CHAPTER 5

Comparative Performance of Amendments and Construction Systems for Sand-Based Greens during the Mature Bentgrass Phase

ABSTRACT

Sand is the growing medium of choice for putting greens. However, pure sand (100%) for root zones has some disadvantages due to poor nutrient and water retention. Sand-based root zones have been amended with the organic materials especially peat moss (10 – 15% v/v) which is recommended by the USGA (United States Golf Association). Organic materials improve nutrient and water retention, but they break down over time. Inorganic amendments such as calcined clays (Profile) and zeolites break down less over time. The objective of this study was to test the changes in ‘Penncross’ creeping bentgrass (*Agrostis palustris* Huds.) root zone properties over time as affected by four amendments and three green construction systems. Four treatments were developed: California (100% sand, v/v), USGA (90% sand and 10% peat, v/v), California-P (82% sand and 15% porous ceramic and 3% humate, v/v), and California-

Z (85% sand and 15% zeolite, v/v). The four treatments were arranged in a randomized complete block design with four replications. The addition of inorganic materials to the California construction system maintained better creeping bentgrass performance through this study. These root zone systems offered better physical and chemical properties such as higher K_{sat}, air-filled porosity, field infiltration rates, lower bulk density, higher cation exchange capacity and plant nutrient levels, and lower chemical leaching concentrations. They also contributed to better quality and color for the creeping bentgrass.

INTRODUCTION

In recent years, amendments used in constructing putting greens have been critically evaluated in terms of their effects on root zone properties. There are many important physical characteristics to consider for turfgrass root zone mixtures. These include a high infiltration rate, adequate aeration, a high cation exchange capacity for retaining plant nutrients, high water retention, and low tendency for compaction. Due to the heavy traffic on putting greens, they are primarily constructed of sand to provide a root zone that is resistant to compaction. However, sands have lower cation exchange and water-holding capacities, and allow for excessive drainage rates (Beard, 1982).

Typically, the addition of certain organic materials as amendments to sand improves root zone properties. Peat is the most commonly used organic material and is recommended by the USGA. The advantages of amending sand with organic materials include increased water and nutrient retention (Hummel, 1993; Nus, 1994). Even though sand-based root zones with organic materials have some benefits, there are also some disadvantages. Disadvantages include organic matter accumulation and decomposition of organic materials over time (Habeck and Christians, 2000; McCoy, 1992), formation of a black layer over time (Berndt and Vargas, 1996), slightly higher tendency for compaction, lower water infiltration, and lower oxygen diffusion rate.

The use of inorganic amendments, such as porous calcined clays (Profile) and zeolite in putting green root zone mixtures, offer a number of benefits for improving sand-based root zones. They are less prone to compaction than organic materials and have higher cation exchange and water holding capacities without reducing non-capillary pore space (air-filled porosity). They are essentially permanent additions to the root zones, demonstrating very little break down over time (Habeck and Christians, 2000; McCoy, 1992). The addition of zeolite may improve the nutrient status of sand-based root zones, especially, selective retention of NH_4^+ and K^+ ions (Huang and Petrovic, 1996; Nus and Brauen, 1991; Petrovic, 1993). Superior establishment rates, reduced nitrate leaching, and increased nitrogen use efficiency have been reported for zeolite-amended sand-based root zones. Calcined clays (Profile), which are clays by nature, have high nutrient holding capacities, particularly for cations like the ammonium (NH_4^+) ion (Bigelow et al., 2000; Huang and

Petrovic, 1994). These inorganic materials may be a suitable replacement for organic matter (especially peat) as an amendment to sand-based putting greens.

An increasing number of golf courses are building greens using a California system which reduces costs by utilizing a 0.25 m to 0.3 m sand layer over native soil without a pea gravel sub-layer (Davis, et al., 1990). Recently, Hummel (1998) recommended the following performance criteria for materials used in a root zone of a California system green: a saturated hydraulic conductivity of 0.38-1.27 m hr^{-1}; total porosity of 35-55%, air-filled porosity of 15-30% and capillary porosity of 10-20%. Under saturated conditions, the gravel layer in USGA system greens provides rapid vertical drainage. In a California-style green, saturation implies that water must move laterally through the root zone for a substantial distance before reaching a drain line and exiting the system (Prettyman and McCoy, 1999). Thus, the same sand mixture placed over a gravel layer will yield greater maximum drainage rates during saturated conditions than when placed over subsoil. This difference is mediated by specifying a California system sand mixture with higher non-capillary porosity (air-filled porosity) and associated infiltration rates relative to USGA recommendations (USGA, 1993).

An important difference between the two construction methods for bentgrass greens in the humid transition zone of the United States may occur during infiltration. In a USGA green system, the textural difference between the gravel and sand-based root zone mixtures causes a large change in pore sizes, so water will not move freely into the gravel until the mixture above the gravel is saturated during conditions of water infiltration. However, water will drain freely through the USGA profile system during saturated conditions due to the presence of a pea gravel layer in the subsoil. In a California green system, the textural difference between the sand-based root zones and the underlying silt loam subsoil does not create as much of a change in pore sizes. The finer subsoil, if unsaturated, will allow water to move out of the sand-based root zone into the subsoil without the upper layer being saturated during water infiltration. Wet soils retain heat for long periods and are associated with a lack of oxygen (Huang et al., 1998a, b). Higher relative soil temperatures and less air imply greater root stress, and, most likely, more summer bentgrass decline. These different systems may cause differences in soil water content and temperature throughout the season.

Over time, the reduced air-filled porosity in a USGA green may not be a positive feature. This green system may result in lower air-filled porosity that decreases water (infiltration rate) and air (oxygen diffusion rate) movement in the putting green root zones (Habeck and Christians, 2000). Lower aeration and water movement cause greater root stress, and possibly more summer creeping bentgrass decline (Carrow, 1996). Before construction, physical properties for the sand-based root zones must meet USGA recommendations that include saturated hydraulic conductivity, bulk density, porosity, and water holding capacity. Over time, these physical properties will change due to an increased thatch layer and compaction as well as decomposition of the peat. Chemical properties, which include pH, organic matter content, cation exchange capacity, and nutrient content will be also changed over time.

The objective of this research was to compare these amendments and systems of green construction in terms of long term performance and resource efficiency by measuring responses such as: ‘Penncross’ creeping bentgrass (*Agrostis* *palustris* Huds.) quality and color, soil physical and chemical properties, and nitrogen and potassium leaching. Also, the mature putting green phase (4 years old) in this Chapter will be compared with results from a previous chapter (Chapter 3) which discussed the establishment and early maturation phases of creeping bentgrass development.

MATERIALS AND METHODS

A study was conducted at the MU Turfgrass Research Center to compare putting green physical and chemical root zone properties over time as affected by the amendments (sand, peat, Profile, and zeolite) and green construction systems (California and USGA green profile). Four treatments were compared: a California profile, a USGA profile, and two modified California profiles. The California profile, referred to as the California treatment, consists of 0.3 m of 100% sand over a 0.13 m layer of silt loam with a drain system (PVC pipe) at the top of the silt loam layer. The USGA profile, referred to as the USGA treatment, consists of 90% sand and 10% Dakota reed sedge peat by volume, with a 0.3 m root zone mixture over a 0.13 m pea gravel layer (2-7 mm diameter) over a drain. The sand/peat mixture was blended at the supplier, Capitol Sand, Jefferson City, MO. There were also two modified California profile green treatments, each consisting of a 0.25 m root zone mixture over a 0.18 m layer of silt loam with a drain at the top of the silt loam layer. The first modified profile, referred to as the California-P treatment, consists of 82% sand, 15% calcined clays (Profile^{TM}), and 3% humate; the second modified profile, referred to as the California-Z treatment, consists of 85% sand and 15% zeolite (ZeoPro^{TM} – Boulder, CO). These two mixtures were blended at the Turf Research Center with a small cement mixer. Two washed river sands were used for the different root zone mixtures in this study: a coarse to medium sand was blended with Dakota reed sedge peat for the USGA treatment and a medium to fine sand was used in the three California-style treatments. Their particle size analyses are presented in Table 3.1.

Treatments were established in 1.2 m by 1.2 m wooden boxes equipped so that drainage leachate could be monitored. The four treatments were arranged in a randomized complete block design with four replicates. The amended and unamended root zones were installed in August and 'Penncross' creeping bentgrass was seeded on September 27, 1998 at 49 kg ha^{-1}. From seeding through May 1999, each plot was supplied with 292.9 kg N ha^{-1}, 97.6 kg P ha^{-1}, and 732.3 kg K ha^{-1}, either from granular fertilizer or, in the case of the ZeoPro amended plots, as nutrients estimated to be available from the nutrient-charged ZeoPro (0.1-0.05-0.6). From June 1999 through November 2001 all plots received 467.0 kg N ha^{-1}, 89.8 kg P ha^{-1}, and 481.03 kg K ha^{-1}. The green was initially mowed to a height of 13 mm

(October 98), reduced to 9 mm (November 98), and then lowered to 6 mm (March 99). Since May 1999, it has been mowed at 4 mm. Mowing occurred four times weekly and clippings were collected. Irrigation was applied every two days based on atmometer-estimated evapotranspiration (measured evaporation adjusted for grass cover; Ervin and Koski, 1997).

The physical properties (4 years old green) of the root zone mixtures were analyzed in the laboratory. Samples (using soil core samplers, 76 mm diam. by 76 mm long) were taken from the creeping bentgrass green field plots 4 years after establishment. Saturated hydraulic conductivity (K_{sat}), air-filled porosity, capillary porosity (determined at –3 kPa soil water pressure; -30cm of soil water tension), total porosity, bulk density, and soil water release curve were conducted on samples, without subsurface pea gravel or silt loam layers. Saturated hydraulic conductivity in the laboratory was determined by the constant head method (Klute and Dirksen, 1986). Water retention over the range of pressures –1, -2, -3, -4, -5, and –6 kPa was determined by the water desorption method (Danielson and Sutherland, 1986). Data for bulk density and water retention were used to calculate total porosity, capillary porosity (at –3 kPa), and air-filled porosity (total porosity minus water retention at –3kPa) (USGA, 1993). Saturated field infiltration rates were determined with a thin-walled single ring infiltrometer (Bouwer, 1986). Irrigation water was applied to each plot to reach near saturated soil water conditions. Infiltration rates were then measured using a 0.13 m inside diameter ring installed to the root zone depth of 0.15 m. After one and half hours irrigation, infiltration rates were measured after 75 mm of water had infiltrated.

Creeping bentgrass quality and color ratings were taken monthly on a scale of 1 to 9, where 9=ideal, 7=acceptable, and 1=completely dead or dormant (Skogley and Sawyer, 1992). Root mass was sampled through 2000 to 2001 during the growing season. Sub-samples in each plot were collected with a 64 mm diameter probe to a 100 mm depth (3.22×10^5 mm^3 sample volume). Roots were separated from the root zone materials with a water wash through a metal screen. Roots were dried at 70 ^{O}C for 24 hours, weighed, and reported as kg m^{-3}.

Soil chemical properties were measured using standard tests at the University of Missouri Soil Testing Laboratory (Denning et al., 1998). Soil samples were collected from each plot (0 to 100 mm) one time per year at the beginning of the growing season in 2000 and 2001. These samples were air-dried and sieved (2 mm) before determining soil chemical properties. Nitrate and potassium leachate were collected and measured with standard laboratory tests (Pritzlaff, 1999; Sauter and Stoub, 1990). These were collected in 2 liter sample containers collected from the drainage leachate during selected weeks of the year.

Statistical analyses of the data were computed using analysis of variance with the Michigan State Statistical software program (MSTAT, 1988) and the GLM model in the SAS software program (SAS, 1990). Significant differences between treatment means were assessed using the LSD (Least Significant Difference) at the $\alpha = 0.05$ level.

RESULTS AND DISCUSSION

Root zone physical properties

Results of laboratory measurements from the field samples (without subsurface pea gravel or silt loam layers) for the saturated hydraulic conductivity (K_{sat}), air-filled porosity, capillary porosity, total porosity, and bulk density are shown in Table 5.1. Changes in results occurred over time compared with the prior to establishment measurements (Table 3.2).

Table 5.1. Physical properties of the zone mixtures from field samples (four years after construction; 2002).

Treatments	K_{sat}	Air-filled porosity	Capillary porosity	Total porosity	Bulk density
	m hr^{-1}	v/v, %	v/v, %	v/v, %	g cm^{-3}
California	0.40b	11.14b	30.59b	41.73c	1.54a
USGA	0.41b	8.83c	33.71a	42.55bc	1.52a
California-P	0.55a	12.89ab	31.37b	44.26a	1.48b
California-Z	0.56a	13.16a	30.52b	43.68ab	1.49b
$LSD_{0.05}$	0.07	1.99	2.16	1.63	0.03

Measurements were conducted on the sand-based root zone mixtures in the laboratory, without subsurface pea gravel or silt loam layers. Air-filled porosity and capillary porosity were determined at –3 kPa soil water pressure. K_{sat} : Saturated hydraulic conductivity.

All treatments exhibited increased capillary porosity (water-filled porosity) and a decreased air-filled porosity after four years (Table 5.1) when compared with the treatments at establishment (Table 3.2). The 10% peat mixture (USGA treatment) had the highest capillary porosity (33.71%) and the lowest air-filled porosity (8.83%) after four years. The 100% sand (California treatment) and 10% peat mixture (USGA treatment) had lower saturated hydraulic conductivity values in lab tests when compared to the 15% Profile (California-P treatment) and 15% zeolite (California-Z treatment) mixtures. Curtis and Pulis (2001) reported that a green has reached a “mature” condition when results showed that the following significant changes had occurred: the infiltration rate had dropped dramatically, air-filled porosity had decreased, and the water holding capacity had increased significantly. Habeck and Christians (2000) also reported that the change in the root zone physical properties over time included a reduction in K_{sat} and air-filled porosity, and an increase in water retention. Our results also follow these observations which implies that the greens were in a mature condition. The two inorganic amended root zone mixtures had lower bulk density values both at establishment and at maturation.

Addition of inorganic materials as amendments in putting greens appears to maintain higher K_{sat} value for the mature green phase. The higher K_{sat} for the Profile and zeolite mixtures were attributed to the lower bulk density. Our data indicated that the California system amended with inorganic materials resulted in better physical performance including maintaining higher K_{sat} and lower bulk density values for the mature greens.

Figure 5.1 presents the root zone water retention characteristics for the root zone samples. The trends in the water retention for all treatments were similar. When tension was increased beyond 40 cm (-4 kPa), little change was observed in the retention curves. Results at establishment are shown in Figure 3.1 and indicate that significant changes occurred in the shape of the water retention curve between 0 and 40 cm tension over the four years study. These differences were probably due to changes in pore size distribution during maturation of the root zone. Accumulation of a thatch layer at the surface was also observed for all treatments and probably caused some of these changes. Inadequate water retention in the root zone is one of the most limiting factors for turfgrass performance for mature greens (Habeck and Christians,

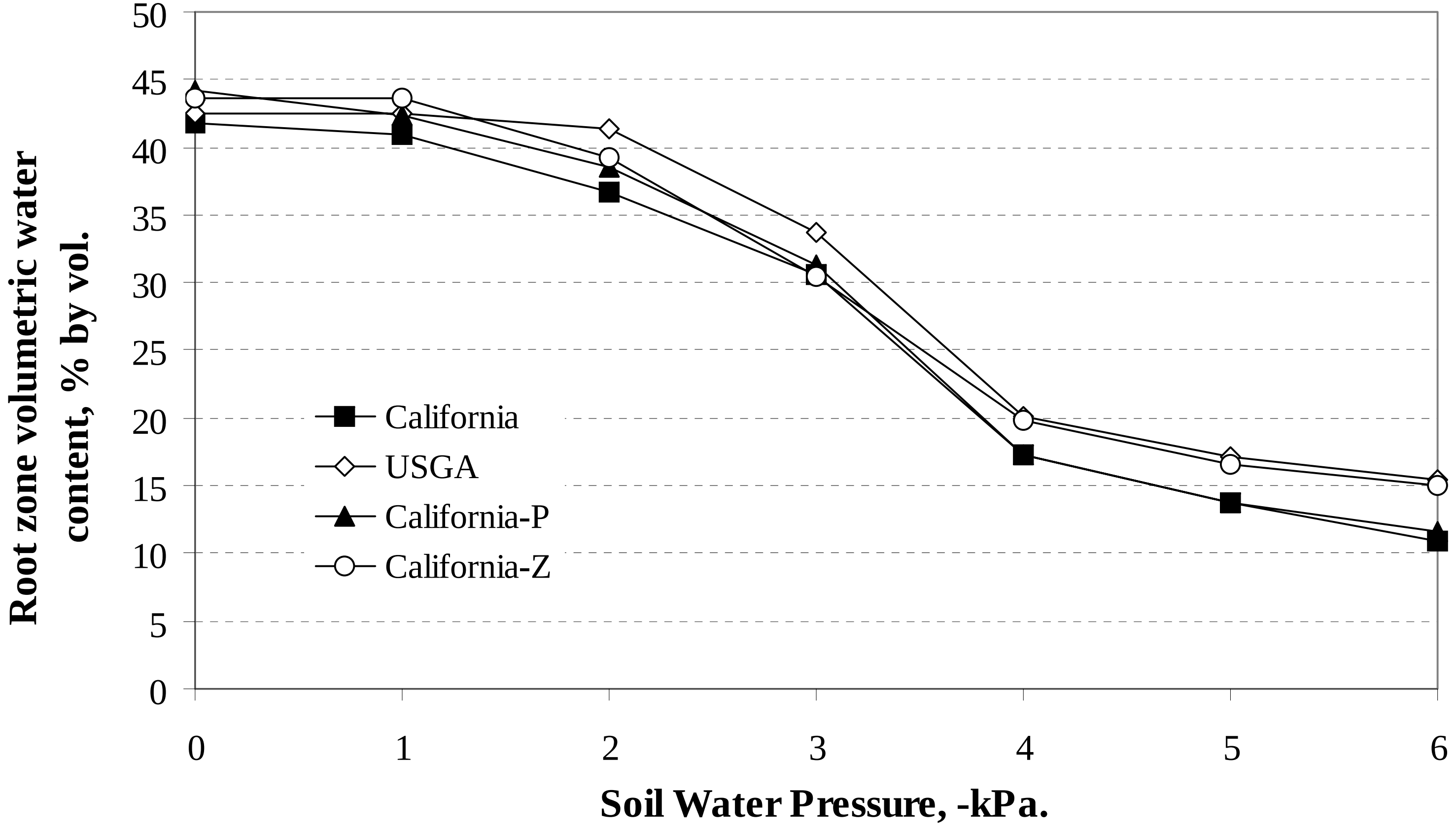

Figure 5.1. Water retention measured at different matric potentials for the selected treatments (mature green phase; after 4 years).

2000). Our results indicate that we found a 60% reduction in the air-filled porosity and a 60% increase in the capillary porosity after four years in the root zone (Table 5.1) when compared to results at establishment (Table 3.2).

Results of saturated field infiltration measurements for the study are shown in Figure 5.2. All treatments had a decrease in the infiltration rate over time. The California-Z treatment had the highest field infiltration rates throughout the study. The California treatment had the lowest infiltration rate which was attributed in part to its higher bulk density (Tables 3.2 and 5.1) and to the higher proportion of fine sand particles (Table 3.1) compared to the other treatments. The saturated field infiltration rates decreased over time, probably due to the increased accumulation of a thatch layer at the surface. Inorganic amendments such as Profile and zeolite were found to have higher infiltration rates three years after establishment. These amendments were found to increase air-filled porosity compared with 10% peat mixture (USGA treatment), decrease bulk density compared with 100% sand (California treatment) and 10% peat mixtures (Table 5.1), and thus were able to maintain higher infiltration rates over time.

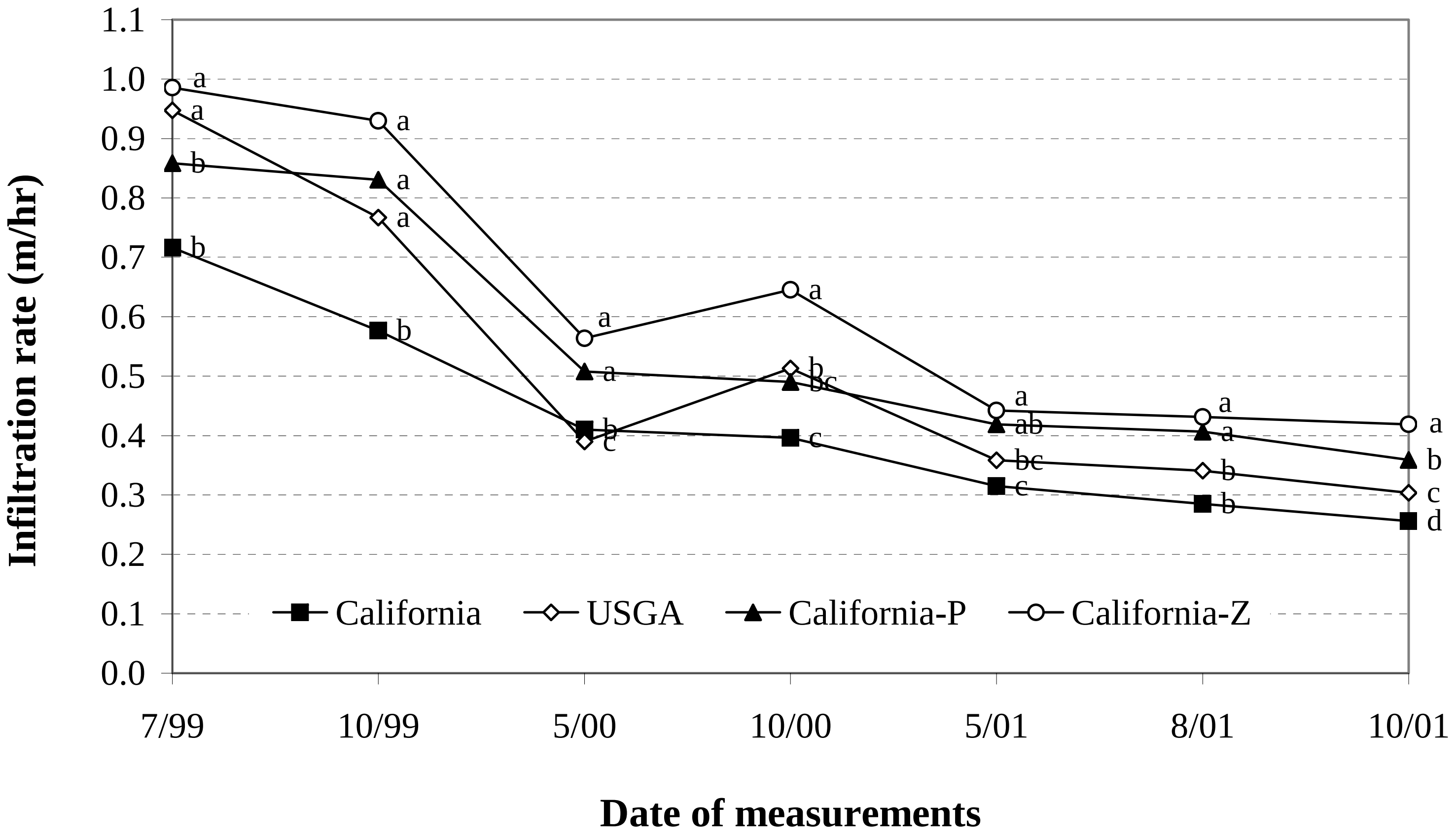

Figure 5.2. Field infiltration rates for the selected treatments from 1999 through 2001. Means separation were determined by LSD $_{0.05}$ and indicated by letters at each date.

Bentgrass growth

Tables 5.2 to 5.5 show creeping bentgrass color and quality ratings during the mature green phase of growth. From 2000 to 2001, the Profile and zeolite-amended (California-P and California-Z treatments) plots had higher overall color and quality ratings compared to the USGA treatment and had equal to or better ratings than the California treatment on all dates (except after the drydown period in July). Usually, there were no significant differences among the modified California treatments for the color and quality ratings during this study.

Table 5.2. Color ratings measured at selected times during the mature bentgrass green phase (2000).

Treatments	Color Rating+							
	4/28	5/29	6/25	7/25*	8/30	9/29	10/28	11/24
California	4.4b	4.6bc	5.3bc	4.0a	4.9bc	5.9a	5.6ab	5.3bc
USGA	4.6b	3.9c	4.9c	3.1b	4.0c	5.0b	5.0b	4.6c
California-P	5.3a	4.6b	5.6b	4.3a	6.3a	6.0a	5.9a	5.9ab
California-Z	5.3a	6.3a	6.1a	3.3a	5.9ab	6.4a	6.3a	6.3a
LSD $_{0.05}$	0.5	0.8	0.4	0.7	1.0	0.6	0.7	0.7

+Rating scale of 1 to 9, 1=completely dead or dormant, 6-7=acceptable, 9=ideal. *End of drydown (measured after no irrigation from June 24 to July 24, 2000).

Table 5.3. Quality ratings measured at selected times during the mature bentgrass green phase (2000).

Treatments	Quality Rating+							
	4/28	5/29	6/25	7/25*	8/30	9/29	10/28	11/24
California	4.1b	4.1c	4.8b	4.4a	5.1b	5.5b	5.3b	4.9c
USGA	3.9b	3.8c	4.8b	2.8b	3.9c	5.0c	4.8c	4.3d
California-P	5.0a	5.0b	5.3b	3.8ab	6.0a	5.6b	5.9a	5.4b
California-Z	5.1a	6.3a	6.0a	3.4ab	6.1a	6.1a	6.1a	6.1a
LSD $_{0.05}$	0.4	0.5	0.7	1.2	0.6	0.5	0.3	0.5

+Rating scale of 1 to 9, 1=completely dead or dormant, 6-7=acceptable, 9=ideal. *End of drydown (measured after no irrigation from June 24 to July 24, 2000).

Table 5.4. Color ratings measured at selected times during the mature bentgrass green phase (2001).

Treatments	Color Rating+						
	5/31	6/25	7/25*	8/31	9/28	10/31	11/30
California	4.9	6.0	5.6a	6.0a	6.1a	6.5a	5.8a
USGA	5.1	5.9	2.6b	2.3b	2.3b	2.8b	2.6b
California-P	5.6	6.3	5.9a	6.4a	6.4a	6.6a	6.1a
California-Z	5.5	6.1	5.3a	6.3a	6.4a	6.4a	5.9a
LSD $_{0.05}$	NS	NS	1.3	0.7	0.6	0.5	0.7

+Rating scale of 1 to 9, 1=completely dead or dormant, 6-7=acceptable, 9=ideal. *End of drydown (measured after no irrigation from June 24 to July 24, 2001). NS : Nonsignificant.

Table 5.5. Quality ratings measured at selected times during the mature bentgrass green phase (2001).

Treatments	Quality Rating+						
	5/31	6/25	7/25*	8/31	9/28	10/31	11/30
California	4.8b	5.9ab	5.1a	5.4a	5.8b	6.1b	5.8a
USGA	4.8b	5.8b	2.5b	2.3b	2.1c	2.6c	2.6b
California-P	5.8a	6.1ab	5.6a	6.3a	6.5a	6.6a	6.1a
California-Z	5.3ab	6.4a	5.6a	6.3a	6.4a	6.6a	5.9a
LSD $_{0.05}$	0.7	0.5	1.3	0.9	0.5	0.5	0.6

+Rating scale of 1 to 9, 1=completely dead or dormant, 6-7=acceptable, 9=ideal. *End of drydown (measured after no irrigation from June 24 to July 24, 2001).

The USGA treatment resulted in the lowest color and quality ratings for most dates both in 2000 and 2001. The Profile (California-P) and zeolite (California-Z) amended plots had darker color and higher quality (recovery) in August, 2000, after an imposed drought compared with the other two treatments. Color and quality ratings for these two treatments after the drought (August and later) in 2001 were equal to or better than the California treatment and consistently higher than the USGA treatment. After 30 days of no irrigation during 2001, the USGA treatment plots did not recover (retained brown or wilted shoot conditions). The California treatment color and quality ratings in 2000 and 2001 were generally equal to or lower than ratings compared to the California-P and California-Z treatments. Differences can be attributed to these two treatments having inorganic amendments that improved bentgrass color and quality from higher nutrient content.

During 2000 and 2001, root mass measurements were variable, making it difficult to reach any meaningful conclusions relative to differences among the treatments (Table 5.6). In 2000, the lowest levels of root mass were found at the end of the growing season in October. Although there were no significant differences in April 2001, root mass increased slightly when compared with measurements in October of the preceding year.

Table 5.6. Root mass (dry weight) for selected root zone treatments during the mature bentgrass green phase.

Treatments	Root mass (kg m^{-3})					
	4/27/00	7/28/00	10/18/00	4/27/01	7/27/01	10/19/01
California	3.71ab	3.85	2.10ab	2.70	1.26	2.05ab
USGA	3.08b	3.00	1.95b	2.83	1.48	1.78b
California-P	4.32a	3.74	2.10ab	2.61	1.39	2.05ab
California-Z	4.31a	3.56	2.59a	3.15	1.77	2.50a
LSD $_{0.05}$	0.89	NS	0.54	NS	NS	0.57

NS : Nonsignificant.

Generally, on dates when significant differences existed the California-Z treatment had significantly higher root mass compared to the USGA treatment. Again, 30 days after no irrigation during summer 2001 (from June 24 to July 24), root mass decreased with no significant differences among the treatments. However by October 2001, differences between the California-Z and USGA treatments were again present.

Root zone chemical properties

In both 2000 and 2001, soil pH was not different among the four treatments. The USGA, California-P, and California-Z treatments had increased values of CEC compared to the California treatment through this study (Tables 5.7 and 5.8). The California-Z treatment contained more available P and K than the California and USGA treatments, while the California-P treatment contained high amounts of available Ca and Mg relative to the California and USGA treatments. Greater nutrient retention due to the additions of inorganic materials (Profile and zeolite) as amendments for the root zone seemed to be associated with higher average quality and color ratings compared with the USGA treatment throughout 2000 and 2001. These results

Table 5.7. Chemical properties in the root zone during the mature bentgrass green phase (June 2000).

Treatments	pH	CEC	OM	P	Ca	Mg	K
		cmol kg^{-1}	%	mg kg^{-1}	cmol kg^{-1}	cmol kg^{-1}	cmol kg^{-1}
California	6.8	2.22b	0.45b	18.74c	1.75b	0.30c	0.16b
USGA	6.9	2.74a	0.70a	19.49c	2.20a	0.37bc	0.16b
California-P	6.9	3.15a	0.58ab	25.47b	2.44a	0.46a	0.23b
California-Z	6.9	3.02a	0.58ab	35.73a	2.18a	0.39ab	0.44a
LSD $_{0.05}$	NS	0.48	0.17	5.80	0.37	0.08	0.08

NS : Nonsignificant.

Table 5.8. Chemical properties in the root zone during the mature bentgrass green phase (May 2001).

Treatments	pH	CEC	OM	P	Ca	Mg	K
		cmol kg^{-1}	%	mg kg^{-1}	cmol kg^{-1}	cmol kg^{-1}	cmol kg^{-1}
California	6.9	2.76c	0.18b	21.90c	2.12c	0.41c	0.18b
USGA	6.8	3.72b	0.33a	23.75bc	2.97b	0.59b	0.15b
California-P	6.8	5.25a	0.35a	33.50ab	4.06a	0.79a	0.38b
California-Z	6.9	4.39b	0.13b	36.40a	3.03b	0.55bc	0.81a
LSD $_{0.05}$	NS	0.80	0.11	11.00	0.57	0.14	0.28

NS : Nonsignificant.

indicate that substituting Profile or zeolite for peat may allow for the maintenance of high quality bentgrass with less fertilizer inputs.

The USGA treatment had the highest nitrate leachate concentration for the November 1998 sampling (data in previous Chapter 3, Table 3.9). However two years after planting, results show that the USGA treatment had the lowest leachate concentrations (July 2000 measurement, Table 5.9). After three years (September 2001 measurement), the USGA treatment resulted in the highest nitrate leachate concentration which was probably due to a poorer recovery of the bentgrass after the drydown period in 2001 compared with 2000 (Table 5.9).

Table 5.9. Nitrate and potassium leachate concentrations during the mature bentgrass green phase.

Treatments	NO_3^- (mg L^{-1})		K^+ (mg L^{-1})	
	7/6/00	9/4/01	7/6/00	9/4/01
California	0.15bc	0.79b	13.85a	19.06a
USGA	0.09c	7.30a	17.17a	19.40a
California-P	0.74ab	0.63b	18.09a	22.32a
California-Z	0.98a	3.47b	6.05b	3.54b
$LSD_{0.05}$	0.65	3.47	4.54	3.59

Hull (2001), found that soil water samples collected below the root zone of killed turfgrass contained nitrate concentrations much greater than those from healthy plots within eight weeks following turfgrass death. Nitrate leachate concentrations from killed turfgrass were three times greater than those from healthy turf. Our results of nitrate leachate concentrations for the USGA treatment (lowest quality and color ratings) after drought periods in 2001 support Hull’s observation. The California-Z treatment, with its high affinity for potassium, consistently had the lowest potassium leachate concentrations both in 2000 and 2001.

In summary, the California-P and California-Z treatments had the higher air-filled porosity and lowest bulk density after four years compared with the USGA treatment. These treatments also had higher saturated field infiltration rates throughout the experiment. The California-P treatment had higher cation exchange capacities and Ca and Mg nutrient levels while the California-Z treatment maintained higher K levels. The USGA treatment had a higher level of nitrate leachate after drought stress in 2001 compared to the other treatments. The California-Z treatment had the lowest level of potassium leachate among the four treatments during both 2000 and 2001. The California-P and California-Z treatments produced bentgrass quality and color that were equal to or better than the California treatment, and consistently better than the USGA treatment, throughout the study. The better physical and chemical properties for the California-P and California-Z treatments probably resulted in the higher creeping bentgrass growth of these treatments compared with the USGA treatment during maturation. These results implied that lower applications of fertilizer and more efficient irrigation might be appropriate for the modified California systems in the hot and humid transition zone. Inclusion of these inorganic amendments in a California construction system may be superior replacements for peat as amendments for sand-based putting greens such as the USGA green system.

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