CHAPTER 3. FREEZING AND THAWING EFFECTS ON SAND-BASED MEDIA MODIFIED WITH SOIL AMENDMENTS

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ABSTRACT

Many inorganic amendments have been suggested for use in sand-based systems to increase nutrient and water-holding capacity, but little is known about their long-term effects on the physical properties of the media. The objectives of this study were to investigate the effects of freezing and thawing on the particle integrity, soil bulk density, and saturated hydraulic conductivity (K_{sat}) of sand-based media amended with predominantly inorganic materials and to measure the particle stability of these sand and inorganic amendment mixtures when subjected to compaction. The amendments included porous ceramic clay (PCC); calcined diatomaceous earth (CDE); zeolite clinoptilolite; zeolite chabasite; a polymer-coated clay with a kelp material incorporated on the exterior of the polymer coating (PC); lapillus; and pumice. A mixture of 85% sand and 15% (v/v) of the soil amendments was prepared in the laboratory. After 20 freeze/thaw cycles, sand amended with PC had a

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Abbreviations: CDE, calcined diatomaceous earth; K_{sat}, saturated hydraulic conductivity; PC, polymer-coated clay; PCC, porous ceramic clay; USGA, United States Golf Association.
Key words: Sports fields, golf greens, sand greens, water infiltration

7.6% decrease in bulk density from the compacted sample. The percentage weight of the.finest fraction that passed through to the 0.106 mm sieve to the bottom pan increased due to freeze/thaw cycles in zeolite clinoptilolite and lapillus treatments compared to the sand control. The fine particles increased from 0.3 and 3.4% to 0.9 and 4.4%, respectively, after freeze/thaw for sand amended with zeolite clinoptilolite and lapillus. After 20 cycles of freeze/thaw, K_{sat} values of sand amended with PCC and CDE were 25 and 33% higher than the control, respectively. Twenty freeze/thaw cycles resulted in 24.7 and 16.2 cm h^{-1} increases in K_{sat} of the sand amended with PC and CDE, respectively. The increases of K_{sat} by PC and CDE are likely due to their bulk density decreases.

INTRODUCTION

The application of soil conditioners to improve the physical attributes of agricultural soils has developed into an active branch of soil science since the 1950s. Significant soil structural improvements have been reported from the use of synthetic organic polymers, such as Krilium™, Bondite™ etc. [De Boodt, 1972; Carrow, 1993]. Although these organic materials have not been widely used in the turfgrass industry, inorganic amendments, such as porous ceramic clay (PCC), calcined diatomaceous earth (CDE), and zeolite have shown promising results in increasing the water- and nutrient-holding capacity of sand-based media used in golf course greens and sports fields [Beard, 1973; Waddington et al., 1974; Ferguson et al., 1986; Carrow, 1993; Huang and Petrovic, 1995; McCoy and Stehouwer, 1998]. Information about the long-term effects of these inorganic amendments on the physical properties of sand-based media is not available, but is needed for predicting problems that might be encountered with such amendments.

The physical stability of these inorganic materials will likely be affected by weathering processes and management practices. Freezing and thawing have long been reported as being responsible for the breakdown of soil particles and aggregates [Pawluk, 1988; Lehrsch et al., 1991; Hower et al., 1992]. The changes of soil texture and structure caused by freezing and thawing have a significant impact on soil water retention and drainage properties [Benoit and Bornstein, 1970]. Waddington et al. [1974] studied the water retention and saturated hydraulic conductivity (K_{sat}) of sand-based media amended with inorganic materials. Although their data showed a general decrease of K_{sat} values over a 9-year period, the K_{sat} fluctuated annually and this may have been caused by freeze/thaw or cultivation practices. Li et al. [2000] investigated the K_{sat} and water retention properties of a sand-based medium amended with PCC, CDE, ceramic, and a polymer-coated clay (PC) with a kelp material incorporated on the exterior of the polymer coating and found that PCC increased K_{sat} by 20%. They also observed that K_{sat} increased following winter freezing and spring thawing. Little is known about the combined effects of weathering and mechanical compaction on the bulk density and particle-size of sand media amended with inorganic materials.

The objectives of this study were to investigate the effects of freezing and thawing on the particle integrity, soil bulk density, and K_{sat} of sand-based media amended with predominantly inorganic materials. A second objective was to measure the particle stability of these sand and inorganic amendment mixtures when subjected to compaction.

MATERIALS AND METHODS

A mixture of 85% sand and 15% (v/v) soil amendment was prepared in the laboratory. The amendments include PCC (Profile, Profile Products LLC, Buffalo Grove, IL.); CDE (Axis, Eagle-Picher Minerals, Inc., Reno, NV); zeolite clinoptilolite (Zeoponix, Inc., Louisville, CO); zeolite chabasite (Europomice, Torino, Italy); PC (Bio-Flex, True Pitch Inc., Altoona, IA), lapillus (Cellere, Viterbo, Italy), and pumice (Pitigliano, Grosseto, Italy). The treatments also included pure sand and/or sand amended with 15% (v/v) of peat (Dakota Peat and Blenders, Grand Forks, ND), an organic amendment, as controls. The physical properties of the materials are listed in Table 1. All materials, except the peat, were oven-dried at 105 °C for 24 h and compacted at 30.3 kJ m^{-2} using 15 drops of the compaction hammer specified by United States Golf Association (USGA) [Hummel, 1993]. The peat was dried at 35 °C and mixed with sand the same way as mixing other amendments. The volumes of the various materials in the mixtures were based on compacted samples of the components. Three equal replications were divided from the total mix by weight. The bottoms of sample rings measuring 52 mm diam. and 61 mm deep were fitted with a double layer of cheesecloth. The soil mixtures were added to the rings and compacted according to USGA specification [Hummel, 1993]. The samples were then saturated from the bottom for 24 h after compaction and subjected to 0, 5, 10, and 20 freeze/thaw cycles. Each freeze/thaw cycle included freezing at -15 °C for 48 h and thawing for 24 h at room temperature.

Changes in volume after 0, 5, 10, and 20 freeze/thaw cycles were recorded by measuring the distance from the surface of the sample to the top edge. Bulk density was calculated as weight divided by the new volume. Particle-size distributions were analyzed after 0 and 20 freeze/thaw cycles by the hydrometer method described by Gee and Bauder [1986].

In study two, a second set of samples was prepared the same way as above and subjected to 0, 5, and 20 freeze/thaw cycles by the same methods. Lapillus and pumice were not included in this study because of material shortage. The K_{sat} value was measured after 0, 5, and 20 freeze/thaw cycles using the method described by Klute and Dirksen [1986].

In a third study, the materials were mixed the same way as described above. The samples were screened through a set of standard sieves, and the fraction that passed the 1.0 mm sieve and retained by the 0.5 mm sieve was collected for mechanical stability evaluation. A 10 mm thick layer of the collected material was put into a cylinder similar to those used for hydraulic conductivity tests except for a solid steel bottom. The samples were compacted with a dynamic energy of 2 kJ m^{-2} by dropping the hammer once. This compaction energy was chosen in order to break less than 1% of sand particles. Particle size distribution of the compacted samples was determined by dry sieving according to the standard USGA procedure for particle size analysis [Hummel, 1993].

RESULTS

The bulk density of all sand and amendment mixtures decreased after the first freezing treatment. At the end of the first freeze/thaw cycle, all mixtures had decreased in bulk density. The bulk density of sand amended with PC decreased 15%. Where an organic component was present in the sand mixtures (peat and PC), there was a reduction of bulk density after wetting followed by an increase in bulk density with each freeze/thaw cycle. This increase never exceeded the initial bulk density following compaction. By the end of 20

Table 1. Physical properties of the inorganic materials used in the freezing and thawing study.

Property	Soil amendments							
	Sand	Zeolite 1†	Zeolite 2‡	PCC§	CDE¶	PC#	Lapillus	Pumice
Gravel (>2 mm), g kg^{-1}	1	2	438	0	0	25	100	159
Very coarse sand (1.0-2.0 mm),†† g kg^{-1}	5	128	377	0	250	82	170	357
Coarse sand (0.5-1.0 mm),†† g kg^{-1}	123	574	24	596	502	490	143	239
Medium sand (0.25-0.5 mm),†† g kg^{-1}	771	243	30	401	215	326	149	114
Fine sand (0.15-0.25 mm),†† g kg^{-1}	89	15	27	3	17	42	115	44
Very fine sand (0.106-0.15 mm),†† g kg^{-1}	6	12	23	0	7	10	75	22
Silt (0.05-0.106 mm), g kg^{-1}	4	14	33	0	9	14	134	31
Clay (<0.05 mm), g kg^{-1}	2	11	50	0	0	8	114	35
pH (1:1 water/material)	6.8	7.8	8.0	6.3	7.0	6.4	7.0	6.8

† Zeolite clinoptilolite.

‡ Zeolite chabasite.

§ PCC, porous ceramic clay.

¶ CDE, calcined diatomaceous earth.

PC, polymer-coated clay with a kelp material incorporated on the exterior of the polymer coating.

†† Dry sieved fraction

freeze/thaw cycles, all the mixtures decreased in bulk density. The greatest decreases in bulk density occurred in sand amended with PC (7.6%) and CDE (2.8%) as compared with the compacted samples (Table 2).

At the end of 20 freeze/thaw cycles, the percentage weight of the finest fraction that passed through to the 0.106 mm sieve increased from 0.3 to 0.9% for zeolite clinoptilolite, and from 3.4 to 4.4% for lapillus (Table 3). None of the other amendments showed a significant increase in the finest fraction after the freeze/thaw treatments compared with the sand control.

The K_{sat} values were increased by amending the sand with PCC (54%), CDE (20%), and zeolite clinoptilolite (17%), whereas the values were decreased by peat (53%), zeolite chabasite (46%), and PC (44%) (Table 4). After 20 freeze/thaw cycles, sand amended with peat and PCC had similar increases in K_{sat} as the sand control, sand amended with zeolite clinoptilolite and zeolite chabasite had lower increases than the sand control, and sand amended with CDE and PC had higher increases than the sand control. As a result, after 20 freeze/thaw cycles, K_{sat} values of sand amended with PCC, CDE and PC were 25, 33 and 18% higher than that of the control, respectively (Table 4).

In addition to the freezing and thawing breakdown of soil particles, management practices and traffic may also lead to particle degradation. In this study, dynamic compaction caused a breakdown of soil particles, resulting in a decrease of up to 3.3% of the particles that had been retained on a 0.5 mm sieve (Table 5). Lapillus amended media had the greatest percentage of particle breakdown. However, since mechanical breakdown is an accumulative effect over time, the long-term effects of this factor should be considered when particle stability is a concern.

Table 2. The effect of freezing and thawing on the change in bulk density of the mixtures including 85% sand/15% amendment (v/v).

Treatment	Bulk density	Bulk density (Bulk density change)					
	After compaction	Saturated	Frozen	1-cycle	5-cycle	10-cycle	20-cycle
	$g\ cm^{-3}$	$g\ cm^{-3}$ (% change)					
Control	1.60	1.62 (1.3)	1.47 (-8.1)	1.59 (-0.7)	1.59 (-0.7)	1.59 (-0.7)	1.59 (-0.7)
Peat	1.47	1.45 (-1.4)	1.35 (-8.4)	1.45 (-1.4)	1.45 (-1.7)	1.46 (-0.9)	1.47 (0.0)
Zeolite 1†	1.52	1.52 (0.0)	1.40 (-7.7)	1.50 (-1.0)	1.51 (-0.6)	1.50 (-1.0)	1.49 (-2.1)
Zeolite 2‡	1.55	1.54 (-0.2)	1.46 (-5.7)	1.54 (-0.6)	1.53 (-1.0)	1.53 (-1.2)	1.52 (-1.8)
PCC§	1.46	1.45 (-0.6)	1.35 (-7.9)	1.44 (-1.4)	1.45 (-1.0)	1.45 (-0.6)	1.44 (-1.7)
CDE¶	1.45	1.45 (0.0)	1.34 (-7.6)	1.44 (-1.0)	1.43 (-1.5)	1.40 (-3.6)	1.41 (-2.8)
PC#	1.61	1.35 (-16.1)	1.31 (-18.4)	1.36 (-15.6)	1.43 (-11.5)	1.46 (-9.5)	1.49 (-7.6)
Lapillus	1.59	1.59 (0.0)	1.46 (-8.2)	1.55 (-2.0)	1.56 (-1.6)	1.53 (-3.4)	1.56 (-1.9)
Pumice	1.50	1.50 (0.0)	1.38 (-7.8)	1.49 (-1.0)	1.49 (-0.8)	1.47 (-2.1)	1.48 (-1.5)
$LSD_{0.05}$††	0.02	1.0	1.6	0.9	1.0	1.2	1.7

† Zeolite clinoptilolite.
‡ Zeolite chabasite.
§ PCC, porous ceramic clay.
¶ CDE, calcined diatomaceous earth.
# PC, polymer-coated clay with a kelp material incorporated on the exterior of the polymer coating.
†† LSD values are based on the changes in bulk density, the numbers in parentheses.

Table 3. Freezing and thawing effects on particle integrity of the mixtures containing 85% sand/15% amendment (v/v).

Treatment	Sieve aperture (mm) 1	0.5	0.25	0.15	0.106	pan
	Percentage weight retained on the sieve before freezing and thawing (%)					
Control	0.5	12.3	77.1	8.9	0.6	0.6
Peat	0.8	13.2	75.6	8.3	0.8	1.3
Zeolite1[†]	1.9	18.5	71.7	7.2	0.4	0.3
Zeolite2[‡]	7.3	12.2	70.9	7.5	0.7	1.4
PCC[§]	0.5	15.5	74.6	8.2	0.6	0.7
CDE[¶]	1.4	13.6	74.8	8.9	0.7	0.6
PC[#]	1.8	16.6	71.2	8.7	0.8	0.9
Lapillus	3.5	13.0	69.7	8.8	1.6	3.4
Pumice	3.7	14.9	72.5	7.2	0.6	1.0
	Percentage weight retained after 20 cycles of freezing and thawing (%)					
Control	0.4 (-0.1)[††]	12.7 (0.4)	77.8 (0.6)	7.8 (-1.1)	0.6 (0.0)	0.6 (0.0)
Peat	0.6 (-0.2)	12.3 (-0.9)	76.9 (1.3)	8.1 (-0.2)	0.9 (0.1)	1.2 (-0.1)
Zeolite 1	1.8 (-0.1)	18.5 (0.0)	70.4 (-1.3)	7.6 (0.4)	0.7 (0.3)	0.9 (0.6)
Zeolite 2	6.2 (-1.1)	12.2 (0.0)	71.5 (0.6)	7.7 (0.2)	0.8 (0.1)	1.6 (0.2)
PCC	0.5 (0.0)	18.5 (3.0)	73.1 (-1.5)	7.0 (-1.2)	0.5 (-0.1)	0.4 (-0.3)
CDE	1.7 (0.3)	14.7 (1.1)	74.7 (-0.1)	7.8 (-1.1)	0.6 (-0.1)	0.5 (-0.1)
PC	1.8 (0.0)	18.6 (2.0)	71.0 (-0.2)	7.4 (-1.3)	0.6 (-0.2)	0.6 (-0.3)
Lapillus	3.7 (0.2)	12.4 (-0.6)	68.6 (-1.1)	9.1 (0.3)	1.8 (0.2)	4.4 (1.0)
Pumice	3.3 (-0.4)	14.1 (-0.8)	72.5 (0.0)	7.9 (0.7)	0.8 (0.2)	1.4 (0.4)
$LSD_{0.05}$‡‡	0.4	1.3	NS	1.0	0.2	0.5

† Zeolite clinoptilolite.
‡ Zeolite chabasite.
§ PCC, porous ceramic clay.
¶ CDE, calcined diatomaceous earth.
# PC, polymer-coated clay with a kelp material incorporated on the exterior of the polymer coating.
†† The values in parentheses are the percentage of change.
‡‡ LSD values are based on the changes in bulk density, the numbers in parentheses.

Table 4. Changes in saturated hydraulic conductivity (K_{sat}) caused by freezing and thawing of the mixtures containing 85% sand/15% amendment (v/v).

Treatment	K_{sat}†			K_{sat} change
	0-cycle	5-cycle	20-cycle	
	…………… cm h^{-1} ……………			
Control	20.1	21.9	30.3	10.2
Peat	9.5	13.9	19.2	9.7
Zeolite 1‡	23.6	21.7	26.2	2.6
Zeolite 2§	11.0	12.4	15.9	4.9
PCC¶	31.7	36.2	38.0	6.4
CDE#	24.2	25.3	40.4	16.2
PC††	11.2	16.9	35.9	24.7
$LSD_{0.05}$	1.2	3.4	5.9	5.3

† K_{sat}, saturated hydraulic conductivity.
‡ Zeolite clinoptilolite.
§ Zeolite chabasite.
¶ PCC, porous ceramic clay.
# CDE, calcined diatomaceous earth.
†† PC, polymer-coated clay with a kelp material incorporated on the exterior of the polymer coating.

DISCUSSION

The greatest bulk density changes occurred after the first freeze/thaw cycle. This change may not be the direct result of wetting, except in the case of PC and peat amended media which showed an immediate decrease in bulk density after saturation. In a freeze/thaw study involving only pure amendments, PC showed a 40% decrease in bulk density after 20 freeze/thaw cycles (data not included), indicating that this material has a great capacity for swelling during freezing. Further study is needed to separate the wetting and freeze/thaw effects by measuring the impact of wetting at each freeze/thaw cycle and comparing the results to those obtained with dry media.

The fact that sand amended with zeolite cinoptilolite and zeolite chabasite had less effect on K_{sat} after 20 freeze/thaw cycles compared with sand control may be explained by the increase in fine particles passing through the 0.106 mm sieve. These two materials also had less effect on bulk density after 20 freeze/thaw cycles. Peat amended media had neither high particle degradation nor large decreases in bulk density and therefore had similar K_{sat} values to those of the sand control (Table 2, 3 and 4).

Particle-size changes in other sieve sizes should also be considered in understanding the effects of freezing and thawing on K_{sat}, because changes in particle-size distribution may cause changes in compressibility. A single mechanical compaction did not cause significant changes in particle size tested in this study. However, subsequent re-compaction may play a role in physical changes. Changes in particle-size distribution due to freezing and thawing have been reported by Hower et al. [1992] for oil shale. Li et al. [2000] reported that K_{sat} increased by PC (19%), peat/sand [5% (v/v)](44%), PCC(72%), and CDE(82%) following winter freezing in the field. Different results were observed in this study, where PC-amended

Table 5. Particle-size distribution caused by mechanical compaction in the mixtures containing 85% sand/15% amendment (v/v) that passed a 1 mm sieve and was retained on a 0.5 mm sieve.

Treatment	Sieve aperture					
	.... mm					
	0.5	0.25	0.15	0.106	0.053	Pan
	Percentage weight retained					
	.... %					
Sand control	99.1	0.7	0.2	0.0	0.0	0.0
Zeolite 1†	98.8	1.0	0.2	0.0	0.0	0.0
Zeolite 2‡	98.0	1.7	0.3	0.0	0.1	0.0
PCC§	98.6	1.1	0.3	0.0	0.0	0.0
CDE¶	98.3	1.5	0.2	0.0	0.0	0.0
PC#	98.2	1.6	0.2	0.0	0.0	0.0
Lapillus	96.7	2.3	0.6	0.1	0.2	0.1
Pumice	97.6	1.6	0.3	0.1	0.3	0.1
$LSD_{0.05}$	0.95	0.55	0.15	NS	NS	NS

† Zeolite clinoptilolite.
‡ Zeolite chabarite.
§ PCC, porous ceramic clay.
¶ CDE, calcined diatomaceous earth.
# PC, polymer-coated clay with a kelp material incorporated on the exterior of the polymer coating.

sand mixture showed the highest increase in K_{sat}. This disagreement may be due to the fact that the sand-based medium tested by Li et al. [2000] was subjected to freeze/thaw cycles for two seasons only whereas we investigated 20 freeze/thaw cycles in this study. In addition, the sand amended with inorganic amendments in the field study also contained 5% (v/v) peat. It should also be noted that the bulk density decreased most after the first few freeze/thaw cycle in this study, whereas particle breakdown were much slower (Tables 2 and 3).

In conclusion, freezing and thawing may result in changes in bulk density, particle degradation and particle-size distribution. These factors may then affect K_{sat}. Further studies on this subject should include measurements of changes in water content during the freeze/thaw processes.

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