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Critique of USGA Reco mmendations for A Method of Putting Green Construction

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Abstract

The United States Golf Association (USGA) originally published specifications for greens construction in a 1960 five-page publication. The document was designed as a guide to golf course builders to ensure greens would provide good playing conditions for many years, and is based on research from the Green Section, UCLA, and Texas A & M College. Reco mmendations from this document were designed to provide a green with sufficient drainage and resistance to compaction, a combination difficult to achieve without a degree of compromise. Since this release, the original reco mmendations have been updated four times, most recently in 2018. The document gives guidance on a range of soil physical properties including bulk density, porosity, saturated hydraulic conductivity, grain size distribution, bridging factors, and amendments. The most recent version of the specifications builds on previous versions; however, some reco mmendations warrant further examination such as the statement that addition of small amounts of soil to a rootzone mix will likely reduce the infiltration rate without a significant increase in water retention.

Keywords: USGA green, Perched water table, Rootzone, Physical properties

Abbreviations: Ksat: Saturated Hydraulic Conductivity, v/v: volume per volume, D15: particle diameter below which 15% of gravel particles by weight are smaller, D85: particle diameter below which 85% of sand particles by weight are smaller, USGA, United States Golf Association.

Introduction

Specifications for a Method of Putting Green Construction, 1960

In the original 1960 version of the reco mmendations [1], a 4-inch (10 cm) gravel layer, overlain with 1.5 to 2 inches (3.8 to 5 cm) of coarse sand, followed by a 12-inch (30- cm) layer of topsoil, is reco mmend. Particle size analysis for the layers is not included. However, it is reco mmended that pea gravel of about 0.25 inches (0.6 cm) be used and the sand be washed coarse sand. Co mmercial concrete sand is deemed satisfactory. To prevent sand migrating into the gravel layer and clogging soil pores, it is reco mmended the coarse sand layer be within a range of five to seven diameters of the gravel diameter. Topsoil is reco mmended to allow passage of water at no less than 0.5 in hr^{-1} (1.3 cm hr^{-1}) and no more than 1.5 in hr^{-1} (3.8 cm hr^{-1}) when subjected to a 0.25 in (0.64 cm) hydraulic head, although it is not clear if this is Ksat or a different measurement. Finally, total pore space of the topsoil should be a minimum of 33%, divided into 12-18% non-capillary and 15-21% capillary pores. It is reco mmended a soil be blended off-site, as few natural soils meet these requirements.

Refining the Green Section Specifications for Putting Green Construction, 1973

In 1973, the reco mmendations were updated for the first time since the original version was released in 1960 [2]. In this revision, water infiltration rate range was increased from 0.5 to no more than 1.5 in hr^{-1} (1.3 to 3.8 cm hr^{-1}) in the 1960 version, to 4 to 6 in hr^{-1} (10 to 15 cm hr^{-1}). Sand particle size reco mmendations become more specific; 100% below 1.00 mm, 35% below 0.50 mm, 15% below 0.25 mm, and 5% below 0.06 mm. To meet these requirements sand of brick and mason classes is reco mmended. Gravel size is specified to a greater degree, between 0.25 and 0.38 in (0.6 and 1.0 cm) diameter. The reco mmendations bring up the concept of gravel uniformity, the idea that gravel must be of similar size, in order for a perched water table to operate properly. Gravel outside the specified range should be removed. Specifications still call for a 2 to 4 in (5 to 10 cm) layer of coarse sand ('choker' layer) above the gravel in order to prevent sand migrating into the gravel and filling pores.

The 1973 specifications also include greater information on bulk density and porosity reco mmendations. Pore space is reco mmended between 40 and 55%, with capillary pores not less than 15%. Bulk density is reco mmended to ideally fall between 1.25 and 1.45 g and cm^{-3}, although 1.20 to 1.60 g and cm^{-3} is deemed acceptable. It is reco mmended topsoil have a water retention capacity between 12 and 25% by weight. It is interesting to note that the original specifications and all versions after 1973 based water retention on volume basis. Sand particle size reco mmendations were included for the first time. Reco mmendations stated no more than 10% of sand particles should be larger than 1 mm and no more than 25% of the particles be smaller than 0.25 mm. Specifications also include reco mmendations for silt and clay quantities, less than 5% and 3% respectively.

USGA Reco mmendations for Putting Green Construction, 1993

Specifications were once again updated in 1993 [3], along with a complementary manuscript outlining the rationale for the latest updates [4]. The 1993 specifications introduced a concept for evaluating 'bridging' between the smallest gravel fraction and the largest sand fraction. Bridging relies on the smallest 15% of the gravel particles and the largest 85% of the sand particles mixing, thereby creating smaller voids that prevent further infiltration of sand into the gravel layers. Bridging is designed to keep the perched water table intact. In order for bridging to occur, reco mmendations require the particle diameter below which 15% of gravel particles by weight are smaller (D15) must be equal to or less than five times the particle diameter below which 85% of sand particles by weight are smaller (D85). Further specifications are placed on the gravel including a permeability factor, and a uniformity coefficient. The purpose of the 'bridging' specification is to eliminate the need for the 2- to 4-inch (5-to 10- cm) "choker" layer to prevent rootzone sand from entering the gravel layer.

A particle size distribution for the reco mmended rootzone is presented: no more than 10% of the particles should be in the fine gravel and very coarse sand range, a minimum of 60% of the particles should fall in the coarse and medium sand range, no more than 20% of the particles should be in the fine sand range, and very fine sand, silt and clay should not exceed 10%. Specifications for amending the rootzone mix using topsoil are included, but not required. If a rootzone amendment is used, sand content of the topsoil should be at least 60%, with clay content of between 5 and 20%; no reco mmendations for silt content are included. The specifications also include the possibility of adding organic amendments such as peat to the rootzone mix; however inorganic amendments are specifically not reco mmended.

Bulk density specifications have been removed from the document; it is concluded that most sands will fall into the range originally suggested and thus they are superfluous. However, bulk density is required to calculate porosity and pore distribution. Porosity of the rootzone is reco mmended to fall between 35% and 55%, with air filled porosity at 40 cm tension of 15% to 30% and water filled porosity at 40 cm tension of 15% to 25%. Our research has shown all pure sands have water filled porosity below 15% at 40 cm tension, and most would fail to meet this requirement [5]. Addition of an organic amendment or native soil to the rootzone could increase the water content at this depth to acceptable levels; however, other properties could be adversely affected, resulting in the mix being unacceptable. Further to this point, 40 cm tension does not exist in a USGA specified rootzone. The capillary break between sand and gravel is designed to create a perched water table. This combined with a 30 cm rootzone means the greatest tension in the rootzone occurs at the surface and is 30 cm. Basing a reco mmendation on 40 cm tension appeared to be redundant and was lowered to 30 cm in later methodologies.

Saturated hydraulic conductivity is separated into two categories for 'normal' and 'accelerated' situations. Normal rate is used where typical conditions for growing turf dominate, and accelerated rate is used where water quality is poor or cool season grasses are being grown out of their desired range. Normal is between 6 and 12 inches hr^{-1} (15 and 30 cm hr^{-1}) and accelerated between 12 and 24 in hr^{-1} (30 and 60 cm hr^{-1}). Overall, 1993 revisions are the most comprehensive and science-based since the original version.

USGA Reco mmendations for a Method of Putting Green Construction, 2004

The reco mmendations were updated again in 2004 (US Greens section staff, 2004 [6]). however, few changes to the soil physical property reco mmendations were made. The accelerated range for Ksat was removed, and Ksat for all rootzone mixes required to be a minimum of 6 in hr^{-1} (15 cm hr^{-1}) with no upper limit included. The update allowed for inorganic amendments to be used, if they meet the criteria for the rootzone mix. However, lack of evidence for long term viability of inorganic amendments is noted. Bridging factor is increased, so gravel D15 must now be equal to or less than eight times rootzone D85. This change means either gravel particle diameter can be increased, or finer sand particles can make up a larger percentage of the rootzone mix. Permeability factors and uniformity factors of the gravel remain largely unaltered, although there is an increase of 0.5 in the uniformity factor, which equates to a possible increase in range of gravel particle sizes to fit the specifications.

Critique of USGA Reco mmendations for a Method of Putting Green Construction, 2018

The most recent version of the publication was released in February 2018 [7] and contains a number of revisions. Soil used for amending the rootzone is a sandy loam with a minimum sand content of 60% and a clay content of 5 to 20%. In the strictest sense, a soil with a minimum of 60% can fall into sand, loamy sand, and sandy loam textural categories as the clay content increases from 5 to 20%. In past specifications, the textural class was not included, and it is unclear why it would be included now, especially in this ambiguous context. Reco mmendations that no more than

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10% of the rootzone is very fine sand, silt, or clay, agrees with Brown et al [5], who demonstrated the addition of more than 20% silt and clay retained excessive water in the rootzone making it unsuitable for play (Table 1); however, 20% and less should be acceptable. Erring on the side of caution in this instance may be preferable, thus, 10% is sufficient.

Table 1: Physical properties of eleven mixtures of a USGA specified sand and fines from a native clay soil by 10% v/v increasing increments.

Sand by volume (%)	Fines by volume (%)	Bulk Density (g and cm^{-3})	Porosity† (%)	Ksat‡ (cm hr-1)
100	0	1.58	40	(268.91a)
90	10	1.55	42	43.49b
80	20	1.55	42	4.67c
70	30	1.56	41	1.36c
60	40	(1.50)	43	0.34c
50	50	1.51	43	0.22c
40	60	1.45	45	0.81c
30	70	(1.40)	47	2.49c
20	80	1.17	56	1.01c
10	90	(1.30)	51	1.79c
0	100	1.08	59	2.99c

† Porosity was calculated as [1 – (bulk density ÷ particle density)], where particle density = 2.65 g and cm^{-3}.

‡ Ksat was established using the constant head method. Means followed by the same letter are not significantly different at P = 0.05.

Addition of soil to rootzone mix is mentioned in the reco mmendations without explanation as to why it may be added, e.g. to reduce Ksat, to increase water retention, or to increase nutrient holding. We feel it is important if soil is going to be added to a sand based rootzone mix the reasons for it should be thoroughly explained and if any additional or specific evaluation of this mixture should be followed. Saturated hydraulic conductivity is defined as infiltration rate in the reco mmendations. While these terms are co mmonly used synonymously, there is a difference. Infiltration rate is a measure of the rate water enters a soil profile from the surface. Ksat is the proportionality factor equating flux (volume of water through a cross-section over a time) to hydraulic gradient (head drop per unit distance) [8]. Water movement through the soil profile under saturated conditions may be described by Ksat; however, our research into Ksat of a sectioned USGA style green indicates infiltration rate is most limited by the presence of thatch [9]. Knowing how quickly a rootzone mixture can conduct water is an important consideration in drainage, but proper maintenance of turfgrass to minimize thatch build up is a more important factor to consider.

The publication states a rootzone mixture with a Ksat less than 6 in hr^{-1} (15 cm hr^{-1}) will have a high risk of experiencing drainage issues when installed. While rootzone mixtures with Ksat below 6 in hr^{-1} (15 cm hr^{-1}) are less likely to drain as well as those greater than 6 in hr^{-1} (15 cm hr^{-1}), they are not likely to have a high risk of drainage problems as long as they are well maintained. The design of the USGA green is such that when the sand layer is saturated, the weight of water will break the capillary tension between the sand and gravel layer and water will freely move into the drainage lines. Rainfall events greater than 6 in hr^{-1} are rare. Drainage issues from most heavy rainfall events are more likely to arise from poor surface drainage or thatch build up. Based on our research and that of Waltz et al [10], finding a sand mix which meets USGA specifications with a Ksat below 6 in hr^{-1} is rare.

The 2018 USGA green reco mmendations include the following statement on page 11: "Adding small amounts of soil to a rootzone mix will likely reduce the infiltration rate without a significant increase in water retention. This is because soil, in and of itself, does not have very high-water retention. The high-water retention observed in sand and soil mixtures is primarily the result of fine soil particles plugging the large pores between the sand particles." Technically, portions of the statement are debatable. Certainly, addition of fines (very fine sand, silt, or clay) to a USGA sand mix will decrease Ksat, but a reduction in Ksat may be irrelevant. Brown et al [5] demonstrated a reduction in Ksat from 106 in h^{-1} (268 cm h^{-1}) for 100% sand to 17 in h^{-1} (43 cm h^{-1}) for the mix with 10% fines (Table 1). A Ksat of 16 in h^{-1} (40 cm h^{-1}) has little infiltration, percolation, or drainage problems in a USGA green. The major parameter reducing infiltration of a green is thatch buildup, not small amounts of fines in the rootzone.

The statement that adding soil to a rootzone mix will not result in a significant increase in water retention is not totally accurate. Figure 1, adapted from Brown et al [5], indicates water retention in the 0 to 50 cm range increases as the quantity of fines increases. The statement that "soil . . . does not have very high water retention" applies to soils with greater than 95% sand, but is not correct for most native soils. Data in Figure 1 suggest

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"available water" (in the 0-50 cm tension range) decreases as fines are added. But plant available water and water retention are two different terms and concepts. Data in Figure 1 also indicates addition of fines increased total porosity while reducing the volume associated with large pores. Our concern with the addition of fines lies more with soil aeration rather than with infiltration and water retention. The last sentence of the statement also seems to contradict the first sentence: The first sentence states adding soil does not increase water retention. The last sentence states adding soil to sand increases water retention, but only because it clogs pores.

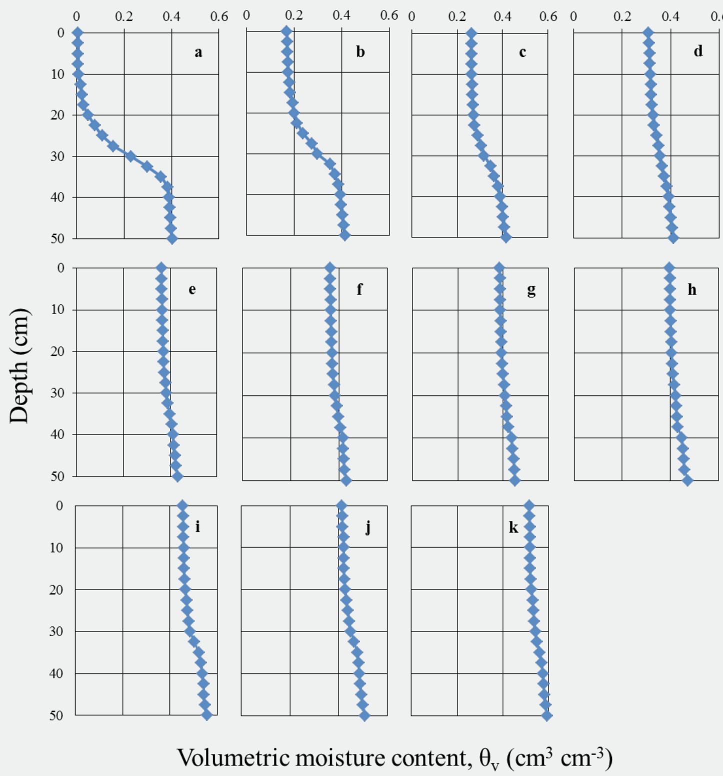

Figure 1: Volumetric moisture retention curves for rootzone mixtures from 100% fines (0:100 in a) to 100% sand (100:0 in k) by 10% v/v increments vs. tension (0 to 50 cm). Adapted from Brown et al (2019).

The statement that the incorporation of inorganic amendments can increase water retention without reducing Ksat is also too simplistic. For example, Waltz et al [10] showed an increase in water retention with the addition of 15% v/v diatomaceous earth and calcined clay to rootzone sand. Ksat was altered; diatomaceous earth caused a statistical drop in Ksat whereas calcined clay increased Ksat.

Recommendations for physical properties of a rootzone suggest the porosity range is between 35 and 55%. This equates to bulk densities between 1.72 and 1.19 g and cm^{-3} respectively (based on a particle density of 2.65 g and cm^{-3}). Porosities of 35% are not unusual when dealing with sand, however porosities as high as 55% are very unusual. Indeed, in order to obtain porosity this high, organic matter or a soil with high particle surface area such as clay is usually required. Brown et al [5] demonstrated porosity as high as 56% can occur with the addition of 80% v/v silt and clay to a USGA specified sand (Table 1) while the addition of 70% silt and clay v/v yielded a porosity of 47%. Waltz et al [10] showed the addition of 15% v/v peat, calcined clay or diatomaceous earth increased porosity from pure rootzone sand, however the highest porosity achieved was 46% in the peat mixture. Rootzone mixtures containing 80% silt and clay will not meet particle size distribution requirements for USGA style putting greens. Reducing porosity reco mmendations to between 35 and 50% would be more realistic for a sand based rootzone mix.

Air-filled and capillary porosity reco mmendations in the document remain the same as previous specifications (15 to 30% and 15 to 25%, respectively). The reco mmendations are based on ASTM F1815 testing, which measures air-filled and capillary porosity at 30 cm tension. At 30 cm tension, most sands that meet USGA specifications are too dry to provide 15% capillary porosity requirements. In many sand mixtures we have analyzed, it has been rare to find a sand that meets both the air-filled and capillary requirements. We conducted research using sand narrowly outside the USGA reco mmendations due to a fine sand content greater than 20%, which should be capable of holding more water at higher tensions than coarser sands [9]. However, based on Figure 2, water content was 0.08 cm^3 cm^{-3} at 30 cm tension,

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therefore, outside the acceptable range. Based on our research, it is likely that a sand meeting USGA particle size requirements would have to be amended in order to meet the air-filled and capillary porosity requirements. Waltz et al [10] created moisture retention curves of sands amended with peat, calcined clay, and diatomaceous earth on a 15% v/v basis. The peat amended sand met the requirements expressed here at the upper boundary of the air-filled porosity and lower boundary of the capillary porosity, calcined clay met the requirements but was at the low reco mmendation of the capillary porosity, and the diatomaceous earth failed to meet the reco mmendations.

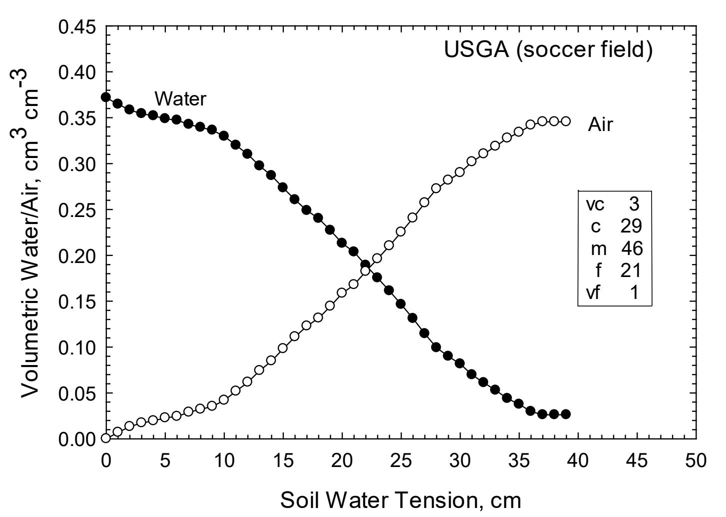

Figure 2: Volumetric water content and aeration porosity as a function of soil water tension for a sand that was used to construct a soccer field at Clemson University. The sand is composed of particle size fractions that meet standards established by the USGA for greens construction.

Further complications of ASTM F1815 are that testing for capillary porosity at 30 cm tension is done with a soil cylinder 7.6 cm in height. At the top of the cylinder the sand will be under 37.6 cm tension and will be drier than the soil in at the bottom of the column, which will mean that the top of the soil is likely drier than the bottom of the soil. The lack of soil moisture uniformity throughout the soil being measured means that results measured are inaccurate; perhaps, a smaller column should be used to make these measurements.

The USGA specifications for golf green construction is celebrating its 60th year in 2020. If followed as intended, they have provided the best guarantee of successful and relatively long-term golf green utilization. Like any construction specification, they have been periodically revised mainly to help reduce construction and material costs while retaining a desirable balance between drainage and nutrient plus moisture retention. When the guidelines were revised in 1993, a competent soil physicist (Hu mmel) spent a sabbatical critically reviewing and revising them. Since then, it appears no similar individual or group of soil scientists has had any major input into the revisions and relatively few improvements have been made. The latest revision has incorporated a few inaccurate, or misleading, statements. Having a competent soil physicist critically review the guidelines each time they are revised appears most beneficial and scientifically sound.

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