Influence of Increasing Fines on Soil Physical Properties of U.S. Golf Association Sand

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Abstract. Drainage is important to golf and athletic facilities trying to avoid lost play time. Native soil containing clay is sometimes incorporated into sand profiles with the intent to increase water and nutrient holding capacities. However, mixes high in silt and/or clay often have drainage problems. Research was conducted on soil physical properties from incremental 10% v/v additions of silt and clay (fines) to a U.S. Golf Association (USGA)-specification sand. Soils were evaluated based on volumetric water retention from 0 to 50 cm matric potential, saturated hydraulic conductivity (K_{sat}), porosity, and bulk density. The soil water characteristic (SWC) for 100:0 (sand:fines) had lower volumetric water content (θ_v) throughout the profile than any other mixture. Addition of 10% fines increased θ_v to more than $0.17 \text{ cm}^3 \cdot \text{cm}^{-3}$ throughout the 0- to 50-cm matric potential range, whereas 20% fines increased θ_v to more than $0.26 \text{ cm}^3 \cdot \text{cm}^{-3}$. The 70:30 mixture had greater θ_v throughout the profile than mixtures containing more than 70% sand. Mixtures with less than 70% sand produced similar SWCs. Increasing sand content increased bulk density, which altered saturated volumetric water content. K_{sat} was reduced from more than $265 \text{ cm} \cdot \text{h}^{-1}$ in 100:0 mixtures to $43 \text{ cm} \cdot \text{h}^{-1}$ for 90:10 mixtures, and to less than $5 \text{ cm} \cdot \text{h}^{-1}$ with $\geq 20\%$ fines. The addition of $\geq 20\%$ by volume of fines to a USGA sand increased water content in the soil to the point it was rendered unacceptable for trafficked turf sites. This research illustrates the influence fine particles, even in small amounts, can have on a USGA sand, and why they should not be added without prior evaluation.

Drainage is an essential part of maintaining healthy and playable high-profile turfgrass facilities. The soil particle size distribution of a sports field influences pore size distribution, and therefore influences drainage. Pore space can be separated into two categories: micropores (capillary pore space) and macropores (noncapillary pore space) (McCarty et al., 2016). Macropores are large (diameter, 0.08–5.0 mm) and drain gravitational water readily through the soil profile. Micropores are small (diameter, $<0.08 \text{ mm}$) and, as a result of capillarity, they retain water and are not involved actively in soil drainage (Brady and Weil, 2002). As a result of the presence of free-draining macropores, sand-based soils drain more rapidly than soils containing large quantities of silt and clay, yet retain less water as a result of fewer micropores. Soils with high concentrations of clay particles tend to be dominated by micropores, which retain soil water and do not drain as freely as sandier soils. The requirement for rapid drainage that allows play to resume after heavy rainfall means many modern sports fields and golf greens

are constructed using sand-based root zones containing a large number of macropores.

In USGA-style golf greens, the profile is 30 cm of sand over a gravel layer, creating a textural discontinuity. This design holds water in the bottom of the green through capillary tension, preventing it from draining until enough pressure potential is applied above to break this tension. USGA greens are designed to provide sufficient water for turf growth in the profile, but still have adequate drainage. Air-filled pore space is more likely to be dependent on the soil water content–soil matric potential relationship than interactions between macropores and micropores for profiles such as this.

Despite the desired drainage advantages of sands, limitations exist. Sands are inert, thus provide little nutrient holding capacity and, as a result of fewer micropores, have limited water holding capacity, which causes problems with rooting depths, organic material accumulation, fertility, and water retention (McCarty et al., 2016). To improve this, turf facilities often combine sand with native soil containing some clay to take advantage of sand's rapid drainage and clay's greater cation exchange capacity. Clay has the added effect of moderating excessive drainage. To reduce construction costs, mixing of sand and native soil often occurs onsite, where native soil is applied to the sand's surface and

rototilled to a depth of 10 to 15 cm (4–6 inches). This method rarely provides uniform mixing, creating chlorotic turfgrass because of soil composition variability creating pockets of high-nutrient and low-nutrient soil (McCarty, 2018). When combining sand with native soil and vice versa, pore spaces in both soil sources can become compromised. Macropores in sand can be filled by finer soil particles, reducing porosity, increasing bulk density, and reducing necessary water movement through the profile.

Two methods to ascertain water distribution and movement in soil are SWC curves and K_{sat} . SWC curves describe soil water retention at different matric potentials or depths (Rowell, 1994). As the matric potential increases, a corresponding increase in water extracted from the soil usually occurs. The point where the matric potential exceeds the soil's ability to retain water at saturation is the air entry point (Hillel, 1982). K_{sat} is a constant that describes the relationship between the flux and hydraulic gradient of a soil under saturated conditions, and is influenced by soil composition, bulk density, and porosity.

Several studies have been performed using various amendments to alter soil characteristics, most notably the work by Waddington et al. (1974). In their research, three sands; blast furnace slag; perlite; calcined clay; and heat-treated composted soil, sand, and organic matter, were mixed with various per volume ratios of reed-sedge peat and Hagerstown silt loam soil. Mixtures were designed to be used as root zone material and were assessed for bulk density, porosity, and air porosity, among other variables. Mixtures were monitored in field plots under compaction and aeration regimes. The authors concluded at least 50% to 60% of the coarse amendments were required to positively modify the Hagerstown soil effectively. The importance of aeration to maintain acceptable high-traffic turf areas was noted.

Our study addressed the situation when sand is added to clay to increase drainage, or soil is added to a sand root zone to reduce drainage and/or improve nutrient holding capacity. Specifically, it investigated the influence of the addition of silt and clay to a USGA-specified sand on soil physical properties by evaluating SWCs, K_{sat} , porosity, and bulk density.

Materials and Methods

Soil from the Bt horizon of a Cecil soil (55% sand, 2% silt, 43% clay) was collected from Clemson University, Clemson, SC; oven-dried; and ground. Sand was separated and discarded from the silt and clay (fines) fraction using a 0.05-mm sieve. A commercial sand was also separated into fractions using soil sieves. Medium sand and coarse sand (0.25–0.50 and 0.50–1.00) was mixed in a ratio of 55:45 per volume to meet USGA recommendations (McCarty et al., 2016). Sand and fines from the native soil were then

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mixed uniformly in increments increasing by 10% v/v to create 11 different soil mixtures ranging from 100:0 to 0:100 sand:soil (Table 1).

To measure soil physical properties of the various mixtures, moistened soil mixes were placed into 5.1-cm diameter and 7.5-cm-tall cylinders with a double layer of cheesecloth attached to the bottom. Cylinders were placed in a container of water and allowed to saturate for 24 h from the bottom up. When saturated, cylinders were removed from the water bath and drained at a 40-cm matric potential. Columns were then compacted with a drop hammer in a consistent manner, with a total dynamic energy of 3.03 J·cm⁻² (Howard, 1959; Kunze, 1956).

SWC curves were created using the Haines method (Rowell, 1994), where samples were placed in a Buchner funnel with a porous sintered glass plate with maximum pore size radii of 10 to 15 µm. Briefly, the funnel was connected to a graduated tube and the mixture was saturated. After saturation, the outlet (side arm) of the graduated tube was lowered below the porous plate at vertical distances from 0 to 50 cm in 2.5-cm increments to create matric potential on the system. Draining water was collected. After equilibrium was established at each matric potential, the outlet was lowered to the next desired height and drainage water was again collected. K_{sat} was measured using the constant head technique (Rowell, 1994), whereas bulk density was determined by oven drying at 105 °C for 24 h and weighing the sample after use. Porosity was calculated using the formula $1 - (\text{Bulk density} \div \text{Particle density})$, where particle density was assumed to be 2.65 g·cm⁻³. Samples were replicated three times, data were analyzed with analysis of variance, and means were separated at $\alpha = 0.05$.

Results

SWCs. SWCs for various mixes ranging from 0 to 50 cm matric potential are shown in Fig. 1. On the extremes, 100% sand had an SWC of a material with a small particle size distribution, and 100% fines had SWC characteristics commonly found in Bt horizons of Piedmont soils (Merdun and Quisenberry, 2004).

Saturated θ_v of the 100% sand was 0.40 cm³·cm⁻³, corresponding to a bulk density of 1.59 g·cm⁻³, which is acceptable for a USGA green sand (McCarty et al., 2016). Little water (≈ 0.01 cm³·cm⁻³) drained in 100% sand when the matric potential increased from 0 to 12.5 cm (Fig. 1). The radius of the largest pore draining at 12.5 cm is 120 µm, using the rearranged simplified formula for capillary rise $r = 0.15/h$, where r is the pore radius and h is the matric potential in centimeters of the air entry point (Scott, 2000). Based on SWCs, the air entry point was assigned at 12.5 cm. Volumetric water content decreased rapidly (0.39 to 0.05 cm³·cm⁻³) as the matric potential increased from 12.5 to 30 cm, which is common in sands with a narrow range in pore diameters (McCarty et al., 2016). Decrease in θ_v was small (0.05 cm³·cm⁻³) as matric potentials increased from 30 to 50 cm.

Nearly all SWCs of the 100% fines mix differ from those of 100% sand. The 100% fines had 43% more porosity than 100% sand (Fig. 1). The air entry point was again assigned at 12.5 cm as a reasonable estimate because no certain value for the air entry point was indicated by the SWCs. Unlike 100% sand, no drastic decrease in soil water content for matric potentials greater than 12.5 cm was measured in 100% fines. Between the 0- and 50-cm matric potential, soil water content decreased by 0.07 cm³·cm⁻³, and it decreased by 0.39 cm³·cm⁻³ in 100% sand (Fig. 1).

Although water retention is important, and desirable, sufficient air space in trafficked turf sites is also essential. SWCs for mixes with 30% or more fines had no more than 8% of total pore volume occupied with air at matric potentials of 50 cm (Fig. 1). A question then arises: Are 90:10 and 80:20 mixes acceptable for a golf green in terms of providing sufficient air space?

Two-layer green. Volumetric water content at “field capacity” for various mixes as found in a USGA green—30 cm of mix overlying 10 cm of gravel—is shown in Fig. 2. The term “field capacity” is obsolete in most scientific literature, but is commonly used by both professionals and nonprofessionals when referring to a given soil water status, and has value when defined properly. In reference to a mix-over-gravel USGA green, “field capacity” denotes soil water

content and soil water potential within the green when the 30-cm mix has been wetted thoroughly and allowed to drain until drainage ceases (McCarty et al., 2016). For example, at the mix–gravel interface, the soil water potential is 0 cm; thus, the mix is saturated. Saturation continues from the interface upward for a distance equal numerically to the air entry point. The matric potential at the mix surface (depth, 0 cm) at equilibrium was 30 cm. Thus, soil water content at field capacity in a USGA-style green varies from saturation at the mix–gravel interface to a water content at the surface corresponding to a 30-cm matric potential.

Figure 2 illustrates water content at field capacity as a function of depth for the various mixes. Figure 2A indicates 100% sand and 0% fines, whereas Fig. 2K provides 0% sand and 100% fines. Other sand:fine ratios are indicated, with the percentage of fines increasing from Fig. 2A to Fig. 2K. The profile was saturated, or close to saturated, from the 30-cm depth (the mix–gravel interface) upward to a 17.5-cm depth (air entry point). Water content in the bottom 12.5 cm of the profile was ≈ 0.20 cm³·cm⁻³ greater in the 100% fines mix than in 100% sand; however, both zones approached saturation. Above the 18-cm depth, about a third of total soil volume is occupied by air in the 100% sand mix, whereas a very small percentage is occupied by air when 20% or more of the mix is fines (Fig. 2).

Air-filled porosity decreased drastically from 0.33 cm³·cm⁻³ for 100% sand to less than 0.10 cm³·cm⁻³ for mixes of 30% or more fines (Fig. 3). The addition of only 10% fines decreased air-filled porosity by $\approx 50\%$ from the 100% sand value.

Bulk density and porosity. Adding 10% to 30% fines to the sand did not affect bulk density (1.58–1.55 g·cm⁻³) or porosity (Table 1). With the addition of $\geq 40\%$ fines, a decline in bulk density commenced, with a decrease of 80% to 100% (1.17–1.08 g·cm⁻³). The direct relationship between bulk density and porosity indicates as bulk density decreased, porosity increased. Porosity as high as 59% was measured in the 0:100 mixture and as low as 40% in the 100:0 mixture.

K_{sat} . Differences were observed in K_{sat} for the various mixtures (Table 1). The 100% sand mixture had a K_{sat} of 269 cm·h⁻¹.

Table 1. Physical properties of 11 mixtures of a U.S. Golf Association-specified sand and fines from a native clay soil by 10% v/v increasing increments.

Sand by volume (%)	Fines by volume (%)	Textural class ²	Fines by wt (%)	Bulk density (g·cm ⁻³)	Total porosity ³ (%)	K_{sat} ⁴ (cm·h ⁻¹)
100	0	Sand	0	1.58	40	268.91 a
90	10	Sand	7	1.55	42	43.49b
80	20	Sandy loam	9	1.55	42	4.67 c
70	30	Sandy clay loam	14	1.56	41	1.36 c
60	40	Sandy clay	19	1.50	43	0.34 c
50	50	Sandy clay	26	1.51	43	0.22 c
40	60	Clay	40	1.45	45	0.81 c
30	70	Clay	56	1.40	46	2.49 c
20	80	Clay	60	1.17	53	1.01 c
10	90	Clay	64	1.30	48	1.79 c
0	100	Clay	100	1.08	57	2.99 c

²U.S. Department of Agriculture soil classification.

³ K_{sat} was established using the constant head method. Means followed by the same letter are not significantly different at $P = 0.05$.

⁴Porosity was calculated as $[1 - (\text{Bulk density} \div \text{Particle density})]$, where particle density = 2.65 g·cm⁻³.

Increased K_{sat} is associated with uniform sands (Bingaman and Kohnke, 1970), and although the sand used in our study was a mixture of medium and coarse sand, it behaved in a similar way.

Fig. 1. Soil water characteristics for root zone mixtures from 100% fines (0:100) to 100% sand (100:0) by 10% v/v increments vs. matric potential (0–50 cm).

The addition of 10% fines to the sand reduced $K_{sat} \approx 6\times$ to $43 \text{ cm}\cdot\text{h}^{-1}$. This decrease in K_{sat} indicates how influential a small quantity of fines can be when mixed with sand. However, a K_{sat} of $43 \text{ cm}\cdot\text{h}^{-1}$ is still considered adequate for competitive sports turf (McCarty et al., 2016).

With 80:20 sand:fines, K_{sat} was reduced $\approx 9\times$ from the 90:10 mixture, $55\times$ from the 100:0 mixture (4.7 vs. 43.5 vs. $269 \text{ cm}\cdot\text{h}^{-1}$, respectively; Table 1), and was considered unacceptable for its intended use on sports fields and golf greens (McCarty et al., 2016). At greater soil-to-sand ratios, statistical differences were not seen; however, K_{sat} as low as $0.2 \text{ cm}\cdot\text{h}^{-1}$ occurred in the 50:50 mixture.

Discussion

This experiment indicates how the addition of small quantities of native soil containing excessive fines to pure sand dramatically

impacts soil physical properties of soil mixtures. As the content of fines is increased, water retained in the mixes also increased correspondingly. The addition of 10% fines altered the shape of SWC curves, indicating this root zone mix retained greater quantities of water throughout the profile. Similar increases in retained water were reported by Waltz et al. (2003), who noted that the addition of 15% peat (v/v) as a soil amendment to washed root zone sand increased the water in the soil profile and in the upper 15 cm compared with a 15% v/v sand root zone mix with calcined clay and diatomaceous earth. Amendments also reduced bulk density and increased porosity compared with pure sand root zones, similar to our study. Juncker and Madison (1967) also observed a decrease in bulk density and an increase in water-holding capacity as peat was added to an Osoflaco sand in 25% increments. Similar to our study, pore size distribution was relatively uniform in the sand, and became much wider with increasing peat content. McCoy and Stehouwer (1998) indicated the addition of internally porous inorganic amendments increased water retention through the profile, whereas Taylor et al. (1997) observed sand amended with peat retained more water at the lower portions of a 30-cm profile than sand alone. However, this varied with the texture of the sand.

As fines content is increased, air-filled porosity decreases. Henderson et al. (2005) examined the strength properties and permeability of sand amended with silt and clay and noted a decrease in air-filled porosity with increasing silt and clay, which coincided with increased capillary porosity. The study also indicated increased bulk density with increasing silt and clay with a corresponding decrease in K_{sat} . Although their study showed an increase in bulk density with increasing silt and clay contrary to our study, silt and clay in the mixtures where in lower quantities, the greatest quantity of silt and clay corresponds to a 50% v/v silt and clay content. In addition, the Proctor test and the California bearing ratio method were used to study these soil properties and, as such, were conducted at greater rates of compaction than our study.

Fig. 2. Volumetric water content with depth for root zone mixtures amended sand-to-fines ratios v/v: (A) 100:0, (B) 90:10, (C) 80:20, (D) 70:30, (E) 60:40, (F) 50:50, (G) 40:60, (H) 30:70, (I) 20:80, (J) 10:90, (K) 0:100.

Fig. 3. Air-filled porosity content for root zone mixtures from 100% fines (0:100) to 100% sand (100:0) by 10% v/v increments.

Similar results were found by Taylor and Blake (1979), who mixed sand with Nicollet loam topsoil and peat in field studies. The authors assumed –30 mbars occurred at the base of a green, and noted mixtures must have 87% sand or greater to achieve 0.10 cm³·cm^{–3} drainage at the soil surface. If the green depth was increased to 40 cm (–40 mbars at the base of the green), this value dropped to 77% sand. They also saw the bulk density of the mixtures decrease as the sand content increased, whereas infiltration and K_{sat} of the mixtures also increased with increasing sand content. However, as with Henderson et al. (2005), mixtures were only done to ≈50% v/v silt and clay and not to the lower quantities in our study.

In the USGA method of putting green construction (U.S. Golf Association Green Section Staff, 2018), mixtures with air-filled porosities less than 0.15 cm³·cm^{–3} are not recommended as root zones. In our research, air-filled porosity decreased to 0.15 cm³·cm^{–3} with the addition of 20% fines. A balance is needed between soil water content and air-filled porosity to prevent a soil from being too droughty or being oversaturated. Our data indicate no more than 10% fines be added to a 55:45 medium:coarse sand—and this should be done only after consideration of local climatic conditions.

Additions of fines dramatically reduced K_{sat} compared to 100:0 or 90:10; however, when fines exceeded 20%, K_{sat} values remained similarly low. Smalley et al. (1962) observed a decrease in K_{sat} with the addition of vermiculite and colloidal phosphate to an Arredondo loamy fine sand. However, addition of fired clay resulted in an increase in K_{sat}.

It is interesting to note that SWCs of mixtures with more than 40% fines behaved very similarly. This is evocative of the textural triangle in which soils with clay

content more than 40% are mostly considered clays. This separation between textural types may be a result of the dominance of physical properties of clays beyond this point, particularly the presence of micropores in the soil.

Our research indicates that two common practices often used to create desirable root zones for sports fields and golf greens can dramatically change soil physical properties. Rototilling several centimeters of native soil into a uniform sand or rototilling several centimeters of sand into the top 10 to 16 cm of native soil, with the intent of improving drainage and reducing bulk density, is mostly a mistake and can actually decrease desirable soil physical properties more than if neither practice was performed. With the soil and sand sources used in our research, a minimum sand:soil ratio of 90:10 was required to provide desirable soil physical properties for commercial turfgrass sites.

Literature Cited

- Bingaman, D.E. and H. Kohnke. 1970. Evaluating sands for athletic turf. *Agron. J.* 62:464–467.
- Brady, N.C. and R.R. Weil. 2002. *The nature and properties of soils*. 13th ed. Prentice Hall, Upper Saddle River, NJ.
- Henderson, J.J., J.R. Crum, and J.N. Rogers, III. 2005. Effects of particle size distribution and water content at compaction on saturated hydraulic conductivity and strength of high sand content root zone materials. *Soil Sci.* 170(5): 315–324.
- Hillel, D. 1982. *Introduction to soil physics*. Academic Press, San Diego, CA.
- Howard, H.L. 1959. The response of some putting green soil mixtures to compaction. MS thesis. Texas A&M University, College Station, TX.
- Juncker, P.H. and J.J. Madison. 1967. Soil moisture characteristics of sand-peat mixes. *Soil Sci. Soc. Amer. Proc.* 31:5–8.
- Kunze, R.J. 1956. The effects of compaction of different golf green soil mixtures on plant growth. MS thesis. Texas A&M University, College Station, TX.
- McCarty, L.B. 2018. *Golf turf management*. CRC Press, Boca Raton, FL.
- McCarty, L.B., L.R. Hubbard, Jr., and V.L. Quisenberry. 2016. *Applied soil physical properties, drainage, and irrigation strategies*. Springer International Publishing, Switzerland.
- McCoy, E.L. and R.C. Stehouwer. 1998. Water and nutrient retention properties of internally porous inorganic amendments in high sand content root zones. *J. Turfgrass Mgt.* 2:49–69.
- Merdun, H. and V.L. Quisenberry. 2004. Relating model parameters to basic soil properties. *Austral. J. Soil Res.* 42:841–849.
- Rowell, D.L. 1994. *Soil science methods & applications*. Longman Scientific & Technical, UK.
- Scott, H.D. 2000. *Soil physics agricultural and environmental applications*. Iowa State University Press, Ames, IA.
- Smalley, R.R., W.L. Pritchett, and L.C. Hammond. 1962. Effects of four amendments on soil physical properties and on yield quality of putting greens. *Agron. J.* 54:393–395.
- Taylor, D.H. and G.R. Blake. 1979. Sand content of sand-soil-peat mixtures for turfgrass. *Soil Sci. Soc. Amer. J.* 43(2):394–398.
- Taylor, D.H., C.F. Williams, and S.D. Nelson. 1997. Water retention in root-zone soil mixtures of layered profiles used for sports turf. *HortScience* 32:82–85.
- U.S. Golf Association Green Section Staff. 2018. USGA recommendations for a method of putting green construction. USGA Green Section Record. 28 Feb. 2018. <<http://archive.lib.msu.edu/tic/usgamisc/monos/2018recommendationsmethodputtinggreen.pdf>>.
- Waddington, D.V., T.L. Zimmerman, G.J. Shoop, L.T. Kardos, and J.M. Duich. 1974. Soil (Gottingen) modification for turfgrass areas: I. Physical properties of physically amended soils. *Penn. Agr. Expt. Sta. Progress Report* 337, University Park, PA.
- Waltz, F.C., V.L. Quisenberry, and L.B. McCarty. 2003. Physical and hydraulic properties of rootzone mixes amended with inorganics for putting greens. *Agron. J.* 95:395–404.