Soil Cation Balance

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BACKGROUND

The concept of cation balance, its importance with regard to plant growth, and its use a tool for managing soil fertility are not new or revolutionary. The origins of the concept date back to the 1890s with research conducted in Germany. Through the years numerous researchers have tested and refined the concept.

The basic elements of the cation balance concept as we know it today were first elucidated by researchers at Rutgers University. They conducted several field trials to determine what was required to grow alfalfa on acid, sandy soils. They concluded from the results of their research that the "ideal" soil for alfalfa production is one that is 80% saturated with cations (80% of the soil cation exchange sites are occupied by Ca, Mg, K, and Na) and among these cations, 65% should be Ca, 10% Mg, and 5% K (Bear and Toth, 1948). They also noted that, from these values, the Ca:Mg ratio should be 6.5 to 1. In about the same time frame, Albrecht and Smith (1952) conducted a series of studies, primarily with soybean, and concluded that the ideal cation saturations are really not fixed numbers but can range between certain values without affecting plant growth. They came up with the standards in use today. They kept the 80% cation saturation standard, claiming that 20% saturation with H+ ions was necessary to "mobilize" nutrients, and expounded on the idea that soil pH was not nearly as important as % base saturation. Besides 80% base saturation, they indicated that the Ca saturation should range between 65 and 85%, Mg between 6 and 12%, and K between 2 and 5%. These are the standards most often employed by today's promoters of the cation balance concept.

THE EVIDENCE

Numerous researchers have studied the effects of base and cation saturations cation on crop yield and nutrient content. For the purposes here, I'm drawing upon three of the studies. The first involved the growing of barley, red clover, corn, and timothy in the greenhouse on eight New York State soils adjusted to various pH levels and combinations of cations (Moser, 1933). The other two studies were conducted at Ohio State University by McLean and Carbonell (1972) and by Eckert and McLean (1981). In the McLean and Carbonell (1972) study, two soils were adjusted to nearly constant % base saturations, while the % saturations with Ca and Mg varied widely. Eckert and McLean (1981) employed a single soil treated to pro-

Table 1. R^2 values for the relationship between crop yield and soil bast saturation, pH, Ca, and Mg.

	R^2 values		
		McLean and Carbonell (1972)	
Soil property	Moser (1933)	German millet	Alfalfa
% base saturation	0.790	--	--
pH	0.752	--	--
% Ca saturation	0.636	0.009	< 0.001
Exchangeable Ca	0.859	0.729	0.880
% Mg saturation	0.590	0.001	0.001
Exchangeable Mg	0.704	0.259	0.335
Exchangeable Ca:Mg ratio	0.173	0.008	0.018

Table 2. Ranges in soil properties associated with highest and lowest yields of German millet and alfalfa.

Soil property	German millet		Alfalfa	
	Lowest yield	Highest yield	Lowest yield	Highest yield
% base saturation	58 to 88	38 to 60	35 to 60	58 to 68
% K saturation†	2.1 to 4.6	2.9 to 5.0	2.0 to 5.0	2.2 to 4.6
% Mg saturation	1.5 to 3.9	2.9 to 13.8	2.7 to 14.6	1.8 to 9.9
% Ca saturation	53 to 84	27 to 49	23 to 53	49 to 84
Ca:Mg ratio	18 to 54	3 to 11	3 to 20	7 to 53

† Range tested = 2 to 5.

vide wide ranges in % base saturation as well as Ca and Mg ratios. In both studies, the crops grown were German millet and alfalfa.

The data from the Moser (1933) and the McLean and Carbonell (1972) studies are well suited to examination of soil treatment effects on crop yield. I applied a standard statistical technique to determine the nature of these relationships. In this technique, a statistical value, R^2, is calculated. A perfect relationship results in an R^2 value of 1.0. The closer the value is to 1.0, the stronger the relationship and the higher the degree of confidence we have in declaring that it is truly a cause-and- effect relationship. This, then, provides the basis for selecting which measure of a nutrient provides the most reliable estimate of the plant available supply of the nutrient in soil.

The R^2 values calculated for the crop yield data gathered by Moser (1933) and McLean and Carbonell (1972) are shown in Table 1. From these values, the following becomes obvious:

1. There was no real difference between crop response to % base saturation and soil pH.
2. The crops were much more responsive to the amounts of exchangeable Ca and Mg than to their % saturations.
3. Ca:Mg ratios of 1.0 to 5.0 in the Moser (1933) study and from 2.2 to 15.0 in the McLean and Carbonell (1972) studies had no influence on crop yields.

The results of the Eckert and McLean (1981) study are suited to interpretation in another manner. They found that crop yields could be separated into two groups highest and lowest. Within each of these groups, there were no significant differences in crop yields. This situation allows examination of the ranges in base and cation saturations for each group for which crop yields were essentially constant. This examination also reveals the amount of overlap in base and cation saturations between the highest and lowest yields.

Examination of the ranges in % base saturation, individual cation saturations, and Ca:Mg ratios associated with the highest and lowest crop yields (Table 2) quickly reveals that:

1. There were no unique base or cation saturations or Ca:Mg ratios associated with the highest or lowest yielding treatments.
2. The highest and lowest yields were often obtained with the same set of soil properties.

These observations led the authors to conclude that crops respond primarily to the amounts of exchangeable Ca, Mg, and K in soil, not their % saturations.

There is an inherent assumption in the cation ratio concept that plants accumulate cations in accord with their ratios in the soil solution, which is why certain ratios of the ions need be maintained on the cation exchange sites. Research conducted by Barber (1984) has shown that the dominant mechanism whereby Ca and Mg ions move through soil to plant roots is different from that for K. The result is that the concentrations of these ions at root surfaces where they might be taken up are not the same as they are in the bulk soil solution. Not only this, but the ratios of these ions at the root surface are very different from their ratios in the soil solution and on the cation exchange sites.

This brings us to an interesting and important question. Do plants take up cations in the same ratio as they are delivered to roots? More than one researcher has answered this question. The work of Steiner (1980) is one such study. He grew lettuce and tomato in nine nutrient solutions that differed widely in the ratios of Ca, Mg, and K and measured the amounts of these nutrients taken up by the two crops. What he observed is shown in Figure 1. The Ca, Mg, and K contents of the plants showed no relationship to the ratios of the ions in the nutrient solutions. In fact, the quantities of Ca, Mg, and K taken up were nearly constant. The interpretation of these observations is that the plants accumulated the nutrients in accord with their physiological need, not according to the ratios of Ca, Mg, and K in the nutrient solutions.

CONCERNS

Even if we ignore the large volume of evidence that base and cation saturations are not valid criteria for managing turfgrass nutrition, other concerns exist. The first arises from the fact that many golf putting greens are constructed with calcareous sands or, through a few years of irrigation with Ca- and Mg-laden water, they become calcareous. When standard soil testing methods are used for calcareous soils, the results are erroneous. Soil exchangeable Ca levels are overestimated and the soil CEC underestimated (Hendershot and Lalande, 1993). This can lead to incorrect soil interpretations and invalid recommendations.

It is true that if mineral soils of temperate climate regions are adjusted to a base saturation of around 80%, their pH will generally fall in the range of 6.5 to 7.0. But this is not true for the more highly weathered soils such as those that may be found in the southeastern part of the USA or for organic soils. These soils tend to attain a pH of 6.5 to 7.0 with base saturations much closer to 50% than 80%. Adjusting their base saturations to 80% results in pH values in excess of 7.0. Sand-peat putting green root zone mixes behave like organic soils. Thus, strict application of the 80% base saturation concept to them runs the risk of elevating their pH to undesirable levels.

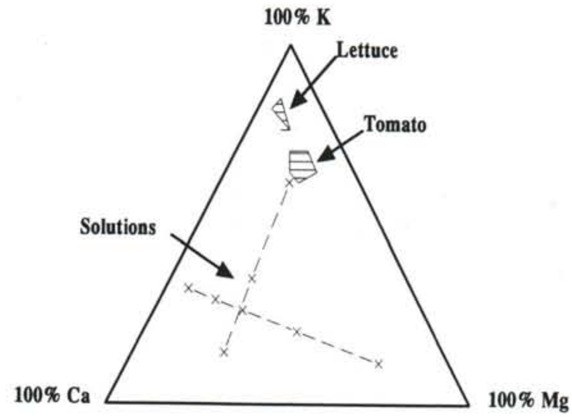

Figure 1. Influence of nutrient solution composition on the Ca, Mg, and K contents of lettuce and tomato.

The third concern is with low CEC root zone mixes. Application of cation saturation criteria to them can result in applying or maintaining inadequate amounts of K and, in some cases, of Mg as well. The trend toward use of root zone mixes with less than the traditional 20% peat can only increase the chances that recommendations based on cation saturations will increase the incidences of K and Mg deficiencies.

A final concern is one that may have already crossed your mind. All of the research cited here was conducted with agronomic and horticultural crops. Where's the research done with turfgrass? The kind of crop grown is important because it is a well-known fact that there is considerable variation in crop requirements for Ca and Mg . For example, legumes such as alfalfa are noted for having high Ca and Mg requirements. In contrast, turfgrass has much lower Ca and Mg needs, and extrapolation to turfgrass from legumes is risky.

The fact of the matter is that there are no published reports of investigations of turfgrass response to ranges in soil base or cation saturations. The closest we can come is the research currently being conducted by St. John et al. (1999). They're growing turfgrass on calcareous sands and, in accord with cation balance theory, are applying gypsum, lime, calcium nitrate, and calcium chelate. None of these treatments has thus far affected growth or the calcium content of Kentucky bluegrass or creeping bentgrass clippings.

CONCLUSIONS

The evidence is overwhelming that the base saturation-cation balance theory is just that – a theory for which there is no substantiating evidence. It's the amounts of exchangeable Ca, Mg, and K in soil that are important, not their ratios. Virtually any soil with a pH > 5.5 contains much more Ca than turfgrass requires and the same generally holds true for Mg.

Employment of the base saturation-cation balance theory as a nutrient management tool in sand putting greens often leads to costly and needless applications of gypsum, magnesium sulfate, or other sources of these nutrients. Strict application of the theory can actually result in K and Mg deficiencies in greens constructed with small amounts of organic amendments. The only beneficiaries of the theory are turf consultants, sales people, and the manufacturers of products designed to correct Ca and Mg imbalances.

The only reliable way to check whether or not soils require Ca, Mg, or K is via testing for the amounts of exchangeable Ca, Mg, and K present. Exchangeable Na is of concern only when putting greens are being irrigated with low-quality irrigation water, and especially with effluent water. In these situations, buildup of exchangeable Na and soluble salts can occur and must be promptly dealt with.

The best I can tell from the scanty literature on the subject, the minimum soil level of exchangeable Ca for turfgrass is 250 ppm, or 625 lb/acre in sand greens. For Mg, the figures are 50 ppm or 125 lb/acre. For sand putting greens that typically have CEC values of around 5.0 meq/100 g, these levels of Ca and Mg amount to saturations of 25 and 8%, respectively. Applying Ca or Mg to achieve levels several-fold greater than these will not benefit the grass, improve soil physical properties or stimulate soil microbial activity.

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PLEASE HELP!

When you receive your Turfgrass Survey questionaire from the Wisconsin Agricultureal Statistics Service, please fill it out and return it promptly. A strong response from golf courses is important!