1. Balanced Soil Cations

The crux of Albrecht's work is to balance the soil fertilizer elements. This can be quite controversial, and will be discussed at length. One of the basic precepts of soil science is cation exchange capacity (CEC). Clay particles are the smallest and most active constituents of soil. The earth, and clay particles, have positively and negatively charged sites. Positively charged atoms or molecules, called cations, are electrically adsorbed on the clay particles, which are predominately negatively charged. These are then called exchangeable nutrients. Plants excrete H+ which is exchanged for the major cations calcium, magnesium, potassium, sodium and others present in lesser amounts. These cations may be removed by plants, leached to lower soil layers, readsorbed by the soil, or moved into the soil solution and moved, depending on the equilibrium established by the conditions in the soil. Cation exchange capacity (CEC) is the total capacity of the soil to hold exchangeable cations. This determination is routine in soil analysis and is reported in milliequivalents of cations per 100 grams of soil. Sand and sandy loam soils are generally the lowest in exchange capacity; clays and organic matter are highest in CEC.

Having determined CEC, the next step is to find out which cations are present on the clay and in what proportions. This is called BASE SATURATION, since the major players in soil fertility are called base (non-acidic) cations (e.g. Ca, Mg, Na, K). From years of research by Albrecht and others, optimum base saturation ratios were determined for many crops. While many other nutrient tests can vary from month to month due to weather and soil cycles (N, P_2O_5, S), the CEC does not change very much over a year, although it can change over decades. Base saturation tests show stable characteristics of soil, and can be used to assess productivity potential. Very few agronomists or soil texts would disagree up to this point. The big question is whether or not optimum base cation saturation ratios exist which can be generalized for most crop situations.

Albrecht's research was unusual in longevity (1916-1959), geographic range (on three continents), and thoroughness. He studied complex relationships rather than simple causes and effects. He analyzed chemical properties of soils, fertilized and tested for yields, correlated quality considerations (protein, amino acid ratios), performed bioassay and feeding trials with animals, followed their development and that of their prodigy, and ultimately correlated health and fecundity of animals with quality of feed and soil properties of the soil on which it was produced. His work was primarily with grains (corn, wheat, etc.), forages (clovers, hay), and legumes (soybeans, beans). This could be used as a major criticism of applying his work to fruit and fiber crops. His studies did show how many different plants get what they need from the soil, and his principles certainly show how to optimize productivity and quality for many crops.

Albrecht believed in getting optimum soil conditions by using soil analysis and his mineral balancing principles. Plants will then use nutrients according to their needs. This was later called the Base Cation Saturation Ratio (BCSR) theory of soil interpretation. I will present a body of research which substantiates this theory. Albrecht clearly stressed quality over quantity. He promoted high yields, but made a good case for nutritional quality being the most important goal for production of protein crops (grains, legumes) and feeds. This emphasis on quality can apply to wine grapes and quality fruit and vegetable production.

The History of BCSR

As early as 1923, sophisticated methods for extracting nutrients and analyzing soils were being used in research. Hissink (1923) discussed the importance of adsorbed bases in soil fertility, pH management, and soil structure. I consider the soil structure, which is important in soil drainage and aeration, to be one of the most important benefits of using the BCSR system. Hissink stressed the relation of the adsorbed bases to one another in "any extensive scheme of soil examination" (p. 276). This theory was reiterated by McGeorge (1930), and Gedroiz (1931), who discussed the role of a calcium dominated exchange complex in pH regulation and best plant growth. Pierre & Scarseth (1931) pointed out the importance of knowing the percentage base saturation, total exchange capacity, and exchangeable hydrogen to evaluate soil reaction (pH) and plant growth. Following this were years of studies on cation ratios; Moser (1933) found no correlation between Ca: Mg ratio and yields, although the active calcium level did determine yields and increase Mg leaching. He did not test the recommended 6:1 Ca:Mg ratio of classic BCSR theory. Hunter, Toth, and Bear (1943) investigated Ca:K ratios in alfalfa. The found a wide range of ratios which produced good yields, although some ratios gave better K uptake. Allaway (1945) found differences in Ca uptake by soybeans based on the type of colloid (clay or organic matter), rather than just the percentage of calcium saturation. He did not examine the other cations or their ratios to calcium. He did conclude that he showed "additional support to the theory that plant feeding is essentially a replacement of nutrient cations from the soil by H ions from the plant" (p. 215).

Attention to specific recommendations for cation ratios - a BCSR theory - began in 1945 when Bear, Prince & Malcolm (1945) recommended the ideal balance for New Jersey soils: an exchange complex of 65% Ca, 10% Mg, 5% K, 20% H. About the same time, William Albrecht (1975), who had published several articles on base saturation and cation ratios from 1930-1945, formulated his recommended range of 60-70%Ca, 10-20% Mg, 2-5% K, 0.5-3%

Na, 10-15% H A key difference between Albrecht and most others was his emphasis on quality of crops, pest & disease resistance, and liming to provide calcium rather than fighting acidity. I will discuss each of these subjects later.

Comparison of BCSR and SLAN

During the period when BCSR was developed, an alternative school of agronomy grew up called SLAN, which stands for "sufficiency level of applied nutrients". McLean (1977) gave a well balanced explanation of the two theories, although he did not mention or cite Albrecht and his hundreds of articles on the subject. McLean also did not address the issues of quality vs. quantity, soil biological activity, or fighting acidity vs. amending calcium. Nevertheless, McLean's overview of the two main schools of fertilization, summarized in Appendix A, shows the strengths and applications of each. More research has been done on the SLAN method since it is more applicable to the use of concentrated chemical fertilizers, which has been the industry trend the last 30 years. McLean called for more research in BCSR, and concluded that: "A combination of these two concepts seems to work best as a basis for soil test interpretation in perhaps a majority of conditions" (p. 51).

Eckert (1987, p. 53) compared the BCSR system with the SLAN concept which states "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." Figure 1 illustrates a typical yield response curve. The key word here is response, which generally means measurable yields or reduction of deficiency symptoms. As more and more of a given nutrient is applied, yields will rise. At a certain point the yield increase will level off or even drop. The range of fertilizer that results in the highest yield is the "sufficiency level". Beyond this range either dollar return or yield increase does not justify the cost. The SLAN method does not stress the effect of one nutrient on another. Its strength for nitrogen, phosphorus and micronutrient recommendations is supported by a large research base.

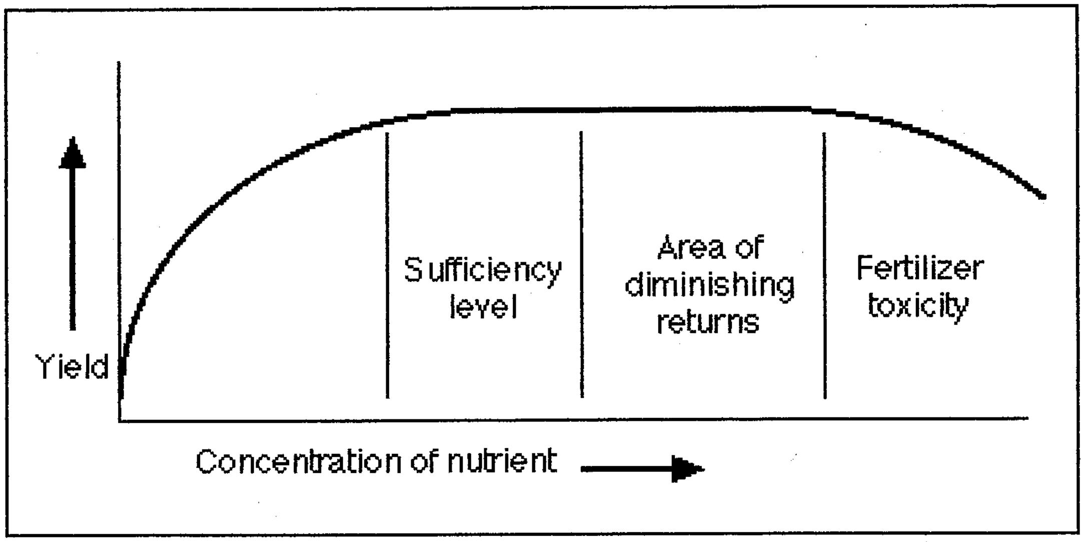

Figure 1. Typical response curve for Sufficiency Levels of Nutrients

McLean (1977) reported that in 1977 the BCSR model was used most by private laboratories in the North Central region of the U.S., while most university laboratories preferred sufficiency levels. This trend seems to be true today in California, based on my experience with private firms and current research from universities. Although standard tests exist and are in use, interpretation and fertilizer recommendations show wide variation. As Eckert stated: "... it seems that wide discrepancies in fertilizer recommendations developed by different laboratories operating in a given region are most often due to differing philosophies of interpretation" (p. 53).

Criticism of the BCSR Approach

Attention to cation ratios and the effects on yields continued. Two studies often quoted by detractors of the BCSR method are interesting. Hunter (1949) tested different ratios on alfalfa. He found no effects on yields but effects on phosphorus uptake and mineral contents were significant. His six different ratios did not include the optimum levels suggested by Albrecht or Bear; potassium was about twice as high as they recommended. He also did not consider sodium (Na) in his greenhouse pot experiments. Hunter did demonstrate a recurring theme in previous research: that Ca, Mg and K interact and increase or decrease uptake of each other.

In another related study, Eckert & McLean (1981) tested millet and alfalfa in greenhouse culture. They tested 18 different Ca:Mg:K ratios; 2 were close to ratios suggested by Albrecht and Bear. They found no consistent effects on yields, and concluded that "once nutrient levels are raised to adequate levels, the ratio of nutrient cations is not particularly important, as long as one is not present in such excess as to hinder uptake of another" (p. 798). They did find that if Ca, Mg, or K were too high in relation to each other, one would interfere with uptake of another. They also suggested a 6-12% Mg range (similar to Albrecht and Bear). They did not test or show Na levels, and used calcium hydroxide as a calcium source (which is highly alkaline). They also did not allow either crop to reach maturity by going to seed. Albrecht clearly pointed out the importance of optimum ratios in protein and seed production. By harvesting plants short of seed set the most serious nutritional stresses of plants were eliminated. Eckert & McLean's studies were not able to show the benefits of cation balance on seed yield or quality.

Field studies (McLean, Hartwig, Eckert, & Triplett, 1983) were initiated in Ohio to compare the SLAN and BCSR concepts for making fertilizer recommendations to maximize yields. Eighteen combinations of different Ca:Mg:K ratios were set up in the field, and corn, soybeans, wheat, and alfalfa were grown in 6 successive years. The researchers concluded that there were no single Ca/Mg or Mg/K ratio (or range of either) that was associated with high yields of crops. Unfortunately, although they carefully laid out the experiment and analyzed the data, the researchers never tested the suggested 65-75% Ca, 10-15% Mg, 2-5% K set forth in the BCSR model! The closest 5 ratios were as shown:

Table 2

Per Cent of CEC as Tested by McLean, Hartwig. Eckert, & Triplett (1983)

pH	%Ca	%Mg	%K
5.8	25%	4.4%	2.3%
5.7	39%	6.8%	2.3%
6.9	49%	7.0%	2.3%
6.2	25%	4.1%	3.9%
6.8	50%	7.4%	3.5%

The highest level of calcium tested by McLean et al. was 59%, below the minimum of 60-75% recommended by Albrecht and others. The problem was the researchers confused pH with calcium level. Albrecht (1940) had warned specifically against this. McLean et al. used calcium hydroxide to raise pH, and thus never had high enough calcium saturation to actually test the BCSR concept. Other problems with the experiment are evident. It began in April 1975. An initial soil analysis showed very acid pH of 4.1 and very low calcium and magnesium (5.8% & 1.7%). After amendments were added to approximate the ratios desired, the soil was not tested again until Spring 1977 - two years later! We really have no indication of what the soil conditions were like the first two years of the experiment.

Comparing the direct response of the crops to nutrient cations by the SLAN method gave better results, although yield responses to increased levels of cations did not always occur. The Ca, Mg and K levels in plants generally increased as soil supplies rose. The study concluded that "emphasis should be placed on providing sufficient, but non-excessive levels of each basic cation rather than attempting to adjust to a favorable basic cation saturation ratio which evidently does not exist" (p. 639).

Recently, Stevens in Tree Fruit Nutrition (Peterson & Stevens, 1994) addressed the issue of BCSR and crop production:

> The concept of ideal cation ratio originated out of greenhouse research in New Jersey that suggested a ratio of 65% Ca, 10% Mg, 5% K, and 20% H would represent an ideal soil. Considerable research has been done to confirm an ideal soil ratio with no success. Data available suggest that trees perform adequately over a wide range of soils

He referred to the work of Bear in New Jersey, yet managed to miss the many articles by Albrecht, and others, on the subject. Later he recommended using the Ca:Mg ratio of 5:1 (close to that of Albrecht & Bear) used by a colleague. The key is the term "adequate performance"; this is not defined but apparently refers to standard industry yields and cosmetic quality. This approach is clearly not enough for those who wish to produce high quality fruit.