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Research was initiated at Iowa State University to determine if the Basic Cation Saturation Ratio theory for soil nutrient tests applies to creeping bentgrass established on either calcareous or silica sand-based rootzones.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 290 projects at a cost of $25 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Basic Cation Ratios for Sand-based Greens

Rodney St. John and Nick Christians

SUMMARY

Recently, there has been an increased use of the Basic Cation Saturation Ratio (BCSR) theory for calcium (Ca), magnesium (Mg), and potassium (K) fertilizer recommendations for sand-based putting greens. The theory states that there is an "ideal-ratio" of the basic cations Ca, Mg, and K, and when the ratio is not "ideal", fertilizer applications must be made to correct the imbalance and promote plant health. The objective of this research was to determine if the BCSR theory applies to creeping bentgrass established on either calcareous or silica sand-based rootzones. The study's findings include:

- Sand-based putting greens have such low cation exchange capacities (CEC), that basic cation ratios are often misleading.
- Due to the dissolution of calcareous sand particles during the soil testing procedure, basic cation ratios created from calcareous sands will also be erroneous and misleading.
- From this research, it appears that creeping bentgrass can tolerate a wide range of basic cation saturation ratios and percentages in soil solution.
- In most cases, using the SLAN (sufficiency level of available nutrients) method of soil test interpretation would give better recommendations for Ca, Mg, and K fertility requirements of sand-based putting greens than the BCSR method.

The two main ways to interpret the results from a soil test analysis are to use the Sufficiency Level of Available Nutrients (SLAN) or the Basic Cation Saturation Ratio (BCSR). The SLAN concept holds that there are "definable levels of individual nutrients in the soil below which crops will respond to added fertilizers with some probability and above which they likely will not respond" (4). In other words, growth and performance will be affected when the nutrient in question falls below a predetermined concentration. These concentration levels have been developed through exhaustive studies performed using many crops, soil types, and different soil testing methods to determine what the minimum concentration for each element is for specific crops around the world.

The BCSR theory is used to interpret soil test results and make fertilizer recommendations primarily for the three basic cations, calcium (Ca), magnesium (Mg), and potassium (K). The BCSR theory states that optimal growth occurs when Ca, Mg, and K occupy the cation exchange sites in an "ideal ratio". The original theory by Bear and Toth (1) stated that the cations must occupy the cation exchange sites in the following percentages, 65% Ca, 10% Mg, 5% K, and 20% hydrogen (H). From these percentages, ideal cation equivalent ratios can be created, Ca:Mg 6.5:1, Ca:K 13:1, Ca:H 3.25:1, and Mg:K 2:1 (1). Graham (5) further broadened the theory to include a range of percentages, 65-85% Ca, 6-12% Mg, and 2-5% K.

Current recommendations by many professional soil testing laboratories utilize Graham's range of percentages, but there are still many rec-

Research conducted by Dr. Rodney St. John (shown above) indicated that using the SLAN (sufficiency level of available nutrients) method of soil test interpretation gives better recommendations for Ca, Mg, and K fertility requirements of sand-based putting greens than the BCSR (Basic Cation Saturation Ratio) method.

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Cation Equivalent Ratio	Exact Cation † Saturation Percentages	Exact † Cation Ratios	Current Cation ‡ Saturation Percentages	Possible Range § of Cation Ratios
Ca:Mg	Ca 65% Mg 10%	6.5:1	Ca 65-85% Mg 6-12%	5.4:1 - 14:1
Ca:K	Ca 65% K 5%	13:1	Ca 65-85% K 2-5%	13:1 - 42.5:1
Mg:K	Mg 10% K 5%	2:1	Mg 6-12% K 2-5%	1.2:1 - 6:1

† Percentages and ratios originally proposed by Bear and Toth (1).
‡ Current range of saturation percentages proposed by Graham (5).
§ Possible range of cation ratios that can be created using Graham's range of saturation percentages.

Table 1. Cation saturation percentages and cation ratios of the current BCSR theory from Bear and Toth (1) and Graham (5) and the possible range of cation ratios that can be created using Graham's saturation percentages.

Treatment Cation Percentages

Treatment	Ca	Mg	K	H
1	0	0	80	20
2	0	0	95	5
3	0	40	40	20
4	0	47.5	47.5	5
5	0	80	0	20
6	0	95	0	5
7	26.6	26.6	26.6	20
8	31.6	31.6	31.6	5
9	40	0	40	20
10	40	40	0	20
11	47.5	0	47.5	5
12	47.5	47.5	0	5
13	65	6	1	28
14	65	6	5	24
15	65	12	1	22
16	65	12	5	18
17	75	9	3	13
18	80	0	0	20
19	85	6	1	8
20	85	6	5	4
21	85	12	1	2
22	85	12	3	0
23	95	0	0	5
24	95	5	0	0
25	0	0	0	0
26	5	95	0	0
27	99	0	1	0
28	1	0	99	0

Table 2. List of treatments as a percentage of CEC used in the greenhouse mixtures experiment. The red letters represent treatments whose nutrient applications were designed to be within the 'ideal soil' cation ratios as described by Graham (5).

ommendations being made requiring Bear's exact cation equivalent ratios. This is currently a problem in the turfgrass industry when interpretations using Bear's exact cation equivalent ratios are used in the marketing of fertilizer products. The use of the BCSR, and more specifically, Bear and Toth's (1) exact cation ratios, often results in recommendations for Ca, Mg, and/or K fertilizer applications that are excessive or not even needed when the soil test results are interpreted using the SLAN method. A range of cation equivalent ratios can be developed using Graham's range of percentages that may provide a better estimate of the soil's ability to supply elements to the plant (Table 1).

The validity of the BCSR theory has been debated extensively since its development. Many studies have shown that crops can grow in soils that have cation ratios outside the "ideal soil" ratios of the BCSR theory. Sartain (9) concluded that 'Tifway' bermudagrass (*Cynodon dactylon* (L.) Pers. x *C. transvaalensis* Burtt Davy) and 'Pennant' perennial ryegrass (*Lolium perenne* L.) did not require a precise soil Ca to Mg ratio. The growth rate of bermudagrass was not affected even in the presence of a 100 to 1 soil extractable Ca to Mg ratio (8).

Eckert and McLean (4) stated that the balance of basic cations was only important when one element became deficient due to an excess of other cations, and that there is no ideal basic cation saturation ratio for all crops. Results from recent BCSR work in turfgrass have echoed Eckert and McLean's statements. St. John et al. (10) found decreasing K and Mg soil and tissue concentrations when excess Ca was applied. Moreover, Woods (12) demonstrated similar reductions where leaf and soil Ca and Mg concentrations were reduced when excess K was applied. McLean et al. (6) went on to state that, "the results strongly suggest that for maximum crop yield, emphasis should be placed on providing sufficient, but non-excessive levels of each basic cation rather than attempting to attain a favorable BCSR which evidently does not exist."

The BCSR has another limitation. It is possible that even if a soil contains exchangeable cations in the correct proportions according to the BCSR theory, a nutrient deficiency can still exist. This is particularly true in low cation exchange capacity (CEC) soils, such as those found in golf course greens and sports fields, where elements like K can occupy a high percentage of the CEC sites but may still be deficient. The BSCR theory is further complicated when the rootzone media is calcareous or gypsiferous. Many times the soil testing chemical will dissolve $CaCO_3$ or $CaSO_4$ particles and over-estimate exchangeable cations and thereby over-estimate CEC (10).

The objective of this research was to determine if the BCSR theory applies to creeping bentgrass established on either calcareous or silica sand-based rootzones.

Greenhouse BCSR Experiments

Treatments were chosen to be the best possible and smallest combination of treatments that will reflect all the combinations of Ca, Mg, K, and H (Table 2). Figure 1 depicts graphical representations of the treatments we used compared to the "ideal soil" according to the BCSR theory. The blue area in both figures represents an area defined by soils that have cations saturating the exchange sites at 65-85% Ca, 6-12% Mg, and 2-5% K as defined by Graham (5).

We were unable to create the precise cation ratios we intended to create due to interactions with the sand media, plant roots, and application method, but many problems applying the BCSR theory to low CEC sand-based rootzones were noted. There were no differences in creeping bentgrass quality or clipping yield among the 28 treatments, yet the measured cation ratios obtained in the pots varied greatly.

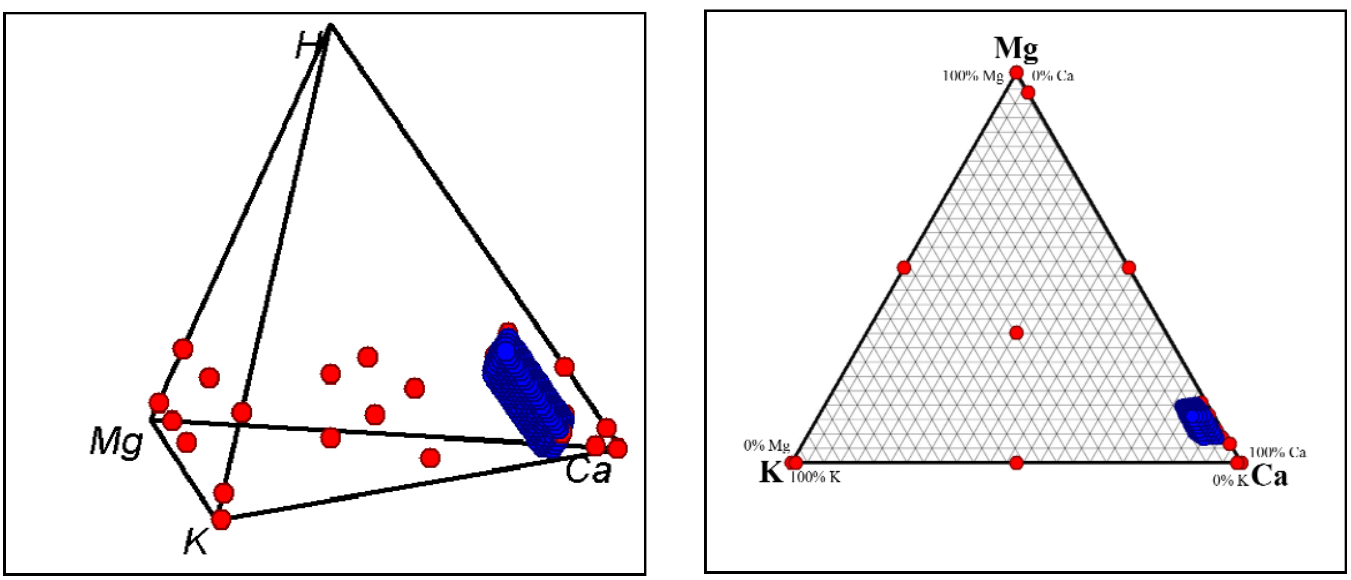

Figure 1. Three- and two-dimensional representations of the treatments used in this study (red) compared to the space occupied by the "ideal soil" according to the BCSR theory. The axis' represent the percent saturation of the cation exchange sites from 0 - 100%. In the two-dimensional plot on the right, H would be the Z-axis coming out of the page and is not shown.

	Calcareous Sand									
	Treatment Cation Percentages				Leaf Nutrient Analysis			Soil Nutrient Analysis		
Treatment	Ca	Mg	K	H	Ca	Mg	K	Ca	Mg	K
	%				$g \cdot kg^{-1}$			$mg \cdot kg^{-1}$		
1	0	0	80	20	10.5	2.4	16.5	1920	30	46
2	0	0	95	5	10.5	2.4	17	1944	28	54
3	0	40	40	20	11.9	2.7	13.5	1825	20	9
4	0	47.5	47.5	5	11.5	2.8	14.5	1789	33	28
5	0	80	0	20	13.2	3.8	9.1	1969	47	21
6	0	95	0	5	12.8	3.9	8.3	1881	56	26
7	26.6	26.6	26.6	20	12.5	2.7	13.1	1905	31	23
8	31.6	31.6	31.6	5	12.4	2.6	13.1	1909	30	28
9	40	0	40	20	12.5	2.4	14	1905	23	42
10	40	40	0	20	13.5	3.3	8	2025	33	31
11	47.5	0	47.5	5	12.4	2.3	14.1	1896	23	37
12	47.5	47.5	0	5	14.5	3.2	8.3	1795	32	13
13	65	6	1	28	14.3	2.9	9.5	1884	22	16
14	65	6	5	24	15.2	2.8	9.8	1885	22	19
15	65	12	1	22	15.2	2.9	9.1	1836	21	10
16	65	12	5	18	15.3	2.9	9.4	1982	26	32
17	75	9	3	13	15.1	3	9.2	1954	25	28
18	80	0	0	20	15.5	2.9	8.2	1793	23	18
19	85	6	1	8	14.5	2.9	8.7	1966	25	18
20	85	6	5	4	14.4	2.8	9.5	2010	24	30
21	85	12	1	2	14.4	2.9	8.9	2012	24	24
22	85	12	3	0	15	2.9	9.3	1894	24	20
23	95	0	0	5	15.7	2.8	8.4	1931	22	20
24	95	5	0	0	15.8	2.9	8.2	2023	25	25
25	0	0	0	0	12.8	2.9	8.1	1996	26	29
26	5	95	0	0	13.2	3.7	8.7	1851	50	18
27	99	0	1	0	14.9	2.8	9.2	1908	23	20
28	1	0	99	0	11.7	2.3	16.8	1971	27	60
Sufficiency Ranges†					5.0-7.5	2.5-3.0	22-26			
Soil Test Designations ‡§							Low	< 250	< 20	41-175
							Very Low			< 40

† Sufficiency Ranges for tissue nutrient content of creeping bentgrass.

‡ Values taken from Puhalla et al. (7). Ca concentrations less than 250 mg kg^{-1} are classified as having 'low' extractable Ca. Mg concentrations less than 20 mg kg^{-1} are classified as having 'low' extractable Mg.

§ Values taken from Christians (2). K concentrations less than 40 mg kg^{-1} are classified as having 'very low' extractable K. K concentrations between 41 and 175 mg kg^{-1} are classified as having 'low' extractable K.

Table 3. Average leaf Ca, Mg, and K concentrations of creeping bentgrass established on calcareous sand fertilized at different basic cation saturation ratios. Average soil extractable Ca, Mg, and K measured using the NH_4Cl extraction technique (11). The concentrations are averages of samples collected from both experiments at the 12-week sampling date. The red letters represent treatments whose nutrient applications were designed to be within the 'ideal soil' cation ratios as described by Graham (5). Creeping bentgrass leaf sufficiency ranges and soil test designations are also listed.

	Silica Sand									
	Treatment Cation Percentages				Leaf Nutrient Analysis			Soil Nutrient Analysis		
Treatment	Ca	Mg	K	H	Ca	Mg	K	Ca	Mg	K
			%			$g \cdot kg^{-1}$			$mg \cdot kg^{-1}$	
1	0	0	80	20	11.0	1.8	20.8	6	21	0
2	0	0	95	5	11.7	1.8	21.4	5	23	0.1
3	0	40	40	20	13.7	2.9	15.3	4	8	0.2
4	0	47.5	47.5	5	13.0	2.9	17.0	7	18	0.8
5	0	80	0	20	13.1	4.6	4.7	5	33	0.8
6	0	95	0	5	14.5	5.2	4.3	2	9	0.3
7	26.6	26.6	26.6	20	14.2	2.8	12.6	7	19	0.3
8	31.6	31.6	31.6	5	13.7	2.8	13.1	6	16	0.7
9	40	0	40	20	14.4	1.9	16.0	3	9	0
10	40	40	0	20	12.9	3.7	4.1	6	16	0.6
11	47.5	0	47.5	5	12.3	2.0	17.0	7	23	0
12	47.5	47.5	0	5	13.1	4.1	3.9	7	17	0.6
13	65	6	1	28	7.6	2.7	4.1	7	26	0.1
14	65	6	5	24	9.1	2.5	5.8	6	19	0.1
15	65	12	1	22	9.3	2.9	4.7	5	9	0.1
16	65	12	5	18	10.4	2.8	5.6	9	30	0.3
17	75	9	3	13	11.5	2.8	4.6	9	18	0.2
18	80	0	0	20	13.4	2.4	4.2	6	11	0.1
19	85	6	1	8	10.7	2.8	4.8	8	21	0.3
20	85	6	5	4	10.5	2.6	5.6	7	16	0.3
21	85	12	1	2	10.2	2.9	4.3	5	24	1.6
22	85	12	3	0	10.9	2.9	5.2	6	19	0.2
23	95	0	0	5	14.2	2.3	4.2	7	17	0
24	95	5	0	0	14.1	2.6	4.1	7	16	0.4
25	0	0	0	0	11.4	2.0	4.4	5	18	0
26	5	95	0	0	11.5	5.2	3.9	3	16	0.3
27	99	0	1	0	13.4	2.2	4.6	9	23	0
28	1	0	99	0	9.8	1.9	20.4	6	21	0.2
Sufficiency Ranges†					5.0-7.5	2.5-3.0	22-26			
Soil Test Designations ‡§							Low	< 250	< 20	41-175
							Very Low			< 40

† Sufficiency Ranges for tissue nutrient content of creeping bentgrass.

‡ Values taken from Puhalla et al. (7). Ca concentrations less than 250 mg kg^{-1} are classified as having 'low' extractable Ca. Mg concentrations less than 20 mg kg^{-1} are classified as having 'low' extractable Mg.

§ Values taken from Christians (2). K concentrations less than 40 mg kg^{-1} are classified as having 'very low' extractable K. K concentrations between 41 and 175 mg kg^{-1} are classified as having 'low' extractable K.

Table 4. Average leaf Ca, Mg, and K concentrations of creeping bentgrass established on silica sand fertilized at different basic cation saturation ratios. Average soil extractable Ca, Mg, and K measured using the NH_4Cl extraction technique (11). The concentrations are averages of samples collected from both experiments at the 12-week sampling date. The red letters represent treatments whose nutrient applications were designed to be within the 'ideal soil' cation ratios as described by Graham (5). Creeping bentgrass leaf sufficiency ranges and soil test designations are also listed.

	Calcareous Sand									
	Treatment Cation Percentages				Saturation Percentages			Cation Ratios		
Treatment	Ca	Mg	K	H	%Ca	%Mg	%K	Ca:Mg	Ca:K	Mg:K
1	0	0	80	20	96	3	1.2	38:1	81:1	2:1
2	0	0	95	5	96	2	1.4	41:1	70:1	2:1
3	0	40	40	20	97	2	0.2	37:1	401:1	11:1
4	0	47.5	47.5	5	96	3	0.7	33:1	131:1	4:1
5	0	80	0	20	96	4	0.5	25:1	184:1	7:1
6	0	95	0	5	95	5	0.7	20:1	145:1	7:1
7	26.6	26.6	26.6	20	97	3	0.6	37:1	162:1	4:1
8	31.6	31.6	31.6	5	97	3	0.7	39:1	142:1	4:1
9	40	0	40	20	97	2	1.1	48:1	89:1	2:1
10	40	40	0	20	97	3	0.8	37:1	126:1	3:1
11	47.5	0	47.5	5	97	2	1	49:1	102:1	2:1
12	47.5	47.5	0	5	97	3	0.4	32:1	263:1	8:1
13	65	6	1	28	98	2	0.4	50:1	240:1	5:1
14	65	6	5	24	99	2	0.5	51:1	204:1	4:1
15	65	12	1	22	98	2	0.3	52:1	362:1	7:1
16	65	12	5	18	97	2	0.8	45:1	121:1	3:1
17	75	9	3	13	97	2	0.7	46:1	138:1	3:1
18	80	0	0	20	98	2	0.5	48:1	206:1	4:1
19	85	6	1	8	97	2	0.4	46:1	222:1	5:1
20	85	6	5	4	97	2	0.8	51:1	129:1	3:1
21	85	12	1	2	98	2	0.6	51:1	165:1	3:1
22	85	12	3	0	97	2	0.5	47:1	189:1	4:1
23	95	0	0	5	98	2	0.5	53:1	190:1	4:1
24	95	5	0	0	97	2	0.6	48:1	158:1	3:1
25	0	0	0	0	97	2	0.7	46:1	132:1	3:1
26	5	95	0	0	95	4	0.5	22:1	196:1	9:1
27	99	0	1	0	97	2	0.5	49:1	185:1	4:1
28	1	0	99	0	96	2	1.5	43:1	64:1	1:1
'Ideal Soil' Saturation Percentages†					65-85%	6-12%	1-5%			
'Ideal Soil' Cation ratios‡								6:5.1	13:1	2:1

† 'Ideal soil' cation saturation percentages (5).

‡ 'Ideal soil' cation ratios (1)

Table 5. Average measured base saturation percentages and cation ratios of calcareous sand samples from pots established with creeping bentgrass receiving various cation nutrient solutions. The cation equivalent weight saturation percentages and ratios were calculated from exchangeable cations and ECEC values measured using the NH_4Cl extraction technique (11). The percentages and ratios are averages of samples collected from both experiments at the 12-week sampling date. The red letters represent treatments whose nutrient applications were designed to be within the 'ideal soil' cation ratios as described by Graham (5).

Calcium saturation percentages of soil samples collected from bentgrass grown on calcareous sands ranged from 95-98% and 20-68% from bentgrass grown on silica sand (Tables 5 and 6), but the leaf Ca concentrations ranged from 7.63-15.73 g kg^{-1} which is well above the sufficiency levels for creeping bentgrass (Table 3). The cation ratios found within the sand samples ranged accordingly; Ca:Mg ranged 1:1 to 220:1; Ca:K 1:1 to 362:1; and Mg:K 0.1:1 to 11:1 (Tables 5 and 6). Based on both the range of applied cation ratios and the varying cation ratios meas-

	Silica Sand									
	Treatment Cation Percentages				Saturation Percentages			Cation Ratios		
Treatment	Ca	Mg	K	H	%Ca	%Mg	%K	Ca:Mg	Ca:K	Mg:K
1	0	0	80	20	34	0	66	n/a†	1:1	n/a
2	0	0	95	5	33	1	65	23:1	1:1	0.0:1
3	0	40	40	20	68	5	28	14:1	2:1	0.2:1
4	0	47.5	47.5	5	40	7	52	6:1	1:1	0.1:1
5	0	80	0	20	21	7	73	3:1	0:1	0.1:1
6	0	95	0	5	53	22	26	2:1	2:1	0.9:1
7	26.6	26.6	26.6	20	47	5	48	9:1	1:1	0.1:1
8	31.6	31.6	31.6	5	57	5	38	11:1	1:1	0.1:1
9	40	0	40	20	58	0	42	n/a	1:1	n/a
10	40	40	0	20	53	6	41	9:1	1:1	0.1:1
11	47.5	0	47.5	5	54	0	46	220:1	1:1	0.0:1
12	47.5	47.5	0	5	49	7	44	7:1	1:1	0.2:1
13	65	6	1	28	32	1	68	50:1	0:1	0.0:1
14	65	6	5	24	42	1	57	47:1	1:1	0.0:1
15	65	12	1	22	66	2	32	42:1	2:1	0.0:1
16	65	12	5	18	33	3	65	12:1	1:1	0.0:1
17	75	9	3	13	52	2	46	35:1	1:1	0.0:1
18	80	0	0	20	61	1	38	52:1	2:1	0.0:1
19	85	6	1	8	37	3	60	13:1	1:1	0.0:1
20	85	6	5	4	57	3	40	22:1	1:1	0.1:1
21	85	12	1	2	22	10	68	2:1	0:1	0.1:1
22	85	12	3	0	53	2	45	23:1	1:1	0.1:1
23	95	0	0	5	59	0	42	n/a	1:1	n/a
24	95	5	0	0	46	4	51	12:1	1:1	0.1:1
25	0	0	0	0	40	0	59	146:1	1:1	0.0:1
26	5	95	0	0	20	20	60	1:1	0:1	0.3:1
27	99	0	1	0	47	0	53	n/a	1:1	n/a
28	1	0	99	0	50.0	3	48	19:1	1:1	0.1:1
'Ideal Soil' Saturation Percentages†					65-85%	6-12%	1-5%			
'Ideal Soil' Cation ratios‡								6:5.1	13:1	2:1

† 'Ideal soil' cation saturation percentages (5).

‡ 'Ideal soil' cation ratios (1)

Table 6. Average measured base saturation percentages and cation ratios of silica sand samples from pots established with creeping bentgrass receiving various cation nutrient solutions. The cation equivalent weight saturation percentages and ratios were calculated from exchangeable cations and ECEC values measured using the NH_4Cl extraction technique (11). The percentages and ratios are averages of samples collected from both experiments at the 12-week sampling date. The red letters represent treatments whose nutrient applications were designed to be within the 'ideal soil' cation ratios.

ured in the silica sand, it appears creeping bentgrass can tolerate a very wide array of cation ratios.

This research further demonstrates several limitations of applying the BCSR theory to sand-based turfgrass systems. First, it is possible that soil samples can have a correct or even a high cation saturation percentage for a particular element, but still be deficient in that element. Potassium saturation percentages of silica sand samples were very high >28% (Table 6), but the leaf and soil extractable K concentrations were deficient, <21 g kg^{-1} and <1.6 mg kg^{-1} (Table 4), respectively. If one was to use the BCSR theory as the only means for soil test interpretation, no extra K would be recommended, but according to Sufficiency Level of Available Nutrient (SLAN) guidelines, these plants were K deficient. Although no growth or quality issues were observed within these experiments, it is probable that problems would eventually occur, if these conditions were to continue.

The dissolution of $CaCO_3$ that occurred during the soil testing procedures with the calcareous sand samples resulted in Ca saturations percentages greater than 95% (Tables 3 and 4). Additionally, the sand samples, especially the silica sand samples, had such a small CEC that the cation saturation percentages and ratios gave widely varying and misleading results (Tables 5 and 6). When sands have such low CEC values and exchangeable cation concentrations, any ratios or percentages created from these low numbers can vary greatly and can change very easily. This problem also holds true when the BCSR theory is applied to results generated from saturated paste or water extract testing procedures.

The nutrient concentrations found in saturated paste extracts are very small and making ratios from these small numbers can be precarious. Change one of the small numbers by just a little bit, and the resulting ratio will be considerably different and misleading. Furthermore, the BCSR theory was created on the premise that the basic cations exist in a specific ratio on the exchange sites, which the concentrations of these cations can be significantly different between what is found on the exchange sites and what is found in solution.

This research demonstrates the difficulties in trying to obtain an "ideal ratio" of cations in low-CEC sand-based media, and that creeping bentgrass can tolerate a wide range of ratios. The BCSR theory may be applicable to turfgrass established on soils that are high in clay or organic matter, but for high-sand, low-CEC rootzones used for putting greens and sports fields, the BCSR theory does not appear to be applicable. It is recommended that the results of BCSR interpretation not be used as the sole determining factor in developing fertility systems for sand-based golf course greens that have either a low CEC or are constructed from calcareous sands.

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