Rationale for the Revisions of the USGA Green Construction Specifications

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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%.

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.

Preparing a firm foundation for a USGA green.

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.

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

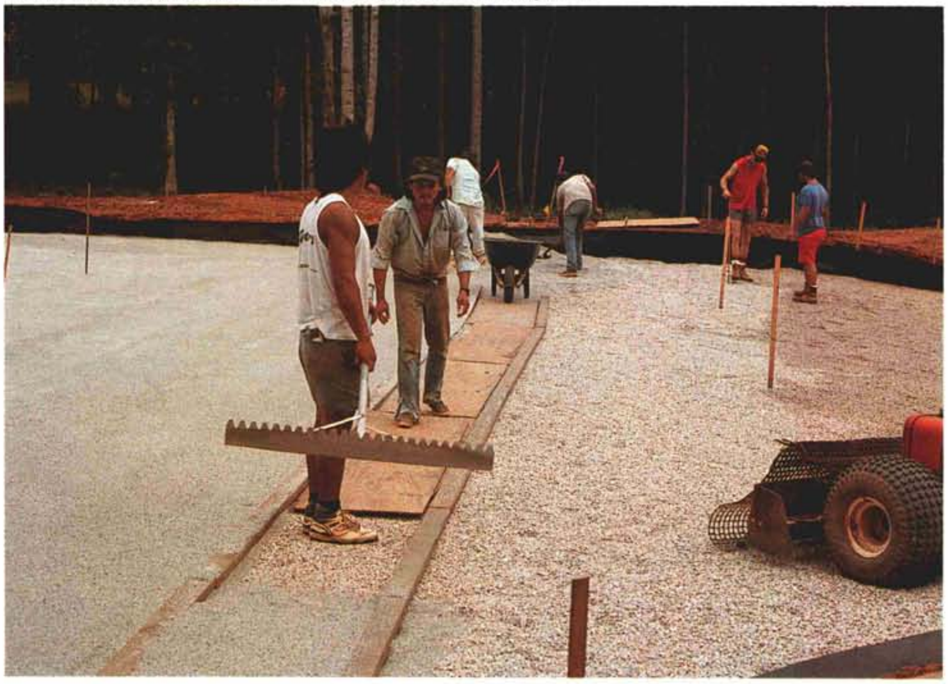
$$D_{15\ gravel} \leq 5D_{85\ root\ zone}.$$

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

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



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

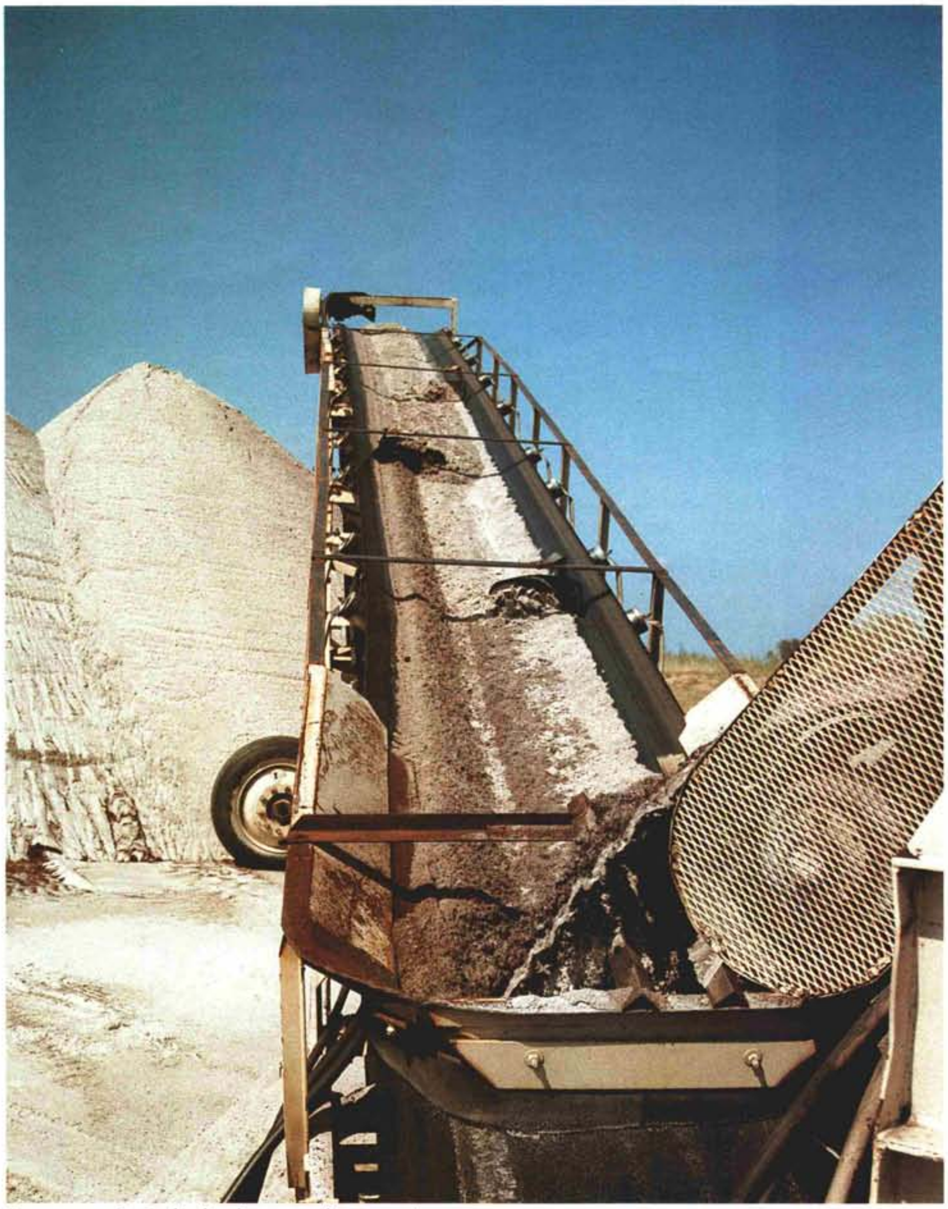
Sand is the primary component of a USGA putting green root zone mix. Back in the early 1950s, Garman (1952) proposed that root zone mixtures should be predominately sand, with 8.2% clay and 20% peat by volume. Lunt (1956) followed with a recommendation that a root zone mix should be composed of 85% to 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 [illegible] 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.

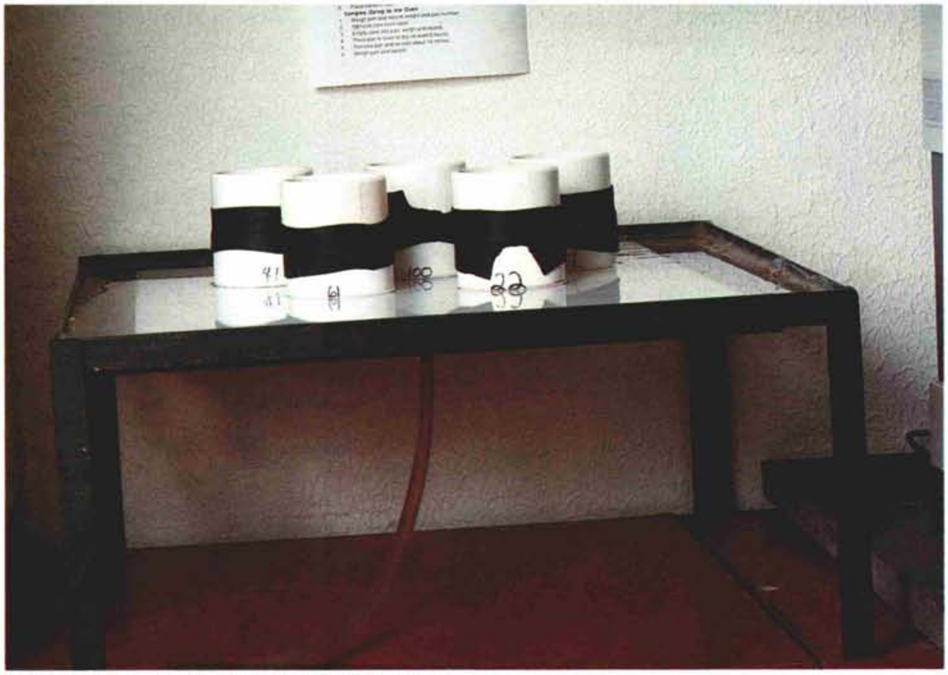
While perlite is resistant to weathering, it is very brittle and may be subject to breakage with compaction and cultivation. Again, there is insufficient field data or experience with perlite to recommend its use.

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.

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.



A tension table used to measure water retention.

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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