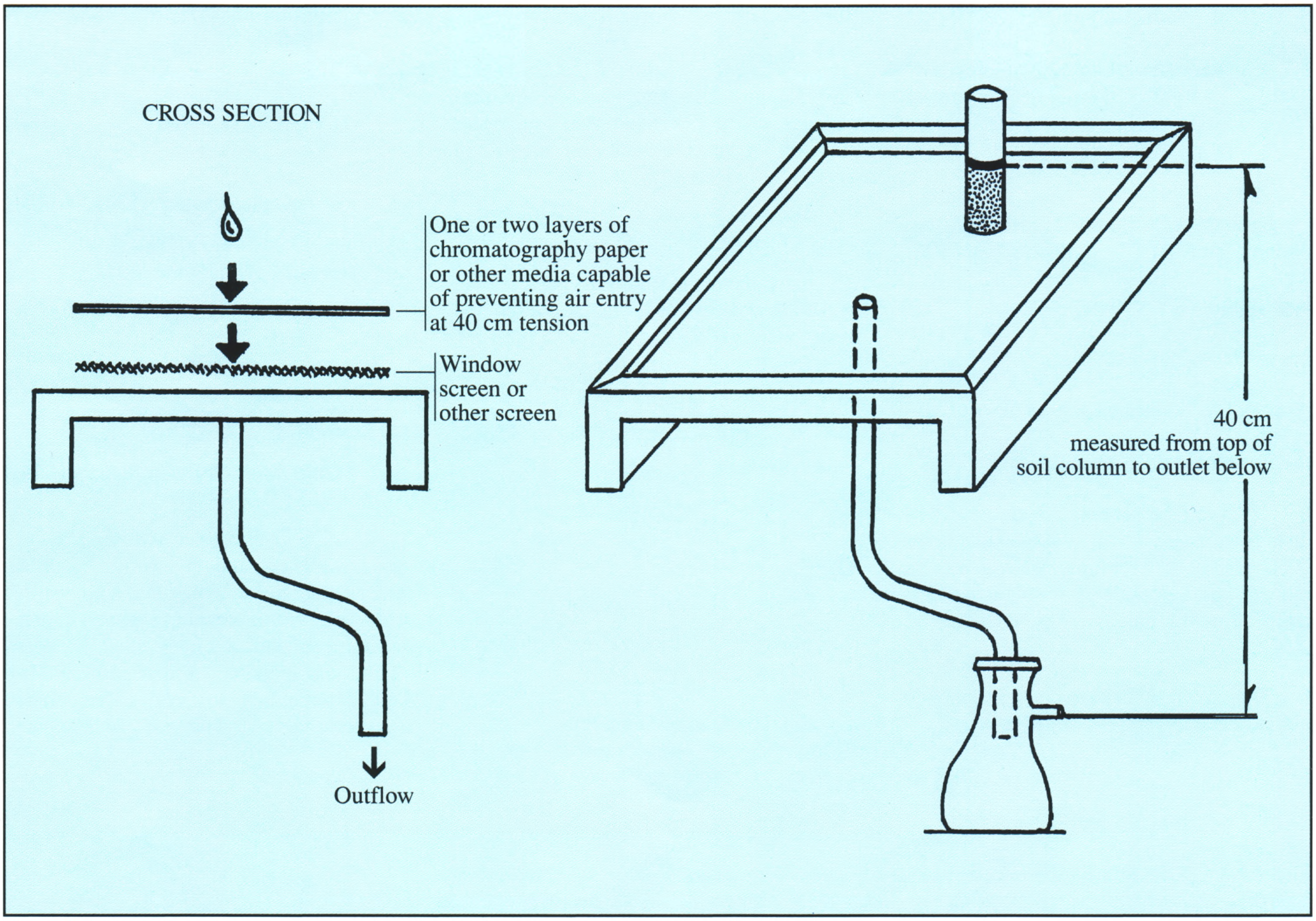


Figure 2. Suggested tension apparatus capable of extracting water out of the cores at 40 cm tension.

below the edge of the cylinder, measure the length of this depression to the nearest 0.1 cm (mm). Subtract this value from the height of the cylinder to determine length of the soil column (L). Record this number (cm).

5.1.9 Calculate the volume of the soil column as follows: $V = L \times A$, where: L = length of the soil column (to the nearest 0.1 cm), and A = cross sectional area of the column ($A = \pi r^2$).

5.2 *Laboratory mixed samples*

5.2.1 Root zone mixes are nearly always mixed on a volume basis. Use a measuring device such as a graduated cylinder or small beaker for measuring sand and soil volumes.

5.2.2 Peat volumes should be measured in a compressed state.

5.2.3 Thoroughly mix the sand, peat and/or soil to the desired volume ratios.

5.2.4 Determine percent organic matter by the Walkley-Black potassium dichromate oxidation technique or loss on ignition method to quantify organic matter content on a weight basis. This value and the method used should be reported so that field checks of mixes can assure that the mix corresponds to that developed in the laboratory.

5.2.5 Follow steps 5.1.1 through 5.1.9 for sample preparation.

6. Quality Assurance/Quality Control

6.1 A minimum of two, and preferably three replicates of each sample should be included for all measurements.

6.2 A well-characterized standard root zone sample should also be included in each and every run of all physical parameters.

Saturated Hydraulic Conductivity

7. Method A

7.1 Place the compacted sample into a pan of water and saturate from the bottom up.

7.2 Place the cylinder with mix onto the permeameter and begin running water through the sample. Tap water may be used. Set the permeameter to a known hydraulic head. For setups where the water flows from the top down, the hydraulic head (h) is measured from the bottom of the soil column to the water level above the soil (Figure 3). Record this value (to the nearest 0.1 cm).

7.3 Measure and record the water temperature (°C).

7.4 After four hours, place a collection bottle, flask, or beaker at the outflow for the cylinders and begin collecting the outflow. Collect effluent for a specific period of time, the time based on the rate of flow. Collection of one or more samples over a 30-minute period is suggested.

7.5 Measure the effluent and record in cm^3 collected over time period t.

8. Method A Calculation

8.1 Calculate the saturated hydraulic conductivity as follows: $K_{sat}=QL/hAt$, where:

K_{sat} = saturated hydraulic conductivity (cm hr^{-1})

Q = quantity of effluent collected (cm^3) in period of time (t)

L = length of soil column (cm)

h = hydraulic head (cm)

A = cross sectional area of the soil core (cm^2)

t = time required to collect Q (hr).

8.2 Correct the saturated hydraulic conductivity for the viscosity of water to that for 20°C (68°F) by multiplying K_{sat} by the ratio of the viscosity of water at the test temperature to the viscosity of water at 20°C.

8.3 Divide K_{sat} by 2.54 to convert cm/hr to in/hr, if desired.

Bulk Density and Water Retention

9. Method B

9.1 Remove the sample from the permeameter and place on the soil water extractor or tension table set at 40 cm tension for at least 16 hours.

9.2 Allow the sample to reach equilibrium weight, then weigh and record weight (0.1g).

9.3 Place the sample in a drying oven set at 105° C and dry for 24 hours. Weigh and record weight (0.1g).

10. Calculation of Bulk Density

10.1 Calculate the bulk density of the soil core as follows:

$$p_d = \frac{M_1 - M_2}{V}$$

where:

p_d = dry soil bulk density (g cm^{-3})

M_1 = mass of oven-dried soil and cylinder (g)

M_2 = mass of cylinder (g)

V = volume of the soil core (cm^3)

11. Calculation of Water Retention

11.1 Calculate the 40 cm water retention as follows:

$$\Theta_{dw} = (\frac{M_w}{M_d} - 1) \times 100$$

where:

Θ_{dw} = water retention on dry weight basis (%)

M_w = net 40 cm weight, ((mass 40 cm soil and cylinder) - cylinder mass)

M_d = net dry weight mass, ((mass oven dry soil and cylinder) - cylinder mass)

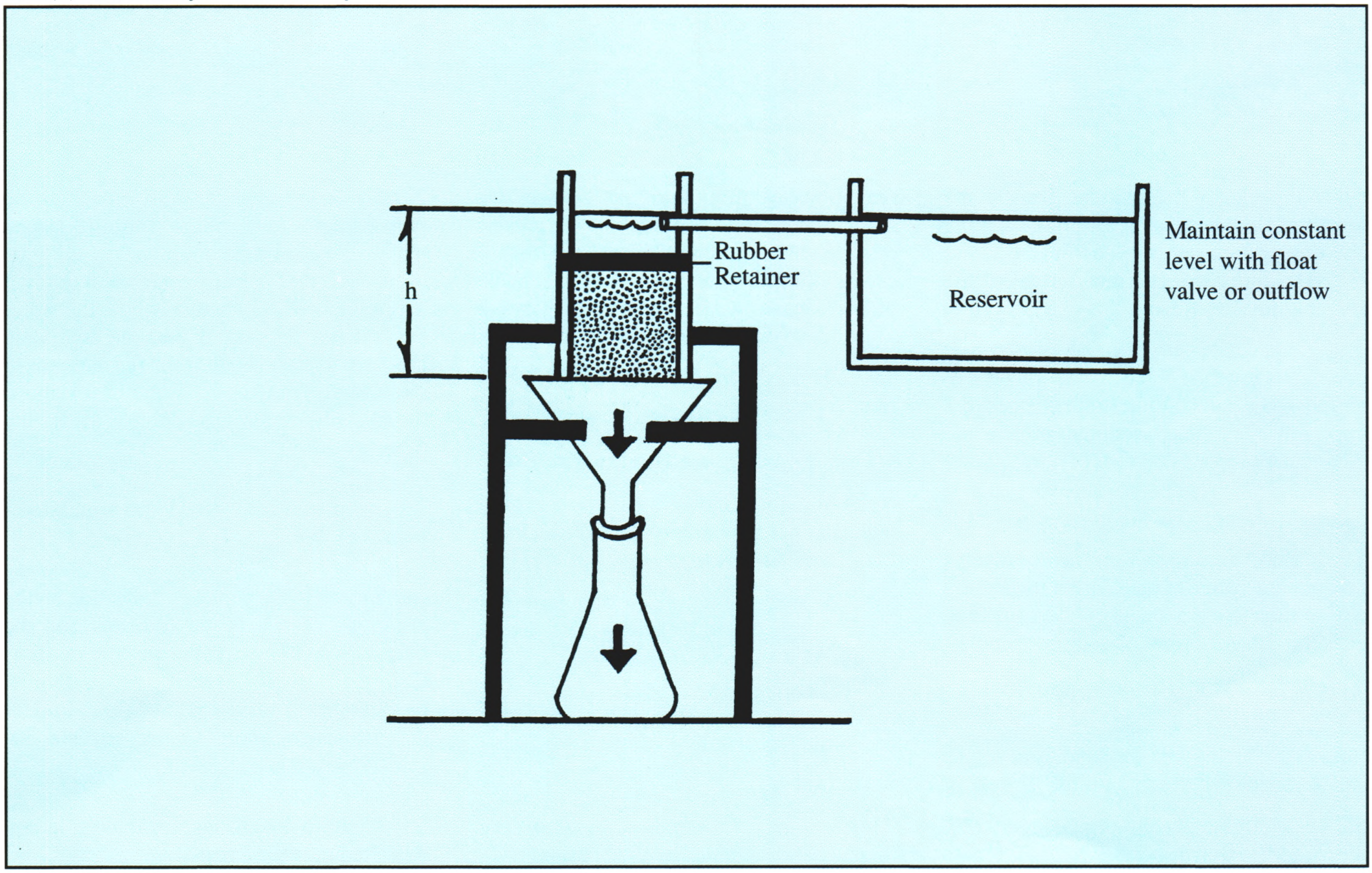
Particle Density

12. Method

12.1 Calibration of Pycnometers (taken from ASTM D 854 - 83)

12.1.1 The pycnometer shall be cleaned, dried, weighed, and the weight recorded. The pycnometer shall be filled with distilled water at room temperature. The weight of the pycnometer and water W_a shall be determined and recorded. A thermometer shall be inserted in the water and its temperature T_i determined to the nearest whole degree.

Figure 3. Suggested permeameter setup to calculate saturated hydraulic conductivity. The hydraulic head (h) is measured from the bottom of the soil column to the water level above the soil.



12.1.2 From the weight W_a at the observed temperature T_i, a table of values of weight W_a shall be prepared for a series of temperatures that are likely to prevail when the weights W_b are determined later (see note 1). These values of W_a shall be calculated as follows:

$$W_a(at\ T_x) = \frac{\text{density of water at } T_x}{\text{density of water at } T_i} \times (W_a\ (at\ T_i) - W_f) + W_f$$

where:

W_a = weight of pycnometer and water, g

W_f = weight of clean, dry pycnometer, g

T_i = observed temperature of water, °C, and

T_x = any other desired temperature, °C

Note 1 — This method provides a procedure that is most convenient for laboratories making many determinations with the same pycnometer. It is equally applicable to a single determination. Bringing the pycnometer and contents to some designated temperature when weights W_a and W_b are taken requires considerable time. It is much more convenient to prepare a table of weights W_a for various temperatures likely to prevail when weights W_b are taken. It is important that weights W_a and W_b be based on water at the same temperature. Values for the relative density of water at temperatures from 18 to 30°C are given in Table 1.

Table 1

RELATIVE DENSITY OF WATER AND CONVERSION FACTOR K FOR VARIOUS TEMPERATURES

Temperature, °C	Relative Density of Water	Correction Factor K
18	0.9986244	1.0004
19	0.9984347	1.0002
20	0.9982343	1.0000
21	0.9980233	0.9998
22	0.9978019	0.9996
23	0.9975702	0.9993
24	0.9973286	0.9991
25	0.9970770	0.9989
26	0.9968156	0.9986
27	0.9965451	0.9983
28	0.9962652	0.9980
29	0.9959761	0.9977
30	0.9956780	0.9974

12.2. Procedure

12.2.1 Place a 10 gram air dried sample into the weighed pycnometer, taking care not to spill any of the mix. Reweigh to obtain the exact soil weight to 0.001g. If a volumetric flask is used, use a 50 gram sample. Determine the water content of a duplicate soil sample by drying it at 105°C.

12.2.2 Add distilled water to fill the pycnometer one half full, or the volumetric flask three-quarters full.

12.2.3 Remove entrapped air by either of the following methods: 1) subject the contents to a partial vacuum (air pressure not exceeding 100 mm Hg), or 2) Boil gently for at least 10 minutes while occasionally rolling the pycnometer to assist in the removal of air. Subject the contents to reduced air pressure either by connecting the pycnometer to an aspirator or vacuum pump, or by the use of a bell jar.

12.2.4 Cool the heated samples to room temperature.

12.2.5 Fill the pycnometer with distilled water, and clean the outside with a clean, dry cloth. Determine the weight of the pycnometer and its contents, W_b, and the temperature in degrees Celsius, T_x, of the contents as described in Section 12.1.

12.3 Calculation and Report

12.3.1 Calculate the particle density (p_p), based on water temperature T_x, as follows:

$$p_p = \frac{W_o}{W_o + (W_a - W_b)}$$

where:

W_o = weight of sample, corrected to oven dry water content.

W_a = weight of pycnometer filled with water at temperature T_x (g), may be taken from the Table described in Section 12.1.

W_b = weight of pycnometer filled with soil and water at temperature T_x (g).

12.3.2 Unless otherwise required, particle density values reported shall be based on water at 20°C. The value based on water at 20°C shall be calculated from the value based on water at the observed temperature, T_x as follows:

$$p_p\ at\ 20°C = K \times P_p\ at\ T_x$$

where K = the values given in Table 1.

Total Porosity

13. Method D Calculation of Total Porosity

13.1 Calculate the total porosity of the sample as follows:

$$S_t = (1 - \frac{P_b}{P_p}) \times 100$$

where:

S_t = total porosity (%)

P_b = dry soil bulk density (g cm^{-3})

p_p = particle density of root zone mix (g cm^{-3})

Pore Distribution

14. Method D Calculation

14.1 Calculate the capillary porosity as follows:

$$\Theta_{vb} = p_b \times \Theta_{dw}$$

where:

Θ_{vb} = volumetric water content at 40 cm tension (capillary porosity)

p_b = dry soil bulk density

Θ_{dw} = water retention

14.2 Calculate the air-filled porosity as follows:

$$S_a = S_t - \Theta_{vb}$$

where:

S_a = air filled porosity

S_t = total porosity

Θ_{vb} = capillary porosity

15. Report

15.1 The report should include the following:

15.1.1 Volume ratio of mixes tested (if laboratory mixed).

15.1.2 Percent organic matter (on weight basis) to the nearest 0.1%

15.1.3 Saturated hydraulic conductivity to the nearest 0.1 in/hr.

15.1.4 Porosity, including distribution of capillary and air-filled to the nearest 1%.

15.1.5 Particle density of the mix(es).

15.1.6 Bulk density of the compacted mix(es).

15.1.7 pH of each mix tested.

Standard Method of Particle Size Analysis and Grading Sand Shape for Golf Course Putting Green Root Zone Mixes

1. Scope

1.1 This method covers the determination of particle size distribution of putting green root zone mixes. Particles larger than 0.05 mm (retained on a No. 270 sieve) are determined by sieving. The silt and clay percentages are determined by a sedimentation process, using the pipet method. This procedure was developed for putting green root zone mixes; those assumed to have sand contents of 80% by weight or greater. Particle size analysis of soils may be performed by this or other methods described in the Referenced Documents listed below. This standard also describes a qualitative evaluation of sand particle shape.

1.2 *This standard does not address the safety problems that may be associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the regulatory limitations prior to its use.*

Referenced Documents

2.1 Methods of Soil Analysis Part 1: Physical and Mineralogical Methods. American Society of Agronomy Monograph No. 9.

2.2 ASTM Standard Method D 422-63. Standard Test Method for Particle Size Analysis of Soils.

3. Apparatus

3.1 *Balance*, sensitive to 0.001 g.

3.2 *Stirring apparatus*, may be either of the following types.

3.2.1 For Method A: An *electric mixer* made for mechanical mixing of soils, or

3.2.2 For Method B: a *horizontal reciprocating shaker,* with holder for 250 mL flasks or bottles.

3.3 *Sedimentation cylinder,* a glass cylinder marked for a volume of 1000 mL. The height of the 1000 mL mark must be 36 ± 2 cm from the bottom on the inside.

3.4 *Thermometer,* accurate to 0.5°C.

3.5 *Pipet rack,* a device for lowering a pipet to a precise depth in the sedimentation cylinder.

3.6 *Pipets*, Lowy or other wide tipped type, 25 mL capacity.

3.7 *Weighing bottles or beakers*, glass with a capacity of 100 mL.

3.8 *Sieves*, square mesh with woven wire (brass or stainless steel). A full set of sieves shall include the following:

No. 10 — 2 mm
No. 18 — 1 mm
No. 35 — 500 micron
No. 60 — 250 micron
No. 100 — 149 micron
No. 140 — 105 micron
No. 270 — 53 micron

3.9 *Sieve shaker,* type that provides vertical tapping action as well as horizontal shaking.

3.10 *Desiccator*

3.11 *Dispersing agent*, a 5% sodium hexametaphosphate (HMP) solution, made by dissolving 50 g of reagent or technical grade HMP in 1000 mL of distilled or demineralized water.

3.12 *Oven*, capable of maintaining a temperature of 105°C.

3.13 *Water,* shall be distilled or demineralized, and brought to the temperature that is expected to prevail during the sedimentation process. If air temperatures are expected to fluctuate, cylinders should be placed in a water bath, and the distilled or demineralized water brought to the temperature of the water bath. The temperature should be at or close to 25°C.

3.14 *Dissecting microscope*, 25x to 50x power.

4. Procedure for Particle Size Analysis

4.1 Dispersion of sample

4.1.1 Weigh out 100 grams of air-dried root zone mix and place in mixing cup (Method A) or flask (Method B). Place a duplicate sample into a drying oven set at 105°C for correction to oven dried basis.

4.1.2 Add 100 mL of dispersing agent. Stir or swirl until the root zone mix is thoroughly wet. Allow to stand for at least 4 hours. If using Method B, place the flasks or bottles on the shaker and shake for at least 16 hours or overnight.

4.1.3 Method A: Add about 100 ml of water to the mixing cup and place onto the mixer. Mix for 5 minutes.

4.2 Determination of the sand fractions

4.2.1 Place a tared 270 mesh sieve onto a large funnel held by a stand over a sedimentation cylinder. Pour the suspension onto the sieve. Rinse remaining sand out of the cup or flask with water onto the sieve. Wash the collected sand with misted water to wash any remaining silt or clay particles through the sieve into the cylinder.

4.2.2 Wash the sand into a tared beaker, and place into an oven at 105°C until dry. Weigh the sand.

4.2.3 Transfer the dried sand to a nest of sieves. Shake the sieves on a shaker for five minutes. Weigh each sand fraction to the nearest 0.1 g.

4.3 Determination of clay (< 2 micron)

4.3.1 Add distilled or demineralized water to the sedimentation cylinder to bring up to the 1000 mL volume. Cover the cylinder with waxfilm, a stopper, or watch glass. Place the cylinder into a water bath, or allow it to stand until the temperature of the suspension is the same as the water bath or the air temperature, respectively.

4.3.2 After the temperature is constant, the silt and clay should be resuspended by one of the two following methods: a) stir thoroughly with a hand stirrer, using an up and down motion for a least 30 seconds; b) stopper the cylinder and shake end over end for one minute.

4.3.3 After the appropriate settling time (8 hr for 20°C), carefully lower the closed pipet to a depth of 10 cm below the top of the suspension. The table below lists the settling times for suspensions at temperatures other than 20°C for determining 2 micron particle size.

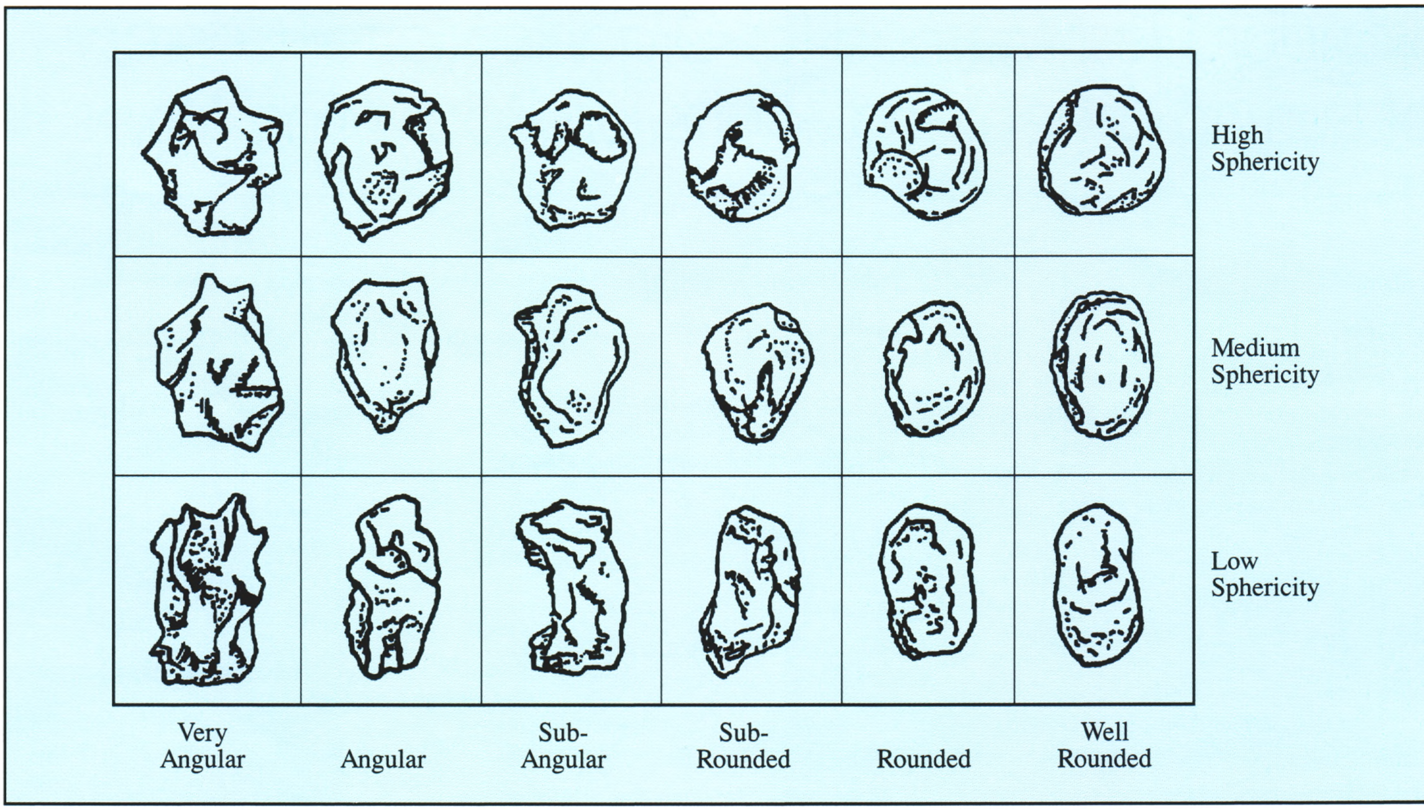


Figure 1. Chart showing the angularity and sphericity of sand grains.

Temperature (°C)	Settling Time (hr)
18	8.41
20	8.00
22	7.63
24	7.28
26	6.95
28	6.65
30	6.37

4.3.4 Turn on the vacuum and withdraw a 25 mL sample in about 12 seconds. Rate of withdrawal is important.

4.3.5 Discharge the sample into a tared beaker or drying dish.

4.3.6 To wash out any residual material in the pipet draw 25 mL of water into the pipet, and discharge into the same drying dish.

4.3.7 Evaporate the water and dry the clay at 105°C.

4.3.8 Cool in a desiccator and weigh.

5. Determination of Correction for Dispersing Solution

5.1 Dispense 100 ml of dispersing solution into 1 L container.

5.2 Add distilled or demineralized water to 1 L volume, stir or swirl until thoroughly mixed.

5.3 Draw 25 ml and dispense into a tared beaker or drying dish.

5.4 Draw 25 ml of water and dispense into same dish.

5.5 Evaporate in an oven at 105°C.

5.6 Weigh the sediment in the beaker (W_D).

6. Calculations

6.1 Percent clay may be calculated as follows:

$$\% \, Clay = \frac{40(W_C - W_D)}{W_S} \times 100$$

where:

W_C = weight of clay in drying dish (g).

W_D = weight of sediment from dispersing solution.

W_S = weight of root zone sample, corrected for initial water content.

6.2 Percent sand for each sand size fraction can be calculated as follows:

$$\% \, Sand = \frac{W_{SA}}{W_S} \times 100$$

where:

W_{SA} = weight of sand retained on sieve.

W_S = corrected weight of the root zone sample.

6.3 Percent silt may be calculated as follows:

$$\% \, Silt = \frac{W_S - W_C - W_{SA}}{W_S} \times 100$$

where:

W_S = corrected weight of the root zone sample (g).

W_C = weight of clay.

W_{SA} = sum of sand weights (g).

7.1 Method 2: Qualitative Assessment of Particle Shape

7.1 Place a small quantity of dried sand in a dish or on a microscope slide. Observe particle shape of several grains of sand. Repeat this two or three times.

7.2 Refer to Figure 1 to describe particle angularity and sphericity (taken from Baker, S.W. 1990, Sands for Sports Turf Construction and Maintenance, Sports Turf Research Institute, Bingley, UK).

8. Report

8.1 The report should include the following:

8.1.1 The particle size analysis, listing the percent sand, silt, and clay.

8.1.2 The percent sand retained on each sieve, expressed as the percentage of the entire sample; that is, the total sand fractions should equal the sand percentage listed in the particle size analysis.

8.1.3 Description of the sand particle shape.

Standard Test Method for Organic Matter Content of Putting Green and Sports Turf Root Zone Mixes

1. Scope

1.1 This test method covers the determination of the percent organic matter of a putting green root zone mixture using the loss on ignition or the Walkley-Black methods. These test methods are useful for quantifying the organic matter content of volume ratio mixed root zone mixes.

1.2 *This standard does not address the safety problems that may be associated with its use, nor the disposal of hazardous waste that may be generated. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties. Agronomy Monograph No. 9, Second Edition.

2.2 ASTM Standard D 2974-87 Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils.

3. Summary of Methods

3.1 *Method A* — Organic matter content is determined by loss on ignition.

3.2 *Method B* — Organic matter content is determined by the Walkley-Black method; a dichromate oxidation procedure whereby the color intensity of the reaction product is determined colorimetrically.

4. Apparatus — Method A

4.1 *Oven*, capable of maintaining a constant temperature of 105°C.

4.2 *Muffle furnace*, capable of producing constant temperatures of 440°C.

4.3 *Evaporating dish or crucible*, made of high silica or porcelain of not less than 10 mL capacity.

4.4 *Desiccator*

4.5 *Aluminum foil*, heavy duty.

4.6 *Balance*, sensitive to 0.01 g.

5. Apparatus — Method B

5.1 *Soil Grinder*

5.2 *Balance*, sensitive to 0.01 g.

5.3 *Sulfuric acid*, concentrated (not less than 96%).

5.4 *Potassium dichromate*, 1N, made by dissolving 49.04 reagent-grade potassium dichromate in water, and diluting to a volume of 1L.

5.5 *Spectrophotometer or colorimeter,* set at or adjustable to 610 nm wavelength.

5.6 *Standard*, 10,000 mg/L as CO_2

5.7 *Pipets*, assorted, capable of measuring volumes of 0.1 to 10 ml.

5.8 *Glassware*, assorted, to include 250 ml erlenmeyer flasks and funnels (75 mm ID).

5.9 *Oven*, capable of maintaining a constant temperature of 105°C.

6. METHOD A: Procedure

6.1 Weigh a crucible or porcelain dish to the nearest 0.01 g and record the weight.

6.2 Place about 50 grams of oven-dried root zone mix into the crucible and weigh to the nearest 0.01 g.

6.3 Place the sample into a muffle furnace and gradually bring the temperature up to 440°C. Leave the sample in the furnace for at least 12 hours.

6.4 Remove the sample from the oven, cover with aluminum foil, and cool it in a desiccator. Remove the foil and determine and record the mass.

7. Calculation of percent organic matter, Method A.

7.1 Calculate percent organic matter as follows:

$$\textit{Organic Matter \%} = \frac{(W_s - W_c) - (W_a - W_c)}{(W_s - W_c)}$$

where:

W_s = weight of crucible with oven dried sample (g)

W_c = weight of crucible (g)

W_a = weight of crucible with ashed sample (g)

8. METHOD B

8.1 Preparing a Standard Curve

8.1.1 Set up five 250 ml erlenmeyer flasks

8.1.2 Use a pipet to pipet the volumes of standard solution into the flasks, as listed below.

mL of 10,000 mg/L CO_2	% organic matter
0	0
0.20	0.9
0.50	2.2
1.00	4.4
1.20	5.3

8.1.3 Pipet 10 mL of potassium dichromate into each flask.

8.1.4 In a well ventilated area, pipet or dispense 20 mL sulfuric acid into each flask.

8.1.5 Cover the flask and allow the reaction to progress for 10 minutes.

8.1.6 Add 100 mL of distilled or deionized water to each flask, swirl briskly.

8.1.7 Read the absorbance for each standard at 610 nm and plot a standard curve.

8.2 Procedures

8.2.1 Obtain a representative, oven dried root zone sample.

8.2.2 Grind a small quantity of sample until 100% passes a 140 sieve (0.1 mm).

8.2.3 Weigh out exactly 1 g of sample (to the nearest 0.01 g), and place in a 250 mL erlenmeyer flask.

8.2.4 Add 10 ml potassium dichromate.

8.2.5 Make up a blank sample by adding potassium dichromate into an empty flask.

8.2.6. Carefully add 20 mL sulfuric acid to both flasks. Be careful of the fumes and the heat generated by the reaction. Allow to sit for 10 minutes.

8.2.7 Add 100 mL of distilled or deionized water to the flasks.

8.2.8 Set up a funnel with No. 2 or similar filter paper. Pour enough of the solution through the funnel to collect about 10 mL.

8.2.9 Read the absorbance of the sample at 610 nm. Refer to the standard curve to obtain percent organic matter.

ASTM D 2974-87
Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils

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THIS STANDARD is issued under the fixed designation D 2974; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

These test methods are under the jurisdiction of ASTM Committee D-18 on Soil and Rock and are the direct responsibility of Subcommittee D18.18 on Peats and Related Materials.

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1. Scope

1.1 These test methods cover the measurement of moisture content, ash content, and organic matter in peats and other organic soils, such as organic clays, silts, and mucks.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Summary of Methods

2.1 *Method A* — Moisture is determined by drying a peat or organic soil sample at 105°C. The moisture content is expressed either as a percent of the oven dry mass or of the as-received mass.

2.2 *Method B* — This is an alternative moisture method which removes the total moisture in two steps: (*1*) evaporation of moisture in air at room temperature (air-drying), and (*2*) the subsequent oven drying of the air-dried sample at 105°C. This method provides a more stable sample, the air-dried sample, when tests for nitrogen, pH, cation exchange, and the like are to be made.

2.3 *Methods C and D* — Ash content of a peat or organic soil sample is determined by igniting the oven-dried sample from the moisture content determination in a muffle furnace at 440°C (Method C) or 750°C (Method D). The substance remaining after ignition is the ash. The ash content is expressed as a percentage of the mass of the oven-dried sample.

2.4 Organic matter is determined by subtracting percent ash content from 100.

3. Apparatus

3.1 *Oven*, capable of being regulated to a constant temperature of 105 ± 5°C.

NOTE — The temperature of 105°C is quite critical for organic soils. The oven should be checked for "hot spots" to avoid possible ignition of the specimen.

3.2 *Muffle Furnace*, capable of producing constant temperatures of 440°C and 750°C.

3.3 *Evaporating Dishes*, of high silica or porcelain of not less than 100 mL capacity.

3.4 *Blender*, high-speed.

3.5 *Aluminum Foil*, heavy-duty.

3.6 *Porcelain Pan*, *Spoons*, and equipment of the like.

3.7 *Desiccator*.

4. Preparation of Sample

4.1 Place a representative field sample on a square rubber sheet, oil cloth, or equivalent material. Reduce the sample to the quantity required by quartering and place in a moisture-proof container. Work rapidly to prevent moisture loss or perform the operation in a room with a high humidity.

Moisture Content

5. Method A

5.1 Record to the nearest 0.01 g the mass of a high-silica or porcelain evaporating dish fitted with a heavy-duty aluminum foil cover. The dish shall have a capacity of not less than 100 mL.

5.2 Mix thoroughly the representative sample and place a test specimen of at least 50 g in the container described in 5.1. Crush soft lumps with a spoon or spatula. The thickness of peat in the container should not exceed 3 cm.

5.3 Cover immediately with the aluminum foil cover and record the mass to the nearest 0.01 g.

5.4 Dry uncovered for at least 16 h at 105°C or until there is no change in mass of the sample after further drying periods in excess of 1 h. Remove from the oven, cover tightly, cool in a desiccator, and record the mass.

6. Method A Calculation

6.1 Calculate the moisture content as follows:

Moisture Content, % = $[(A - B) \times 100]/A$

where:

A = mass of the as-received test specimen, g, and

B = mass of the oven-dried specimen, g.

6.1.1 This calculation is used primarily for agriculture, forestry, energy, and horticultural purposes, and the result should be referred to as the moisture content as a percentage of as-received or total mass.

6.2 An alternative calculation is as follows:

Moisture Content, % = $[(A - B) \times 100]/B$

where:

A = as-received test specimen, g, and

B = mass of the oven-dried specimen, g.

6.2.1 This calculation is used primarily for geotechnical purposes, and the result should be referred to as the moisture content as a percentage of oven-dried mass.

6.3 Take care to indicate the calculation method used.

7. Method B

7.1 This method should be used if pH, nitrogen content, cation exchange capacity, and the like are to be tested.

7.2 Mix the sample thoroughly and select a 100 to 300 g representative sample. Determine the mass of this sample and spread evenly on a large flat pan. Crush soft lumps with a spoon or spatula and let the sample come to moisture equilibrium with room air. This will require at least 24 h. Stir occasionally to maintain maximum air exposure of the entire sample. When the mass of the sample reaches a constant value, calculate the moisture removed during air drying as a percentage of the as-received mass.

7.3 Grind a representative portion of the air-dried sample for 1 to 2 min in a high-speed blender. Use the ground portion for moisture, ash, nitrogen, cation exchange capacity tests, and the like.

7.4 Thoroughly mix the air-dried, ground sample. Weigh to the nearest 0.01 g the equivalent of 50 g of test specimen on an as-received basis. Determine the amount, in grams, of air-dried sample equivalent to 50 g of as-received sample, as follows:

Equivalent Sample Mass, g = 50.0 - [(50 × *M*)/100]

where:

M = moisture removed in air drying, %.

7.5 Place the sample in a container as described in 5.1 and proceed as in Method A.

A muffle furnace, used for organic matter analysis.

8. Method B Calculation

8.1 Calculate the moisture content as follows:

Moisture Content, % = (50 - *B*) × 2

where:

B = oven-dried sample, g.

8.1.1 This calculation gives moisture content as a percentage of as-received mass.

8.2 An alternative calculation is as follows:

Moisture Content, % = [(50 - *B*) × 100]/*B*

8.2.1 This calculation gives moisture content as a percentage of oven-dried mass.

Ash Content

9. Method C

9.1 Determine the mass of a covered high-silica or porcelain dish.

9.2 Place a part of or all of the oven-dried test specimen from a moisture determination in the dish and determine the mass of the dish and specimen.

9.3 Remove the cover and place the dish in a muffle furnace. Gradually bring the temperature in the furnace to 440°C and hold until the specimen is completely ashed (no change of mass occurs after a further period of heating).

9.4 Cover with the retained aluminum foil cover, cool in a desiccator, and determine the mass.

9.5 This method should be used for all geotechnical and general classification purposes.

10. Method D

10.1 Determine the mass of a covered high-silica or porcelain dish.

10.2 Place a part of or all of the oven-dried test specimen from a moisture determination in the dish and determine the mass of the dish and specimen.

10.3 Remove the cover and place the dish in a muffle furnace. Gradually bring the temperature in the furnace to 750°C and hold until the specimen is completely ashed (no change of mass occurs after a further period of heating).

10.4 Cover with the retained aluminum foil cover, cool in a desiccator, and determine the mass.

10.5 This method should be used when peats are being evaluated for use as a fuel.

11. Calculation for Methods C and D

11.1 Calculate the ash content as follows:

Ash Content, % = ($C \times 100$)/B

where:

C = ash, g, and

B = oven-dried test specimen, g.

Organic Matter

12. Calculation

12.1 Determine the amount of organic matter by difference, as follows:

Organic matter, % = 100.0 - D

where:

D = ash content, %.

13. Report

13.1 Report the following information:

13.1.1 Results for organic matter and ash content, to the nearest 0.1%.

13.1.2 Furnace temperature used for ash content determinations.

13.1.3 Whether moisture contents are by proportion of as-received mass or oven-dried mass.

13.1.3.1 Express results for moisture content as a percentage of as-received mass to the nearest 0.1%.

13.1.3.2 Express results for moisture content as a percentage of oven-dried mass as follows:

(*a*) Below 100% to the nearest 1%.

(*b*) Between 100% and 500% to the nearest 5%.

(*c*) Between 500% and 1000% to the nearest 10%.

(*d*) Above 1000% to the nearest 20%.

14. Precision and Bias

14.1 The precision and bias of these test methods have not been determined. Data are being sought for use in developing a precision and bias statement.

ASTM C-88-90
Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate

ASTM C-131-89
Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

ASTM procedures C-88-90 and C-131-89 are special situation tests that rarely will be required, and have not been published here. They are available from the American Society of Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

TURF TWISTERS

BUILD USGA RECOMMENDATION GREENS

Question: After years of debate, my club has finally decided to rebuild the two worst greens on the course. They are almost totally surrounded by trees, and I have had trouble growing grass on them. I just can't wait for the new USGA spec greens to solve all of my problems! Just wanted to say thanks. (Kentucky)

Answer: We have some "good news" and some "bad news" for you and your course. It is true that a green built to USGA recommendations helps provide an excellent grass growing medium, but even a perfectly constructed green will not guarantee success in heavy shade. Sand-based construction is primarily for better drainage and resistance to compaction. A good draining soil cannot overcome other limiting factors, such as the lack of sunlight. The grass should be better, but probably not as good as desired unless some trees and overhanging limbs are removed.

TO GET CONSISTENCY

Question: During past grow-ins, my Tifdwarf bermudagrass sprigs rapidly covered the surface of the greens. However, the putting surface lacked smoothness and firmness. Can you suggest a way to help correct this problem? (Louisiana)

Answer: In addition to frequent topdressing, try rolling the greens. A 1- to 2-ton commercial asphalt roller can be leased from your local rental company. Roll the greens in two directions after the sprigs have become well established (3 to 4 weeks). This action will both smooth and firm your putting surfaces, giving your golfers the uniformity they desire.

AND GOOD RESULTS FOR MANY YEARS

Question: We are preparing to go to great expense to restore our old greens to their original shape through reconstruction. Is there any easy way to mark the perimeter of our new greens so their exact shape can be maintained over the years? (Kansas)

Answer: Although a good surveyor can be certain the lines are never lost, few of us have the skills necessary to reestablish such precise curves with a transit. However, since you are going to rebuild, you have a great opportunity to "mark" both the perimeter of the green and drain lines electrically. After the shell of the new green has been shaped and the drain lines installed, lay a #14 irrigation wire along the shell's perimeter and in each drain ditch. Splice all connections to make certain you have continuity. The ends of the wire can be laid beside the rear flush point. In the future, the exact shape of the green and the location of all drain lines can be easily found with a wire-tracking device.