Carl Rosato's Soil Fertility, from: http://woodleaffarm.com/enlivening-soil/

Soil Fertility

Fertile soil is a mixture of well-balanced minerals, high organic matter, humus, humic, fulvic and carbonic acids, good aeration and bountiful soil life. The biology or life in the soil is at its healthiest when the nutrients are plentiful and balanced, and there is sufficient oxygen and water. The top few inches of soil is the most vital, holding about 70% of the life and 70% of the organic matter. Below 6 inches the roots are feeding on mostly soluble nutrients since the micro-organisms are not able to thrive without sufficient oxygen. It is possible to create biological activity deeper with deep double dug or mechanical disturbance like spading. It is crucial to leave the soil as undisturbed as possible, although nontillage is very difficult in organic annual crops.

Increasing the quantity of earthworms and planting deep-rooted plants will let air into lower levels of the soil. Micro-organisms like bacteria, fungi, actinomycetes, algae, nematodes and protozoa, need oxygen to contribute directly to the release of nutrients to the plant. Some species of mycorrhizae tolerate very low oxygen levels, and infest roots much deeper than other species of beneficial microbes, providing nutrients and root protection. There are many symbiotic relationships going on between roots, organic matter, clay and micro-organisms to support the plant. Soil that is worked too wet annihilates air and water space, destroying the environment that microbes need. Soil that is worked too dry creates similar problems. Tending soil for optimum production means adding minerals and compost every year. Balanced, fertile soil makes for higher yields, better flavor, less disease and insect pressure and more nutritious food.

Compost

The best and cheapest organic fertilizer is compost. It contains organic matter, humus, calcium, phosphorus, potassium, nitrogen and many micro-nutrients, billions of microbes in each ounce and is a great food source for the biology in the soil. Compost made from plant residues and animal manures that have been fully decomposed can be applied every year at 1 to 8 tons per acre. In poor soils initial compost applications should be much higher, *if* the compost is fully digested and mature with proper C:N ratio. Vegetable crops often benefit from higher application rates, if the compost is aerobically digested and mature. Compost made from branches, leaves and plant residues without manures are best for orchards since this best supports fungal growth. Forests have soils that are inhabited predominantly by fungal growth. Orchard (non-tilled) soil biology closely resembles forest soil biology. Compost containing woody residues mixed into the soil robs plants of soil nutrients. If the compost contains woody residues, it is not finished, or was made incorrectly. It should be used as mulch or added to the top of the soil. Too much compost in the soil is hard for the soil to break down quickly and will temporarily tie up nutrients. If the compost has a proper C:N ratio of approx. 10-12:1, it does not tie up nutrients. High carbon composts always tie up nitrogen and sulfur, and sometimes other nutrients when worked in to the soil.

% SOM	Sand	Silt Loam	Silt Clay Loam
1	1.0	1.9	1.4
2	1.4	2.4	1.8
3	1.7	2.9	2.2
4	2.1	3.5	2.6
5	2.5	4.0	3.0

Water and Soil Organic Matter. The table at left shows Soil Organic Matter and Available Water Capacity, Inches of Water per Foot of Soil. Increasing organic matter in your soil can increase its soil moisture holding capacity significantly, as well as increasing its ability to aborb rainfall and irrigation water. Hudson, B.D. 1994. Journal of Soil and Water Conservation, 49(2). 189-194, March-April

Taking a Soil Sample

The aerobic zone is usually only 6-7" deep and should be all you need to sample for annual crops. Perennial crops may need to be sampled at greater depth to determine toxicity issues such as sodium, boron and carbonates. If the soil is double dug or mechanically deep tilled or spaded, soils sampling could go to 8" plus. Using a tube type soil probe or a shovel, take a minimum of five probes in different zones of the area being tested. Do not combine probes from areas that are not uniform to the sample desired, ie rocky, clayey, silty, flooded, or where noted difference in crop or weed growth occurs. Sample these areas separately but don't combine them with the "normal" sample. Mix the soils together for each sample. It should be about 1½ cups. Don't touch the soil with your hand. Don't use a rusty shovel. Don't place sample in plastic bag. The highest rates of soil fertility are seen in the testing done in May and June, the lowest in the winter. To get consistent results test soil at the same time of the year from test to test. Scrape away the surface organic material or get an abnormally high reading.

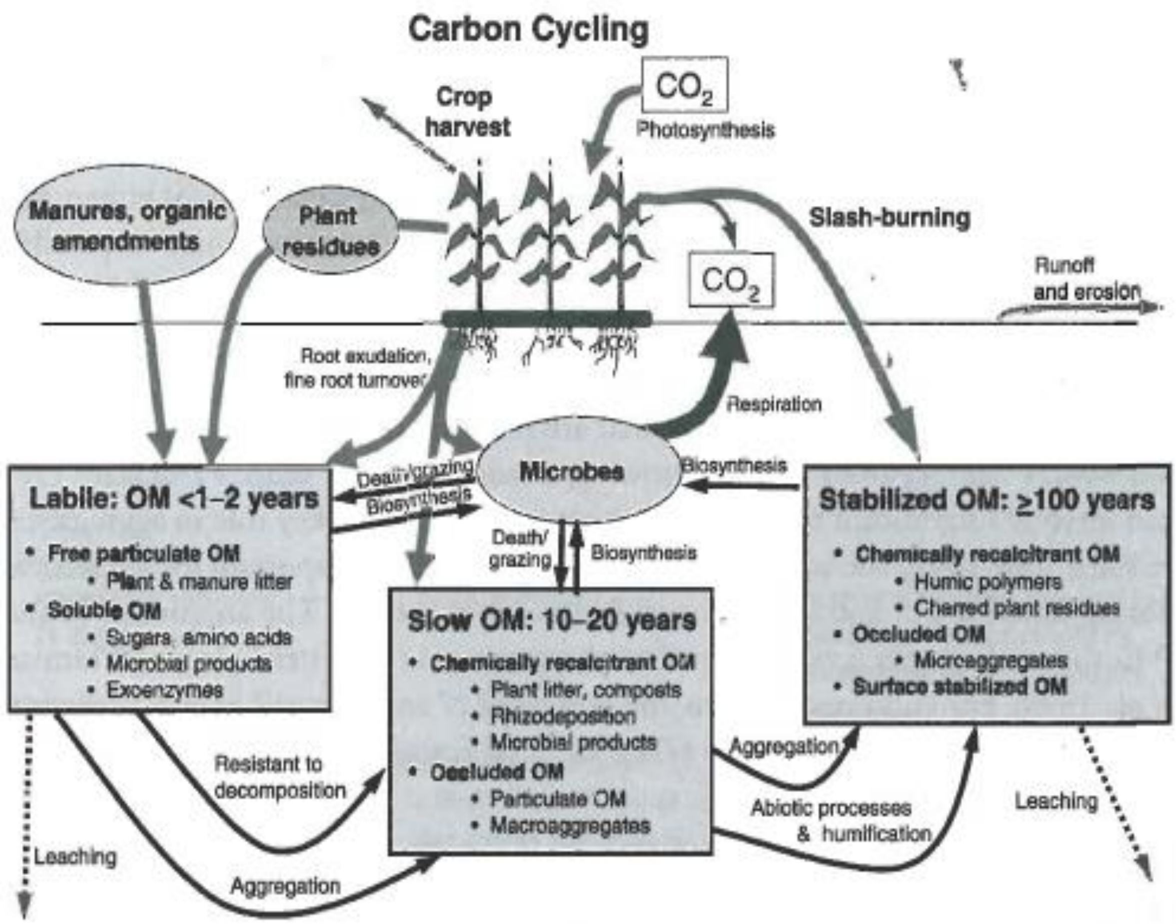
Reading the Soil Test

There are many labs around the country that give soil results. The following recommendations are based on lab results from A&L Ag Labs in Modesto, California. Every lab uses different testing methods so the numbers may not be the same. It is best to use one lab consistently to track annual results.
(Note: To covert pounds per acre to pounds per 100 square feet divide by 440.)

Organic Matter (O.M.)

Increasing organic matter levels will help with the soils texture, structure, drainage, aeration, water holding capacity and availability, nutrient availability, root development and dramatically improve soil biology. Working soil wet destroys organic matter. Organic matter (humus) holds three times more nutrients than clay and up to 5 times as much water.
2% Organic matter is poor. Over 4% O.M. to 10% is ideal. Above 10% organic matter often inhibits micro-nutrient uptake, and if composed primarily of woody materials will greatly reduce nitrogen availability. Most soils need additional organic matter every year, especially if tilled, or

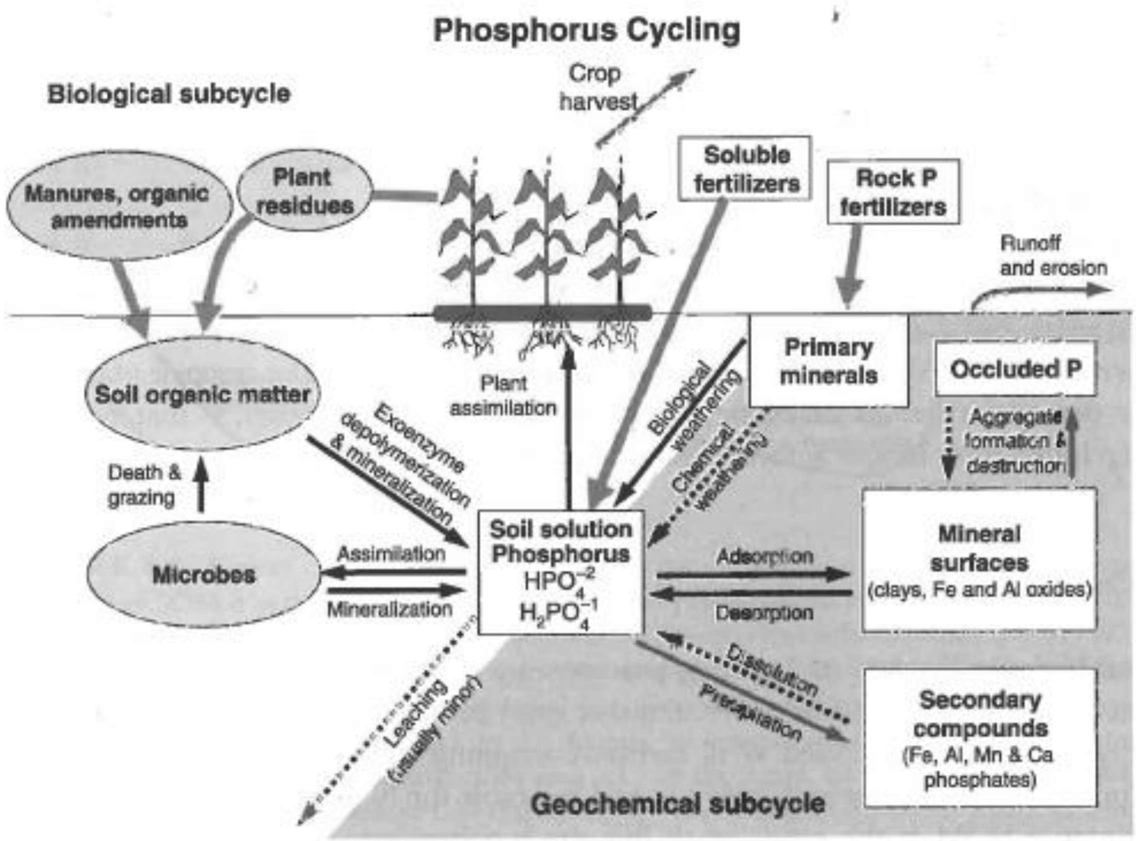
in arid climates. Compost, cover crops, mulches and leaving the soil undisturbed are the best choices for increasing organic matter.



Phosphorus

Phosphorus is most important in the storage and transfer of energy in the plant. It is essential in every metabolic process, protein synthesis, sugar development and legume nitrogen fixation. It is crucial for root development. Optimum phosphorus levels are needed for rapid seedling growth, winter hardiness, disease resistance, efficient water use, early maturity, and maximum yield. Phosphorus needs to be placed where it will be used, as it is less mobile in the soil than any other nutrient. Legumes can move phosphorus to deeper areas of the soil, where it will become available for other crops after the legume roots decay.
Phosphorus becomes immobilized at low pH by large concentrations of aluminum, zinc and iron, and at high pH by too much calcium.
Soft rock phosphate is the fastest working phosphate. Legumes can move phosphorus to deeper areas of the soil, where it will become available for other crops after the legume roots decay. 300#/acre is the minimum application. 2000#/acre of soft rock phosphate should supply enough phosphorus for years. When planting perennial crops in low P soils, add soft rock phosphate to

the planting hole, 1-10 pounds per hole depending on perennial size.
P1 tests immediately availability. 25 ppm is the minimum and above 40 ppm is ideal.
P2 tests for future availability. 40 ppm is the minimum and 60 ppm is ideal. Above 60 PPM often ties up trace minerals such as zinc and copper. The greater the OM, the greater the availability of phosphorus.



Potassium

Potassium is a regulator of metabolic activities. It is essential for photosynthesis and protein synthesis as well as carbohydrate transport and storage. It promotes root reserves, winter hardiness, cell development, strong walls, and reduces stalk lodging. Potassium improves water use efficiency, increases yield, improves crop quality, and reduces incidence of disease.
Most soils have less than 1% of the potassium available due to insufficient microbial activity and organic matter content. There are about 30,000 to 50,000 lbs. per acre of potassium in an average soil, but most of this is not plant available until microbial activity releases it. It is possible to release small amounts of potassium over time by increasing microbial activity with compost, compost tea and cover crops.
Apply mined granular sulfate of potash (50% K_2SO_4) in April for orchard crops, or solution grade sulfate of potash may be added to irrigation during the growing season, or foliar fed if severely deficient. Avoid winter and autumn applications as the potassium will be tied up in the soil before it can be used. Too much potassium ties up boron, calcium and manganese.
2% cation saturation potassium is the minimum and 5% to 7% is much better.

Magnesium

Magnesium is an essential component in the chlorophyll of green plants. It is also necessary for metabolic processes and in every operation involving phosphorus. Magnesium levels have important interactions with calcium, sulfur, and nitrogen. The ratio of magnesium to calcium should be around one to six. Excess magnesium will reduce potassium availability. Having a soil with too much magnesium will take more nitrogen because the excess magnesium makes the soil too tight. Excess magnesium is what makes clay soils "tight", restricting air and water availability, water drainage, root development and restricting microbial activity and organic matter decay.

The higher levels of magnesium in a sandy soil will help to tighten the sand. For sandy soil the optimum would be 16% to 20% and for clay soils closer to 12%. It will always be necessary to add more nutrients to a clay soil than to a sandy soil.

Note: Two pounds of sulfur will leach out one pound of magnesium when there is at least 60% calcium saturation.

Calcium

Calcium is part of cell walls and membranes; it controls movement in and out of cells, reacts with waste products and neutralizes toxic materials. Calcium activates many enzyme systems, it improves microbial activity and it enhances uptake of other nutrients. Essential for cell division. Increases cell density, and improves texture (crunch) of crops. Critical for balancing excess nitrogen. Critical for disease suppression. Having the correct amount of calcium in the soil will require less nitrogen. The calcium will loosen the soil and make more nitrogen available. Too much calcium can tie up all other nutrients especially magnesium, potassium, boron, zinc and copper.

Calcium cation saturation needs to be over 60% before you add gypsum (calcium sulfate) to lower excess magnesium otherwise the sulfur in the gypsum will take out the calcium first. Add limestone first to raise calcium to 60%, and then add enough gypsum to raise calcium levels to 68%. One third of applied calcium will become available the first year and it takes 3 years to be completely utilized. Solution grade limestone will become 100% available within 1-3 months.

Limestone applied to the surface of the soil will work its way into the soil at the rate of 1" per year.

Calcium leaches with excess rain or irrigation. Don't add over 4 tons per acre of limestone in any one year.

Limestone is about 33% calcium. Don't apply more than 4 tons of limestone in any one year.

Gypsum contains about 22% calcium and 16% sulfur. Gypsum will not change the pH because the sulfur and the calcium balance each other out.

Dolomite has 11% magnesium and 25% calcium. Only add dolomite when magnesium and calcium are low.

Sodium

Widespread in nature, sodium is found in all plant material. Although it does not seem to be necessary to the growth and development of plants, it is used advantageously, particularly when potassium is low. Sodium seems to be able to partly substitute for potassium.
Excess sodium is a problem in many dry areas particularly if the irrigation water is alkaline. Sodium toxicity to plants is often observed in saline and alkali lands and unfavorable soil structures can be present due to high sodium as well. Excess sodium suppresses soil biology, root development and nutrient availability. Any time your sodium and potassium together are over 10% then the manganese won't be able to get into the plant.
Apples get their best color with sodium levels over .5%. .5 – 3% is ideal.

pH

The acidity and alkalinity of soil is measured as pH . For the most fertile soil, the cation saturation is balanced and the pH will fall into a range of 6.3 – 6.8. Outside this pH range nutrients become unavailable and soil biology is suppressed. Decay of organic matter into humus is also reduced.

C. E. C.

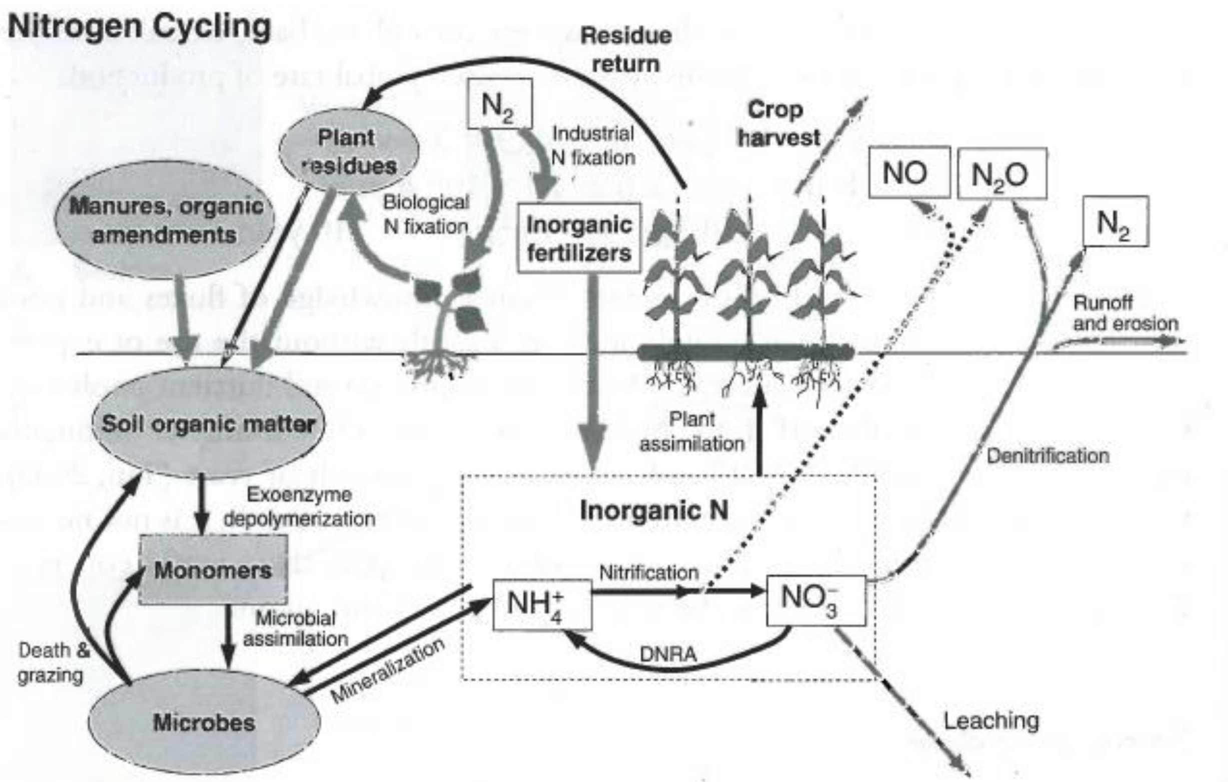
C.E.C. is the Cation Exchange Capacity and is a number that represents the soils ability to hold onto and provide nutrients. A sandy soil has a C.E.C. of between 4 and 9 and cannot hold onto very many nutrients. A heavier clay soil would have a C.E.C. of over 16 and hold more nutrients than a sandy soil. The strongest soils have CECS in the 20's to 30's. CEC measures the quantity of clay and humus in a soil. By increasing the humus the CEC will increase, providing improved nutrient retention and availability. CEC goes up 2 points for every 1% organic matter goes up.

Cation Saturation (Base Saturation)

Cation saturation is the percentage of calcium, magnesium, potassium, sodium and hydrogen held on the clay and humus sites on a soil test. The ideal calcium would be 68% to 72%. The ideal magnesium depends on how much sand or clay the soil contains. For sandy soil the optimum would be 16% to 20% and for clay soils closer to 12%. The ideal potassium would be at least 2% and 4% to 6% is better. The ideal sodium is at least .5% and not over 3%.

Nitrogen

Nitrogen is an essential constituent of proteins such as chlorophyll, enzymes, and hormones. It has a predominant role among the soil nutrients and is needed in substantial amounts, but is also the most likely to be deficient. Deficiency limits crop growth and yield. It is rapidly used by crops, can be volatilized into ammonia, and is easily leached as nitrate. Nitrogen is most stable when in humus and microbial bodies. Increased active organic matter increases available nitrogen. The organic form of nitrogen (carbon bound) is released to the soil and plant by aerobic microbial activity. However, an excess of nitrogen can produce an imbalance in plant metabolism resulting in poor plant quality and susceptibility to pests and disease, increased water absorption by crop, reduced flavor and keeping quality.
Dangers of nitrogen overuse include: zinc deficiency, copper deficiency, burns out humus, drives out calcium but leaves magnesium and depletes sulfur. The more excess nitrogen that you use the more you will have to replace nutrients that were carried away by the leached nitrogen.
Nitrogen and sulfur can leach out calcium. Nitrogen never leaches out magnesium, only sulfur does. The best methods to increase nitrogen levels are legume cover crops, compost and protein nitrogen sources.



Sulfur

Sulfur is a component of several amino acids that are essential for forming plant protein. It helps develop enzymes and vitamins, promotes nodule formation on legumes, aids in seed production, is necessary for good root development, improves taste, increases protein and reduces nitrates. It is involved in the chlorophyll production process, and sulfur deficient plant tissue symptoms resemble nitrogen deficient symptoms.

Sulfur is often deficient in all soils except where sulfur based fertilizers are applied. Without sufficient sulfur the rate of organic matter decomposition is decreased, due to a deficiency in sulfur reducing decomposing bacteria and Actinomycetes. Humus and organic matter helps hold sulfur in the soil. Sulfur feeds microbes and builds organic matter levels. Sulfur is very soluble and needs to be added in some form every spring. (unless there is no deficiency. Soils high in active organic matter often have adequate sulfur)
Two pounds of sulfur can leach out one pound of either calcium or magnesium. Start adding sulfur after calcium level is above 60% base saturation. Sulfur can also leach out sodium and boron. If gypsum is applied the sulfur will leach out the excess cation, and the calcium will replace it in the cation balance on the humus and clay.
Sulfur will leach out most minerals (cations, but not anions) that are in excess.
Every spring if no other sulfur source is being added and sulfur is needed, add either 250#/acre of gypsum or 50#/acre of Tiger 90 soil sulfur to supply enough sulfur for the growing season. Split spring sulfur into two or three smaller applications, a month apart if possible. Many manures and some composts are a significant source of sulfur.
Sulfur at 20 ppm. is the minimum and over 30 ppm. is ideal.

Zinc

Zinc is essential for the transformation of carbohydrates, development of new leaves, seed formation and formation of protein.
Zinc should always be at a higher level than copper. (this is very hard to accomplish on crops where copper is often applied as a fungicide)
36% Zinc sulfate is a good form to apply. Good results can also be achieved with with zinc ligno or amino chelates.
10 lbs. of zinc sulfate will raise zinc levels 1.8 ppm. in a clay soil, more is needed than in a sandy soil. Don’t add more than 40#/acre of zinc sulfate to raise levels 7.6 ppm.
Zinc is needed at a minimum of 4 ppm; 6 to 8 ppm is ideal and above 10 ppm is excessive.
Copper is often above 10 PPM on soils where copper is used as a fungicide regularly.

Manganese

Manganese holds and sets fruits, vital in many plant functions.
Manganese sulfate is 23-27% manganese and it is the best form for raising soil levels.
25#/acre of manganese sulfate will raise levels by 3.5ppm.
Add a maximum of 200#s/acre of manganese sulfate to raise levels 28ppm.
Keep at about 80% of iron.
Manganese is needed at a minimum of 15 ppm, 30 ppm is ideal.

Iron

Iron is essential for the formation of chlorophyll and for photosynthesis.
Iron always has to be higher than manganese; when manganese is higher than iron it will tie up the iron. Over 75% cation saturation calcium will start tying up iron.
Ferrous sulfate (aka iron sulfate) is the best form to apply. (Note: Don't get it on the leaves or it will burn them. Ferrous sulfate will stain concrete.)
100#/acre ferrous sulfate will raise iron levels 10.5 ppm.
Don't apply more than 400#/acre ferrous sulfate per year to raise levels 44 ppm.
Iron is needed at a minimum of 20 ppm, over 40 ppm. is ideal.

Copper

Copper is a enzyme activator and is a catalyst for respiration.
Copper and boron are disease fighters. Very high organic matter soils tie up copper, most severe copper deficiencies are on high (above 5%) organic matter soils. Excessive copper can effect phosphate, zinc and iron uptake.
Above 10 ppm, plenty of phosphates are needed because copper can tie up phosphorus the same way phosphorus can tie up copper.
Too much nitrogen stops the uptake of copper.
Add no more than 10#/acre of 23% copper sulfate every six months to the soil, this will raise soil levels .6 ppm.
Copper is needed in the soil at 1.5 ppm minimum and over 4 ppm is excessive.

Boron

Boron promotes maturity with increased set of flowers, fruit, seed, yield and quality.
Boron is necessary for nitrogen conversion. Good boron levels make for good disease resistance
Boron is the only micro-nutrient that once corrected will still need to be applied every few years.
For excessive boron levels, make sure you have good calcium levels and then emphasize potassium. High calcium soils can cause a tie up of boron, but will prevent toxic effects of excessive boron.
Add no more than 10# Solubor per acre once a year to raise levels .2 ppm. Adding only 10 pounds of Solubor per acre every year for over 20 years my numbers still don't go up, so I will start adding 10#s per acre twice a year and see if that makes the numbers go up. (Solubor is used as a liquid, Fertibor or Granubor are solids)
For fungus control keep boron levels above 1.5 ppm.
Boron levels of .8 ppm is the minimum, 1.5 ppm is ideal and 2 ppm is the maximum.

Formula to determine the optimum nutrient levels.
To figure desired calcium: CEC X optimum % (68%) X400 minus existing calcium.
To figure desired magnesium: CEC X optimum % (12% to 18%) X 240 minus existing magnesium.
An example for calcium would be a soil with a CEC of 10.0, and a desired calcium percent of 68%. Change from PPM to #/acre on soil test by multiplying by 2.
10 X .68 X 400 = 2720 lbs. of calcium. If the soil already has 2120 lbs. of calcium, 2720-2120 = 600 lbs. of calcium needed. With 600 lbs. of calcium in a ton of limestone this soil would require a ton to raise calcium levels to 68%.

Organic Fertilizers

• Kelp is a fair source of micro-nutrients. It does not contain a significant amount of any trace mineral. If a trace mineral is deficient in a soil analysis kelp will not resolve it. Add 400 lbs. per acre to give the soil a balanced dose of micro-nutrients.
• Magnesium sulfate (Epsom salts) has 10% magnesium and 6% sulfur.
• Dolomite has 11% magnesium and 25% calcium. Only add dolomite when magnesium and calcium are low.
• Potassium-magnesium-sulfate (sul-po-mag) has 11% magnesium, 22% sulfur and 22% potassium.
• Limestone is about 33% calcium. Don’t apply more than 4 tons of limestone in any one year.
• Gypsum contains about 22% calcium and 16% sulfur. Gypsum will not change the pH because the sulfur and the calcium balance each other out.
• Soil Sulfur is 92% sulfur. Don’t apply more than 400#/acre in any one year.
• Sulfate of potash has 50% potassium and 18% sulfur.
• Azomite is an ancient seabed deposit. Apply at 400 to 1,000#/acre.
• Activate is a humate. Apply at 50 to 400#/acre.
• Nutra-min is an ancient seabed deposit. Apply at 400 to 2,000#/acre.
Tricks of the trade!
• Sweetness? Keep high levels of potassium, copper, sulfur and phosphorus.
• For disease resistance keep high levels of copper, boron and phosphorus.

Recommended Reading:

The Soul of Soil, Grace Gershuny & Joseph Smillie
Hands on Agronomy, Neil Kinsey
Fertile Soils, Robert Parnes
Know Your Soil, Amigo Cantisano (many thanks to Amigo for adding great text and editing this paper
A Soil Owner’s Manual, Jon Stika

Building Soils for Better Crops, Fred Magdoff and Harold Van Es. . (free pdf download: http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition)
Crop Rotations for Organic Farms A Planning Manual. C. L. Mohler and S.E. Johnson, editors. (free pdf download: http://www.sare.org/Learning-Center/Books/Crop-Rotation-on-Organic-Farms