THE ADVISABILITY OF USING CATION BALANCE AS A BASIS FOR FERTILIZER RECOMMENDATIONS

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The question of the importance of using the base cation saturation ratio concept (BCSR) in the nutrition of crops and for making soil test recommendations have been raised many times over the past 100+ years. Recently this issue has surfaced again as a part of programs promoted as "sustainable farming systems" or friendlier to the land or other parts of the environment. As others before them, the primary promoters of this concept are businesses promoting the use of calcitic limestone, or gypsum ($CaSO_4$) to bring Wisconsin soil into better cationic "balance."

The Base Cation Saturation Ratio Concept and Research

In 1892, O. Loew published a paper in Germany that was apparently the first to suggest that Ca:Mg ratio of soils influenced crop yields (Loew, 1892; Moser, 1933). Most researchers up to the early 1930s concluded that cation ratios per se had little effect on crop growth within limits normally encountered. Adverse effects of a high Ca:Mg ratio were shown to be the result of a deficiency of Mg and vice-versa. In addition to reviewing the pre-1931 literature, Moser (1933), in conducting his own research, found no significant correlation between the Ca:Mg ratio of either New York soils and the average annual yield of barley, red clover, corn, and timothy grown in rotation. He concluded that the significant factor in determining yields was exchangeable Ca. He did not consider the influence of soil pH. Analysis of the author's data showed that pH and exchangeable Ca correlated equally well with average crop yield r = 0.83 for pH and 0.85 for exchangeable Ca).

Two of the strongest proponents of the ratio or balance concept are William A. Albrecht at Missouri and Firman Bear and others in New Jersey. Albrecht and his students published a variety of papers related to this topic starting in 1937. Interestingly, much fo the early work on the influence of Ca and Mg on crop growth and quality was conducted in the greenhouse with artificial media. Often, statistical analyses of the results were not reported. In one of their earliest studies, Albrecht (1937) found no nodules on alfalfa plants at pH 5.5 unless Ca was added to the clay in sand-clay mixtures in which the alfalfa was grown. Because Ca increased the number of nodules more than did raising the pH at the low level of Ca with which he was working. Albrecht concluded that Ca was more important than pH in nodulation. Subsequent experiments by Albrecht and his students arrived at a similar conclusion—that pH was relatively unimportant in comparison to nutrient supply (Albrecht and Schroeder, 1941; Harston and Albrecht, 19042) in spite of the fact that they did not control the soil pH changes when they added Ca.

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Albrecht and his students also conducted a series of biological assays on the effects of lime and fertilizer additions. These were regarded as more meaningful than yield data or chemical analysis of forage by Albrecht and Smith (1941) and Smith and Albrecht (1942). For example, McLean et al. (1943) fed rabbits lespedeza hay grown on five different soil types supplied with and without P and lime. Two of the soils also received K after K-deficiency symptoms appeared. Hay yields increased 71% as a result of the treatments. Rabbits fed hay from treated soil gained 20% more weight than those fed hay from unfertilized soil. After 6 weeks of feeding, the rabbits were killed and the femur bones measured. Bones from rabbits fed fertilized and limed lespedeza were heavier, longer, wider, stronger, and retained more P and Ca than those fed hay from control treatments. However, this research gave no data on optimum amounts of P, Ca, lime, or other nutrients to apply.

The actual basic cation saturation ratio (BCSR) concept of soil test interpretation as currently being used in the USA was developed in New Jersey (Beat et al., 1945; Bear and Toth, 1948). This concept states that an optimum soil environment for plant growth is created when the soil cation exchange complex is satisfied in the ratio of 65% Ca, 10% Mg, 5% K, and 20% H (Bear et al., 1945). Later, Graham (1959) modified Bear's original concept, stating that crop growth and yield would be little affected by saturations within ranges of 65 to 85% Ca, 6 to 12% Mg, and 2 to 5% K, with H ions occupying remaining sites.

Interestingly, this conclusion for an ideal ratio was more driven by the need to saturate the exchange sites with the least expensive basic cation than any agronomic consideration (Bear and Prince, 1945). For example, in a greenhouse experiment in which 20 New Jersey soils were cropped to alfalfa, the three soils that gave the highest yields of eight cuttings had an average of 15% exchangeable Ca, 11% exchangeable Mg, 2.2% exchangeable K, 67% exchangeable H, and a Ca:Mg ratio of 1.4:1. If percent Ca in the alfalfa issue is used as the important criterion, the four soils giving the highest concentration averaged 22% exchangeable Ca, 16% exchangeable Mg, 1.6% exchangeable K, and 57% exchangeable H (Bear and Prince, 1945). This and a later paper (Bear and Toth, 1948) seemed to indicate that the main justification for recommending 65% exchangeable Ca as "ideal" was primarily to minimize luxury consumption of K, especially on sandy soils where 5% exchangeable K was needed to supply adequate K. The idea of splitting K applications to achieve the same result was mentioned but, apparently, did not enter into consideration for the cation composition of the ideal soil.

The BCSR concept does possess a certain appeal on theoretical grounds. It has been shown that the percentage base saturation of an individual cation can affect its availability to plants (McLean et al., 1969), and that uptake of one cation may influence uptake of others (Bear and Prince, 1945; Omar and El Kobbia, 1966). For the soils where this concept was developed where luxury consumption of K and generally low to deficient levels of Mg, especially for annuals, were present, the more broad interpretation was generally workable. On the practical side, however, research into the effects of varying soil cation ratios on crop yield has generally not supported the concept of an "ideal" ratio.

Hunter, who worked with Bear at the inception of the BCSR concept (Hunter et al., 1943; Hunter, 1949), found no best Ca:K or Ca:Mg ratios for alfalfa even when the Ca:K ratios were varied from 1:1 to 100:1 and Ca:Mg ratios ranged from1:4 to 32:1. Similarly, Giddens and Toth (1951) found no effects of varying soil cation ratios on the growth of ladino clover as long as Ca was the dominant ion on the exchange complex. Foy and Barber (1958) showed no yield response in corn to varying soil K:Mg ratios, despite the appearance of severe Mg-deficiency symptoms at wider ratios. McLean and Carbonell (1972) showed no effect of varying soil Ca:Mg ratios on yields of alfalfa or German millet. More recently, Reid (1996) showed no effect of suing liming materials with different Ca:Mg ratios on the yield or percent legume in the stand for alfalfa or birdsfoot trefoil.

A more surprising situation occurred during the 170s and 1980s when E.O. McLean, a former student of Albrecht's, conducted a broad-sweeping series of experiments on the use of basic cation saturation compared with sufficiency levels as a basis for recommending Ca, Mg, and K (McLean and Carbonell, 1972; Eckert and McLean, 1981; McLean et al., 1983). Following a field study in which corn, corn, soybean, wheat, and alfalfa were grown sequentially at Ca:Mg ratios from 2.3 to 26.8 and Mg:K ratios between 0.6 and 3.6 led McLean et al. (1983) to conclude that "for maximum crop yield, emphasis should be placed on providing sufficient but not excessive levels of each basic cation rather than attempting to attain a favorable basic cation saturation ratio which evidently does not exist." In their study, the treatments producing the five highest yields for each crop had wide ranges in Ca:Mg and Mg:K ratios that were, to a large extent, common to the ratios associated with the five lowest yield treatments.

Wisconsin Research

Wisconsin also conducted some early Ca:Mg ratio studies when Simson et al. (1979) varied the Ca:Mg ratio of one Wisconsin sandy loam and two silt loam soils in the field by topdressing established alfalfa with 0 to 1600 lb/acre of Ca as gypsum or 0 to 1500 lb/acre of Mg as Epsom salts. At a fourth site, 0 to 1025 lb Ca and 0 to 630 lb Mg/acre were applied prior to planting corn. After 1 year, the soil Ca:Mg ratios varied from 0.8 to 5.0. Alfalfa dry matter yields ranged from 1.8 ton/acre in two cuttings on a silt loam affected by drought to 4.6 ton/acre on another silt loam. Although soil Ca:Mg varied more than five-fold, plant tissue Ca:Mg varied only from 0.8 to 1.8 in alfalfa and 0.44 to 1.06 in corn. The authors showed that movement of Ca and Mg to root surfaces in the transpiration stream was more than sufficient to meet crop needs. The plant excludes excess Ca and Mg at the root surface. They concluded that if soil pH is near neutral and sufficient quantities of K, Ca, and Mg are present, varying soil Ca:Mg ratio within the range of 0.8 to 5.0 will have no effect on alfalfa or corn yields. No Ca deficiency or Mg toxicity could be induced at any of the four sites by applying up to 1500 lb/acre of soluble Mg.

Two recent studies have been conducted that further expanded the research base on use of cation ratios as a basis for soil test recommendations. The first study, reported by Kelling et al. (1996), compared a commercial high-Ca program with the UW recommendations. The research concluded that “adding calcium when sufficient levels are already present in the soil is not useful.”

A second study adjusted the Ca:Mg ratio of a Dakota sandy loam and a Withee silt loam by adding 0, 800, 1600, or 3200 lb Ca/acre or 0, 486, 962, or 1924 lb Mg/acre. Corn followed by alfalfa were the test crops used. After the first cutting, the plots were split and 0, 100 lg Ca/acre, or 61 lb Mg/acre were topdressed. The results of seven site-years of research on the influence of Ca and Mg additions to soil on the yield and quality of corps resulted in the following conclusions:

1) Alfalfa yields were more closely correlated with exchangeable K than any other factor, including exchangeable Ca or Mg, Ca:Mg ratio, or percent exchangeable Ca or Mg.

2) Neither the initial nor annual applications of Ca or Mg had any effect on either grass or broadleaf weeds at any location. Exchangeable Ca or Mg, Ca:Mg ratio, and percent exchangeable Ca or Mg all failed to show any significant correlation with weed populations.

3) Earthworm populations in 1993 were unaffected by Ca or Mg applications at any site. Their populations were more closely correlated with pH, organic matter, and available soil P than to exchangeable Ca or Mg, Ca:Mg ratio or basic cation saturation percentage.

4) Alfalfa quality as measured by crude protein, ADF, or NDF {what do these stand for??} was more closely related to pH, organic matter, and exchangeable K than to soil parameters that included Ca or Mg.

5) This study found no justification for recommending calcitic lime over dolomitic lime or adding Ca or Mg to soils already containing adequate amounts of these elements. The use of Ca:Mg ratios or basic cation saturation percentages to assess the availability of Ca, Mg, and K in soils is ill-advised.

Summary

Two concepts of soil test interpretation currently dominate the soil testing field: the basic cation saturation ratio (BCSR) and sufficiency level concepts. The latter is by far the most popular among publica laboratories. Both concepts can provide reasonable fertilizer recommendations, if interpreted properly. However, the BCSR concept follows a rather tortuous path in interpretation and can often generate recommendations that are prohibitively expensive and not justified by agronomic research. Furthermore, the concept itself has been altered to suit the purposes of some agribusinesses. Although not perfect, the sufficiency level concept is backed by a much larger research base, and is preferable for interpretation of soil test results from both economic and agronomic standpoints. As stated by E.O. McLean (1983) “emphasis should be placed on providing sufficient, but not excessive levels of each basic cation rather than attempting to attain a favorable BCSR which does not exist."

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