The Case for Optimum Ratios

It is very difficult to sort out all the aspects of crop production: soil, water and plant reactions. Generalizations in the field sciences are always subject to exceptions and limitations; however they are used often in agriculture. Optimum ranges, averages, etc. are used every day to formulate, modify, or explain management decisions. The BCSR system of looking at soil fertility is another valuable tool that deserves more consideration.

Recently, the literature is full of references to the importance of ratios of the major cations. Neilsen and Hansen (1984), studied mineral content of plants. They suggested that both ratios and content of exchangeable cations should be used to prescribe fertilizers. Alexander (1990) proposed using the calcium (Ca) : Magnesium (Mg ratio) as a direct index of fertility in soil classification. Raij (1990), discussed different methods of testing for pH, and suggested that more attention be paid to the "cationic suite" (p. 472).

There are many studies on the importance of cation ratios for tree fruits and vines. Lagatu and Maume (1927) showed that calcium could inhibit potassium

(K) uptake in grapes; Hagler (1954) later found that grapes grew better when Ca > Mg > K. Plisek (1989) reported on a BCSR system that is in use in orchards in the Republic of Czechoslovakia. This is similar to my proposal. Fallahi (1993), working with cherries, indicated a balanced ratio approach is needed due to the effects of nutrients on one another. The use of BCSR theory as a tool to manage the nutrients calcium, magnesium, potassium and sodium is one important aspect of its utility. Several other aspects of crop production can be managed using this tool.

Soil structural properties: drainage and aeration.

Soil physical characteristics such as dispersion/flocculation, hydraulic conductivity, tensile strength, and tilth are all related to the base saturation ratios found on the clay colloid. Dispersion is the property of clay to spread or suspend in water suspension. Such soils are said to have massive structure. When the clay in soil disperses, the soil loses its pore structure, water does not penetrate, crusts and cracks can form upon drying, and farm machinery can compact the soil more. Soils such as these have a high tensile strength, "sticky" or "plastic" consistency when wet, and problems with seed germination, root penetration and soil aeration. Flocculation is the opposite - clay forms granules called aggregates, which allow space for water and air in the soil pores. Seed germination, root growth, and aeration are all better in well flocculated soils. Hydraulic conductivity, the measure of the ease of water movement through soil, is much greater in aggregated soil.

It has been known for a long time that calcium-dominated soils provide good soil structure (Hissink, 1923). The effect of excess sodium on soil structure has been studied for many years; this was reported as early as 1937 (U.S.D.A. Soil Survey Manual). High sodium seals topsoil and causes a crust to form. One remedy is the application of calcium amendments such as gypsum (calcium sulfate). The calcium replaces sodium on the clay exchange sites, sodium is leached out and physical and nutritional conditions are improved.

I have used the approximate Ca: Mg ratio of 6:1, based on Albrecht's system, as a guideline for liming to obtaining optimum tilth (tensile strength) and drainage (hydraulic conductivity) since 1979. Some researchers and consultants in the field have stated that no significant relationship exists between cation ratios, tilth and drainage in low sodium soils. However, recent evidence shows a rather strong relationship. Palaveyev and Penkov (1990) described high Mg soils throughout Germany, USSR, Bulgaria, Sudan , and USA. These soils exhibit poor water percolation, more swelling, with crusting and cracking upon drying. Keren (1991) tested water infiltration in Israeli soils. He found both dissolved salts and adsorbed cations affected water percolation, and that high Mg lowered infiltration. Barzegar, Murray, Churchman and Rengasamy (1994) worked with five different Australian soils. They found exchangeable cation ratios affected crusting and sealing. The relationship Na > Mg > Ca showed the order of decreasing dispersion. They concluded: "when the soils were saturated with Ca, the clay particles were flocculated and formed aggregates with a porous granular structure on drying" (p. 196). Dexter and Chan (1991) found a similar relationship in natural soils, and observed that the cations that give rise to greatest dispersion (Na & Mg) result in hard packed soils upon drying. Farmers call such conditions `tight soils', and have to adopt cultural practices such as increased tillage or irrigation to deal with them. These measures are temporary, and can result in more compaction. Curtin, Steppuhn and Selles (1994) also confirmed that Mg causes dispersion in soils, and estimated that Mg is about 5% as dispersive as Na. While at first this may seem insignificant, many soils in northern California have 10-80 times as much Mg as Na. Serious drainage and aeration problems are found in area soils caused by dispersion from high Mg.

According to Bell (1995), all clays react to some extent to liming. They shrink and crack less, and hold more water because Ca has displaced other cations and caused flocculation. The positive effects of cation balance on soil structural properties have several practical applications in northern California, making the BCSR approach useful.

Erosion and BCSR.

When the clay in the soil is tight, dispersed, and has massive structure, water does not infiltrate or percolate as well as when there is ample pore space and aggregation. During northern California's rainy season, we often receive high amounts of rainfall in short periods of time - runoff, soil erosion and flooding are common. Keren (1991) found that soil Mg content has an effect on erosion in light to medium textured soils, and that Ca/Mg ratio was important. Liming soils in our area would reduce erosion and provide faster drainage when flooded.

Compaction and BCSR.

Soil compaction - the hardening of soil from heavy rain or field equipment reduces yields in several ways. Roots are unable to penetrate zones of compacted soils; water pools and puddles, keeping air from roots which can shut down or even die. Nutrient availability is hampered in compacted areas of fields. Locally, compacted areas are caused by tillage equipment (discs and rototillers), tractors with sprayers, and winter rainfall. New vineyard or orchard ground is commonly ripped with a chisel below compacted areas to shatter the hard layer. Subsoil equipment loosens soils and improves both drainage under wet conditions, and water retention and availability during dry seasons. Kirchof, Jayawardae, Blackwell and Murray (1995) working with vineyards in Australia with acid clay soils similar to ours, warned that soils can soon be recompacted under heavy trafficking - if calcium amendments (gypsum or limestone) are not applied. In our area, paying attention to calcium level and ratio would result in less compaction, better drainage in winter, and better water availability in summer.

BCSR and Nutrient Toxicities.

The BCSR method works well as a tool in dealing with severe imbalances or toxicities of nutrients. One of the roles of calcium is protecting plant membranes from the toxicity of other ions - and this depends on the ratio of Ca to other ions (Carter, Webster & Cairns, 1979). Protection from excess major cations (Na, K, Mg, Al) and such micronutrients as boron (B), iron, (Fe) and manganese (Mn) have all been reported. Chapman (1966) discussed the use of calcium in reducing boron content of grapefruit; I have personally used limestone several times to alleviate excess B in vineyard soil or water. Liming soils raises Ca levels and ratios on the clay and releases Mg or K to the soil solution where either will be available for plant uptake or leaching out of the root zone (Phillips,1988). I have recommended this technique for dealing with excess K in wine grapes and generally manipulating tree and vine nutrition. The key to several practical problems lies in application of the BCSR theory; I will discuss specific cases in northern California later.

BCSR and Groundwater Pollution from Fertilizers

Earlier, I explained the concerns in California with pollution of groundwater with fertilizers. Orchards and vineyards are the least efficient in utilizing applied nitrogen (N) when compared to other crops. Sanchez, Khemira, Sugar, and Righetti (1996) discussed this problem, estimating that recommended rates are 2-3 times the requirement of high yielding pear trees, and that in "pear orchards in the Pacific Northwest alone, excessive nitrogen applications could easily amount to 1,000,000 kg /yr" (p. 329). They suggested several improvements in

N fertilization: match the application rates to crop removal plus amounts needed for tree growth; better timing; foliar N sprays; and applying split applications of lower rates rather than all at once. They did not discuss specific soil conditions for best N uptake.

Losses of nitrogen have been very well studied. The nitrogen market is the largest sector of the fertilizer industry. The manufacturers have allocated research money to study its use and the problems associated with it. Most chemical forms of N are soluble, volatile when wet, and chemically reactive. These properties result in the inefficiencies of its uptake. For instance, up to 70% of urea nitrogen, a source commonly used in Northern California, can be lost under certain conditions (Morse, 1996). Dixon (1990, p. 5) called nitrogen a "fugitive nutrient' and reported research on seven crops in southern California over four years. In these studies, 70% of applied N could not be accounted for in the crop or the soil. He outlined the routes by which N escapes crop use: 1)Temporary or permanent storage in the soil; 2) leaching by irrigation or rain; 3) removal by erosion; or 4) volatilization and escape as a gas. One of the keys to keeping N available to plants is soil aeration and drainage.

Nitrogen exists in biological and chemical cycles in the organic matter component of the soil. It can change from one form to another rapidly, thus measures of N content of soils are only accurate for a short period of time. Appendix C shows a simplified nitrogen cycle is; it is taught in every high school biology class. The application of the N cycle concept in agriculture is actually rare. The statistics on N inefficiency attest to this. Weinbaum (1990) gave a very good account of the N cycle in orchards in the semi-arid central valley of California. In such areas, agricultural soils contain from 1-2% organic matter; I find northern California's can have up to 4%. I will show the importance of this with some simple calculations. Organic matter typically contains 5% total N.

Each year only 2% of this nitrogen becomes available (soluble) as a result of microbial activity. Since the average acre of soil 1 foot deep weighs about 3,400,000 pounds, a simple series of calculations demonstrates the potential amount of N that is in the top foot of soils and could be available for crop assimilation. Table 2 shows conservative estimates of amounts of N in organic matter and amounts available to plants. Column 1 shows the percentage of organic matter (OM) in the top foot of soil. Column 2 is the weight of dry matter that OM would represent. Column 3 is the total pounds of nitrogen contained in that dry matter. Column 4 is the weight of the nitrogen released annually, at a conservative rate of 2% per year.

Table 3

Potential Pounds of Nitrogen Released by Soil Organic Matter

% Organic Matter of soil	Weight @ 3.4×10^6 #/ac	# N/ac @ 5% of O.M.	# Plant Available @ 2% per year
1%	34,000 #	1700 #	34 #
2%	64,000 #	3400 #	68 #
3%	102,000 #	5100 #	102 #
4%	136,000 #	6800 #	136 #

Note the very large gap between the N contained in soil organic matter and the amount that becomes available to plants. This is literally thousands of pounds per acre: 1,666 # at 1% O.M. and 5,100 # at 3% O.M. content. Most crops require only 100-200# N per acre. Our northern California soils typically contain 1-3% organic matter. Managing organic matter and releasing nutrients for plant use before adding extra fertilizer should be the initial management strategy.

The main forms of nitrogen taken up by plants are generally considered to be NO_3^- and NH_4^+ (nitrate and ammonium). Rateaver and Rateaver (1993) document several organic forms of N also commonly used by plants. For simplification most workers just consider the inorganic chemical forms because they are present in large volumes. Most of the ammonium is converted by soil organisms to nitrate (see N cycle, Appendix C). According to Barber (1984), in acid soils or under cool conditions (both of which are common in northern California), fertilizer N applied as ammonium may remain as NH_4 for long periods of time - basically until soil warms and organisms can start the N cycle working. Few references would disagree with this. There exists a large gap in the literature on what specific soil nutritional conditions result in efficient conversion of the N in organic matter or fertilizer form to plant available form. Generally, a pH of 6.0-7.5 in moist, loose, well drained soil represents the best conditions. This is the condition of soils with optimum BCSR. The key is soil air and biological activity - and achieving the conditions needed to optimize both.

The ratio of major cations on the soil colloid regulates soil tilth, drainage, and aeration. Balancing these ratios by assuring dominance by Ca and appropriate amounts of other major cations results in increases in available N to plants. Albrecht (1975) discussed the importance of Ca in biological decomposition of organic matter, and liberation of nitrogen by both legume and free living bacteria. He explained how to release the thousands of pounds per acre of nitrogen, tied up in the protein of organic matter (p 148):

> The size of the microbial crop as reflected by its activity and like any other vegetation is determined by the nutrients being mobilized in the soil. If calcium is deficient there, then the organic matter grows a less proteinaceous composition or is mainly of carbonaceous content. Such vegetation is a poor microbial diet. It reflects this fact when it accumulates or remains for a longer time while the proteinaceous, or more calcium-rich decays more rapidly.

The calcium content of soils and protein production is a recurring theme in Albrecht's work; I will elaborate on this later.

Many researchers report increased nitrogen uptake by plants from the application of limestone. Of all these researchers, only Albrecht attempted to separate the effects of pH and Ca level. Bailey (1995) found liming increased N uptake of grasses through raising Ca level and pH. Curtin (1995) reported increased NO_3 production in both laboratory and field limed soils, due to increased microbial activity. Lyon (1921) reported increased available N in low Ca soils that were limed. Adams & Martin (1984) explained that liming improves N use by crops by maintaining a soil pH favorable for plant growth and microbial activity. They cited studies where liming improved nitrification even when soils were initially near neutral. Albrecht (1975) stressed the importance of calcium rather than pH for N fixers. Bear (1964) attributed increases in nitrification following liming to improved soil structure and aeration in addition to pH. Generally as soils become more acid, microbial populations shift from bacteria and actinomycetes to fungi - and away from ammonium and nitrate oxidizing organisms (Jackson, 1967). Forms of N easily lost are then produced.

Liming increases N availability (solubility), thus increased Ca levels could increase nitrate leaching into groundwater if it is not taken up by the crop. Lyon (1921) reported increases in N lost to drainage from raising Ca levels from liming. I have found in my experience that N fertilizers can and should be reduced by 25-50% after application of limestone, which will maintain or increase yields.

Phosphorus and potassium uptake can be very inefficient; 7-15% of P and 30-50% of K reach the crop on average (Dixon, 1989). Phosphorus runoff into streams and lakes is a serious pollution concern. Liming can increase soluble levels and uptake of both P & K in soils. This means that farmers can decrease amounts of P & K fertilizers used, saving money and benefiting water quality. Simultaneous optimum crop production and minimum pollution requires monitoring nutrients with soil and tissue testing in any fertilization program.