Standard Guide for Construction of High Performance Sand-Based Rootzones for Athletic Fields[1]

This standard is issued under the fixed designation F2396; 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.

1. Scope

1.1 This guide covers techniques that are appropriate for the construction of high performance sand-based rootzones for sports fields. This guide provides guidance for the selection of materials, including soil, sand, gravel, peat, and so forth, for use in designing and constructing sand-based sports turf rootzones.

1.2 Decisions in selecting construction and maintenance techniques are influenced by existing soil types, climatic factors, level of play, intensity and frequency of use, equipment available, budget and training, and the ability of management personnel.

1.3 This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This guide is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "standard" in the title of this document means only that the document has been approved through the ASTM consensus process.

1.4 The values stated in SI units are to be regarded as the standard. The values in parentheses are for information only.

1.5 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, 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 requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C88 Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate

C131 Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

C1444 Test Method for Measuring the Angle of Repose of Free-Flowing Mold Powders (Withdrawn 2005)[3]

D422 Test Method for Particle-Size Analysis of Soils

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))

D1883 Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils

D1997 Test Method for Laboratory Determination of the Fiber Content of Peat Samples by Dry Mass

D2944 Test Method of Sampling Processed Peat Materials

D2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils

D2976 Test Method for pH of Peat Materials

D2980 Test Method for Volume Mass, Moisture-Holding Capacity, and Porocity of Saturated Peat Materials

D3080 Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions

D4427 Classification of Peat Samples by Laboratory Testing

D4972 Test Method for pH of Soils

F1632 Test Method for Particle Size Analysis and Sand Shape Grading of Golf Course Putting Green and Sports Field Rootzone Mixes

F1647 Test Methods for Organic Matter Content of Athletic Field Rootzone Mixes

F1815 Test Methods for Saturated Hydraulic Conductivity, Water Retention, Porosity, and Bulk Density of Athletic Field Rootzones

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

F2060 Guide for Maintaining Cool Season Turfgrasses on Athletic Fields
F2107 Guide for Construction and Maintenance of Skinned Areas on Baseball and Softball Fields
F2269 Guide for Maintaining Warm Season Turfgrasses on Athletic Fields
F2651 Terminology Relating to Soil and Turfgrass Characteristics of Natural Playing Surfaces

3. Terminology

3.1 *Definitions:*

3.1.1 Except as noted, soil-related definitions are in accordance with Terminology F2651.

NOTE 1—Particle size ranges for sand, silt, and clay used in this standard vary somewhat from ranges given in Test Method D422.

4. Significance and Use

4.1 A dense, uniform, smooth, and vigorously growing natural turfgrass sports field provides the ideal and preferred playing surface for most outdoor field sports. Such a surface is pleasing to the spectators and athletes. A thick, consistent, and smooth grass cover also increases playing quality and safety by providing stable footing for the athletes, cushioning their impact from falls, slides, or tackles, and cools the playing surface during hot weather. Sand is commonly used to construct high performance sports turf rootzone systems. Sand is chosen as the primary construction material for two basic properties, compaction resistance and improved drainage/aeration state. Sands are more resistant to compaction than finer soil materials when played upon within a wide range of soil moisture conditions. A loamy soil that may provide a more stable surface and enhanced growing media compared to sand under optimal or normal conditions will quickly compact and deteriorate in condition if used in periods of excessive soil moisture, such as during or following a rainy season. A properly constructed sand-based rootzone, on the other hand, will resist compaction even during wet periods. Once compacted, sands are easier to decompact with the use of mechanical aeration equipment. Even when compacted, sands will retain an enhanced drainage and aeration state compared to native soil rootzones under the same level of traffic. As such, sand-based rootzones are more conducive to providing an all-weather type of playing surface. Properties of both the soil and grass plants must be considered in planning, constructing, and maintaining a high quality sports turf installation. Turfgrass utilized must be adapted to the local growing conditions and be capable of forming a thick, dense, turf cover at the desired mowing height. Unvegetated sand in and of itself is not inherently stable; therefore, it is imperative that grasses with superior wear tolerance and superior recuperative potential are utilized to withstand heavy foot traffic and intense shear forces. Sand does, however, have incredible load bearing capacity and if a dense, uniform turf cover is maintained, the sand-based system can provide a very stable, firm, smooth, and uniform playing surface. A successful sand-based rootzone system is dependent upon the proper selection of materials to use in the project. The proper selection of sand, organic amendment, soil and gravel is of vital concern to the performance of the system and this guide addresses these issues.

4.1.1 During construction, consideration should be given to factors such as the physical and chemical properties of materials used in the area, freedom from stones and other debris, and surface and internal drainage.

4.1.2 Maintenance practices that influence the playability of the surface include mowing, irrigation, fertilization, and mechanical aeration and are factors addressed in other standards (see Guides F2060 and F2269).

4.2 Those responsible for the design, construction, or maintenance, or a combination thereof, of natural turf athletic fields for high-performance, all-weather purposes will benefit from this guide.

4.3 A successful project development depends upon proper planning and upon the selection of and cooperation among design and construction team members. A high-performance, sand-based rootzone project design team should include a project designer, an agronomist or soil scientist, or both, and an owner's representative. Additions to the team during the construction phase should include an owner's project manager (often an expansion of role for the owner's representative), an owner's quality control agent (often the personnel that is employed in advance with the intent of becoming the finished project's sports field manager), an owner's testing agent (often an expansion of roles for the project's agronomist/soil scientist), and the contractor.

4.3.1 Planning for projects must be conducted well in advance of the intended construction date. This often requires numerous meetings to create a calendar of events, schedule, approvals, assessments, performance criteria, material sourcing, geotechnical reports, and construction budgets.

NOTE 2—Other specifications on soils for athletic field construction have been published and have been considered during the development of this guide.

5. Construction

5.1 The steps to be used in construction of a new athletic field include:

5.1.1 Survey and stake the site to establish subgrade and finish grade elevations.

5.1.2 Construct and prepare subgrade, and provide a correct and certified subgrade.

5.1.3 Install subsurface drainage system, frame out warning tracks, skinned areas, and so forth, as appropriate.

5.1.4 Install irrigation system (irrigation system may be installed prior to rootzone installation).

5.1.5 Prepare for rootzone installation.

5.1.5.1 Secure suitable sand, properly tested and approved.

5.1.5.2 Blend any amendments with sand to project specifications, approve using QC program.

5.1.5.3 Install approved gravel (if included in design).

5.1.6 Install rootzone blend.

5.1.7 Bring field to final grade and contour in accordance with specifications, compact to specifications.

5.1.7.1 A pre-plant fertilizer application may be applied at this point as specified.

5.1.8 Establish turf by appropriate methods (seed, sprigs, plugs or sod).

5.1.9 Fertilize the installation as appropriate based upon soil testing.

5.1.10 Turf is to be established based upon grow-in recommendations from a competent agronomist or soil testing laboratory, as appropriate for the turf species utilized and the climate of the site.

5.2 *Survey and Stake*—This procedure should be done to conform to the project designer's specifications as appropriate for the sport. In the case of the construction of a replacement field, this step may be deleted or modified as appropriate. Care should be taken to protect staking during the construction process.

5.3 *Construct and Prepare Subgrade*—Contour the subgrade in accordance with specifications at a suggested tolerance of ±12.5 mm (½ in.) within 3 m (10 ft) of linear direction as specified in 5.5.6. The subgrade should be installed at a depth such to accommodate the final profile depth of rootzone and any gravel layer (if included). The subgrade should be compacted sufficiently (suggested 85 % minimum to 90 % maximum proctor density) to prevent future settling. Subgrade should be designed to conform to surface contour of finished playing surface.

5.4 *Subsurface Drainage System*—Many types of designs exist for subsurface drainage most commonly including a grid or herringbone pattern. The project specifications should include a subsurface drainage design to facilitate drainage for a 25 year storm event. Most commonly used drainage systems for sand-based athletic fields include utilizing perforated drainlines 10 cm (4 in.) in a 4.5 m (15 ft) to 6 m (20 ft) spacing between drainline laterals.

5.4.1 *Drainline Trenches*—Trenches constructed for drainlines should be excavated into a properly prepared, graded, and compacted subgrade. Drainage trenches should be of a depth such to conform to the drainage contours. All drainage trenches and drainline installations should maintain a minimum positive slope gradient of ≥0.5 % toward drainage outlets with trench bottoms compacted to subgrade specifications. Drainage excavations should be made such that a minimum of 5 cm (2 in.) of bedding material can be contained around the installed drainline (below, to each side, and above). For example, a 10 cm (4 in.) diameter drainline installation will require a minimum dimension of 20 cm (8 in.) wide by 20 cm (8 in.) depth (for example, 10 cm drainline + (5 cm/side × 2 sides) = 20 cm; 10 cm drainline + 5 cm top + 5 cm bottom = 20 cm). Once drainage trenches are excavated, all excavated material should be removed from the subgrade surface and disposed off site. The subgrade should have no elevations of subgrade soil material such to hinder the flow of water along the subgrade interface into the drainage trench. Once drainage trenches have been excavated, the trench bottoms should be sufficiently compacted to the subgrade compaction specifications prior to installation of drainage system. Subgrade shall be re-surveyed and certified prior to gravel or rootzone import.

5.4.2 *Surface Drainage*—To maintain adequate surface drainage, all field installations should include a minimum of 0.5 % slope gradient (simple slope or crown) to remove water off of the playing field in case of a storm event with severe rainfall intensity and to facilitate the use of tarps. It is recommended that an adequate number of small size surface drainage inlets be installed in the perimeter of the installation (in out-of-play areas) and tied into the drainage collection system for removal of surface runoff with the subsurface drainage water.

NOTE 3—In planning and designing projects, consideration shall be given to the permeability of the rootzone when determining the slope of the finished surface and the need for adjacent surface drainage systems. Further consideration shall be given in cold climates where frost penetration may impact the permeability of the rootzone when determining the slope of the finish surface and the need for adjacent surface drainage systems. Generally, the need for improved surface drainage increases as the permeability of the rootzone decreases.

5.4.3 *Sub-Surface Drainage Material*—Three recommended options exist for the use of drainage material. Option 1 could utilize sand rootzone material to backfill around drainlines within the drainage trenches. Option 2 could utilize gravel material to backfill around drainlines in the drainage trenches. Option 3 could include the use of gravel to backfill around drainlines in drainage trenches and to form a drainage layer overlying the subgrade before placement of rootzone sand blend. All backfill treatments shall be compacted to specifications prior to further installation procedures. It is recommended that backfill for trench bottoms is installed and compacted prior to installing drain pipe into the trenches. It is recommended that the trench bottom remain unobstructed as installed and no soil pilings, wood blocks, concrete or metal blocks are used to adjust and maintain slope of drainlines. Any blocks used for this purpose must be removed from under the drainlines and any cavities backfilled before proceeding. It is recommended that drainage trenches (bottom and sides *only*) should be lined with a woven geosynthetic filter fabric to prevent contamination (lateral movement of subgrade materials into trench fill). Geosynthetic filter fabric should *not* be used to cover the drainage trench. It is recommended that all drainlines are installed straight (without 'snaking') within the trenches. It is recommended that sleeves (of oversize PVC piping) should be installed across the drainage trenches at appropriate points as indicated by the irrigation design to facilitate irrigation pipe installation at points where the irrigation line crosses over the drainage trenches.

5.4.3.1 *Option 1*—Rootzone sand (with or without other rootzone amendments) may be utilized to backfill around drainlines. If sand is utilized for this purpose, the drainage pipe used in these installations must be of a type that utilizes slitted perforations with slit openings meeting a specification of D_{85} sand/slot width >1.5, to reduce the potential for particle migration into the drainage system (**7**).

5.4.3.2 *Option 2*—Gravel may be used for backfill of drainage trenches. If gravel is used for backfill, it should conform to the specifications in Table 1. Soft gravel minerals (such as limestone, sandstone, or shale) are not acceptable for use and all questionable gravel material should be tested for weathering stability using the sulfate soundness test (see Test Method C88). A loss of material greater than a 12 % by weight is unacceptable. Likewise, any gravel material that is suspect in its mechanical stability should be tested utilizing the LA

TABLE 1 Gravel Filter/Drainage Layer Specifications (7, 8)

Performance Factor	Criteria	Acceptable Value
Filtering Factors	D_{15} of gravel/D_{85} of rootzone mix	<5
	D_{50} of gravel/D_{50} of rootzone mix	<25
Permeability Factor	D_{15} of gravel/D_{15} of rootzone mix	≥5
Uniformity Factors	D_{90} of gravel/D_{15} of gravel	≤2.5
	>12 mm fraction	0 %
	<2 mm fraction	≤10 %
	<1 mm fraction	≤5 %

Abrasion test (see Test Method C131). An LA Abrasion test value greater than 40 is unacceptable.

5.4.3.3 *Option 3*—Gravel may be used to backfill drainage trenches and to form a drainage layer beneath the sand rootzone. If gravel is used for this purpose, the same gravel should be used for backfill and the drainage layer, and should conform to the specifications given in Table 1. Soft gravel minerals are not acceptable for use and all questionable gravel material should be tested for weathering stability using the sulfate soundness test (see Test Method C88). A loss of material greater than 12 % by weight is unacceptable. Likewise, any gravel material that is suspect in its mechanical stability should be tested utilizing the LA Abrasion test (see Test Method C131). An LA Abrasion test value greater than 40 is unacceptable. A gravel drainage layer should be a minimum of 7.5 cm (3 in.), with 10 cm to 15 cm (4 to 6 in.) preferred. During installation, the gravel is typically dumped from the delivery trucks onto the perimeter, and then distributed over the construction site by a small, tracked, crawler tractor (or similar), being careful to avoid driving over and crushing the drain lines. Contour and compact the gravel in accordance with specifications at a suggested tolerance of ±12.5 mm (½ in.) within 3 m (10 ft) of linear direction and as specified in 5.5.6.

5.4.3.4 *Discussion*—If gravel is utilized as a drainage layer, it will improve the drainage of the system under conditions of saturated flow only. Saturated flow conditions typically only occur during intense or prolonged rainfall events. Under unsaturated conditions, the use of a gravel layer will impede drainage and will serve to retain additional moisture within the rootzone profile. This condition is commonly referred to as a 'perched' or 'suspended' water table. The water perched in the rootzone at the interface with the gravel will be retained in a condition nearing saturation. While such conditions may be beneficial in terms of water conservation, care must be exercised in the design of the rootzone system, such that excessive moisture is not retained that could lead to anaerobic rootzone conditions. Such conditions are common on poorly designed gravel, underdrained, sand-based rootzone systems. If a gravel underdrain system is used, the design parameters should be adjusted to assure a minimum of 15 cm (6 in.) of well aerated rootzone. If the capillary rise of salts or other contaminants from the subgrade are of concern on a particular project, the use of a gravel layer is recommended to prevent this occurrence.

5.4.3.5 *Determination of Well-Aerated Rootzone Conditions*—A well-aerated rootzone is normally that portion of the rootzone that retains ≥20 % air-filled porosity (AFP) after gravitational drainage ceases (as determined at 40 cm tension). To determine the depth of sand required to obtain the desired well-aerated profile depth, a soil moisture retention curve of the rootzone material must be determined. Considering that the perched water above a gravel layer will be retained at a tension of approximately 10 cm tension, the moisture retention status of the rootzone material should be considered at tensions greater than 10 cm until the proportion of air-filled pores within the rootzone material reaches 20 % or greater. For example, let's hypothesize that a soil moisture retention curve shows that a material reaches 20 % AFP at 21 cm tension. To provide a 15 cm well-aerated rootzone, our profile depth would be 21 cm (AFP threshold tension) – 10 cm (tension of perched water) + 15 cm of well-aerated rootzone, for a total rootzone depth of 26 cm. Moisture retention points should be determined utilizing methodologies in Test Method F1815.

5.5 *Sand-Based Rootzone*—Materials used to provide the sand for the rootzone shall meet the performance criteria established in this guide. Additions of peat or soil, or both, may be included in small proportions as part of the rootzone blend, if the inclusion of these materials will not bring the resulting blend out of specifications and if they are uniformly blended together to form a homogeneous blend.

5.5.1 *Sand Type*—Quartz sands are recommended; if sand contains more than 5 % calcium carbonate equivalent, the sand has the potential for particle cementation due to dissolution and reprecipitation of carbonates. Other sands are not recommended due to their propensity to weather (by either mechanical or chemical means, or both) over a relative short period of time (1 to 5 years) that may influence the performance of the construction. For example, granitic material often contains appreciable amounts of feldspar or mica which is much more readily subject to weathering. Caution should be given to sands that contain appreciable proportions of mica minerals. Mica grains have a flat or plate-like morphology and redistribution of these grains with a rootzone profile may create layers that impede drainage and aeration.

5.5.2 *Particle Size Distribution*—Particle size analyses (Test Methods D422 or F1632) are based on oven-dried mass of a weighed sample; shaker is the preferred method of dispersion to prevent fracturing of sand particles that may falsely influence the sand size distribution. There are many published specifications within the turf industry for sand size distribution for sand-based rootzone constructions. Many of these specifications are primarily intended for golf green construction. As such, the amount of coarse material allowed is limited in order to produce a very smooth surface under extremely short mowing conditions to facilitate smooth roll of the small golf ball. Such conditions are not required for athletic field construction and the use of higher proportion of coarser sand material can be utilized. Table 2 includes a recommended sand particle size distribution (before amendments), but is not inclusive of all size distributions of sands that could be used to produce a high performance sand-based field. Additionally:

5.5.2.1 No more than 30 % in the combined very coarse sand, fine gravel, and gravel fractions.

5.5.2.2 At least 60 % of the total sand should be in the combined medium sand and coarse sand fractions.

TABLE 2 Recommended Particle Size Distribution of Rootzone Sand[A]

Size Fraction	Particle Diameter Range	Specified Range (%)
Gravel	>4.75 mm	0 %
Gravel	3.4 to 4.75 mm	<5 %
Fine gravel	2.0 to 3.4 mm	<20 %
Very coarse sand	1.0 to 2.0 mm	<20 %
Coarse sand	0.5 to 1.0 mm	25 to 50 %
Medium sand	0.25 to 0.5 mm	>25 %
Fine sand	0.15 to 0.25 mm	<10 %
Very fine sand	0.05 to 0.15 mm	<5 %
Silt	0.002 to 0.05 mm	<5 %
Clay	<0.002 mm	<3 %

[A] See 5.5.2.1-5.5.2.4 for additional recommendations.

5.5.2.3 No more than 15 % in the combined fraction less than 0.25 mm (fine sand, very fine sand, silt and clay fractions).

5.5.2.4 A Coefficient of Uniformity (CU = D_{60}/D_{10}) value of 2.5 to 4.5.

5.5.3 *Sand Shape*—Although acceptable sand-based rootzones can be constructed with sands of all shapes, this factor is worth consideration in athletic field construction. Sand shape is generally classed as to angularity and sphericity. Angularity includes well-rounded, rounded, subrounded, subangular, angular, and very angular. Sphericity includes high sphericity, medium sphericity, and low sphericity. Sand shape should be classified according to Figure 1 of Test Method F1632. While no sand will have sand grains of uniform shape, there is normally a predominant shape of grains from a single sand source. The shape and dimension of sand grains affect its stability. For example, rounded grains are the least stable because of the lack of edges to interlock the grains. As such the sand grains tend to act like small ball bearings. Angular sands to have greater stability because the sharper edges have a greater grain-grain interlock and resistance to shear. Sands that have a predominance of grains that show extremes in angularity (extremely angular or extremely round) that fit outside the classification in Test Method F1632 should be avoided. Likewise, extremely high or low sphericity particles should be avoided, including plate-like particles. Many dune sand sources may contain sand grains that have internal fracture planes. During the saltation process, dune sands can become rounded as they roll and skip along the surface as a function of the wind. However, during strong wind events, the grains can be moved at a high velocity, whereby the grains impacting upon each other develop 'cracks' or fracture planes within the grain. When rootzones are constructed with these sands, traffic and other weathering factors may cause the grains to fracture along these planes, resulting in the formation of silt-size quartz grains which may then be prone to particle migration and subsequent accumulation in layers. Sand grains should be examined under 20 to 50× magnification for sand size, shape, and potential fracture planes.

5.5.4 *Rootzone Amendments*—Two types of amendments are commonly included in a blend with sand that together make up the rootzone material. This would most commonly include a blend with soil or peat, or both.

5.5.4.1 *Soil*—Soil is commonly used as a component of a sand-based rootzone construction in order to provide some enhanced capacity for moisture and nutrient retention and sometimes to improve the mechanical stability of the rootzone. Proportions of soil in a high performance rootzone mix typically range from 5 to 15 % by volume. The amount of soil to include in a blend depends upon the make-up of the soil component, and the effects of the soil additions to the physical performance characteristics of the resulting blend. Ideally, the soil component would be one that is composed purely of clay. Clay minerals generally have good moisture and nutrient retention capacities, and if present in high enough proportions may significantly improve rootzone stability by enhanced cohesive properties. When clay is included in a blend with sand in the appropriate proportion, the clay will coat the sand and form bridges between sand grains without clogging up the large pores (interstitial pores or packing voids) of the sand matrix. If a pure clay source is used, many sands will accommodate 10 to 15 % clay additions without clogging. However, care must be used in the blending and preparation process because a small increase in clay content can cause a drastic detrimental change in the performance of the rootzone. This is a primary reason for a well-designed calibration and quality control program. Other soils may be used as a component of a sand-based rootzone blend, but should be restricted to those soil textures that are low in silt content. Silt is normally a fine-grained, non-plastic soil material and is subject to migration and layering. Soils that exhibit a silt to clay ratio greater than 2 should not be used. Likewise, those soils with a fines (silt + very fine sand + fine sand) to clay ratio greater than 3 should be avoided. Generally, soils containing more than 6 % organic matter should not be used, nor any mucky-type soils. Peat may be used to increase the organic matter content in a three-way blend of sand-soil-peat.

5.5.4.2 *Peat*—Peat is commonly used as an amending source in a sand-based rootzone. Proportions of peat included in a blend (usually 15 to 20 % by volume) should give an organic matter content of 0.3 to 2.0 % by mass. As with soils, peat adds water and nutrient retention capacity, but will add little in terms of increased soil strength (cohesion). Peats can also slow water movement through excessively drained sands. Finer peats, whether by decomposition or by finer grinding, generally have a greater effect on slowing water movement. Three sources of peat have been used successfully to modify sands. They are moss peats (sphagnum and hypnum), reed-sedge peats (derived from reeds, sedges, marsh grasses, and other plants of the wetland), and peat humus, which is decomposed peat (usually derived from moss or reed-sedge sources). Peats to avoid in modifying sands are woody peat (derived from trees and shrubs) and sedimentary peat (derived from plants that grow in water and found on pond and lake bottoms). Peats can be classified according to fiber content (see Classification D4427). In general, moss peats fall into the fibric classification, which indicates the greatest fiber content; reed-sedge peats into the hemic classification (a mid-range of fiber content); and peat humus into the sapric classification (lowest fiber content). The acceptable sources of peat range in their physical and chemical properties and information in Table 3 can be utilized during the selection of a peat. Fibric peats are characterized by low ash contents, and low volume weights

TABLE 3 Suitability Ratings of Properties of Organic Amendments for Utilization in High Performance Sand-based Athletic Field Rootzones

Rating\Property	C/N Ratio	Ash Content	pH
Preferred	20:1 to 30:1	<12 %	4.5 to 7.0
Acceptable	30:1 to 50:1	12 to 17 %	3.5 to 4.5
Marginal	50:1 to 80:1	17 to 30 %	3.0 to 3.5
Unacceptable, or use only with caution	<20:1 or >80:1	>30	<3.0 or >7.0

(bulk densities). Because of a lower volume weight, a greater amount on a volume basis than with the other sources will be needed to achieve a desired organic matter content in the blend, which is reported on a mass basis. The low volume weight peats do not mix as readily as heavier peats when being mixed on-site by tillage, but this problem is largely negated by off-site mixing with various blending equipment. Off-site mixing is preferred for high performance sand-based rootzones. The fibric peats decompose more rapidly than hemic and sapric peats; however, their longevity is such that they provide benefits until organic additions from the turfgrass stand contribute significantly to the soil organic matter pool. With sphagnum moss peat, low pH may create the need for lime additions to the mix, and relatively low nitrogen (N) content and wide C/N ratio could lead to N tie-up by microorganisms and the need for additional N fertilization. Potential problems encountered with fibric peats are reduced with hemic peats, which are denser, somewhat lower in acidity, higher in N content, and more readily mixed. Also sapric, or decomposed peats, have fewer problems with pH, N content, and volume weight; however, they contain more ash and some low quality sapric peats may contain mineral soils that result in unacceptably high ash contents. The organic matter in sapric peats, already being in a somewhat decomposed state, is more stable than organic matter in the more fibrous peats. Peats considered for inclusion in high performance sand-based rootzones can be classified according to Classification D4427, and further tested by methods listed in 5.5.5.3. Suggested recommendations for peat/organic amendments for high performance sand-based rootzones are given in Table 3.

5.5.4.3 *Discussion*—Often the use of composts are proposed as substitutes for peat products. While in some instances, composts may produce satisfactory products for inclusion in a rootzone construction, the variability of compost products tends to be much higher than those of natural peat deposits. This variability is especially true over time and from season to season. Composts also typically contain higher ash content, may contain contaminants of soil or other earthy materials, may contain wood, and may not be completely stable in terms of chemical and physical properties. Composts may also contain high elevations of trace metals or salts, or both (although testing can be used to determine the level of these constituents). The use of composts in a high performance sand-based rootzone should be approached with a high degree of caution and employed with thorough quality control in the sourcing and construction phases. Under strict control and testing, composts have and may be used for high performance sand-based rootzone constructions. It is recommended that only compost products be used that have been used successfully in high performance sand-based field mixes in the past, and only in amounts sufficient to meet the performance parameters outlined in this guide. Mix design and testing should be performed by laboratories experienced in evaluating composts and compost amended mixes.

5.5.4.4 *Quality Control (QC) Program*—Every high performance sand-based rootzone should be constructed using a well designed and administered calibration and QC program. Such program should set the parameters to be included in the QC testing, the procedures for sampling, sampling intervals, handling the samples (chain of custody), the limits/tolerances or confidence intervals for accept/reject status within a sample, and the allowable variability of test parameters between samples.

5.5.5 *Rootzone Blending*—Rootzone blending is perhaps the most critical aspect of the construction process. Once amendment ratios are known, the components of the blend should be prepared.

5.5.5.1 *Sand*—The sand should have been previously processed, stockpiled, tested, approved, and quality control tested.

5.5.5.2 *Soil*—Any soil amendments should have been tested and approved and then prepared for blending by first shredding, screening, and the removal of any objectionable stones or other items. Once the soil has been prepared in this manner, the soil should be transported to the blending site for stockpiling. Once the material arrives on site, it should be protected from weather, particularly rain. During the processing and transportation of the soil component, it may be beneficial to mix or homogenize the soil material as much as is feasibly possible. Once homogenized and transported to the blending site, an additional sample should be taken and tested for conformance with the original tested material so that any adjustments in the blending proportions needed to compensate for variance in the soil stockpile may be made. It should be noted that soil components (particularly topsoils) are a potential source of weeds by seeds or plant parts. Consideration for eradication or fumigation of these materials may be warranted.

5.5.5.3 *Peat*—The peat product used for amending the sand should have been tested and approved prior to shipment of material to the blending site. Once the material arrives on site, it should be protected from weather, particularly rain. As peat is unloaded or unpackaged, it should be visually inspected for apparent uniformity within the shipment. If the project owner, project designer, or agronomist is sufficiently familiar with the peat material from past projects, the only QC testing that may be required for the peat is the calibration and QC for organic matter content of the resulting sand-peat mix. If the peat product/source is new or unfamiliar to the project personnel, additional QC tests should be performed at set testing intervals prior to blending. Peat QC test parameters may include ash content, organic matter, pH, fiber content, moisture content and volume weight (see Test Methods D1997, D2944, D2974, D2976, D2980, and Classification D4427) and C/N ratio. The above advice also applies to composts used as organic amendments.

5.5.5.4 *Blending*—The blending operation should only proceed once all of the materials have been tested and approved and transported to the blending site. It is recommended that blending operations proceed off-site as to the installation. Possible blending sites include: *(1)* the location for sand materials supply or stockpile; and *(2)* in an area adjacent to field site (such as a paved parking lot). The materials to be blended should be blended in a slightly moist to moist condition. Excessively wet material will not blend together properly and uniformly. Blending should be performed using commercial soil blending equipment designed for this purpose. The project designer should calculate production to include a minimum of 5 % (10 % preferred) additional rootzone material to account for shrinkage. Any leftover rootzone material could be stockpiled by the owner for use in future maintenance (topdressing) operations and for other repairs. The blending should be initiated with the preparation of a 'batch' for calibration purposes. A calibration batch stockpile is normally composed of a 100 ton minimum. The calibration batch should be sampled and tested to assure the blending equipment is properly calibrated before proceeding further. Each test for calibration may delay the blending operation 24 to 48 h, awaiting test results and recommendations from the testing laboratory. Another option would be to employ a commercial testing agent with the capacity to perform on-site testing with mobile laboratory equipment. The mobile laboratory may be utilized throughout the calibration and blending process to facilitate the logistics of the operation. It is recommended that 1 of 10 tests conducted by the mobile laboratory are duplicated at the regular laboratory facility to assure accuracy of the on-site testing data.

5.5.5.5 *Stockpile Storage and Transportation*—During the blending operation, and once the rootzone material has been blended and all QC approvals have been met, the stockpiled material should be protected against the effects of weather. If heavy rain is expected, the stockpiles should be covered, if possible. To protect against wind erosion of soil or organic components, the stockpiles should be kept moist on the surface of the stockpile. Once stockpiled rootzone material is to be transported to the construction site, care should be taken to ensure that the loading equipment and haul vehicles/containers are properly sanitized such to contain no foreign soil, aggregate, asphalt, and so forth that might contaminate the blended rootzone material. When the stockpile material is being picked up for loading, care should be exercised to assure that the bucket of the loading equipment is not picking up underlying soil or asphalt and that cleated tires or tracks are not 'tilling' other material into the rootzone mix.

5.5.6 *Grading Requirements*—All grades should conform to those grades and elevations as specified in the construction documents. The suggested method for grade evaluation and grade tolerances are:

5.5.6.1 For general conformance, perform an as-built survey based upon an 8 m (25 ft) grid to be within:

(1) Subgrade, ±12.5 mm (½ in.).

(2) Gravel Drainage Layer (if used), ±12.5 mm (½ in.).

(3) Surface/Finish, ±6 mm (¼ in.).

5.5.6.2 For specific conformance and acceptability of grades between grid points (spot check), it is recommended that any observed (or suspected) high and low points be checked using a 3-m (10-ft) straight edge with tolerances based upon:

(1) Subgrade, ±12.5 mm (½ in.) in any linear direction.

(2) Gravel Drainage Layer (if used), ±12.5 mm (½ in.) in any linear direction.

(3) Surface/Finish, ±6 mm (¼ in.) in any linear direction.

5.5.6.3 Grades shall be correct, certified, and approved (at each phase: subgrade, gravel layer (if used), and finish grade) by the owner or project designer, or both, prior to proceeding to the next phase of construction. Correct and certified grade shall be given by the production of an as-built drawing/diagram depicting elevation and location data that has been prepared and stamped by a licensed surveyor. The certified as-built drawing/diagram shall be submitted for approval to the owner or project designer, or both, as specified in the construction documents prior to proceeding to the next phase of the field construction.

5.6 *Installation*—Installation procedures include the installation of the drainage trench backfill material, installation of any gravel drainage layers, delivery, and installation of the rootzone material, installation of the irrigation, finish grading of the site, and then turf establishment. Rootzone installation depth shall conform to project designer's specifications. Typical rootzone placement depths range from 15 cm (6 in.) to 30 cm (12 in.) for installations without a gravel drainage layer. If a gravel drainage layer is used, the rootzone placement depth must be correlated with the desired depth of well-aerated rootzone. Typically, the profile depth of a sand-based field installed over a gravel drainage layer ranges from 23 cm (9 in.) to 40 cm (16 in.).

5.6.1 *Installation of Drainage Materials*—Drainage trench installation should be completed to the point of backfill and compaction (see 5.4.3) prior to installation of the irrigation system. If a gravel drainage layer is a component of the system design, the installation of the gravel layer should be completed following the rough installation and pressure testing of the irrigation system.

5.6.2 *Installation of the Irrigation System*—Irrigation system shall be designed and installed to provide head to head coverage with uniform distribution (**9**). Suggested irrigation design uniformity values (CUIRR or Christiansen's coefficient of uniformity) are: *(1)* football, soccer, or other rectangular field designs: ≥90 %; and *(2)* baseball/softball, cricket, or other non-rectangular field designs: ≥84 %. Irrigation pipe should be installed to a depth sufficient to be protected from mechanical aeration maintenance practices. Normally, this would be at a depth of 36 cm (14 in.) or more from finished grade. In the case of shallow profile designs of less than 20 cm (8 in.), the irrigation lateral and mainlines may be installed within the subgrade below the depth of the entire drainage system. The installation of the irrigation lines below the drainage system serves to isolate the irrigation lines from potential damage from aeration or other maintenance practices. Irrigation mainlines and lateral lines (with sleeving, if included) should be installed prior to placement of the gravel drainage layer (if used) or rootzone materials, or both. Irrigation lines crossing drainage trenches may be 'sleeved' across the drainage trench to facilitate subsequent irrigation system installation without disturbing the drainage trench system. Irrigation lines *should not* be installed within the same trenches as the drainage system in order to minimize the disturbance of one system to the other as they are being installed or repaired. The irrigation system mainlines should be pressure checked (24 h static pressure) before backfilling and prior to proceeding with the next construction phase.

5.6.2.1 *Complete Installation of Gravel Drainage Layer*—If a gravel drainage layer is used as a component of the rootzone design, this gravel layer may be installed once the irrigation system rough installation and a pressure check are completed.

5.6.3 *Delivery and Installation of the Rootzone*—The rootzone material should be transported to the site and dumped around the perimeter of the site. A small crawler tractor is ideally suited to spread the rootzone material working from the perimeter inward toward the center of the field. Wheeled tractors or larger tractors may cause excessive pressure that could lead to crushing of the drainage pipes, rutting of the subgrade, or over compaction of the rootzone material. As subsequent rootzone material is moved to the site for dumping, a plywood course should be constructed over the installed rootzone to facilitate the movement of trucks onto the field for dumping of the load. The plywood course not only protects the rootzone from rutting and excessive compaction, but also allows the trucks to deliver their load without becoming stuck in the sand. Under no circumstances should trucks or other equipment be allowed to travel over the uncovered subgrade. Once the delivery of the rootzone material is completed, the field may be shaped, rough-graded, and compacted as specified.

5.6.4 *Final Field Preparations*—Final field preparations include bringing the field to final grade and contour and may include pre-plant fertilization and pre-plant irrigation.

5.6.4.1 *Finished Grade*—Once the rootzone material has been installed and rough graded, the field should be graded to final (finish) grade and contour. It is strongly recommended that laser guided leveling equipment is specified and utilized for this critical aspect of the construction process. A smooth and uniform grade is a very important aspect of proper conditions for enhanced playability and safety of an athletic field. The specified grade and contour should conform to a ±6 mm (±¼ in.) within 3 m (10 ft) in any lateral distance for general conformance and specific conformance as outlined in 5.5.6. Such tolerances are only achievable with laser-guided equipment. During the finish grade operation, compaction should be achieved by irrigating and rolling the surface utilizing a lightweight roller (less than 2 ton) with at least two passes in perpendicular directions. Finished grade should be within specified tolerances, correct and certified as specified (see 5.5.6) before turf installation.

NOTE 4—In general, as the soil component in a sand-based rootzone increases, rolling should be performed with lighter equipment also giving a higher level of attention to the moisture content of soil component. In any case, it is recommended that when using soil components with an increased potential to compact in a blend with sand, rolling shall be done with caution.

5.6.4.2 *Pre-Plant Operations*—Pre-plant operations may include the use of a pre-plant fertilizer or other soil fertility amendment. Applications can be made as a granular product that is spread across the field or as a liquid application that is sprayed across the field or injected into the irrigation system. Once the pre-plant materials are applied, it may be desirable to lightly irrigate or 'water-in' the applied materials. Any pre-plant operations must be performed with care to avoid rutting or disruption of the final grade in any manner. Only lightweight or walk-behind equipment is advisable.

5.6.5 *Turf Installation*—The turf to be used in the athletic field project should be thoughtfully considered and specified by the project's project designer, owner, or project agronomist. It should be of a species and cultivar adapted to the local climate, capable of withstanding the stresses imposed on an athletic turf, while providing good playability and aesthetic characteristics. Depending upon turf species and cultivar selected, turf installation methods may include seeding, sprigging, plugging, or sodding. Any turf installation methods used must be carried out in a manner that protects the integrity of the finished grade. No heavy machinery such as tractors, hydrospray tanks, or trucks should be allowed on the surface, unless equipped with turf-type tires.

5.6.5.1 *Seeding and Sprigging*—Seeding and sprigging offer the most flexibility of the methods because they do not pose the risk of contamination of the rootzone with attached soil, they can be spread or planted mechanically or by the use of hydroseeding/hydrosprigging. If the project construction timeframe allows, seeding or sprigging are the preferred methods of establishment. Any mechanical sprigging equipment or seeders should be outfitted such to avoid disruption of finished grade. The use of heavy or large hydrosprig/hydroseed equipment intended for use in the hydroseeding or hydrosprigging of roadside and highway landscapes should be avoided, except where the equipment can be kept off the field and the hydroseed/hydrosprig material applied by use of a hose. Seeds or sprigs should be Certified turfgrass seed/sprigs (if available). Seeds or sprigs shall be free of, or below acceptable threshold levels for, objectionable or noxious weeds, foreign turfgrass cultivars, off-types of the same species, insects, nematodes, diseases, or any other objectionable material.

5.6.5.2 *Plugging*—Establishment of rapidly growing warm season turf cultivars that propagate by spreading through rhizomes or stolons (for example, seashore paspalum and bermudagrass), may be established by plugging. Plugging has some distinct advantages as an establishment method. Installed plugs have an established root system, and therefore are not as subject to stresses of drought should an interruption in water supply occur, or if limited water quantities are available for irrigation. If the growing medium of the plugs was a 'soil-less' mix, then minimum contamination of the rootzone can be expected. Plugs can be planted on a wide variety of spacings, depending upon the desired rate of grow-in desired and the turf cultivar utilized. Typical plug planting spacing ranges from 20 cm (8 in.) to 40 cm (16 in.) on center. Plugs should be free of weeds, contaminants, off-type turf, or any other objectionable

TABLE 4 Sod-soil to Rootzone Sand Compatibility Recommendations

Criteria	Preferred	Acceptable	Marginal	Unacceptable
$D_{50}R/D_{50}S$	<2.5	2.5 to 5.0	5 to 10	>10
Silt and clay (%)	<5	5 to 10	10 to 15	>15
Silt to clay ratio	<2	2 to 5	5 to 7	>7
Gravel (>2 mm) (%)	0	0 to 2	2 to 5	>5

R = Rootzone S = Sod-soil

TABLE 5 Recommended Physical Properties of the Rootzone Mix (Test Method F1815)

Physical Property	Specified Range
Total porosity	35 to 45 %
Bulk density (kg·m^{-3})	1.5 to 1.7
Air-filled porosity	15 to 25 %
Capillary porosity	15 to 25 %
Saturated hydraulic conductivity (cm/h)	≥25
(Saturated hydraulic conductivity [in./h])	(≥10)

material. Plugs for athletic fields are best planted by hand. Another method of plug establishment is sometimes utilized whereby a mechanical planter processes sod into irregular pieces and then plants them as 'plugs.' This method of plugging irregular sod pieces may also be used for satisfactory establishment of turf and can be done mechanically with due caution to avoid disruption or rutting of the finished grade.

5.6.5.3 *Discussion*—Plugging as used in this guide defines the use of discreet media-rooted turf plugs (as often coming in a plastic media tray). This method of plugging should not be confused with the practice of planting irregular sod pieces, which is also referred to as plugging in some areas. Plugging by the use of irregular sod pieces is a practice more closely resembling a sprigging operation and the establishment of turf by this practice should conform to the specifications as given for mechanical sprigging.

5.6.5.4 *Sodding*—Sodding offers the quickest establishment of any turf installation method. Sod can come in rolls or slabs of various dimension and thickness. If sod is to be used, it is preferable to wash the soil from the sod before installation to avoid contamination of the rootzone. If washed sod is not available, then only sod grown in sand or loamy sand soil should be considered. Any sod-soil considered for installation in the project should meet the criteria as outline in Table 4. Big-roll sod is the preferred sod type in order to reduce the seams in the finished installation. Sod delivery and installation procedures should be such to avoid compaction and disruption of the finished grade. (Sod may also be planted mechanically as irregular sized pieces in a process called 'plugging,' see 5.6.5.2.) Sod deliveries should be made off the field and the sod moved in on a pallet-by-pallet or roll-by-roll basis as appropriate. Specialized sod handling and installation equipment only should be used during this process to protect the finished grade. For example, with big-roll sod installations, rubber-tracked handling and installation equipment is commercially available.

5.6.5.5 *Recommended Sod Specifications*—If sod is the chosen turf establishment method, the following criteria is a recommended specification for the sod to be used:

(1) Certified Turfgrass Sod—Superior sod grown from Certified (if available), high quality seed (stolons) of known origin, or from plantings of Certified grass seedlings or stolons. It shall be inspected by a sports turf consultant and owners' representative at the sod farm at which it is grown to ensure satisfactory genetic identity and purity, overall high quality, and freedom from noxious weeds, as well as excessive quantities of other crop and weedy plants at time of harvest. All seed or original plant material in mixture should be Certified. Turfgrass sod shall meet the published state or government standards for Certification of the species and cultivar as specified.

(2) Sod may be washed (soil-less) or a special "sand base" material meeting compatibility specifications for sand-based athletic fields as given in Table 4. Sod-soil containing greater than 15 % silt and clay are unacceptable. In most cases, sod thickness should not contain a soil layer greater than 12.5 mm (½ in.). Thick cut (>12.5 mm or >½ in.) sod may be used in cases where insufficient time exists for establishment of sod before play is initiated. In any case, sod-soil should meet appropriate compatibility criteria as given in Table 4.

(3) Strip Size—Sod shall be big roll turf cut to the supplier's standard width and length. Maximum allowable deviation from standard widths and lengths shall be plus or minus 12.5 mm (½ in.) on width and plus or minus 5 % on length. Broken strips and torn or uneven ends will not be accepted.

(4) Time Limitations—Sod shall be harvested, delivered, and transplanted within a 12 h period unless a suitable preservation method is approved by the project designer or project agronomist prior to delivery. Sod not transplanted within this period shall be inspected and approved by the project agronomist and project designer prior to its installation.

(5) Thatch—Sod shall be relatively free of thatch. A maximum of 12.5 mm (½ in.) (uncompressed) thatch will be permitted.

(6) Diseases, Nematodes, and Insects—Sod supplier should be required to supply (and warrant) sod that shall be relatively free (below established acceptable threshold levels) of diseases, parasitic nematodes, and soil-borne insects.

(7) Weeds—Sod shall be free of objectionable grassy and broad leaf weeds.

(8) Sod supplier to identify specific fields for harvest, inspection, and submit a fertility and management program schedule for 6 months prior to harvest.

6. Recommended Rootzone Performance Criteria

6.1 Several criteria should be considered for proper design of high performance sand-based rootzone construction. These include physical performance criteria, chemical performance criteria, and mechanical performance criteria. The rootzone performance criteria should be considered on the entire rootzone mix rather than on any component separately.

6.2 *Recommended Physical Performance Specifications*—Physical performance criteria (as determined at 40 cm tension for water retention and air-filled porosity) include permeability or saturated hydraulic conductivity, water retention, air-filled

TABLE 6 Recommended Chemical Properties of the Rootzone Mix

Chemical Property	Specified Range
pH (Test Method D4972)	5.0 to 7.5
Calcium carbonate equivalent, preferred	<5 %
Calcium carbonate equivalent, marginal	5 to 15 %
Organic matter (Test Methods F1647)	0.5 to 2.5 %
Nutrient content	Adjust for local conditions
Heavy metals or other phytotoxic ions	Adjust for local conditions, do not exceed regulated thresholds

TABLE 7 Recommended Mechanical Properties of the Rootzone Mix

Mechanical Property	Specified Range
Friction angle (degrees) (Test Method D3080) or, alternatively	38 to 50
Angle of repose (degrees) (Test Method C1444)	35 to 45
CBR (%) (Test Method D1883)	12 to 25
Coefficient of Uniformity (CU) of sand component	2.5 to 4.5

porosity, and bulk density. The recommended physical performance criteria are given in Table 5. The physical performance criteria should be given priority over the sand size distribution specifications.

6.3 *Recommended Chemical Performance Specifications*—Chemical performance criteria include pH, calcium carbonate equivalent, organic matter content, nutrient content and the presence of any heavy metals or phytotoxic ions/substances. The recommended chemical performance criteria are given in Table 6.

6.4 *Recommended Mechanical Performance Specifications*—Mechanical performance criteria (for sands) includes shear resistance (specified as friction angle determined by direct, simple, or triaxial shear methodolgies (see Test Method D3080) when compacted to an initial standard proctor density of 85 % and at 40 cm soil tension (see Test Methods D698)), California Bearing Ratio (confined CBR) at 40 cm soil tension and 85 % standard proctor density (see Test Method D1883) and coefficient of uniformity (CU = D_{60}/D_{10}) of the sand component.

7. Keywords

7.1 athletic field; baseball; clay; cricket; football; natural turf; sand; soccer; softball; soil; sports field; sports turf; turfgrass

APPENDIX

(Nonmandatory Information)

X1. RESOURCE MATERIALS

X1.1 For additional information related to sports fields, consult the following sources of information:

X1.1.1 Sports Turf Managers Association (STMA). STMA, 805 New Hampshire, Suite E, Lawrence, KS 66044, http://www.sportsturfmanager.com.

X1.2 For additional information related to soil modification for athletic field construction, you may desire to consult the following publications:

X1.2.1 Adams, W. A., and Gibbs, R. J., *Natural Turf for Sport and Amenity: Science and Management*, (Oxford Press, 1994).

X1.2.2 Davis, W. B., Paul, J. L., and Bowman, D., "The Sand Putting Green Construction and Management," *University of California Bulletin, Publication # 21448*, University of California, ANR Communication Services, 1990.

X1.2.3 Davis, W. B., Farnham, D. S., and Gowans, K. D., "The Sand Football Field," *California Turfgrass Culture*, Vol. 24(3), 1974, pp. 17–20.

X1.2.4 Goss, R. L., and Cook, T., "Construction and Maintenance of Natural Grass Athletic Fields," *PNW Publication 0240*, Washington State University Cooperative Extension, 1983.

X1.2.5 Harper, J. C., "Athletic Fields—Specification, Outline, Construction, and Maintenance," Penn State University, 1983.

X1.2.6 Keith J. Karnok, ed., *Turfgrass Management Information Directory*, Third Edition, (Hoboken, New Jersey: John Wiley & Sons, Inc.).

X1.2.7 Landschoot, P. J., "Using Composts to Improve Turf Performance," *Cooperative Extension Circular 5M49ps5733*, Penn State University, 1996.

X1.2.8 Peacock, C. H., "Athletic Fields: Design, Construction, and Maintenance," *Bulletin 202*, University of Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, 1999.

X1.2.9 Taylor, D. H., Blake, G. R., and White, D. B., "Construction and Maintenance of Athletic Fields," *University of Minnesota Extension Bulletin 3105*, 1987.

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(8) USGA, Green Section, *USGA Recommendations For A Method Of Putting Green Construction*, USGA, Golf House, Far Hills, NJ, 1993,http://www.usga.org/green/coned/greens/recommendations.html#gravel.

(9) Christiansen, J. E., "Irrigation by Sprinkling," *California Agricultural Experimental Station Bulletin 670*, University of California: Berkeley, CA, 1942.