CHAPTER 2. INORGANIC SOIL AMENDMENT EFFECTS ON SAND-BASED SPORTS TURF MEDIA

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ABSTRACT

Inorganic soil amendments have been suggested for use in turf to alleviate soil compaction, increase water retention and hydraulic conductivity, and improve many other soil physical properties. The objectives of this study were to determine the effects of ceramic, porous ceramic clay (PCC), calcined diatomaceous earth (CDE), and polymer coated clay (PC) on the physical characteristics of sand-based media and to determine the effects of these amendments on bulk density following freeze-and-thaw treatments. Inorganic materials were added to a sand-based golf green at 10% on a volumetric basis during construction in 1996. Data collected from the field included saturated hydraulic conductivity (K_{sat}), water retention, water release curves, bulk density and total porosity on compacted samples collected at construction, and undisturbed samples collected from the treated plots 1 and 2 yr after establishment. The PCC treatment had an 8 and 7% higher cation exchange capacity (CEC) than the control in 1997 and 1998, respectively. The PCC increased the K_{sat} by 26 and 20% in the compacted and undisturbed samples, respectively, in

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Abbreviations: CDE, calcined diatomaceous earth; CEC, cation exchange capacity; CU, coefficient of uniformity; K_{sat}, saturated hydraulic conductivity; PC, polymer coated clay; PCC, porous ceramic clay; USGA, United States Golf Association.

1998. The CDE increased water retention by 13% in both compacted and undisturbed samples. Saturated hydraulic conductivity of the sand-inorganic mixtures decreased over the 2 yr, although some increases in K_{sat} were observed each spring. The K_{sat} of plots receiving all inorganic amendments was reduced by 75% in November of 1998. The K_{sat} values in the spring of 1999 increased from the low levels of 1998 by 19% (PC), 44% (control), 59% (ceramic), 72% (PCC), and 82% (CDE). The changes of K_{sat} over the winter may have been induced by freezing and thawing. These changes may not necessarily be caused by total porosity increases, instead they may be caused by increases in macropores. This hypothesis was further tested in the laboratory in a freeze-and-thaw study conducted in 1999. The PC, control, CDE and PCC decreased bulk density by 10.7, 7.2, 2.5, and 2.2%, respectively, following a freeze-and-thaw cycle.

Soil conditioners are substances that improve the physical properties of soils and promote plant growth (Wallace and Terry, 1998). Soil conditioners have been used extensively in agriculture since the early 1950s (De Boodt, 1972). For golf course putting greens, topsoil often is removed from the site and replaced with sand-based media in order to prevent compaction and improve drainage. Sand-based media have a lower water and nutrient holding capacity than most clay and loam soils. Many inorganic amendments have been suggested for use in these sandy soils to increase plant available water and to improve CEC, while maintaining high drainage and aeration properties. Several soil amendments, including calcined clay, diatomite, expanded shale, perlite, pumice, sintered fly ash, slag, and vermiculite have been suggested for use in sand-based turf growing media (Carrow, 1993). So far, research on the impact of inorganic amendments on soil physical properties has been limited to clinoptilolite zeolite (Ferguson et al., 1986; Huang and Petrovic., 1995) and calcined clay (Beard, 1973; Waddington et al., 1974). McCoy and Stehouwer (1998) also investigated the water and nutrient retention properties of CDE and PCC in a laboratory study. Little field information has been collected to compare the effects of most inorganic soil amendments on the soil physical properties of a sand-based golf putting green. The objectives of this study, therefore, were to investigate the effects of four inorganic soil amendments, ceramic, PCC, CDE, and PC, on the soil physical parameters of sand-based media and to determine the effects of these amendments on bulk density following freeze-thaw treatments.

MATERIALS AND METHODS

A sand-based golf course green was constructed at the Iowa State University horticulture research station in Ames, IA in the summer of 1996. A network of 10 cm diam. drain lines was trenched into the subsoil at 4.6 m intervals. The sand had a coefficient of uniformity (CU) of 1.7, with 0.2% in the 1- to 2- mm particle-size range; 1.8% in the 0.5- to 1-mm particle-size range; 18.7% in the 0.25- to 0.5-mm particle-size range; 55.3% in the 0.15- to 0.25-mm particle-size range; 19.7% in the 0.1- to 0.15-mm particle-size range; 3.2% in the 0.05- to 0.1-mm particle-size range; and 1.1% in the ≤ 0.05-mm particle-size range. The green consisted of a 30-cm sand root zone placed over a 10-cm deep gravel blanket. No intermediate layer was used between the sand and gravel. The treatment included the following inorganic amendments: porous ceramic clay (PCC) (Profile, Profile Products LLC, Buffalo Grove, IL.); calcined diatomaceous earth (CDE) (Axis, Eagle-Picher Minerals, Inc., Reno, NV); ceramic (Bio-ceramic, Korea); and polymer coated clay with a kelp material incorporated on the exterior of the polymer coating (PC) (Bio-Flex, True Pitch, Altoona, IA)

(Table 1). The top 15 cm of sand from each plot was removed and combined with 5% (v/v) peat (Dakota Peat and Blenders, Grand Forks, ND). This low level of peat was used so that the organic matter (OM) would not mask the effects of inorganic amendment therefore facilitating evaluation of the inorganic materials. The field study consisted of a control with peat only and the four soil amendment treatments added at 10% (v/v). The mixture was replaced on the plot area and allowed to settle during the winter. Treatments were replicated three times in a randomized complete block design resulting in 15 plots as experimental units each measuring 5 m^2. The area was seeded with 73 kg ha^{-1} of 'Crenshaw' creeping bentgrass on 13 May 1997. Fertilizer was applied at seeding to supply 50, 90 and 80 kg ha^{-1} of N, P and K, respectively.

Samples from each treatment were collected at construction and stored in plastic bags to prevent drying. The amount of media needed for each test was calculated from the desired bulk density, the known volume of the cylinders and the water content determined by oven-drying. Each sample was put into a cylinder that had a double layer of cheesecloth attached at the bottomand another cylinder attached at the top. The media were compacted by 15 drops of a 1.36-kg hammer from a height of 30 cm (Hummel, 1993). The compaction tests, conducted to evaluate base-line soil physical properties, were replicated 3 times. Soil samples from the green were collected for chemical testing in November 1997 and 1998. The samples were submitted to Harris Laboratory of Lincoln, NE, and analyses of CEC, pH, OM, NO_3-N, P, K, Ca, Mg, S, Zn, Mn, Cu, Fe, and B were conducted. Laboratory methods included: soil pH (1:1 water/soil ratio); organic matter (by loss-on-ignition); Ca, Mg, K, and Na extracted by a modified ammonium acetate method; Zn, Mn, Cu and Fe extracted by a

Table 1. Physical and chemical properties of the inorganic amendments used in the golf green media.

	Inorganic Amendment			
Property	Ceramic†	PCC‡	CDE§	PC¶
Gravel(>2 mm, g kg^{-1})	0.0	0.0	0.0	46.0
Very coarse sand (1.0-2.0 mm, g kg^{-1})	441.0	1.0	448.0	137.0
Coarse sand (0.5-1.0 mm, g kg^{-1})	376.0	520.0	416.0	522.0
Medium sand (0.25-0.5 mm, g kg^{-1})	92.0	466.0	127.0	289.0
Fine sand (0.15-0.25 mm, g kg^{-1})	32.0	12.0	1.0	28.0
Very fine sand (0.05-0.15 mm, g kg^{-1})	43.0	1.0	1.0	12.0
Silt (0.05-0.02 mm, g kg^{-1})	18.0	0.0	1.0	3.0
Particle density (g cm^{-3})	2.6	2.5	2.2	2.5
CEC# ($cmol_c$ kg^{-1})	30.7	33.6	27.0	22.4
pH (1:1 water to material)	7.0	6.3	7.0	6.4

† Ceramic.

‡ PCC, porous ceramic clay.

§ CDE, calcined diatomaceous earth.

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

CEC, cation-exchange capacity.

modified diethylenetriaminepentaacetic acid method; P was extracted by Bray I; S and B were determined by inductively coupled plasma spectroscopy; and NO_3 by the Cd reduction method. Two, undisturbed soil columns measuring 5.2 cm in diam. and 6.1 cm long also were collected from the top 10 cm of each plot in November 1997 and 1998. Saturated hydraulic conductivity at 34 cm constant water head, water retention at –4 kPa water potential, and soil bulk density were determined for undisturbed field samples and compacted samples as described by Klute and Dirksen (1986). The K_{sat} data were converted to values at 20°C before statistical analysis. Water release curves were determined by the pressure plate method using the drying process described by Klute (1986).

In April 1999, two undisturbed soil samples measuring 5.2 cm in diam. and 6.1 cm long also were collected from each plot to test the effect that winter freezing and spring thawing had on saturated hydraulic conductivity and bulk density. Freeze and thaw effects were further evaluated in the laboratory by mixing 15% of each inorganic amendment with 85% (v/v) of the same sand used in the field test. The pure sand was mixed with 5% peat by volume and was used as one control. In addition, pure sand was used as another control. Three replicated samples from each inorganic amendment treatment and the control then were compacted in brass tubes measuring 5.2 cm in diam. and 6.1 cm long as described above (Hummel, 1993). The volume of each sample was recorded after compaction by measuring the distance from the surface of the sample to the top edge of the cylinder. These samples were saturated from the bottom for 24 h and put in a freezer at -15 °C for 2 d. The soil columns then were thawed and oven dried at 105 °C for 24 h. The volume change was recorded as earlier described and bulk density was calculated for each sample.

RESULTS AND DISCUSSION

The field plots modified with PCC had an 8 and 7% higher CEC than the control in 1997 and 1998, respectively (Table 2). The higher CEC in the medium containing PCC resulted in a 100% increase in exchangeable K and a nearly 30% increase in exchangeable Mg, but a 4% decrease in exchangeable Ca (Table 2). McCoy and Stehouwer (1998) also reported that PCC had a very high selective K retention with a subsequent reduction in exchangeable Ca. None of the other materials consistently affected the availability of these cations in the sand medium.

The PC reduced K_{sat} by 13% (5.2 cm hr^{-1}) in the undisturbed media in 1997 and by 19% (6.4 cm hr^{-1}) in the compacted samples (Table 3). However, the PCC had no effect on K_{sat} in 1997 and it increased K_{sat} by 26% (6.8 cm h^{-1}) and 20% (2.6 cm h^{-1}) in the compacted and undisturbed samples, respectively, in 1998. This increase in K_{sat} was probably due to lower bulk density and higher porosity of the sand and PCC mix (Table 3). In McCoy and Stehouwer's (1998) study, the sand mixture with PCC had a lower K_{sat} than sand mixed with CDE. This may be due to the fact that in McCoy and Stehouwer's (1998) study, staticpressure was used to compress the soil samples, whereas in this study the USGA procedure was used for compaction.

The water release curves of the undisturbed samples were similar during the drying process (Fig. 1). At a water potential of –4 kPa, sand modified with PCC and CDE had 13 and 20% greater water retention than the control in 1997 and 1998, respectively (Table 3). Water retention of the sand amended with ceramic and PC was not different from the control. Water retention in compacted and undisturbed samples was highly correlated (r = 0.97).

Table 2. Soil test results for 1997 and 1998 of a sand-based golf green amended with 5% peat and 10% inorganic soil amendments on a volumetric basis with a control containing 5% peat only.

Treatment	CEC†		pH		OM‡		NO_3-N		P		K		Mg		Ca		S		Zn	
	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998
	--- $cmol_c$ kg^{-1} --				----- g kg^{-1} ------		----------------- mg kg^{-1} -----------------													
Control	8.8	8.3	8.3	8.3	4	5	1	1.3	7.7	3.0	25	25	103	80	1551	1486	1.7	1.0	0.9	0.8
Ceramic††	9.2	8.1	8.3	8.3	4	5	1	2.3	6.3	4.0	27	25	114	78	1625	1454	1.0	1.0	1.4	0.9
PCC‡‡	9.5	8.9	8.2	8.2	4	5	1	1.3	7.7	4.3	51	49	145	114	1604	1534	1.3	1.0	0.9	0.7
CDE§§	8.8	8.1	8.3	8.3	4	4	1	1.3	8.7	4.7	25	25	105	73	1548	1478	1.7	1.0	0.7	0.7
PC¶¶	8.0	7.8	8.3	8.2	5	6	1	1.7	7.3	3.0	24	22	108	79	1394	1414	2.7	1.7	1.2	0.9
$LSD_{0.05}$	0.4	0.6	NS	NS	NS	NS	NS	NS	NS	NS	8	4	14	12	49	NS	NS	0.5	NS	NS

Treatment	Mn		Cu		Fe		B		AK§		AMg¶		ACa#	
	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998
	----------- mg kg^{-1} -----------								------- % base saturation -------					
Control	3.1	2.8	0.5	0.6	11.9	6.57	0.3	0.3	0.7	0.8	9.8	8.1	88.7	90.1
Ceramic	3.6	2.8	2.1	0.9	15.5	6.57	0.3	0.3	0.8	0.8	10.3	8.0	88.1	90.2
PCC	2.9	2.5	0.9	0.6	17.3	7.87	0.3	0.3	1.4	1.4	12.8	10.8	84.9	86.9
CDE	3.3	2.5	0.4	0.7	15.3	7.23	0.3	0.3	0.7	0.8	10.0	7.5	88.4	90.8
PC	3.3	2.9	0.9	0.7	11.9	6.13	0.3	0.3	0.8	0.7	11.3	8.3	87.2	90.0
$LSD_{0.05}$	NS	0.3	NS	NS	NS	NS	NS	NS	0.2	0.2	1.2	0.7	1.3	0.8

† CEC, cation-exchange capacity.
‡ OM, organic matter.
§ AK, actual potassium.
¶ AMg, actual magnesium.
# ACa, actual calcium.
†† Ceramic.
‡‡ PCC, porous ceramic clay.
§§ CDE, calcined diatomaceous earth.
¶¶ PC, polymer coated clay with a kelp material incorporated on the exterior of the polymer coating.

Therefore, compacted laboratory samples could potentially be used to predict available water for plant use. Our study tested the water content up to –0.2 MPa. Further testing at –1.5 MPa (permanent wilting point) is needed to determine if these amendments retain plant-available water. Both PCC and CDE decreased bulk density by 7.6% when compared with the control. The PCC and CDE both increased the total porosity of the green mix. As water pressure becomes more negative, sand modified with PCC released more water than that modified with CDE (Fig. 1), suggesting that CDE has more internal micro porosity than PCC. Our results were similar to those reported by McCoy and Stehouwer (1998). Only PCC increased both K_{sat} and water retention. Macropores are more responsible for hydraulic conductivity, whereas micropores are more responsible for water retention (Rowell, 1994). Hence, PCC probably provided for a more favorable ratio of macropores and micropores. The ratios were 3.77 and 3.63 for PCC and CDE, respectively. These ratios were calculated by dividing saturated water content by water content, where significant differences existed at –8 kPa.

The K_{sat} of all treatments was reduced by almost 75% in November 1998, compared with the same time in 1997. The mechanism of this decrease is unknown. One possible cause may have been compaction occurring as a result of normal management practices (i.e. mowing and irrigation) as evidenced by the increase in bulk density (Table 3). However, undisturbed soil samples collected in April 1999 had an increase of K_{sat} of 19.2% (PC), 43.5% (control), 58.6% (ceramic), 72.1% (PCC), and 81.7% (CDE), when compared with K_{sat} values in November 1998. This means that although K_{sat} generally decreased over the 2-yr study period, there may be a temporary increase in the spring. Such changes may have been induced by the effects of freezing-thawing on the bulk density and porosity of the media during the winter. However, the increase in K_{sat} was not in proportion to total porosity increases, suggesting that the inorganic amendments vary in their impact on the micropores and macropores of the sand mixture (Table 4).

The bulk density of the sand mixtures with PC, 5% peat control, CDE and PCC decreased by 10.7, 7.2, 2.5, and 2.2%, respectively, by freezing and thawing (Fig. 2). The decrease of bulk density caused by freezing and thawing was negligible in the mixture of the pure sand control and the sand-ceramic mixture. These lab results agree with field data collected in November 1998 and April 1999 (Table 4). Based on their swelling properties during freezing and thawing, the sand-amendment mixtures could be classified into three groups as follows: those that did not change in bulk density (ceramic and pure sand); those that decreased greatly in bulk density (PC and sand-5% peat); and an intermediate group (PCC and CDE) in which bulk density was decreased slightly.

CONCLUSION

The four inorganic soil conditioners used in this study had different impacts on the CEC and hydraulic properties of the sand. The PCC increased both the saturated hydraulic conductivity and the amount of available water in the sand-peat media. The sand-peat media mixed with PC had both lower saturated hydraulic conductivity and water retention. The results from field samples were similar to those from the samples collected at construction and tested in the laboratory. The stability of hydraulic properties also was different among the inorganic soil amendments during the study. Saturated hydraulic conductivity in 1998 decreased by almost 75% from the value of the first year. Winter freezing and spring thawing play a very important role in alleviating soil compaction by decreasing the soil bulk

Table 3. Physical characteristics of a sand-based golf green amended with 5% peat and 10% inorganic soil amendments on a volumetric basis with the control containing 5% peat only. Samples from each treatment were collected at construction and were compacted. Undisturbed soil columns were collected from each plot in November 1997 and 1998.

	Undisturbed								Compacted			
	K_{sat}†		W_{ret}‡		D_{b}§		P_{t}¶		K_{sat}	W_{ret}	D_{b}	P_{t}
Treatment	1997	1998	1997	1998	1997	1998	1997	1998				
	---cm h^{-1}----		---g kg^{-1}----		---g cm^{-3}---				cm h^{-1}	g kg^{-1}	g cm^{-3}	
Control	45.7	10.0	241	182	1.49	1.57	0.44	0.41	33.9	219	1.49	0.44
Ceramic#	43.9	10.6	237	194	1.51	1.53	0.43	0.42	37.7	209	1.51	0.43
PCC††	46.8	12.6	272	219	1.43	1.45	0.46	0.45	40.7	235	1.43	0.46
CDE‡‡	44.5	10.9	273	219	1.43	1.45	0.46	0.45	33.4	249	1.43	0.46
PC§§	39.5	9.9	236	196	1.53	1.58	0.42	0.40	27.5	203	1.53	0.42
$LSD_{0.05}$	3.8	1.4	12	17	0.05	0.05	0.02	0.02	3.5	22	¶¶	¶¶

† Ksat, saturated hydraulic conductivity.

‡ W_{ret}, water retention at –4kPa water potential.

§ D_{b}, soil dry bulk density.

¶ P_{t}, total porosity.

Ceramic.

†† PCC, porous ceramic clay.

‡‡ CDE, calcined diatomaceous earth.

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

¶¶ No statistical analysis because the errors of compacted samples are not from treatment.

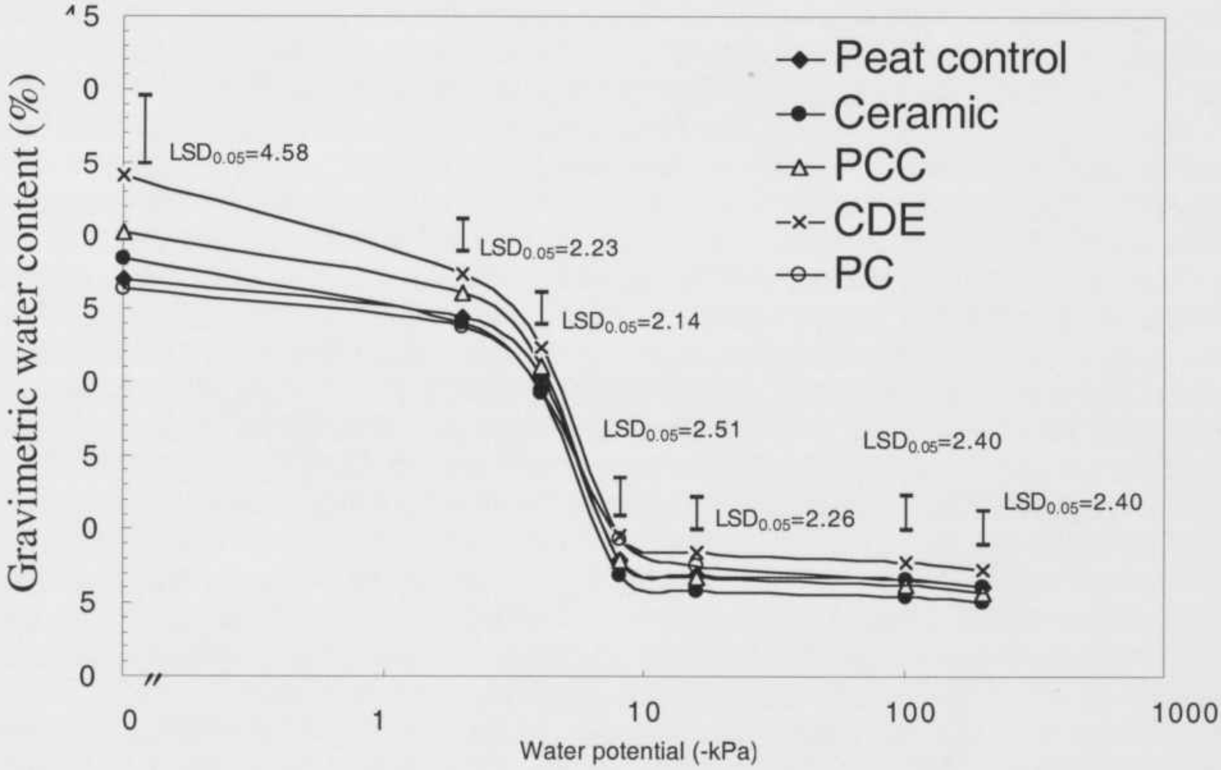

Figure 1. Water release curve of sand-based golf green amended with 5% peat and 10% inorganic soil amendments on a volumetric basis with a control containing 5% peat only. Undisturbed soil columns were collected from each plot in November 1998.

Table 4. Saturated hydraulic conductivity changes for the winter of 1998 in response to changes in bulk density and porosity of a sand-based golf green amended with 5% peat and 10% inorganic soil amendments on a volumetric basis with the control containing 5% peat only. Undisturbed soil columns were collected from each plot in November 1998 and April 1999.

Treatments	Bulk density			Porosity			K_{sat}		
	Nov. 1998	Apr. 1999	% Change	Nov. 1998	Apr. 1999	% Change	Nov. 1998	Apr. 1999	K_{sat} Change
	--------g cm^{-3} -----------						----------------- cm h^{-1} ------------		
Control	1.57	1.55	-1.3	0.41	0.44	7.31	10.00	14.35	4.35
Ceramic†	1.53	1.53	0.0	0.42	0.43	2.38	10.60	16.81	6.21
PCC‡	1.54	1.46	-5.2	0.45	0.46	0.22	12.60	21.68	9.08
CDE§	1.45	1.42	-2.1	0.45	0.47	0.44	10.90	19.80	8.90
PC¶	1.58	1.53	-3.2	0.40	0.40	0.00	9.90	11.80	1.90
$LSD_{0.05}$	0.05	0.05	NS	0.05	0.05	NS	1.4	1.2	4.04

† Ceramic.

‡ PCC, porous ceramic clay.

§ CDE, calcined diatomaceous earth.

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

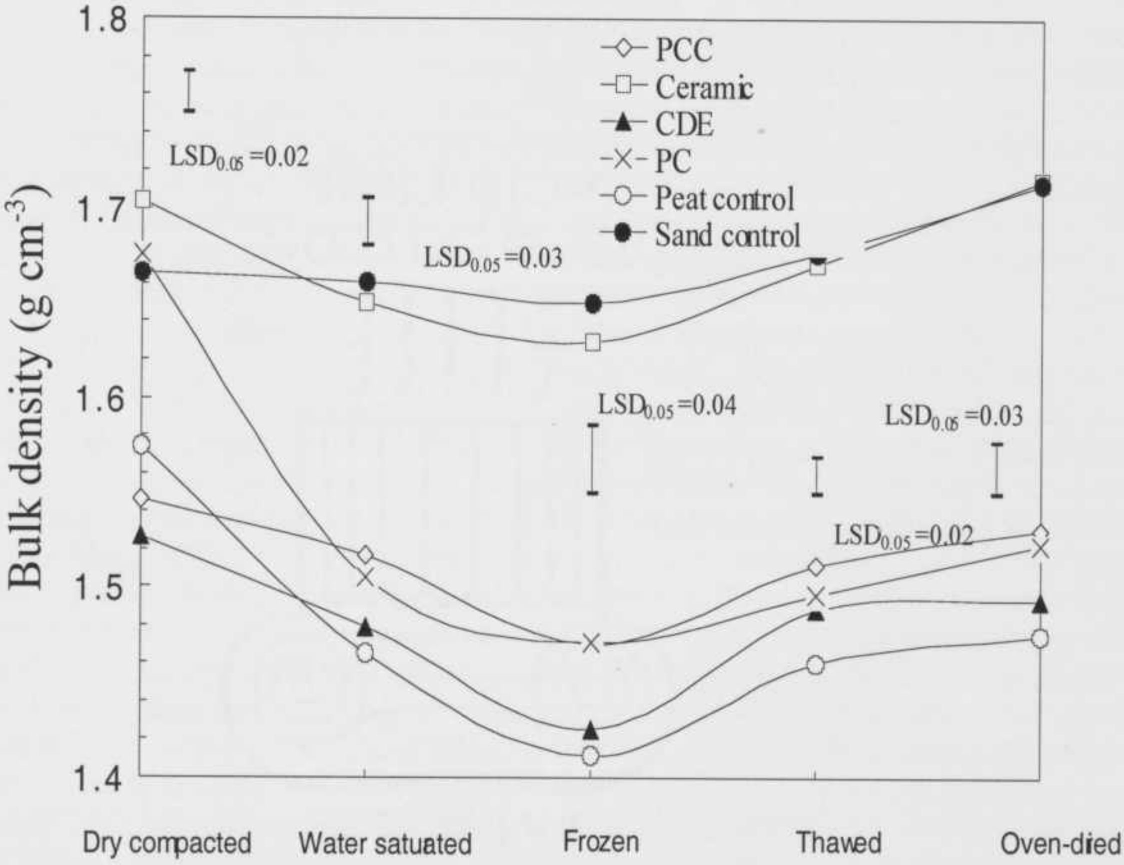

Figure 2. Freeze-thaw effects on bulk density of sand amended with 15% soil amendments on a volumetric basis in 1999. The pure sand and sand-5% peat were used as controls. The soil cores were compacted according to USGA specifications, saturated from the bottom for 24 h, frozen at -15°C for 2 d, thawed, and oven dried at 105°C.

density. However, decreased soil bulk density and increased total porosity is not always accompanied by an equivalent increase in K_{sat} because of variations in the macropores and micropores (Rowell, 1994). In general, both CDE and PCC showed positive effects on water-holding capacity and K_{sat} in a sand-based golf green. Furthermore, PCC increased the CEC of the media and increased K availability.

The results presented here agree with those of McCoy and Stehouwer (1998), who found that PCC resulted in selective retention of K vs. Ca. Our results further indicate good agreement between laboratory data on compacted samples collected at construction and undisturbed field samples collected during the 2 yr of the study. In general, K_{sat} was lower two years after construction. However, PCC and CDE increased the K_{sat} in the spring after winter freezing-thawing both in field and laboratory studies.

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