

CHEMICAL AND PHYSICAL STABILITY OF CALCAREOUS SANDS USED FOR PUTTING GREEN CONSTRUCTION

Eric Miltner and Gwen Stahnke, Washington State University, Puyallup WA
Paul Grossl, Utah State University, Logan UT

Executive Summary

A calcareous sand can be defined as any sand that contains at least 1% CaCO_3 (calcium carbonate, or calcite) by weight. These sands exist in various places around the U.S. and the world, and are often used for construction of golf course putting greens and other sand-based root zone media. However, their use is discouraged because of suspected yet unconfirmed problems associated with their long-term stability. It is suspected that calcareous sands may break down, resulting in restricted or plugged pore space. The result of this is poor drainage, restricted rooting due to root zone saturation, and eventually severe thinning or death of the turf. To date, there are no reported systematic investigations into the occurrence or cause of this problem. Two primary approaches are being used in this project: controlled studies using simulated golf green profiles to study the weathering process of these sands; and a field survey which involves collection of intact cores from putting greens constructed with calcareous sands, with subsequent examination of the physical and chemical properties of these soil cores. Our objectives are to determine (1) if the use of calcareous sands results in eventual failure of the putting green to support healthy plant growth and playability, and (2) to determine the mechanism of this process, and if current management practices contribute to the problem.

A series of laboratory experiments have been conducted using small PVC columns to simulate putting green profiles. The columns were filled with several sands of varying calcite content. Dilute acid was added to the columns on five day intervals, and water was added on the days in between. The addition of acid simulates some of the reactions that occur following fertilization. Chemical properties of the drainage water were measured, as well as physical and chemical properties of the sand at the conclusion of the experiments. These studies confirmed that calcium carbonate does break down in response to acidification of the soil. A more in-depth long term experiment is currently underway that will evaluate the impact of different fertilization rates and irrigation water quality on this weathering process. Measurements of physical properties of the sand columns will be made to determine whether or not drainage or water holding capacity are impacted.

Samples have been collected from a number of golf course greens built with calcareous sands. Because these have only been evaluated at one single time, it is difficult to determine if properties of the sands are changing over time. The results from some of these samples indicate that calcium carbonate may be breaking down on these putting greens, which could eventually lead to problems in soil physical properties. Some of these golf courses will be monitored over time, and additional courses will be sampled. Controlled experiments as described above will also be continued.

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Eric Miltner and Gwen Stahnke
Washington State University, Puyallup WA
Paul Grossl
Utah State University, Logan UT

Introduction

A calcareous sand can be defined as any sand that contains at least 1% CaCO_3 (calcium carbonate, or calcite) by weight. These sands exist in various places around the U.S. and the world due to pedogenic processes. They are often used for construction of golf course putting greens and other sand-based root zone media. Because of either perceived or real problems associated with these sands, their use is discouraged. However, transport costs of non-calcareous materials often make calcareous sands the only choice in some areas. The potential problems associated with these materials are not well defined or understood. In general, the types of problems that may occur are related to undesirable soil physical properties (aeration, hydraulic conductivity, water holding capacity) relative to USGA recommendations. Greens built with these sands that meet USGA recommendations at the time of construction may deteriorate due to weathering or mineral transport in the soil profile. Greens that have reduced hydraulic conductivity, reduced air-filled porosity, and perhaps even visual layers of mineral precipitates have been reported by superintendents and USGA agronomists. However, there are no reported systematic investigations into the occurrence or nature of these problems. It is the objective of this research project to determine if physical and/or chemical characteristics of putting greens change as a result of weathering of calcareous sands, and to determine the mechanism of this weathering. Ultimately, we hope to provide guidelines for formulating recommendations concerning suitability for use of calcareous sands for putting green construction.

Research Initiated, Progress and Results

Two primary approaches are being used in this project. The first is a series of controlled studies using simulated golf green profiles constructed in PVC columns to investigate the weathering potential of various sands. The second is a field survey which involves collection of intact cores from putting greens constructed of calcareous sands. These cores will be analyzed for changes in the physical and chemical properties of the root zone to determine if weathering in the field is occurring, and if this weathering can be detected through laboratory measurements.

Controlled experiments:

Two short term experiments have been conducted as preliminary investigations prior to initiating a longer term column study. These experiments were designated as Small Column 1 (SC1) and Small Column 2 (SC2). Both experiments were similar in design and objective, but included different sand media. Each experiment included four sands placed into PVC columns measuring 1 inch (2.5 cm) I.D. x 14 inches (35 cm) in depth, replicated three times. Properties of these sands are in Table 1 (SC1) and Table 4 (SC2). Every five days, hydrochloric acid was added to each column (0.2669M, pH = 0.60, EC = 10,700 $\mu\text{S}/\text{cm}$, Ca = 27 mg/L). This resulted in acidifying the columns at a rate equivalent to adding 0.75 lb N (as NH_4^+) per 1000 sq. ft. in each application (assuming complete nitrification of ammonium). This high rate of N was used to create an accelerated rate of weathering so that changes might be induced over the 30 day period of the experiments. In addition to acidification, distilled deionized water was added each day (excluding days of acid addition) at a rate equivalent to 0.15 in. (3.8 mm) of irrigation (pH = 6.96, EC = 17 $\mu\text{S}/\text{cm}$, Ca = 2.6 mg/L). Percolate was collected continuously, and collection bottles were changed every ten days. Electrical conductivity (EC), pH, and Ca content of percolate samples were measured, and at the conclusion of the 30 day experiments columns were sectioned into 3 inch (7.5 cm) depth increments and analyzed for particle size distribution and calcium carbonate content.

For SC1, there were differences in particle size distribution for all of the sands at the end of the experiment, but no consistent trends that would attribute these differences to the acid treatment (data not shown). For the Portland, Spokane, and Las Vegas sands, there was a trend toward decreased calcium carbonate content in the upper depth (Table 2), although this was only statistically significant for the Las Vegas sand. This may indicate that calcium carbonate is breaking down in the upper three inches due to acidification. Analysis of the column drainage showed increasing EC and decreasing pH with time for all sands except for Maui (Table 3). EC was initially used as an indirect method of estimating Ca content of the percolate, under the assumption that changes would be due primarily to increased Ca in percolate following degradation of calcite. An increase in the concentration of positively charged ions in solution results in an increase in the EC of that solution. The increase in EC from the Portland sand could be attributed to the acidity of the solution (as pH decreases, concentration of H^+ increases). Changes in EC were greater in the Spokane and Las Vegas sands than the Portland sand, and this was presumed to be due to the presence of Ca^{2+} . An ion specific electrode (ISE) was obtained to directly measure Ca^{2+} , and this was confirmed. The highly calcareous Maui sand showed no significant changes in calcium carbonate content or in EC, pH, or Ca content of the percolate.

Different sands were used for SC2. The sand used for the non-calcareous control was changed because a local source with a better particle size distribution was found. In addition, several sand samples originating from Ontario, Canada were collected that were 30 to 40% calcite, and one of these with an appropriate particle size distribution was chosen. For this experiment, distilled deionized water was run through the columns for ten days prior to adding acid. Percolate chemistry was quantified, and this appears as "Time 0" in Table 6. This baseline measurement was not taken in SC1. All other experimental procedure were identical to those in SC1. As in the first experiment, there were no changes in particle size distribution attributable to

acidification (data not shown). Although there were no significant differences in calcite content of the sands at the conclusion of the study (Table 5), trends of decreasing calcite in the uppermost depth and increased calcite deeper in the profile were evident in the Milton and Spokane sands. This could be indicative of calcite leaching. Analysis of percolate chemistry yielded results similar to those seen in SC1. EC increased significantly by day 30 for percolate from all sand except for that from Kauai. Percolate pH decreased at different rates for each of the sands. Increases in Ca in percolate appeared to correlate with changes in EC and pH. There was a slight increase in Ca content of percolate from the Kauai sand.

Considering the results of both experiments, the decrease in pH of the percolate and the presence of calcium carbonate in the sand columns at the end of the studies indicate that the calcium carbonate and acid are not reacting to completion in the columns. The sands from Hawaii may be an exception. The large amounts of calcium carbonate in these sands appear to effectively buffer the added acid, as indicated by the lack of change in chemical properties of the percolate. It may take much more acidification to induce changes in these sands. It appears that the chemical properties of the other calcareous sands are changing as a result of acidification. The combination of increased EC, increased Ca content, and decreased pH of the percolate along with a trend towards decreasing calcite content in the upper depth of the sand columns indicates that calcite is being dissolved and leached through the sand profile. We have not detected changes in particle size distribution that correlate with the chemical analyses. Any physical changes occurring in the profile will have to be measured by another method, such as porosity or hydraulic conductivity. These two experiments satisfied the objective of confirming that chemical changes in these sands can be induced by the addition of acid.

Field Survey:

Intact core samples from several golf courses have been collected and analyzed. Two courses in Utah, built with sand from the same source (approximately 6% calcium carbonate) were sampled in May 1998. One course was built in 1989 (EM) and the other in 1993 (LR). Samples were separated into 3 inch depth increments and analyzed for particle size distribution and calcium carbonate content. No differences in particle size distribution were detected between depths for any of the samples. Samples from LR had lower calcium carbonate content in the upper depth, but not significantly (Table 7).

Samples were submitted from two Texas courses by USGA Green Section Agronomists Jim Moore and Brian Maloy. The first course, SV, had a history of greens with poor growth. Analyses by a commercial lab found dramatic decreases in air-filled porosity accompanied by increases in capillary porosity over time. The greens were built with a calcareous sand and were topdressed (upper 1 inch approximately) with what was described as a silica sand. The samples were separated into depths of 0 - 1" (topdress layer) and 1 - 5, 5 - 8, and 8 - 12 inches. The topdressing layer was easily distinguishable both visually and by particle size analysis. Although the topdressing sand was described as non-calcareous, this upper layer had a calcium carbonate content of 6.5%. This was significantly lower than the 8.5 to 10.8% contents in deeper layers. The second Texas course, TCC, was built in 1994-95 using a calcareous sand. Through 1996, greens were topdressed with the construction sand. The following year a coarser sand, also

described as calcareous, was used. In 1998 a silica sand was used. Samples were collected from two "good" greens and two "poor" greens, as described by the superintendent and B. Maloy. Cores were separated into 3 inch depth increments. Because the topdressing layer was small and visually indistinguishable, it was included in the upper depth. The topdressing sands did impact the upper profile, resulting in approximately 8% more particles in the 0.5 - 1.0 mm range and about 8% less in the 0.05 - 0.25 mm range, as compared to the underlying layers. There were no differences in particle size distribution among the layers below the 3 inch depth. Calcite content was much lower in the upper 3 inches as compared to below (Table 5). It is unlikely that the amount of topdressing sand applied over three years was enough to dilute the calcite content of this top layer to less than 50% of its original amount. Calcite degradation seems likely. There were no significant differences between the samples from good and poor greens. Calcium carbonate analysis of samples from both Utah and Texas indicates that degradation of calcite in sand near the surface may be occurring. However, these changes are not great enough to induce a measurable change in particle size distribution.

In April of 1999, samples were collected from 11 putting greens at four different golf courses in Hawaii. One course was on the island of Oahu and the others on the island of Kauai. In each case, greens were constructed using sands of local origin. These sands are generally derived from coral reefs that are weathered by ocean waves, grinding the coral into sand-sized particles. They are usually 80% or higher calcium carbonate equivalent. At each site, we were able to sample greens built at different times. Although different construction materials were used in each case, this still might give some indication of the influence of time on weathering processes. Results of analyses of selected samples will be discussed.

At WCC on Oahu, holes 10 and 13 were built in 1967 using a local beach sand. Holes 14 and 17 were built in 1982, using a different local sand. An imported silica sand has been used for topdressing of all greens since 1993. This upper layer was easily identified by sight in the core samples. Tables 8 and 9 show that this layer was very consistent between the newer and older greens, and finer in size than the underlying layers. The 2.5 - 5.5 inch layer also appears to be different, and probably represents a different topdressing material. Again, this layer is similar in greens 13 and 14. The sand below 5.5 inches is quite different between the two greens, due to different construction materials. The uppermost layer, referred to as a "silica sand" by the superintendent, is much lower in calcium carbonate than underlying layers, but is still quite high compared to most of the mainland sands we have collected. Below this top layer, there are no consistent patterns in calcite content. For hole 13 (Table 8), differences in calcite content seem to correlate by depth with differences in particle size, indicating that calcite is primarily a function of the sand, not management practices or weathering. For hole 14 (Table 9), the 2.5 - 5.5 inch layer is higher in calcite than in hole 13, although based on particle size and topdressing practices we assumed these to be of similar origin. The bottom two depths for hole 14 were lower in calcite content than the middle depth. This could be due to another topdressing layer, given the age of this green. Conversely, calcite may be lower at the deepest depths due to weathering.

MPR and PPR are two courses at the same location on Kauai. MPR was built in 1970 and PPR was built between 1988 and 1991. Differences in particle size distribution indicate a topdressing layer in the 0 - 3 inch depth in MPR green #3 (Table 10). The 6 - 15 inch depth is

consistent in both particle size and calcite content. The 3 - 6 inch depth is consistent in particle size, for particles greater than 1mm, with the underlying depths. Differences in the 0.15 to 1 mm size ranges compared to depths below could be due to weathering. Lower calcite content in upper depths could support the hypothesis of weathering and leaching of dissolved calcite. Based on the age of the green, however, the 3 - 6 inch layer could also be a different sand deposited by topdressing. For green #5 at PPR, particle size distribution is relatively consistent throughout the profile (Table 11). When cores were removed from this green, a fabric barrier was discovered at the sand/gravel interface. The sand was saturated for approximately 5 inches above this fabric, indicating that water movement through the fabric had become restricted. One hypothesis associated with the weathering process is that calcite that dissolves closer to the surface could leach through the profile. If there is a "zone of saturation" in the profile (such as near the sand/gravel interface, or as caused by the fabric) calcite might accumulate near this saturated zone and precipitate from solution due to mass action. High calcite values in the 3 - 9 inch depth (just above the saturated zone) could support such a mechanism. These samples will be re-analyzed due to the high values, but any analytical error that might have occurred would be expected to be consistent among samples.

Samples collected from golf courses so far have produced no consistent, significant results. However, in many cases the data could support a hypothesis of calcite weathering. Analyses of some of these samples need to be completed, and additional golf course samples are needed to provide additional information. Although these samples vary widely from course to course, and correlating our analyses to management practices is difficult, these samples have provided important information on the nature and occurrence of calcareous sands.

Future Efforts

Based on the results of experiments SC1 and SC2, initiation of a larger, longer term column study is underway. This experiment incorporates several different sands, acidification rates, and water quality factors. In addition to chemical analyses, physical attributes of the profiles (hydraulic conductivity, porosity) will be evaluated at the study's conclusion. Physical differences that cannot be detected by particle size analyses may be detected by measurement of hydraulic properties. Additional small column studies similar to the ones discussed here will be conducted. These offer a relatively fast way to evaluate sands and other factors.

Table 1. Particle size distribution and calcium carbonate content of sands used in Experiment SC1.

Sample I.D.	Particle size (mm) percent by weight							CaCO ₃ equivalent (% by weight)
	2 - 3.4	1 - 2	0.5 - 1	0.25 - 0.5	0.15 - 0.25	0.05 - 0.15	< 0.05	
Portland	1	5	14	42	28	9	1	0.2
Spokane	0	2	27	54	14	3	1	5
Las Vegas	1	6	29	47	16	0	0	10
Maui	0	1	4	32	52	10	1	71
USGA	3% max.				20% max.	5% max	8% max	
	10% max 1 - 3.4 mm		60% min. 0.25 - 1 mm		10% max < 0.15 mm			

Table 2. Percent calcium carbonate by weight of sands at conclusion of Experiment SC1.

Depth (inches)	Portland	Spokane	Las Vegas	Maui
0 - 3	0.1	3.5	9.6	83.3
3 - 6	0.3	4.9	10.0	84.9
6 - 9	0.4	4.6	11.1	82.9
9 - 12	0.3	4.5	11.5	83.3
LSD (P=0.05)	ns	ns	1.0	ns

ns = not statistically significant.

Table 3. EC, pH, and Ca concentration of percolate from sand columns for Experiment SC1.

Time (days)	EC ($\mu\text{S cm}^{-1}$)				pH				Ca (mg L^{-1})			
	Portland	Spokane	Las Vegas	Maui	Portland	Spokane	Las Vegas	Maui	Portland	Spokane	Las Vegas	Maui
10	603	693	1210	2940	8.0	8.2	8.6	8.2	52	53	26	200
20	578	3657	2800	2010	8.0	7.8	8.1	8.4	94	853	263	64
30	2407	6330	8180	2717	6.9	7.2	7.6	8.3	513	2100	1567	159
LSD (P=0.05)	1065	2973	404	ns	0.5	0.5	0.2	ns	169	851	183	ns

Table 4. Particle size distribution and calcium carbonate content of sands used in Experiment SC2.

Sample I.D.	Particle size (mm) percent by weight							CaCO ₃ equivalent (% by weight)
	2 - 3.4	1 - 2	0.5 - 1	0.25 - 0.5	0.15 - 0.25	0.05 - 0.15	< 0.05	
Milton	2	6	27	50	13	2	0	0
Spokane	0	2	27	54	14	3	1	5
Ontario	2	5	12	66	14	1	0	40
Kauai	0	1	4	38	51	5	1	71
USGA	3% max.				20% max.	5% max	8% max	
	10% max 1 - 3.4 mm		60% min. 0.25 - 1 mm		10% max < 0.15 mm			

Table 5. Percent calcium carbonate by weight of sands at conclusion of Experiment SC2.

Depth (inches)	Milton	Spokane	Ontario	Kauai
0 - 3	0.0	3.9	40.9	73.3
3 - 6	0.7	4.2	40.2	72.5
6 - 9	0.3	4.4	40.7	71.2
9 - 12	0.2	4.0	39.5	69.5
LSD (P=0.05)	ns	ns	ns	ns

ns = not statistically significant.

Table 6. EC, pH, and Ca concentration of percolate from sand columns for Experiment SC2.

Time (days)	----- EC ($\mu\text{S cm}^{-1}$) -----				----- pH -----				----- Ca (mg L^{-1}) -----			
	Milton	Spokane	Ontario	Kauai	Milton	Spokane	Ontario	Kauai	Milton	Spokane	Ontario	Kauai
0	61	120	410	800	6.9	6.5	6.8	7.0	16	69	125	76
10	66	157	463	890	7.0	6.2	6.4	7.0	13	55	124	58
20	148	137	513	690	6.0	6.7	6.5	6.7	44	61	218	45
30	3767	1967	2900	863	5.3	6.0	6.0	6.9	2073	1197	1225	103
LSD (P=0.05)	691	495	776	92	0.2	0.4	0.3	ns	671	692	328	34

Table 7. Percent calcium carbonate by weight of sand from EM and LR greens in Utah, and "good" and "poor" greens at TCC, Texas.

<u>Depth (inches)</u>	<u>EM</u>	<u>LR</u>	<u>TCC "good"</u>	<u>TCC "poor"</u>
0 - 3	7.4	5.8	6.3	5.6
3 - 6	6.5	8.0	14.2	15.0
6 - 9	7.7	7.4	15.6	15.7
9 - 12	5.4	7.4	14.2	14.6
LSD (P=0.05)	ns	ns	2.5	3.9

Table 8. Particle size distribution and calcium carbonate equivalent for sand from WCC putting green #13, built 1967. Silica sand topdressing since 1993 (upper 2.5").

Depth (in.)	Particle size (mm) percent by weight							CaCO ₃ equivalent (% by weight)
	≥2.0	1 - 2	0.5 - 1	0.25 - 0.5	0.15 - 0.25	0.05 - 0.15	< 0.05	
0 - 2.5	6	6	20	61	6	0	0	13
2.5 - 5.5	3	8	46	37	4	1	1	68
5.5 - 8.5	3	6	35	51	2	1	1	97
8.5 - 11.5	3	8	34	49	3	1	1	101
11.5 - 15	14	13	28	35	6	3	1	98
USGA	3% max.				20% max.	5% max	8% max	
guidelines	10% max 1 - 3.4 mm		60% min. 0.25 - 1 mm		10% max < 0.15 mm			

Table 9. Particle size distribution and calcium carbonate equivalent for sand from WCC putting green #14, built 1982. Silica sand topdressing since 1993 (upper 2.5").

Depth (in.)	Particle size (mm) percent by weight							CaCO ₃ equivalent (% by weight)
	≥2.0	1 - 2	0.5 - 1	0.25 - 0.5	0.15 - 0.25	0.05 - 0.15	< 0.05	
0 - 2.5	5	5	19	62	7	1	1	17
2.5 - 5.5	6	11	42	35	4	1	1	84
5.5 - 8.5	5	15	47	28	3	1	1	94
8.5 - 11.5	4	13	47	30	3	1	1	77
11.5 - 15	4	14	44	34	4	2	1	70
USGA	3% max.				20% max.	5% max	8% max	
guidelines	10% max 1 - 3.4 mm		60% min. 0.25 - 1 mm		10% max < 0.15 mm			

Table 10. Particle size distribution and calcium carbonate equivalent for sand from MPR putting green #3, built 1970.

Depth (in.)	Particle size (mm) percent by weight							CaCO ₃ equivalent (% by weight)
	<u>>2.0</u>	<u>1 - 2</u>	<u>0.5 - 1</u>	<u>0.25 - 0.5</u>	<u>0.15 - 0.25</u>	<u>0.05 - 0.15</u>	<u>< 0.05</u>	
0 - 3	15	8	25	36	14	2	0	88
3 - 6	3	14	37	34	9	2	1	87
6 - 9	3	14	65	15	2	1	0	95
9 - 12	1	14	67	16	1	1	0	94
12 - 15	2	12	71	13	1	1	0	97
USGA	3% max.				20% max.	5% max	8% max	
guidelines	10% max 1 - 3.4 mm		60% min. 0.25 - 1 mm		10% max < 0.15 mm			

Table 11. Particle size distribution and calcium carbonate equivalent for sand from PPR putting green #5, built 1988 - 91. Poly fabric at bottom, lower 4 - 5" saturated.

Depth (in.)	Particle size (mm) percent by weight							CaCO ₃ equivalent (% by weight)
	<u>≥2.0</u>	<u>1 - 2</u>	<u>0.5 - 1</u>	<u>0.25 - 0.5</u>	<u>0.15 - 0.25</u>	<u>0.05 - 0.15</u>	<u>< 0.05</u>	
0 - 3	6	8	28	37	19	2	0	97
3 - 6	3	8	24	40	20	4	0	108
6 - 9	4	9	28	36	20	3	0	104
9 - 12	4	10	25	35	21	4	1	95
12 - 15	6	9	23	32	23	5	2	94
USGA	3% max.				20% max.	5% max	8% max	
guidelines	10% max 1 - 3.4 mm		60% min. 0.25 - 1 mm		10% max < 0.15 mm			