

&lt;국의 우수논문&gt;

## Amendments and Construction Systems for Improving the Performance of Sand-Based Putting Greens

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### ABSTRACT

Physical and chemical properties of root zone mixes 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 with three amendments (sand, peat, and zeolite). The objective of this study was to determine if an amended California construction system would improve green performance during establishment (1998-1999) and maturation (2000-2001). Three treatments were tested: California (100% sand), USGA (90% sand and 10% peat, v/v), and California-Z (85% sand and 15% zeolite, v/v). Treatments were arranged in a randomized complete block with four replicates. Physical and chemical properties of the root zone and bentgrass performance were compared for the treatments. The California-Z treatment had the highest saturated hydraulic conductivity, field infiltration rate and the lowest bulk density. It also had the highest cation exchange capacity and plant available nutrient concentrations among the three treatments. The California-Z treatment produced bentgrass quality and color during green establishment and maturation that were equal to or higher than the California treatment, and consistently higher than the USGA treatment. The addition of an inorganic amendment to the California system improved physical and chemical properties of the root zone and improved quality and color of bentgrass during green establishment. During green maturation, creeping bentgrass in the California-Z treatment was equal (6 of 15 sampling dates) or 20% higher (9 of 15 dates) in quality compared to the California system.

### INTRODUCTION

Sand provides an ideal physical root zone media for bentgrass putting greens due to its particle size distribution that provides a firm surface for foot traffic while remaining highly permeable. However, sands have low water and nutrient retention properties.

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Organic and inorganic amendments are often added to sand-based root zones to improve water and nutrient retention and to decrease bulk density (Hummel, 1993; Huang and Petrovic, 1994).

Although peat fulfills the above three functions, it has some potential shortcomings. First, it is thought that peat decomposes over time and may therefore not be a permanent addition. Second, the addition of peat to sand-based mixes reduces water and air movement in the root zone over time (McCoy, 1992; Habeck and Christians, 2000).

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). Creeping bentgrass establishment (Nus and Brauen, 1991) was reported to be significantly higher (36%) for zeolite amended sand-based root zones compared to sawdust amended root zones; however establishment with zeolite amended root zones was not significantly better than peat amended root zones. Additionally, zeolite is a more permanent addition to the root zone, demonstrating good stability in weathering, impact, and abrasion tests (Petrovic and Wasiura, 1997). The addition of zeolite has improved the nutrient status of sand-based root zones, especially, selective retention of  $\text{NH}_4^+$  and  $\text{K}^+$  ions (Nus and Brauen, 1991; Petrovic, 1993). Given such properties, this inorganic material may be an alternative for peat as an amendment for sand-based putting greens.

An increasing number of golf courses are building greens in a California construction system which reduces costs by utilizing a 0.25 m to 0.30 m sand layer over native soil without a pea gravel sub-layer (Davis, et al., 1990). With proper attention to sand particle size distributions, physical performance criteria, and drainage spacing, the California system greens can be successful. Recently, Hummel (1998) recommended criteria for physical properties (Table 1) for a root zone with a California system green.

Root zones for USGA construction systems after three or four years usually have increased water retention and reduced air-filled porosity compared to systems at establishment; this is usually not considered to be a positive feature. The reduction in air-filled porosity for the mature USGA green construction system will decrease water (infiltration rate) and air (oxygen diffusion rate) movement in the putting green root zone (Habeck and Christians, 2000). Decreases in air and water movement can cause an increase in root stress, and possibly more summer creeping bentgrass decline (Huang, et al., 1998). Before construction, physical properties for the sand-based root zone must meet USGA recommendations that include saturated hydraulic conductivity, bulk density, porosity, and water holding capacity (USGA, 1993). Over time, these physical

**Table 1.** Root zone physical property specifications and measured properties prior to establishment for USGA and California construction systems.

Treatments	K <sub>sat</sub>	Air-filled porosity	Capillary porosity	Total porosity
	m hr <sup>-1</sup>	v/v, %	v/v, %	v/v, %
Requirements for USGA and California Systems				
California	0.381.27	15-30	10-20	35-55
USGA	0.15-0.30 (normal)	15-30	15-25	35-55
	0.30-61 (accelerated)			
Root Zone Mixes*				
California	0.58	26.3	13.1	39.4
USGA	0.28	16.3	21.7	38.0
California-Z	0.62	28.5	14.8	43.3

\*Root zone physical properties were analyzed by Tifton Physical Soil Testing Laboratory (Tifton, Georgia).

K<sub>sat</sub>, saturated hydraulic conductivity

properties in the USGA root zone will change due to an increased thatch layer as well as decomposition of the peat. Root zone chemical properties including pH, organic matter content, cation exchange capacity, and nutrient concentrations may also change; although these properties may improve with time.

The objective of this study was to evaluate creeping bentgrass performance during establishment and maturation and evaluate changes in root zone physical and chemical properties influenced by root zone mixes and green construction systems.

## MATERIALS AND METHODS

A study was conducted at the University of Missouri-Columbia Turfgrass Research Center in the field to compare three treatments for sand-based root zone greens. This experiment was arranged as a randomized complete block design with four replications. Three treatments were compared: a California profile, a USGA profile, and modified California profile. The California profile (referred to as the California treatment) consisted of 30 cm of 100% sand over a 13 cm layer of silt loam with a drain that was placed at the base of the sand-based root zone. The USGA profile (referred to as the USGA treatment) consisted of 90% sand and 10% Dakota reed sedge peat (v/v), with a 30 cm root zone mix over a 13 cm pea gravel layer (2 - 7mm diameter) with a drain at the bottom of the gravel layer. The sand/peat mix was blended by the supplier. The modified California profile (referred to as the California-Z treatment) consisted of 85% (v/v) sand and 15% (v/v) zeolite (ZeoPro™ - Boulder, CO) in a 25cm root zone layer over a 18 cm layer of silt loam with a drain placed at the base of the root zone layer. This

latter root zone mixture was blended with a small cement mixer. Two sands were used for the different root zone mixes for the three treatments in this study: One sand (coarse to medium sand) was blended with Dakota reed sedge peat for the USGA treatment and the other sand (medium to fine sand) was used in the two California treatments. A finer sand was used with the California system since California specifications allow a higher fine sand content (Table 2) and since this system does not have peat added to the root zone. The particle size analyses for the root zone mixes are presented in Table 2.

Treatments were established in 1.2m by 1.2m wooden boxes with the greens at the ground level. The amended and unamended root zones were installed in August and Pennncross creeping bentgrass was seeded on September 27, 1998 at 49 kg ha<sup>-1</sup>. From seeding through May 1999, each plot was supplied with 292.9 kg N ha<sup>-1</sup>, 97.6 kg P ha<sup>-1</sup>, and 732.3kg K ha<sup>-1</sup>, 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). Equal fertilizer applications for the plots were done monthly from April through December each year with heavier applications during the growing season; no fertilizer was applied from January through March. From June 1999 through November 2001 all plots received 467.0kg N ha<sup>-1</sup>, 89.8kg P ha<sup>-1</sup>, and 481.03kg K ha<sup>-1</sup>.

The green was initially mowed at 13mm (October 98), reduced to 9mm (November 98), and then lowered to 6mm (March 99). Since May 1999, it has been mowed at 4mm. Mowing occurred four times weekly with clippings collected. Top dressing was applied to

**Table 2.** Particle size distribution (PSA) requirements of the root zone for USGA and California systems. Measured PSA for zeolite amendment and root zone mixes prior to establishment.

	Particle Size, diameter(mm)						
	Gravel	VCS*	CS	MS	FS*	VFS*	Silt+Clay
	>2.0	1-2	0.5-1	0.25-0.5	0.1-0.25	0.05-0.1	<0.05
%							
Requirements for USGA and California Systems							
California	Gravel+VCS<10		CS+MS+FS=82 - 100			VFS+Silt+Clay<8	
USGA	Gravel+VCS<10		CS+MS>60		FS<20	VFS+Silt+Clay<10	
	(Gravel<3)		(VFS<5; Silt<5; Clay<3)				
Zeolite Amendment							
Zeolite	0.0	24.1	56.8	15.8	2.3	0.7	0.3
Root Zone Mixes							
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-Z	0.1	5.1	16.5	50.6	27.3	0.3	0.1

\*VCS: Very coarse sand, CS: Coarse sand, MS: Medium sand, FS: Fine sand, VFS: Very fine sand.

\*FS is 0.15-0.25 mm and VFS is 0.05-0.15 mm for USGA construction systems.

\*\*USGA includes 90% inorganic (listed in this table) plus 10% peat by volume.

the plots four times each year of the study during the growing season (first week of June, July, August and September). Materials for topdressing were the same as the root zone mixtures. Aeration was done in the middle of July each year of the study. Irrigation water was applied every two days during the morning after mowing based on atmometer estimated evapotranspiration (Ervin and Koski, 1997). No irrigation was applied during late June through late July in 2000 and 2001 (30days) to evaluate the effects of drought stress periods on bentgrass performance.

The root zone physical properties were analyzed by Tifton Physical Soil Testing Laboratory (Tifton, Georgia) using ASTM F1815 (2000). The expected ranges for the physical properties of the California and USGA root zones are shown in Table 1. The California, USGA, and California-Z root zone mixes met the criteria with respect to physical properties (Table 1).

Additional physical analyses of the root zone mixes were conducted using soil cores (76 mm diam. by 76mm long) taken from the root zone mixes in the field and analyzed using physical property testing procedures (Klute and Dirksen, 1986; Danielson and Sutherland, 1986). These samples were collected from the 1.0 to 9.0 cm depth. These additional measurements were made in the Soil Physics Laboratory at the University of Missouri. Core samples were prepared with materials used during the establishment of the plots and compacted to densities similar to the plots at establishment. Intact core samples were removed from the plots at the end of the field experiment (May 2002). Saturated hydraulic conductivity (Ksat), air-filled porosity, capillary porosity (determined at 3 kPa soil water pressure; 30 cm of soil water tension), total porosity, and bulk density were conducted on the sand-based root zone mixes, 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 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 -3kPa), and air-filled porosity (total porosity minus water retention at -3kPa).

Field infiltration rates were determined two times per year with a thin-wall single ring infiltrometer (Bouwer, 1986). Measurements were taken in October of all three years of the study and also during May or July. Irrigation water was applied to each plot to reach near saturated soil water content. Infiltration rates were measured using 13cm inside diameter rings inserted to a root zone depth of 15cm. Following one and half hours of irrigation to ensure that the root zones were as close to saturation as possible, infiltration rates were measured after 75mm of water had infiltrated.

Establishment rate was estimated visually on a percent cover basis (bimonthly during

grow-in). Quality and color ratings were taken monthly during the growing season each year. A scale of 1 to 9 was used, where 9=ideal, 7=acceptable, and 1=completely dead or dormant (Skogley and Sawyer, 1992).

Soil chemical properties were measured on soil samples taken each year during May using standard tests at the University of Missouri Soil Testing Laboratory (Denning et al., 1998). Soil samples were collected from each plot (0 to 100mm) each year at the beginning of creeping bentgrass growing season. These samples were air-dried and sieved (2mm) before determining soil chemical properties. All data were analyzed with MSTAT (MSTAT, 1988) to detect differences among treatment effects. Means were separated with Fishers protected least significant difference (LSD) test at a 95% probability level.

## RESULTS AND DISCUSSION

### Physical properties of the root zone

Results of laboratory measurements for the saturated hydraulic conductivity (Ksat), air-filled porosity, capillary porosity, total porosity, and bulk density are shown in Table 3. Samples from the initial period were packed samples attempting to replicate conditions at establishment. Our results showed that both amendments (peat and zeolite) during the initial establishment period increased the capillary porosity of the root zone mixtures compared to the 100% sand, resulting in higher water retention at -3 kPa (Table 3a). The 10% peat mixture had capillary porosity that was equal to or better than the California-Z and higher than the California treatment. The air-filled porosity values for the 100% sand and 15% zeolite mixtures were not statistically different compared with the peat mixture. The higher saturated hydraulic conductivity for the pure sand (California) and zeolite mixtures (California-Z) relative to the peat mixture (USGA) can be attributed to the absence of peat in these treatments.

Curtis and Pulis (2001) reported that the 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 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 Ksat 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 3.5years after establishment (Table 3b). All treatments were observed to have an increased capillary porosity (water-filled porosity) and a decreased air-filled porosity 3.5years after

**Table 3a.** Physical properties of the root zone mixes during the initial establishment period

Treatments	K <sub>sat</sub>	Air-filled porosity	Capillary porosity	Total porosity	Bulk density
	m hr <sup>-1</sup>	v/v, %	v/v, %	v/v, %	gcm <sup>-3</sup>
California	0.73a	33.37	8.10b	41.47b	1.55b
USGA	0.56b	31.90	10.79a	42.70b	1.52b
California-Z	0.76a	33.74	10.59a	44.32a	1.48c
LSD <sub>0.05</sub>	0.05	NS	1.71	1.36	0.01

NS, nonsignificant.

**Table 3b.** Physical properties of the root zone mixes from intact field samples 3.5 years after construction(May 2002).

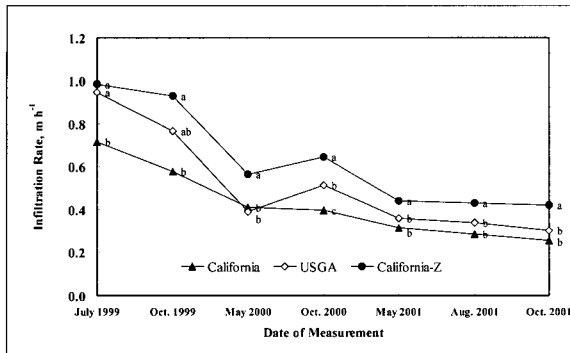
Treatments	K <sub>sat</sub>	Air-filled porosity	Capillary porosity	Total porosity	Bulk density
	m hr <sup>-1</sup>	v/v, %	v/v, %	v/v, %	gcm <sup>-3</sup>
California	0.40b	11.14a	30.59b	41.73b	1.54a
USGA	0.41b	8.83b	33.71a	42.55ab	1.52a
California-Z	0.56a	13.16a	30.52b	43.68a	1.49b
LSD <sub>0.05</sub>	0.02	2.12	2.77	1.22	0.02

Measurements were conducted on the sand-based root zone mixes 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. Ksat : Saturated hydraulic conductivity.

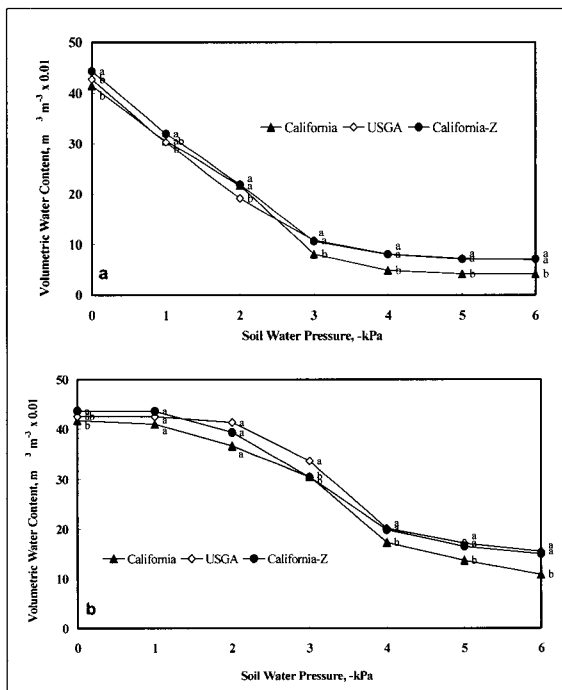
construction (Table 3b) when compared with the treatments at the initial establishment period (Table 3a). The peat mixture had the highest capillary porosity (33.71%) and the lowest air-filled porosity (8.83%) after 3.5 years (Table 3b). The 100% sand and peat mixtures had lower saturated hydraulic conductivity and lower air-filled porosity in lab tests when compared to the zeolite mixture. All treatments had similar bulk density and porosity values throughout the experiment with the inorganic amended root zone mixture having the lowest bulk density and highest porosity. Addition of an inorganic amendment to the putting green root zone appears to maintain a higher Ksat and air-filled porosity for the mature green phase. Data indicate that the California system amended with an inorganic material resulted in better physical properties during the mature green phase of the experiment.

Results of field infiltration rate measurements for the study are shown in Figure 1. All treatments show 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 proportion of fine sand particles (Table 2) compared to the other treatments. The field infiltration rates decreased over time, probably due to the increased accumulation of a thatch layer at the surface. The inorganic amended treatment (California-Z) was found to have a

higher infiltration rate compared to the other treatments 3.5years after establishment. This treatment was found to increase air-filled porosity and decrease bulk density compared with the peat mixture, and thus was able to maintain a higher infiltration rate over time.



**Figure 1.** 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.



**Figure 2.** Water retention measured in cores at selected soil water pressures for the treatments (a) before establishment (September 1998) and (b) during the mature green phase (May 2002). Means separation were determined by LSD 0.05 and indicated by letters at each pressure

rate over time.

Figure 2 presents the root zone water retention characteristics for the three treatments at the initial establishment period and 3.5years after construction. The general shapes of the water retention curves for the three treatments at establishment were similar. As the soil water pressure decreased (tension increased), a linear decrease in the water content occurred between 0 and 3kPa. Rapid drainage enables putting greens to dry faster, allowing more golf playing time and better aeration conditions for turf growth. The rate of water released from the root zones decreased as the soil water pressure decreased below 3kPa. When soil water pressure decreased below 4kPa, little change was observed in the retention curves. The USGA and California-Z treatments had >10% volumetric

water content at -3kPa which is an adequate water content during the creeping bentgrass establishment period. Figure 2a in general, also indicates that root zone mixtures amended with organic or inorganic materials had a higher water retentive capacity.

Water retention curves 3.5years after green construction for the



treatments are shown in Figure 2b. When soil water pressure was decreased below 4kPa, little change was observed in the retention curves. Results indicate that significant changes occurred in the shape of the water retention curves between 0 and 4kPa soil water pressure between establishment and 3.5years later. These differences were probably due to changes in pore size distribution during maturation (after 3.5years) of the root zones. Build up of a thatch layer at the surface was observed for all treatments and probably caused some of these changes. Our results indicate that we found a 60% reduction in the air-filled porosity and a 60% increase in the capillary porosity 3.5years after establishment (Table 3b) when compared to results at establishment period (Table 3a).

### Chemical properties of the root zone

Results of the root zone chemical properties for the treatments are shown in Table 4. During establishment in 1999, the USGA and California-Z treatments had higher cation exchange capacities (CEC) and organic matter contents compared to the California treatment. The California-Z treatment contained more plant available P and K relative to the California and USGA treatments (Table 4a). The California-Z and USGA treatments had higher Ca and Mg concentrations compared to the California treatment. Nus and Brauen (1991) reported that the addition of clinoptilolitic zeolite improved the nutrient status (especially  $\text{NH}_4^+$  and  $\text{K}^+$ ) of sand-based root zones during green establishment. In 2001, the USGA and California-Z treatments had higher values of CEC compared to the California treatment with the highest value in the California-Z treatment throughout this study (Table 4b). The California-Z treatment also contained

**Table 4a.** Chemical properties in the root zone during establishment(May 1999).

Treatments	pH	CEC	OM	P	Ca	Mg	K
		cmol kg <sup>-1</sup>	%	mg kg <sup>-1</sup>	cmol kg <sup>-1</sup>	cmol kg <sup>-1</sup>	cmol kg <sup>-1</sup>
California	7.3	2.21b	0.15c	13.74b	1.68b	0.26b	0.25b
USGA	7.2	3.33a	0.73a	15.65b	2.64a	0.41a	0.28b
California-Z	7.3	3.50a	0.30b	30.73a	2.65a	0.43a	0.40a
LSD <sub>0.05</sub>	NS	0.37	0.11	2.81	0.29	0.05	0.04

CEC, cation exchange capacity.

OM, organic matter.

**Table 4b.** Chemical properties in the root zone during the mature bentgrass green phase(May 2001).

Treatments	pH	CEC	OM	P	Ca	Mg	K
		cmol kg <sup>-1</sup>	%	mg kg <sup>-1</sup>	cmol kg <sup>-1</sup>	cmol kg <sup>-1</sup>	cmol kg <sup>-1</sup>
California	6.9	2.76b	0.18b	21.90b	2.12b	0.41b	0.18b
USGA	6.8	3.72a	0.33a	23.75ab	2.97a	0.59a	0.15b
California-Z	6.9	4.39a	0.13b	36.40a	3.03a	0.55a	0.81a
LSD <sub>0.05</sub>	NS	0.80	0.09	13.83	0.42	0.12	0.34

more plant available P and K than the other treatments during the mature green phase.

### Creeping bentgrass performance

Climatic conditions for bentgrass establishment during the fall of 1998 were good and bentgrass germination and development were excellent. Establishment rates (a visual percent cover) for each plot were not significantly different 66days after seeding (September 27 to December 2, 1998; data are not shown). Tables 5 to 6 show creeping bentgrass color and quality ratings during establishment and maturation of the green. During 1998 to 1999, zeolite-amended (California-Z treatment) plots had the highest color and quality ratings (Tables 5a and 6a). Miller (2000) reported that bermudagrass was found to establish more rapidly and had greater growth with ZeoPro-amended root zones when compared with 100% sand and other root zone mixtures. Our results also showed that higher late fall color (12/2/98) of the California-Z treatment plots was probably due to

**Table 5a.** Color ratings measured at selected times during bentgrass establishment(1998-1999).

Treatments	Color Rating <sup>†</sup>					
	12/2/98	4/26/99	6/14	8/19	10/22	12/23
California	5.5b	5.0b	7.1ab	6.8b	6.5b	4.4b
USGA	5.5b	4.8b	6.8b	6.4b	6.0b	4.1b
California-Z	7.0a	7.3a	7.3a	8.1a	7.5a	4.9a
LSD <sub>0.05</sub>	1.2	1.3	0.4	0.7	0.7	0.4

<sup>†</sup>Rating scale of 1 to 9, 1=completely dead or dormant, 6-7=acceptable, 9=ideal.

**Table 5b.** Color ratings measured at selected times during the mature bentgrass green phase(2000).

Treatments	Color Rating <sup>†</sup>							
	4/28	5/29	6/25	7/25*	8/30	9/29	10/28	11/24
California	4.4b	4.6b	5.3b	4.0	4.9b	5.9b	5.6ab	5.3b
USGA	4.6ab	3.9b	4.9b	3.1	4.0b	5.0b	5.0b	4.6b
California-Z	5.3a	6.3a	6.1a	3.3	5.9a	6.4a	6.3a	6.3a
LSD <sub>0.05</sub>	0.7	1.0	0.4	NS	0.9	0.8	0.8	0.8

<sup>†</sup>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 5c.** Color ratings measured at selected times during the mature bentgrass green phase(2001).

Treatments	Color Rating <sup>†</sup>						
	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-Z	5.5	6.1	6.1a	5.3a	6.3a	6.4a	5.9a
LSD <sub>0.05</sub>	NS	NS	1.5	1.0	0.8	0.6	0.6

<sup>†</sup>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 zeolite amendment containing 0.1% nitrogen. Early spring color (4/26/99) was also higher for the California-Z treatment (Table 5a). By late spring(6/14/99), the quality ratings indicate the California-Z treatment had the greatest overall quality (Table 6a).

From 2000 to 2001, the zeolite-amended(California-Z treatment) plots produced bentgrass color and quality ratings that were equal to or better than the California treatment, and consistently higher than the USGA treatment (Tables 5b and 5c; Tables 6b and 6c). The USGA treatment had the lowest color and quality ratings both in 2000 and 2001. The California-Z treatment plots had darker color and higher quality(recovery) after the drought periods that occurred(July 2000 and 2001) than the other two treatments in August. The USGA treatment did not recover after the drought in 2001.

Nus and Brauen(1991) found that the addition of clinoptilolitic zeolite provided better conditions and a greater bentgrass establishment rate and bentgrass quality. Our results

**Table 6a.** Quality ratings measured at selected times during bentgrass establishment(1999).

Treatments	Color Rating*					
	6/14	7/21	8/19	9/21	10/22	12/23
California	6.9b	6.6b	6.6b	6.6b	6.6b	4.5b
USGA	6.6b	6.1c	6.1c	6.4b	6.1c	4.4b
California-Z	7.5a	7.3a	8.0a	8.1a	7.4a	5.3a
LSD <sub>0.05</sub>	0.6	0.3	0.5	0.4	0.4	0.5

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

**Table 6b.** Quality ratings measured at selected times during the mature bentgrass green(2000).

Treatments	Color Rating*							
	4/28	5/29	6/25	7/25*	8/30	9/29	10/28	11/24
California	4.1b	4.1b	4.8b	4.4a	5.1b	5.5b	5.3b	4.9b
USGA	3.9b	3.8b	4.8b	2.8b	3.9c	5.0b	4.8c	4.3c
California-Z	5.1a	6.3a	6.0a	3.4ab	6.1a	6.1a	6.1a	6.1a
LSD <sub>0.05</sub>	0.5	0.6	0.6	1.5	0.8	0.6	0.4	0.4

\*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 6c.** Quality 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	4.8	5.9b	5.1a	5.4a	5.8b	6.1a	5.8a
USGA	4.8	5.8b	2.5b	2.3b	2.1c	2.6b	2.6b
California-Z	5.3	6.4a	5.6a	6.3a	6.4a	6.6a	5.9a
LSD <sub>0.05</sub>	NS	0.4	1.6	1.1	0.6	0.6	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).

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 5 and 6), except after drydown periods(July 2000 and 2001). Greater nutrient retention due to the addition of an inorganic amendment (zeolite) to the root zone (California-Z) seemed to correlate with higher average quality and color ratings throughout this study compared to the California treatment. These results suggest that substituting zeolite for peat may allow for the maintenance of higher quality creeping bentgrass with less frequent(monthly) fertilizer inputs; however, in this study the differences between the USGA and California-Z treatments may have been due in part to differences in particle size between these two treatments.

In conclusion, the California-Z treatment had a higher Ksat and lower bulk density compared to the USGA treatment throughout the experiment and a higher Ksat, and lower bulk density compared to the California treatment at the end of the experiment. The California-Z treatment also had highest field infiltration rates during two years (2000, 2001) after green establishment. The California-Z treatment had higher cation exchange capacities and plant nutrient levels compared to the California treatment at both establishment and maturation periods. These results indicate that the addition of zeolite may, in many cases, serve as a preferred amendment choice for improving the performance of sand-based putting greens. The California-Z treatment produced higher bentgrass quality and color throughout the three years. Therefore, the California-Z treatment showed the best creeping bentgrass performance that was attributed to better physical and chemical properties when compared with the California treatment and better chemical properties when compared to the USGA treatment. These properties were improved by the addition of zeolite within the California system, which allowed for better bentgrass performance during the establishment and maturation periods.

### 〈국문 적요〉

## 골프장 putting green개선을 위한 토양 개량제와 green 구조시설

Putting green은 골프장 전체 면적의 2% 로 작은 면적이지만 green의 건강한 상태는 골프장의 성공여부를 좌우한다.

이실험은 University of Missouri-Columbia, Turfgrass Research Center에서 어느 putting green root zone 구조와 토양 개량제가 가장 건강하고 최적의 putting green 조건을 유지하는가를 비교하기 위하여 1999년 6월 부터 2002년 12 월 까지 실행되어졌다.

California putting green root zone system (30cm의 100% 모래층 밑에 13cm silt loam 토양층)은 특히 putting green의 가격을 줄일수 있으며 배수가 잘되고 공기 순환에 있어서는 좋은 조건이지만 낮은 수분 보존량과 잔디에 공급되어지는 영양분이 낮은 것으로 조사 되어지고있다. USGA (United States Golf Association) putting green root zone system [30cm의 90% 모래와 10% Peatmoss (organic material; 유기물) 혼합물층 밑에 13cm 자갈층]은 California system (100% 모래)의 단점을 보완할수 있지만 년수가 지남에 따라 문제점이 발견 되어졌다. 시간의 흐름에 따른 organic matter의 축적과 분해 그리고 잦은 잔디관리 장비의 운행과 player들의 발자국에 의한 green compaction (압축)의 증가가 putting green에서의 수분 침투량 (Infiltration rate)과 공기순환을 방해하며 이로인해 잔디의 성장을 저해하며 green의 질을 낮게 만든다. Putting green root zone mixtures에서의 유기물질인 peatmoss사용에 비해 Zeolite와 같은 무기물질의 사용이 토양 물리적, 생리적 특성에 있어 우수함이 조사되어지고 있다. 년수가 지날수록 증가하는USGA green (10% peatmoss)의 단점 (organic matter의 축적과 분해 증가, 수분 침투력과 공기순환 감소, 높은 수분함량)에 비해 10-15% Zeolite (무기물)의 사용이 보다 나은 putting green 물리적, 생리적 조건들을 오래도록 유지할수 있으며 건강한 잔디상태를 보존 할수 있을 것이다.

이실험은 수정된 Modified California putting green root zone system [25cm 의 85% 모래와 15% Zeolite (inorganic material; 무기물) 혼합물층 밑에 18cm silt loam 토양층]이 California 와USGA green system과 비교할때 보다 나은 putting green 조건을 유지하는가를 위해 조사되어졌다.

수정된 Modified California green system이 건강한 putting green을 유지하기 위한 우수한 물리적 조건 (높은 수분 침투력과 수분 함량, 낮은 토양밀도)과 생리적 조건 (높은 양이온 교환력과 유효 식물영양분 함량)을 가지고 있음이 조사되어졌다. 또한 우수한 putting green잔디품질을 이 실험 기간 동안 유지하였다. 결론적으로 California system (100% 모래)에 15%의 무기물질 (Zeolite)이 첨가 되어진 Modified California putting green system이 최적의 putting green조건과 우수한 Bentgrass잔디품질을 4년 동안 유지하였음을 이 실험을 통해 조사 되어졌다.

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