CHAPTER 3

Comparative Performance of Amendments and Construction Systems for Sand-based Greens during Bentgrass Establishment

ABSTRACT

Physical and chemical properties of the root zone and methods of green construction are important considerations for improving turfgrass quality for putting greens. This study compared ‘Penncross’ creeping bentgrass (*Agrostis palustris* Huds.) performance as affected by three root zone construction systems [California, U. S. Golf Association (USGA), and two modified California] with four amendments (sand, peat, Profile, and zeolite). Four treatments were developed: California (100% sand by volume), USGA (90% sand and 10% peat by volume), California-P (82% sand and 15% Profile with 3% humate by volume), and California-Z (85% sand and 15% zeolite by volume). The objective of this study was to determine if the alternative systems, which were California systems with inorganic amendments, would improve grass establishment and root zone chemical and physical properties, while reducing nitrate and potassium leaching during the turf establishment period. The four

treatments were arranged in a randomized complete block design with four replicates. The 15% Profile mixture (California-P treatment) without a gravel sub-layer had higher saturated hydraulic conductivity and lower bulk density compared to the other treatments. Also, the California-P treatment had higher capillary porosity at field capacity than the other treatments. Air-filled porosities were not significantly different among the four treatments. The California-Z treatment had saturated field infiltration rates that were equal to or higher than other treatments during the establishment period. The California-P treatment showed higher cation exchange capacity, percent organic mater content, and more available Ca, Mg, and K nutrient levels. The California-Z treatment had higher P nutrient content during bentgrass establishment. The USGA treatment initially had the highest level of nitrate leaching; however, no significant differences among treatments occurred after one year. Also, the USGA treatment had the highest potassium leachate concentration among the four treatments for the dates measured. In central Missouri’s humid and temperate climate, treatments with inorganic amendments produced the higher creeping bentgrass quality and color. This was attributed to better root zone physical and chemical properties of these treatments. These putting green construction systems also provided the greatest physical and chemical benefits during establishment and early maturation.

INTRODUCTION

Sand provides an ideal physical root zone media for bentgrass putting greens due to particle size distributions that provide a firm surface which remain highly permeable. However, sands have low water and nutrient retention properties. Organic and inorganic amendments are added to sand-based root zones to improve water and nutrient retention and to decrease bulk density (McCoy, 1991).

Although peat does fulfill the above three functions, it has some potential shortcomings. First, peats are not permanent root zone additions as they decompose over time. Second, the addition of peat to sand-based mixtures reduces air-filled porosity (McCoy, 1992) and peat is of limited effectiveness in reducing nitrate leaching (Brown et al., 1977).

The use of inorganic amendments for putting green root zone mixtures such as calcined clays and zeolites may offer a number of benefits for improving sand-based root zones. Some of these materials possess high cation exchange and water holding capacities without reducing air-filled pore space (Huang and Petrovic, 1994). Superior grass establishment (Nus and Brauen, 1991), reduced nitrate leaching, and increased nitrogen use efficiency (Huang and

Petrovic, 1994) have been reported for zeolite amended, sand-based root zones. Additionally, zeolite is a more permanent addition to the root zones, demonstrating good stability in weathering, impact, and abrasion tests (Petrovic and Wasiura, 1997). Given such properties, these inorganic materials may be an appropriate alternative for peat as an amendment for sand-based putting greens.

An increasing number of golf courses are also building greens in a California system style (Davis, et al., 1990), cutting costs by utilizing a 0.25-0.30 m sand layer over native subsoil and drainage system. With proper attention to sand and gravel particle size distributions, physical performance criteria, and drainage spacing, California system greens can be successful.

The objective of this study was to determine if the physical and chemical property differences inherent in three types of putting green construction systems would significantly affect the performance (root zone physical and chemical properties, bentgrass growth, and nutrient leaching concentrations) of ‘Penncross’ creeping bentgrass (*Agrostis palustris* Huds.) green during establishment and early maturity. Additional root zone putting green data will be presented in Chapter 5 to document quantitative physical and chemical effects after establishment.

MATERIALS AND METHODS

This experiment was arranged as a randomized complete block design with four replications. Four treatments were compared: a California profile, a USGA profile, and two modified California profiles. The California profile (referred to as the California treatment) consisted of 0.30 m of 100% sand over a 0.13 m layer of silt loam with a drain system (PVC pipe) which was placed below the root zone mixture layer. The USGA profile (referred to as the USGA treatment) consisted of 90% sand and 10% Dakota reed sedge peat (v/v), with a 0.30 m root zone mixture over a 0.13 m pea gravel layer (2 –7 mm diameter) and a drain at the bottom of the gravel layer. The sand/peat mixture was blended by the supplier, Capitol Sand in Jefferson City, MO. The first modified California profile (referred to as the California-P treatment) consisted of 82% sand, 15% calcined clays (Profile™), and 3% humate (to increase water and nutrient holding capacity) in a 0.25 m root zone mixture over a 0.18 m layer of silt loam with a drain which was placed below the root zone mixture layer. The second modified California profile (referred to as the California-Z treatment) consisted of 85% sand and 15% zeolite (ZeoPro™ – Boulder, CO) in a 0.25 m root zone mixture over a 0.18 m layer of silt loam with a drain which was placed below the root zone mixture layer. These latter root zone mixtures were blended on-site with a small cement mixer. Figure 3.1 shows the root zone profile of the four treatments.

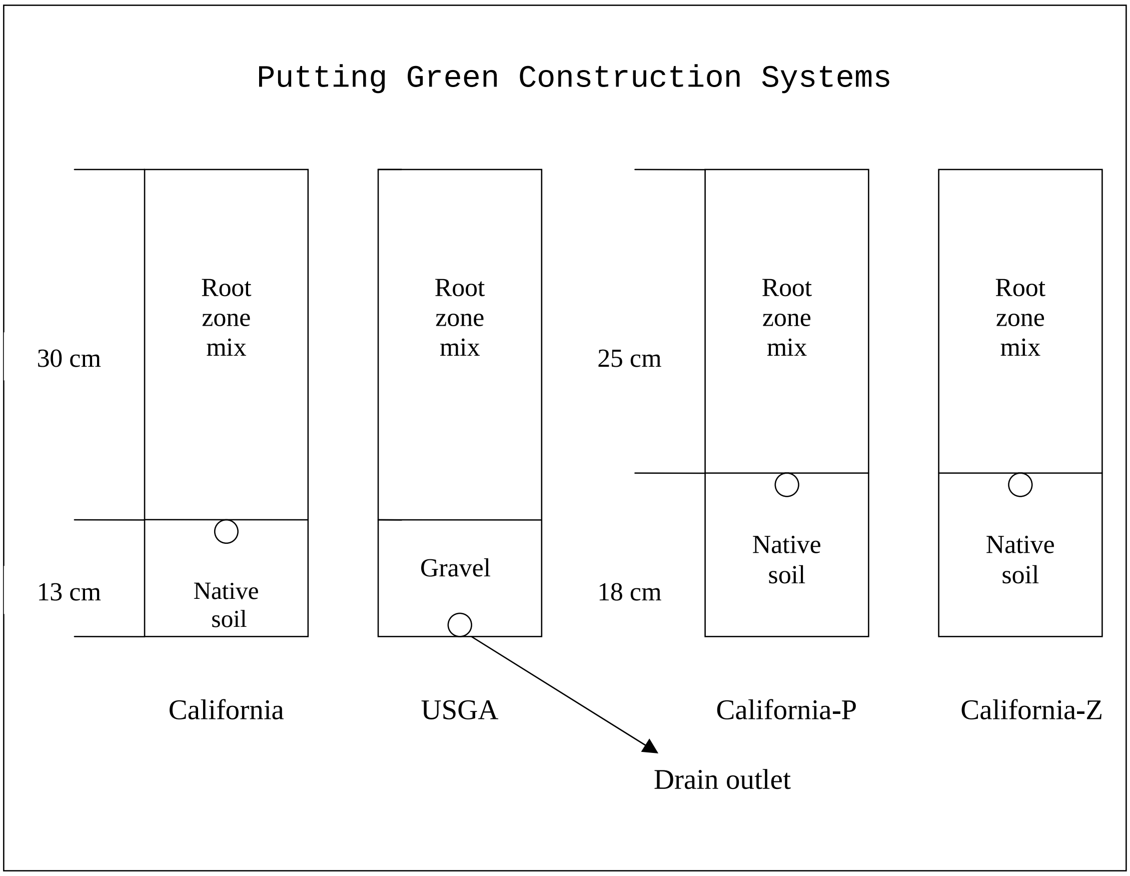

Figure 3.1. Diagram showing the green construction systems for the four treatments.

Two washed river sands were used for the different root zone mixtures in this study: one sand (C-M-S: coarse to medium sand) was blended with Dakota reed sedge peat for the USGA treatment and another sand (M-F-S: medium to fine sand) was used in the three California 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 amended and unamended root zones were installed in August and 'Penncross' creeping bentgrass was seeded on September 27, 1998 at 49 kg ha^{-1}. During the initial germination period, all plots were covered by a geotextile seed blanket to improve germination (7 days). From seeding through November 1999, each plot was supplied with 379 kg N ha^{-1},109 kg P ha^{-1}, and 903 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). 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 was mowed at 4 mm. Mowing occurred four times weekly and clippings were collected. Irrigation was applied every two days based on atmometer-estimated evapotranspiration (an evaporation measurement adjusted for evapotranspiration from grass; Ervin and Koski, 1997).

Table 3.1. Particle size distribution of amendments and root zone mixtures.

	Particle Size, diameter (mm)						
	Gravel	V.coarse S	Coarse S	Medium S	Fine S	V.fine S	Silt,Clay
	>2.0	1-2	0.5-1	0.25-0.5	0.1-0.25	0.05-0.1	<0.05
	%						
Amendments (prior to establishment)							
C-M-S	0.4	11.9	36.6	38.9	11.1	0.6	0.5
M-F-S	0.1	0.6	7.7	53.6	37.8	0.2	0.0
Profile	0.01	0.01	76.2	23.3	0.2	0.01	0.01
Zeolite	0.0	24.1	56.8	15.8	2.3	0.7	0.3
Root zone mixtures (prior to establishment)							
California	0.1	0.6	7.7	53.6	37.8	0.2	0.0
USGA	0.7	5.1	24.9	51.9	17.1	0.2	0.1
California-P	0.08	2.3	16.9	59.5	20.2	0.7	0.3
California-Z	0.1	5.1	16.5	50.6	27.3	0.3	0.1

V: Very, S: Sand, C-M-S: coarse to medium sand, M-F-S: medium to fine sand. USGA includes 90% inorganic (listed in this table) plus 10% peat by volume. California-P includes 97% inorganic plus 3% humate by volume. California-Z includes 100% inorganic by volume.

The physical properties (prior to establishment) of the root zone mixtures were analyzed in the laboratory. Physical analyses of the four root zone mixtures were conducted using soil cores (76 mm inside diameter, 76 mm length) and standard testing procedures for sand–based putting green root zones (USGA, 1993b). Measurements consisted of 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 curves were conducted on the sand-based root zone mixtures without subsurface pea gravel or silt loam layers. Saturated hydraulic conductivity was determined by the constant head method (Klute and Dirksen, 1986). Water retention of each mixture 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, 1993b). Saturated field infiltration rates were determined with a thin-wall single ring infiltrometer (Bouwer, 1986). Irrigation water was applied to each plot to reach near saturated soil water content. Infiltration rates were then measured using 0.13 m inside diameter rings inserted to a root zone depth of 0.15 m. Following one and half hours irrigation, to ensure saturated soil conditions, infiltration rates were measured after 75 mm of water had infiltrated.

The creeping bentgrass green establishment rate was estimated visually on a percent cover basis (bimonthly during grow-in). 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 in April and August of 1999. Two subsamples per 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 ^oC 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). Nitrate and potassium concentrations were measured with standard laboratory tests (Pritzlaff, 1999; Sauter and Stoub, 1990) from 2 liter samples collected from the drainage leachate during selected times of the establishment year. Soil samples were collected from each plot (0 to 100 mm) during May

1999, air-dried and sieved (2 mm), before determining soil chemical properties.

Statistical analysis of the data was computed using analysis of variance in the Michigan State Statistical software program (MSTAT, 1988) and the GLM model in the SAS 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

Table 3.2. Physical properties of the root zone mixtures prior to establishment.

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	0.73b	33.37	8.10c	41.47d	1.55a
USGA	0.56c	31.90	10.79b	42.70c	1.52b
California-P	0.81a	32.03	13.38a	45.41a	1.45d
California-Z	0.76b	33.74	10.59b	44.32b	1.48c
$LSD_{0.05}$	0.04	NS	1.77	1.03	0.019

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. NS : Nonsignificant.

Laboratory determinations showed that the 100% sand (California treatment), 15% Profile (California-P treatment), and 15% zeolite (California-Z treatment) root zone mixtures consisted of higher amounts of fine sand (> 20%) while the 10% peat root zone mixture (USGA treatment) consisted of higher amounts of coarse size sand (> 25%) (Table 3.1). Results of root zone physical properties (without subsurface pea gravel or silt loam layers) are shown in Table 3.2. The capillary porosity and air-filled porosity are very important properties of putting green root zone mixtures because these represent water and air that remain after gravitational drainage ceases and is available for plant growth. The USGA recommendations for the capillary and air-filled porosity are 15 - 25% and 15 - 30%, respectively (USGA, 1993a). Addition of organic or inorganic materials could increase root zone water content for the putting green root zones. Our results showed that three amendments (peat, Profile, and zeolite) increased the capillary porosity of the root zone mixtures in relation to the 100% sand treatment, resulting in higher water retention at –3 kPa (-30 cm of soil water tension). The Profile amendment with sand-based root zone had the highest capillary porosity at the –3 kPa (soil water pressure) in lab tests for the root zone mixtures without any root zone gravel or soil sub-layer. The air-filled porosities for the four treatments were not significantly difference prior to establishment. The air-filled porosity values for the 15% Profile, 100% sand, and 15% zeolite mixtures were about 4, 5 and 6% higher, respectively, compared with the 10% peat mixture. In the prior to establishment measurement, the root zones had higher air-filled porosity than capillary porosity.

The USGA treatment (10% peat mixtures) had the lowest saturated hydraulic conductivity (K_{sat}). The higher saturated hydraulic conductivity for the Profile and zeolite mixtures than the USGA treatment can be attributed to their higher total porosity and lower bulk density. The higher K_{sat} in the inorganic amended, sand-based root zone mixtures can be attributed to the macropores formed in the mixtures when compared to the organic amended root zone. This is mainly because water movement in the soil is controlled by the size and configuration of the pores (Ok, 1998).

The trends of root zone water retention of all soil cores were similar (Figure 3.2). As the tension increased, an abrupt drop in the retention curve occurred between 10 cm to 30 cm (-2 to –3 kPa). Rapid drainage enables putting greens to dry faster, hence, allowing more golf playing time and better aeration conditions for turf growth. This is why sand is recommended for the construction of putting green root zone mixtures. However, the amount of water released from the soil core slowed when tension increased beyond 30 cm (-3 kPa).

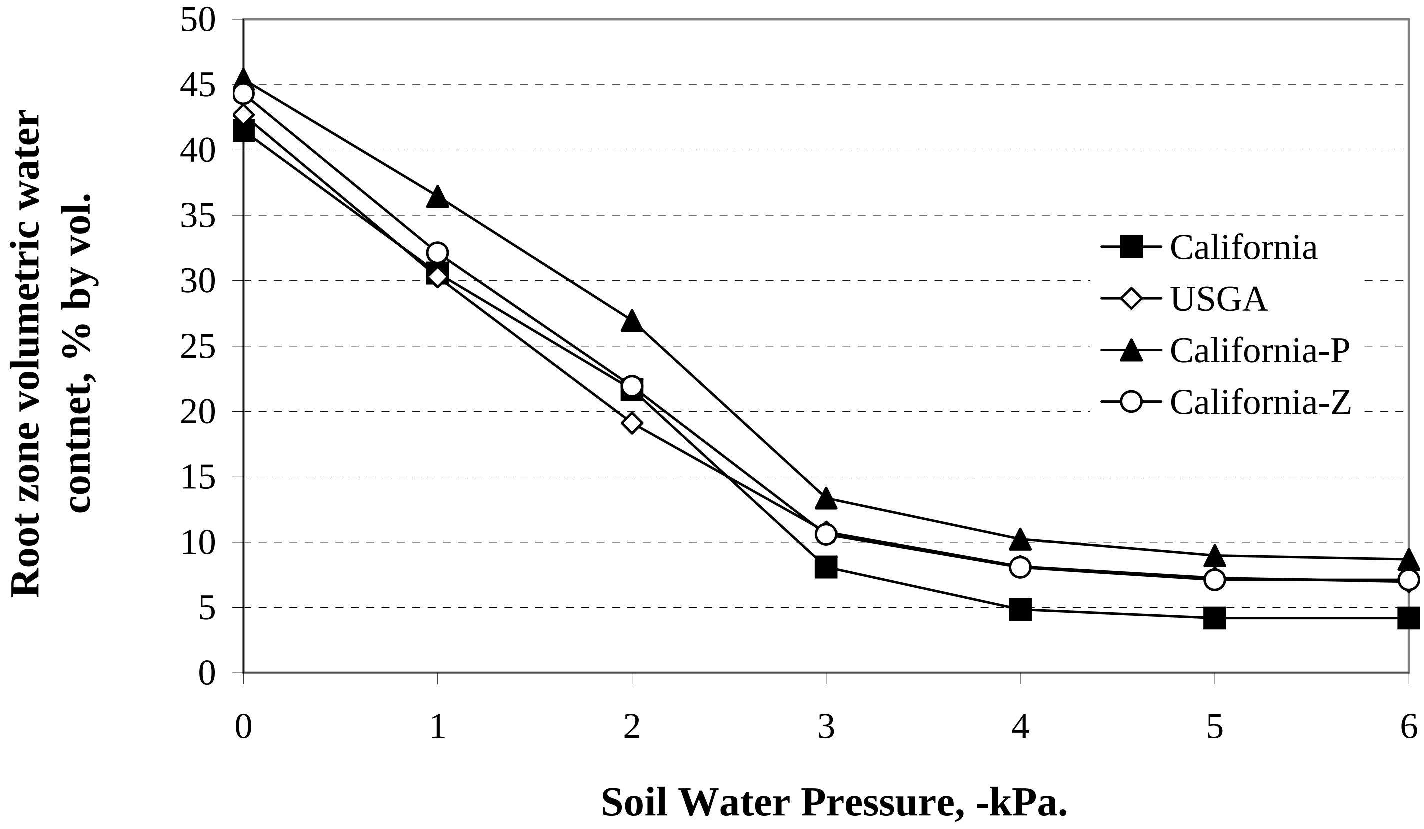

Figure 3.2. Water retention measured at different matric potentials for the selected treatments prior to establishment.

When tension exceeded 40 cm (-4 kPa), little change was observed in the retention curves. The USGA, California-P, and California-Z treatments had > 10% volumetric water content at –3 kPa (-30 cm of soil water tension) which is an adequate water content during the creeping bentgrass establishment period. Figure 3.2, in general, also indicates that soil mixtures amended with organic or inorganic materials had a higher water retentive capacity. Peat, Profile, and zeolite amended sand-based root zones had higher root zone volumetric water content after reaching –3 kPa (-30 cm of soil water tension) in relation to the 100% sand treatment.

The USGA treatment had higher saturated field infiltration rates compared to the California and California-P treatments 10 months after seeding (July measurement), > 0.90 m h^{-1} (Table 3.3). This early measurement of saturated field infiltration rates for the USGA treatment may be due to the higher hydraulic conductivity of the combined layers in the USGA system (with gravel sub-layer in the USGA treatment). The highest saturated field infiltration rate found for the California-Z treatment, which was equal to or better than the USGA treatment, could be attributed to its higher portion of the

Table 3.3. Field infiltration rates measured during establishment (1999).

Treatments	Infiltration rates (m hr^{-1})	
	July	October
California	0.72b	0.58b
USGA	0.95a	0.77a
California-P	0.76b	0.83a
California-Z	0.99a	0.93a
LSD $_{0.05}$	0.18	0.17

Infiltration rates were measured after 75 mm of water had infiltrated the root zones.

macro-pore space. Although the USGA treatment consisted of higher amounts of coarse sand (> 24%) (Table 3.1), its field infiltration rate declined the most compared with the California treatments 13 months after construction (October measurement). All treatments had a slight decrease in infiltration rate over this three month period, however, the California and USGA treatments had a greater reduction (19%) in field infiltration while the California-Z treatment had a 6% decrease. This reduction was not observed for the Profile treated plots. The decrease in field infiltration rates over time was probably due to decreased air-filled porosity and accumulation of organic matter and a thatch layer in the root zones (Habeck and Christians, 2000; Curtis and Pulis, 2001).

Bentgrass growth

Climatic conditions for bentgrass establishment during the fall of 1998 were good and bentgrass germination and development were excellent (Table 3.4). The California and USGA treatments had better early bentgrass establishment compared to the inorganic amended treatments (California-P and California-Z treatments).

Table 3.4. Estimated percent bentgrass cover during establishment.

Treatments	10/14/98 7 DAS*	12/2/98 66 DAS	4/21/99 177 DAS	6/14/99 299 DAS
	% Cover			
California	46a	74	88	100
USGA	36ab	73	80	100
California-P	19b	58	75	100
California-Z	15b	69	83	100
LSD $_{0.05}$	27	NS	NS	NS

*DAS : Days after seeding. NS : Nonsignificant.

No differences among treatments occurred three months after seeding. Waltz and McCarty (2000) reported that an 85% sand with 15% peat (v/v) root zone mixture established bentgrass more quickly than 100% sand or various mixtures of sand with inorganic amendments. They concluded that the peat's added water holding potential allowed for improved germination. However, in our study, the 100% sand (California treatment) had the highest initial ground cover. This was most likely associated with the fact that during the initial germination period, all plots were covered by a geotextile seed blanket which improved germination. Additionally, the California (100% sand) treatment had the higher fine sand content (> 37%) which may have allowed greater retention of surface water and resulted in a higher rate of initial development (Tables 3.1 and 3.4). Our results agree with Waltz and McCarty (2000) who reported that nine months after seeding, all plots had adequate cover. Further, our results showed that there were no significant differences among the treatments from 66 days after seeding until 100% cover on all plots (Table 3.4).

During 1999, zeolite-amended (California-Z treatment) plots at most dates had the highest color and quality ratings (Tables 3.5 and 3.6). Bentgrass and bermudagrass were found to establish more rapidly and had greater grass quality and color with ZeoPro-amended root zones when compared with 100% sand and other root zone mixtures (Andrew et al., 1999). Our results also suggest that the highest late fall color (12/2/98) of the California-Z treatment plots may be due to zeolite having 0.1% nitrogen. Early spring color (4/26/99) was also highest for the California-Z treatment (Table 3.5). By late spring (6/14/99), full cover and higher color ratings gave the California-Z treatment the greatest overall quality (Table 3.6).

Table 3.5. Color ratings measured at selected times during bentgrass establishment (1998 – 1999).

Treatments	Color Rating*							
	12/2	4/26	6/14	7/21	8/19	9/21	10/22	11/22
California	5.5b	5.0b	7.1ab	6.9bc	6.8b	6.4b	6.5b	5.6bc
USGA	5.5b	4.8b	6.8b	6.4c	6.4b	6.4b	6.0b	5.1c
California-P	5.5b	5.3b	6.9ab	7.0ab	6.8b	6.6b	6.4b	6.0b
California-Z	7.0a	7.3a	7.3a	7.5a	8.1a	7.9a	7.5a	7.0a
LSD $_{0.05}$	1.1	1.2	0.4	0.6	0.6	0.4	0.6	0.8

*Rating scale of 1 to 9, 1=completely dead or dormant, 6-7=acceptable, 9=ideal.

Table 3.6. Quality ratings measured at selected times during bentgrass establishment (1999).

Treatments	Quality Rating*						
	6/14	7/21	8/19	9/21	10/22	11/22	12/23
California	6.9b	6.6b	6.6b	6.6bc	6.6b	5.6bc	4.5b
USGA	6.6b	6.1c	6.1b	6.4c	6.1c	5.5c	4.4b
California-P	6.4b	6.6b	6.6b	7.0b	6.8b	6.3ab	4.8b
California-Z	7.5a	7.3a	8.0a	8.0a	7.4a	6.8a	5.3a
$LSD_{0.05}$	0.5	0.2	0.5	0.6	0.4	0.7	0.4

*Rating scale of 1 to 9, 1=completely dead or dormant, 6-7=acceptable, 9=ideal.

Table 3.7. Root mass (dry weight) for selected root zone treatments during establishment.

Treatments	Root mass (kg m^{-3})	
	4/27/99	8/4/99
California	2.71a	4.88a
USGA	2.08ab	5.05a
California-P	1.71b	3.71ab
California-Z	2.20ab	2.71b
$LSD_{0.05}$	1.0	1.8

At seven months after seeding (April 1999), root mass was significantly lower for the California-P treatment compared to the other treatments (Table 3.7). In August 1999, the California-Z treatment had a root mass that was equal to the California-P treatment but lower than the California and USGA treatments. However, as expected, all treatments increased in root mass relative to the April measurement.

Root zone chemical properties

There were no differences in soil pH in the root zones during the establishment period (Table 3.8). All three amendments increased the CEC (cation exchange capacity)

Table 3.8. Chemical properties in the root zone during the establishment (May 1999).

Treatments	pH	CEC	OM	P	Ca	Mg	K
		cmol kg^{-1}	%	mg kg^{-1}	cmol kg^{-1}	cmol kg^{-1}	cmol kg^{-1}
California	7.3	2.21c	0.15d	13.74c	1.68c	0.27c	0.25c
USGA	7.2	3.33b	0.73b	15.66c	2.65b	0.40b	0.28c
California-P	7.1	5.57a	0.88a	21.99b	4.26a	0.74a	0.55a
California-Z	7.3	3.50b	0.30c	30.74a	2.66b	0.43b	0.40b
$LSD_{0.05}$	NS	0.37	0.09	4.42	0.31	0.07	0.07

NS : Nonsignificant.

relative to the 100% sand plots. The USGA, California-P, and California-Z treatments had increased values of CEC compared to the California treatment with the highest CEC value in the California-P treatment. Cation exchange capacity is an important property for holding plant nutrients in the root zones. Both inorganic amendments (Profile and zeolite) for sand-based root zones increased the CEC that may enhance the root zone plant nutrient status. Our results showed that the treatments with higher CEC also had higher root zone plant nutrient contents. The California-Z treatment contained more available P than the others, while the California-P treatment also contained high amounts of available Ca, Mg, and K relative to the California and USGA treatments. Nus and Brauen (1991) reported that the addition of clinoptilolitic zeolite improved the nutrient status (especially NH_4^+ and K^+) of sand-based root zones and provided greater bentgrass establishment rates. Our results demonstrated that higher nutrient levels due to the addition of zeolite were associated with the highest average color and quality ratings over the establishment period (Tables 3.5 and 3.6). Greater nutrient retention due to the additions of Profile and zeolite seemed to be associated with higher average color and quality ratings during the establishment period. These results indicate that substituting Profile and zeolite for peat may allow for the maintenance of higher quality creeping bentgrass with less fertilizer inputs.

During the initial establishment period, when creeping bentgrass was in an immature stage, there were shallow and few grass roots, and less of a thatch layer in the root zones. During this period, the USGA treatment had the highest nitrate leachate concentrations while the California-P treatment had the lowest leachate concentration for the November 1998 sampling (Table 3.9). However, 9 to 12 months after seeding, the results showed that there were no significant differences in nitrate

Table 3.9. Nitrate and potassium leachate concentrations during bentgrass establishment.

Treatments	NO_3^- (mg L^{-1})			K^+ (mg L^{-1})		
	11/9/98	6/18/99	9/2/99	11/9/98	6/18/99	9/2/99
California	44.1b	0.25	0.20	14.70ab	33.38b	38.85b
USGA	64.6a	0.23	0.18	18.63a	84.53a	49.30a
California-P	11.2c	1.90	0.45	13.18b	19.00bc	35.75b
California-Z	46.5b	2.93	0.34	13.11b	10.50c	4.58c
$LSD_{0.05}$	11.91	NS	NS	4.64	21.94	10.31

NS : Nonsignificant.

leaching among the treatments. Nitrate (NO_3^-) is highly soluble in soil solution and readily moves downward through the root zone. Nitrate leachate has been noted to be especially pronounced in developing turfgrass as compared to mature turfgrass (Hull et al., 2001). Brauen and Stahnke (1995) found that during the first fall following seeding and when the creeping bentgrass was very immature, nitrate leachate concentrations were increased. Our results also demonstrated that nitrate leachate concentrations increased at the first late fall sampling (11/09/98) following seeding, whereas they were drastically decreased during the following growing season (Table 3.9).

The California-Z treatment, with its high affinity for potassium, had the lowest K^+ leachate concentrations, whereas the USGA treatment had the highest measured losses in June and September 1999 (Table 3.9). Losses through the USGA treatment may be more associated with large flushing events through the gravel layer under the root zone for this treatment during the establishment period and early maturation. Nitrate leachate concentrations through the sand-based putting green root zones are an important concern, especially during the creeping bentgrass establishment when grass is immature. Both of the inorganic amended sand-based root zones with the California construction system minimized nitrate and potassium leaching through the root zone profile during the establishment period.

In conclusion, the California-P and California-Z treatments showed the best root zone performance of creeping bentgrass, which was attributed to better physical and chemical properties when compared to the California and USGA treatments. These properties were improved by the addition of Profile and zeolite within the California system. In particular, the addition of zeolite allowed for better bentgrass quality and color during the establishment period. These results indicate that inorganic materials may serve as a preferred amendment alternative to organic amendments for improving the performance of sand-based putting greens. The California system may reduce chemical leaching concentrations when compared to the USGA green system that includes a gravel sub-layer in the root zone. This means that the California putting green method may improve plant nutrient status during turfgrass establishment.

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