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Freeze-thaw cycles and soil amendments

Soil amendments in sand-based media are affected by cycles of freezing and thawing.

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Freezing and thawing are major factors in soil weathering and soil formation that can reduce compaction in turf areas with heavy traffic. This natural process can also cause detrimental effects such as frost heaving, which can damage irrigation systems and may harm the grass by tearing the roots and exposing roots and crowns to desiccation. In some cases, freezing and thawing may also break down soil particles, increasing the percentage of fine particles that can slow drainage (3).

Soil amendments

Soil amendments are often used to increase the ability of sand-based root-zone media to hold water and nutrients, while maintaining an acceptable water infiltration rate (8). These soil amendments usually have particle sizes close to that of the sand in the media, but they hold more water than sand because of the fine pores in their structure. Some materials also have greater nutrient-holding capacities than does sand because their surface areas are larger and their cation exchange capacities are greater.

Many factors must be considered when choosing a soil amendment, including the stability of the material when it is mixed with sand and the degree to which the soil properties are going to change over time (4). A golf green and natural soil undergo the same weathering forces. The speed of soil formation processes is determined partly by soil moisture and temperature and partly by the organisms present in the media (7).

Golf green soil conditions

A golf green is generally exposed to favorable soil genesis conditions. The factors that affect soil weathering are usually accelerated by golf course management practices. Ordinary conditions on a golf green include plenty of moisture in the green's root-zone media, concentrated solutes from fertilization, enriched organic matter and an active microbial population.

Freezing-thawing cycles accelerate soil-weathering processes by breaking down the soil parent materials in temperate regions. As these processes progress, the saturated water conductivity may drop from 6 to 10 inches per hour to less than 1 inch per hour. This is the justification behind USGA testing procedures ASTM C88-90 and C131-96 for sand stability (1,2).

In procedure ASTM C88-90, samples are repeatedly immersed in a saturated salt solution followed by drying and particle-size analysis. The purpose of this test is to simulate the chemical weathering process.

In procedure ASTM C131-96, an apparatus known as a Los Angeles machine is used to simulate impact, abrasion and grinding in a rotating steel drum containing a specified number of steel spheres. After the prescribed number of revolutions, particle size is analyzed and reported as the percentage lost from degradation compared to the original media.

In one study (5), newly built greens were tested for saturated water conductivity and then retested after one year, six years and 19 years. Saturated water conductivity had decreased by 52.9 percent after one year, by

KEY points

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- **Soil amendments** are often used in an attempt to increase the ability of sand-based root-zone media to hold water and nutrients.
- **Soil amendments** undergo the same weathering forces as the rest of the soil.
- **After freeze-thaw treatments,** the amended soils tested showed particle size degradation and decreased bulk density.
- **Hydraulic conductivity** increased for all the sand and amendment mixtures.

87.1 percent after six years and by 82.9 percent after 19 years. In the same greens, the original weight of clay-sized particles increased by 833 percent, 1,110 percent and 254 percent in one-year, six-year and 19-year-old greens, respectively. It was not determined whether clay-sized particles increased because of soil particle degradation, addition in topdressing, deposition by wind or irrigation water, or a combination of all of these factors.

In sand-based greens modified by inorganic amendments, saturated water conductivity had decreased from 72 to 78 percent two years after construction (6). Although saturated water conductivity decreased in general, from spring to midsummer, saturated water conductivity in these same greens increased over the low levels of the previous year by 19 to 82 percent.

Photo courtesy of Cale Bigelow

A variety of amendments are available for use in putting greens.

Objectives

Although the sand particles in golf greens generally remain quite stable during freeze-thaw cycles, the amendments used to modify sand-based systems may be subject to weathering. To investigate the effects of weathering on soil amendments, a study was conducted at Iowa State University and at the University of Pisa, Italy.

The objectives were to determine the stability of several inorganic soil amendments that are used in putting green root zones and other sand-based systems. The amendments include:

- Profile (porous ceramic clay, Profile Products LLC, Buffalo Grove, Ill.)
- Axis (calcined diatomaceous earth, Eagle-Picher Minerals Inc., Reno, Nev.)
- zeolite clinoptilolite (Zeoponix Inc., Louisville, Colo.)
- Bio-flex (polymer-coated clay, True Pitch Inc., Altoona, Iowa)
- pumice (Pitigliano, Grosseto, Italy)
- peat (Dakota Peat and Blenders, Grand Forks, N.D.)

Materials and methods

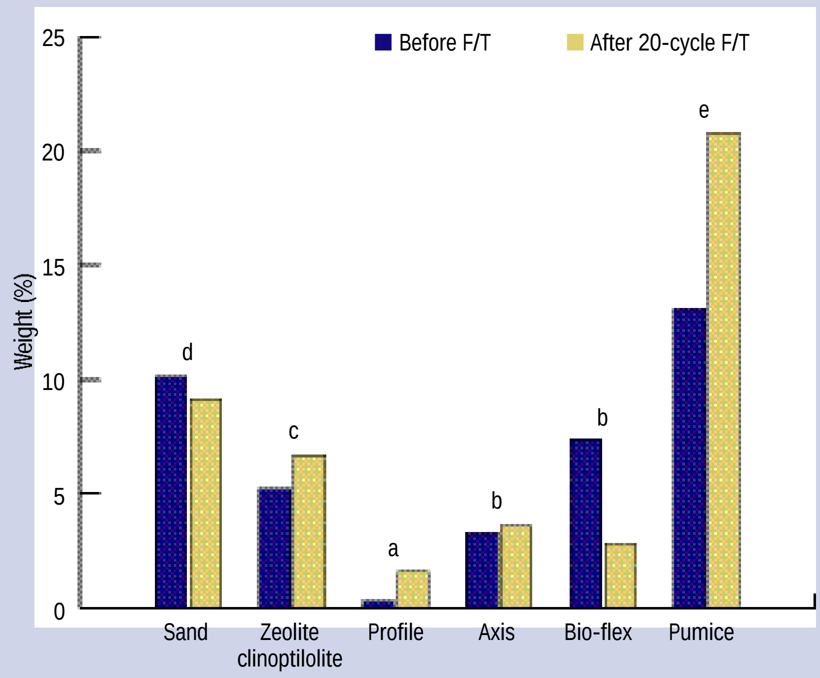
A mixture of 85 percent sand (2.0 percent very coarse, 18.7 percent coarse, 55.3 percent medium, 19.7 percent fine, and 4.3 percent very fine) and 15 percent (volume/volume) soil amendment was prepared by compacting the mixtures into brass rings according to USGA specifications. The sample rings were 2.04 inches in diameter and 2.40 inches deep and were fitted with double layers of cheesecloth at one end.

FREEZING AND THAWING VS. BULK DENSITY

	Bulk density (grams/cubic centimeter)						
Treatment	Original	Saturated	Frozen	1-cycle	5-cycles	10-cycles	20-cycles
Control (sand)	1.60	1.62	1.47	1.59	1.59	1.59	1.59
Peat	1.47	1.45	1.35	1.45	1.45	1.46	1.47
Zeolite clinoptilolite	1.52	1.52	1.40	1.50	1.51	1.50	1.49
Profile	1.46	1.45	1.35	1.44	1.45	1.45	1.44
Axis	1.45	1.45	1.34	1.44	1.43	1.40	1.41
Bio-flex	1.61	1.35	1.31	1.36	1.43	1.46	1.49
Pumice	1.50	1.50	1.38	1.49	1.49	1.47	1.48

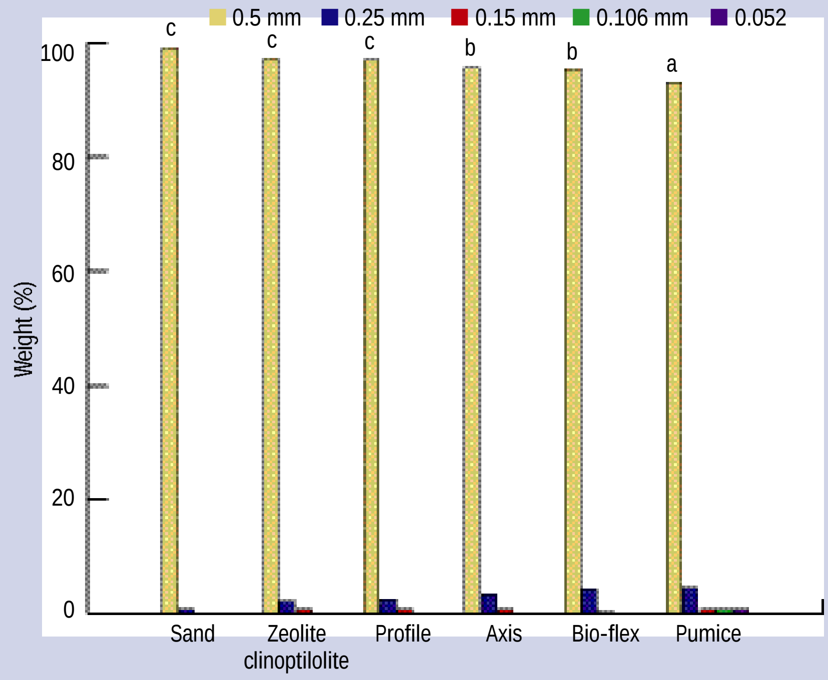
Note. — With the exception of the control,which was pure sand,the mixtures are 85 percent sand and 15 percent amendment by volume.

FREEZING AND THAWING VS. FINE PARTICLES



Fine particle (<0.15 mm) content was affected by 20 cycles of freezing and thawing (F/T). Columns labeled with the same letter are not significantly different from one another.

FINE PARTICLES VS. HAMMER



A hammer was dropped on particles retained on a 0.5-mm sieve.The weight of particles 0.5 mm or larger decreased by 0.9 to 7 percent as a result of the hammer drop.Columns labeled with the same letter are not significantly different from one another.

Using water, the samples were saturated from the bottom up for 24 hours after compaction and then subjected to one, five, 10 and 20 cycles of saturation, freezing and thawing. Freezing was conducted at -22 F, and thawing was conducted at 73.4 F. The volume changes were measured by recording the sample depth in the sample rings at the end of one, five, 10 or 20 freeze-thaw cycles.

The original weight of the sample divided by the new volume gave new bulk densities. Bulk density was determined in order to measure the amount of compaction and pore space before and after the freeze-thaw treatments.

Particle-size distribution and saturated water conductivity were also measured at the end of one, five, 10 and 20 freeze-thaw cycles. The saturated water conductivity, which is expressed in inches/hour, was determined by measuring the volume of water moving across a unit of area in a unit of time at the water head gradient in the 2.40-inch soil depth.

Results

Freezing and thawing

After the freeze-thaw treatments, the bulk density of root-zone mixtures decreased by 1.5 to 7.6 percent. The decrease in bulk density was caused by expansion of the volume of pore water when it was frozen and the force of the ice heaving up in the soil. This decrease is generally considered good because lower bulk density means more pore spaces, which are essential to aeration and drainage in any soil media. However, freezing and thawing can break down soil amendments. For that reason, particle size of the pure soil amendments also was analyzed after one, five, 10 and 20 freeze-thaw cycles, as was that of the sand/amendment mixtures (data not shown). Fine particles (<0.15 mm) increased by weight by 1.5 percent (zeolite clinoptilolite), 1.3 percent (Profile), 0.3 percent (Axis) and 7.7 percent (pumice) as a result of freezing and thawing.

Bio-flex has a polymer coating that decreased, rather than increased, the weight of fine particles. The reason for this is not clear, but we think that the polymer may help the fine particles to aggregate.

Mechanical compaction

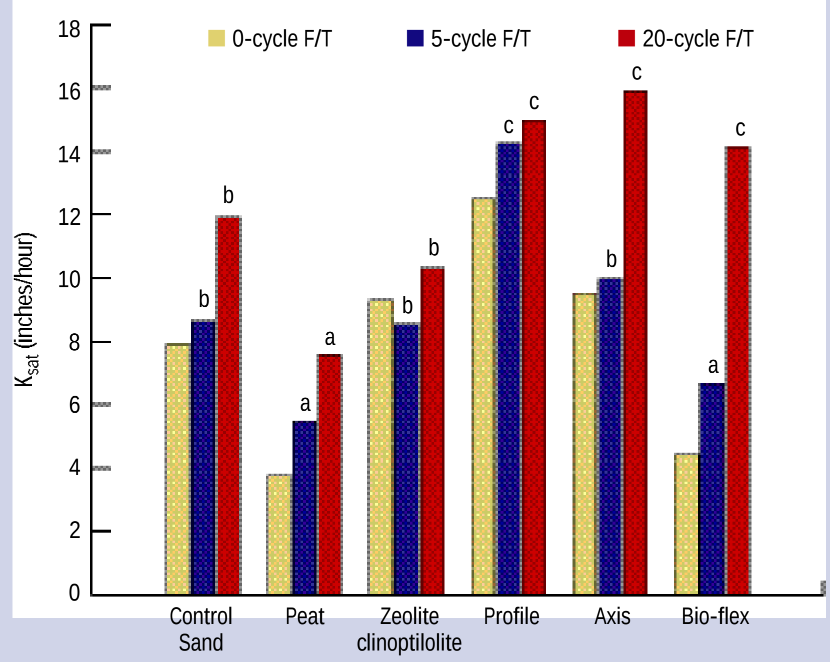
Another potential source of particle size degradation is mechanical compaction. Particles that were retained on a 0.5-mm sieve decreased by 0.9 to 7 percent by weight after a single drop of the hammer on the samples. The breakdown of soil particles by freezing and thawing and mechanical compaction can decrease the macropores and counteract the benefits that would normally be obtained from decreasing bulk density.

Hydraulic conductivity

After 20 freeze-thaw cycles, hydraulic conductivity (K_{sat}) increased for all the sand and amendment mixtures by 11 to 220 percent. This increase in saturated water conductivity was a result of the decrease in bulk density after the freeze-thaw treatment. Whether freezing and thawing has a positive or negative effect on the physical characteristics of a medium depends on the materials used to amend that medium.

Although the freeze-thaw cycles can increase fine particles and thereby decrease K_{sat}, the freeze -thaw cycles also decrease bulk density and increase particle arrangement, resulting in more pore space for drainage and therefore greater K_{sat}.

FREEZING AND THAWING VS. HYDRAULIC CONDUCTIVITY



After 20 freeze-thaw (F/T) cycles, hydraulic conductivity (K_{sat}) for all the sand and amendment mixtures increased by 11 to 220 percent. Columns labeled with the same letter are not significantly different from one another.

Conclusions

Although more work is needed, this study shows clearly that freezing and thawing can substantially affect the mechanical stability of amendments used in sand-based systems. The chemical and mechanical stability of sand and soil amendments should be considered when these materials are used for golf green root-zone mixtures. Materials that are mechanically stable and swell within a certain range after winter freezing are ideal for temperate regions that experience many freezing and thawing cycles each year.

The long-term effects of soil amendments remain to be investigated. Sand amended with Axis, Profile and Bio-flex showed significant increases in K_{sat} compared to pure sand or sand and peat mixtures. However, pure sand and peat and sand mixtures were also within the acceptable range defined by USGA recommendations.

As long as bulk density decreases during freezing and thawing, without a significant increase in fine particles and the resulting reduction in water infiltration, such materials as Axis, Profile and Bio-flex used in this study these materials may be helpful in alleviating soil compaction. Field studies involving irrigation of modified sand-based media applied before winter freezing would provide more useful information on soil amendments.

Acknowledgments

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