Analysis Interpretation

This is the main point of this project. I have demonstrated the need for proper fertilization, the lack of knowledge and use of soil science in the area, and the benefits of proper fertilization. Proper soil sampling, appropriate analysis, and interpretation of the results provide the information to make soil science work. Presentation of agronomic facts can then be followed by fertilizer recommendations geared towards production, efficiency, and economics. There are many ways to address a particular situation, and a complete and straightforward model for soil analysis can provide the basic information needed for fertilizer decisions.

All laboratories involved with agricultural testing provide instructions for proper soil sampling. A composite sample, or mixture of several cores or sub samples is usually used. Although this can be difficult to discern from lab report forms, most laboratories assume a 6 2/3 " plow depth and report results on this basis. While this results in lessor amounts of fertilizers recommended, saving farmers money, it is not realistic. Even the shallowest rooted crops do not confine their feeder roots to the top seven inches; the top 12-18" is probably more realistic. Tree fruits and vines have their feeder roots in a zone below the top 6" down to 3' or even more. A nutritional picture of the top soil just above and at feeder root level is more appropriate.

Using the top 12" for soil analysis is a compromise with several useful attributes. The top soil is where the majority of the air, organic matter, and biological activity exists. Plaster (1992) showed the number of bacteria in the top 12" to be about 10 billion per gram of soil; from 12-24" the number drops to about 1 billion. The bacteria that carry out the carbon, nitrogen, phosphorus, and sulfur cycles all need air to carry out the transformations that provide plant food. Higher availability and chelation of micronutrients occurs in the organic matter of the topsoil (Stevenson, 1986). Finally, the top soil is the component that can be most easily changed by farming practices.

The hybrid soil analysis model I have used for over 20 years uses BCSR to balance Ca, Mg, K, Na and H levels, to provide all the physical, biological, and chemical benefits of a well balanced soil previously discussed. Nitrogen, phosphorus, sulfur and micronutrients are all recommended based on general SLAN levels for each crop. Experience has shown that this results in such an improvement in fertilization practices and field results that oversimplification is not a problem. Tissue analysis, field observations, quality, pest and disease relationships can all be used to fine tune any program based on this hybrid model. It is based on sound theory, ample research, and long experience. The following guidelines pertain to lab reports similar to those from A & L and Harris Laboratories, two of the largest agricultural laboratories in the United States. The guidelines can be adapted to any laboratory format using the right conversion factors. The most important consideration is appropriateness of the test for the locality and crop, and optimum levels to compare with test results.

Most nutrients or elements in lab results are given in parts per million; this is a standard unit of concentration. Eventually these numbers must be converted to pounds/acre (or kg/ha) for calculating fertilizer amounts. Converting to pounds/acre per foot of soil depth is a simpler method for farmers and field workers. Whether one wishes to fertilize the top 6" or all 3' of the root zone of trees or vines, the figures can be derived with simple computations. Nutrient levels in parts per million times 2 gives pounds/ac of a 6 2/3 " deep soil (A & L Agricultural Laboratories. Agronomy handbook). Multiplying parts per million times 4 gives a good approximation of pounds per acre-foot.

Organic matter (OM) and cation saturation are expressed in percentages. These are best used in that form; if pounds per acre of OM are needed the percentage can be multiplied by the approximately 4 million pounds in an acre of soil 12" deep.

Organic Matter - This is a measurement of the total carbon from acid digestion; it does not differentiate between raw, humus, or active organic matter. There are now several laboratories that test biological aspects of soils as the interest in quality of OM increases. Organic matter can release from 25 pounds to hundreds of pounds of nitrogen annually for every 1% OM in the soil, depending on the conditions previously discussed.

pH - This is the measure of the active hydrogen in a saturated paste of soil and distilled water. pH is only a reflection of conditions at the time of sampling because it is highly subject to change from rain, irrigation, or fertilization .

Buffer pH - using a calcium or potassium salt to remove more hydrogen from the clay, this measurement attempts to add accuracy to the pH test - however the test is not applicable at pH 6.5 or above, thus it is not usable on the majority of crop soils.

Cation Exchange Capacity (CEC) - This is reported in milliequivalents per 100 grams of soil (meq/100 g), and can be measured directly or computed from the sum of the cations. The latter method is more common, and is adequate for most purposes. The CEC is dependent on the amounts and types of clay and organic matter present. Soil texture can be estimated from CEC, within limited geographic areas, although particle size or soil texture analysis is simple and gives more accurate and reliable percentages of sand, silt and clay. Most laboratories that do nutritional analysis will also do tests for soil physical properties. For drain fields and wastewater systems an accurate assessment of soil texture is needed; estimates from CEC are not acceptable.

Table 8

Estimates of Soil Texture Based on Total CEC

1-5	Sand	15-20	Clay loam
5-10	Sandy loam	20 -30	Clay
10-15	Silt loam	30 +	Heavy clay, high organic matter

These relationships can vary depending on the method used by different laboratories; however cation ratios generally correspond well across labs. Soil texture measurements do not give any specific nutritional information at all - a highly leached, low calcium sandy loam is very different from a high calcium desert sandy loam. Although high CEC soils do hold more nutrients, because of the high clay or OM content, the ratios of the major cations are a much better indicator of soil fertility and productivity.

Percent Cation Saturation - this is the proportion of the CEC occupied by the major nutrient cations. This characteristic of soil will not change much during the season until fertilization or addition of salts adds or removes cations. These ratios are used to calculate excess or deficit amounts of Ca, Mg, K, and Na because they are a very good indicator of potential productivity. Appendix H shows the optimum ranges in parts per million (ppm) of each of these major cations; levels in soil which are below these values are subtracted from optimum levels to find pounds/acre- foot of amendments needed to achieve optimum balance. For example, Appendix H shows that for a soil with a CEC of 11, calcium should be from 1430-1650 ppm to be in the 65-75% range. If the actual value is 950 ppm, 480 ppm more is needed to reach the minimum level for optimum conditions (see Table 9).

Table 9

Calculating Amounts of Cations Needed to Achieve Optimum

CEC	ppm Ca (tested)	ppm Ca optimum	ppm needed
11	950	1430 -1650	480 - 700
		ppm Mg optimum	ppm needed
11	287	134 - 201	0

For magnesium, the field had 287 ppm, which is above the 134-201 optimum range, so there is an excess of magnesium. Since these are ratios, the addition of calcium will lower the ratios of other cations.

The same principle is used for all the cations: Ca, Mg, K, and Na. The ppm optimum minus ppm in the field gives the ppm needed. Multiply by 4 to get pounds/acre foot of the element needed. For example, the soil in Table 9 needs

480-700 ppm of calcium, multiplied by 4 = 1920 to 2800 pounds per acre foot of pure calcium.

To calculate the amounts of amendments to add, divide the decimal, derived from the percentage contained in the amendment, into the pounds of nutrients needed:

1920 #/ac ft Ca needed divided by:

0.40 for pure limestone (40% Ca)

= 4800 #/ac limestone = 2.4 t/ac ft

OR

0.38 for 96% limestone (38% Ca)

= 5052 #/ac limestone = 2.5 t/ac ft.

Thus the amount of limestone needed to reach the lower optimum level of 65% Ca is 2.5 tons per acre for every foot in depth. For light textured sandy or loam soils, the lower level (65%) should suffice, however for clay soils or where there are drainage problems, the upper level (75%) should be reached. By calculating pounds needed per acre - foot the grower has the latitude to add enough for 1/2 foot of soil for row crops (divide the amount by 2) or treat the top 3' of a new vineyard site prior to ripping the soil (multiply the amount needed per foot by 3).

The same procedure is used to calculate the amounts of potassium or magnesium needed to balance the soil, or counteract excess levels of sodium. At this point decisions on the most economical way to accomplish optimum soil balance can be made with the whole picture in mind. For example, nutrients such as potassium can be concentrated only in the root zone, using lower amounts of fertilizer. This is often done with nutrients which do not move or migrate easily through the soil, such as potassium, phosphorus, and micronutrients.

Nitrogen - The soil test for nitrate (NO_3) gives the soluble N content at the time of sampling. Since most of the N is in the organic matter, the analytical result shows only the amount of N which has been mineralized or which has been provided by fertilizers in soluble form. Low levels could be due to leaching, poor bio-activity, or low organic soil N reserves. Adequate to high levels reflect recent fertilization, an active nitrogen cycle, or residue from crop or amendments. Excess levels could be a sign of excess fertilizers or poor N cycling. Multiplying the amount of NO_3 in parts per million times 4 gives pounds/acre foot. Tissue analysis of the crop is the best indication of N status; instruments are now available to field test NO_3.

Phosphorus - Three standard tests are generally used to show the P status of soils. The P1 (weak Bray) test shows soluble phosphorus, which is readily available to plants. P1 levels in ppm must be multiplied by 9.2 to determine the pounds per acre-foot of P_2O_5 (phosphate). Optimum levels for most crops are 150-250 pounds per acre, which is equivalent to 16 to 27 ppm. The P2 test measures soluble phosphate plus part of reserve phosphorus - that portion which is held in the soil for slow release. Levels of P2 considered optimum are 200 - 300 pounds per acre foot (22-32 ppm). If soluble P1 is high but P2 is low it may indicate future P deficiency problems. Adequate to high P2 reserve level with low soluble P1 indicates loss of P due to leaching or poor bio-activity. A third test, the $NaHCO_3$ (Olsen method) is used in soils above 7.0 pH to measure soluble, readily available P. This is not the best indicator of phosphorus in our area.

Potassium - The amount of adsorbed K on the colloid in relation to other cations is shown by its percentage of CEC. Except for very sandy soils, where the optimum percent K might not be enough for crop needs, this is the best indicator of potassium status. In the case of very sandy, low CEC soils (which are not common in the area), a higher level may be used and organic matter content should be increased for best K utilization. The field K value is compared to optimum levels. Three percent is the minimum for orchards and vineyards, and 5% is the maximum suggested level. Deficits are made up with potassium fertilizers, excesses with application of calcium and/or magnesium amendments. Multiply K in parts per million times 4 to get pounds per acre foot, or times 4.8 to convert to potash (K_2O). Then convert the % of K_2O in the fertilizer to a decimal and divide it into the pounds needed. For instance, potassium sulfate is 52% K_2O; to get 75 pounds of K_2O would require 144 # of fertilizer. Potassium fertilizers are usually concentrated near trees or vines, even though in theory the whole field would be better with optimum K throughout. When potassium fertilizers are banded, or applied to the base of trees or vines, 1/4 to 1/2 the computed total rate is used.

Sulfur - The test for the soluble SO_4 f orm of sulfur measures what the organic matter has mineralized and released for plant use. Levels from 28-48 pounds per are foot (7-12 ppm) are considered adequate. Low sulfate-S levels are often encountered in this area despite years of applications of sulfur fungicides; this reflects the extensive leaching or volatilization of the soluble form. Sulfur nutrition should be considered if poor uptake of N is occurring.

Micronutrients Zn, Mn, Fe, and Cu are usually extracted during analysis with a chelating agent. Boron is measured using hot water or other extractants.

These extraction methods simulate the processes of soil organic matter converting micronutrients into available forms from inorganic sources in the soil. Good organic matter management results in both increased availability of micronutrients and buffering of excesses. Recommended ranges for micronutrients are listed in Table 10.

Table 10

Recommended Optimum Micronutrient Levels

Micronutrient		ppm	#/ac ft
Zinc	Zn	1-3	4 -12
Manganese	Mn	9-12	36 - 48
Iron	Fe	11-16	44 - 64
Copper	Cu	0.9-1.2	3.6 - 4.8
Boron	B	0.5-1.0	2 - 4

Limestone requirement - This is the most important aspect of the hybrid model. Its strength is in addressing soil structure, biological activity, and the areas where the pH theory breaks down. The need for calcium amendments is traditionally correlated with pH but is best determined by the BCSR. The amount of calcium that is in the field compared to the level needed to achieve 65-75% Ca saturation is one of the most important calculations used in advanced fertility programs. The ratio of calcium to magnesium should be about 6:1 to achieve all the benefits of the BCSR method. Gypsum is only recommended to supply Ca for acid loving crops or when the carbonate-bicarbonate balance shows the need for soil acidification (see the section "The pH dilemma"). Calcitic limestone is generally used; dolomitic limestone only when BCSR shows low magnesium.

Other results commonly found on soil analyses are: Excess lime, soluble salts (ECe), and often other elements or nutrients such as chloride, molybdenum, and ammonia. The following are common soil tests which can be easily misinterpreted:

The Excess Lime or Excess Carbonate test began 100 years ago as a geologists' test. A few drops of concentrated acid dropped on a rock produces rapid bubbling as CO_2 gas is liberated from the rock.This test has been used ever since to indicate the presence of limestone ($CaCO_3$). Unfortunately, it neither tests for, nor necessarily indicates, the presence of limestone. When used on soils, it shows the presence of carbonates - which may be all or part sodium, potassium, or magnesium carbonates, as well as calcium carbonate. A common test for fertilizers is the "$CaCO_3$ equivalent" , a titration with acid to show neutralizing capacity of a liming material. Unfortunately, materials such as sodium carbonate have a high $CaCO_3$ equivalent with no calcium content. The amount of acidity needed to dissolve excess carbonates can be calculated from this titration, however if the percentage of Ca is not tested, acid amendments will be recommended which can dissolve Ca and cause soil deterioration. "Excess lime" is an oversimplified, misinterpreted test. It does indicate the presence of carbonates and thus a true alkaline soil reaction. Many high carbonate soils need calcium, and respond well to applications of limestone. Some serpentine soils in the area show these characteristics. They are particularly vulnerable to mismanagement if only the pH test theory is used. Soils of this type are described in the next section.

The Soluble Salts test is a measurement of the electrical conductivity (ECe) of the soil solution. In this case electrodes literally measure the extent of electrical flow. While this can show excess amounts of salts, it does not tell which particular salts are present. While sodium, sulfate and chloride can be detrimental in high amounts, calcium, potassium, nitrate and others are essential nutrients. This test does not distinguish between nutrients and toxic salts; its value is limited to showing potential problems but no specific reason for the problems. Because of our high rainfall conditions, excess soluble salts are rare in the soils of this area. However, over fertilization can result in high amounts of soluble salts in the root zone, and typical salt burn symptoms.

Appendix I has step-by-step instructions for converting data from laboratory analyses to reports that are more easily understandable. The format and calculations are outlined, and examples of interpretations are shown in narrative form.