Before You Begin….

The following comments will make more sense if you have first read The Intelligent Gardener — Growing Nutrient Dense Food.

We find the intricacies of soil analysis fascinating, and are pleased to present our understanding in the following pages. However, if you simply want to know what minerals your soil needs, use the OrganiCalc on-line calculator at GrowAbundant.com.

The target mineral values in these worksheets represent years of field trials, correlating Logan Labs test results to crop production and quality. Results from other labs vary widely, even those using the same Mehlich 3 procedures. Use these worksheets with Logan Labs soil test results.

Check the Logan report for special conditions…

- **Sample depth is not 6 inches:** The default Logan Labs test reports the Ca, Mg, K, Na, and P in lbs per acre, and the phosphorus as phosphate. If your sampled depth was not 6", you will need to re-calculate Logan's reported lbs/ac. If you told Logan your sample depth was 3", for example, multiply the reported lbs/ac by 2 (6/3). If you told Logan your sample depth was 12", multiply the reported lbs/ac by 0.5 (6/12). This adjusts the reported lbs/ac to the standard 6" depth.

  It is possible to receive a Logan report with the results in a different format. The Ca, Mg, K, Na, and P can be reported in ppm, and the phosphorus as elemental P. You can enter these numbers directly into the ppm sections of the worksheets, no matter what the sample depth.

  In either case, run through the worksheets in the standard manner, determining the lbs/ac of minerals, at 6" depth (1 ppm = 2 lb/ac). When you are completely finished, adjust your results to your actual working depth in inches. This will give the mineral weights for your depth. For example, if you want to mix your minerals into the top 3 inches rather than the top 6", multiply the results by 0.5 (3/6), and apply half the minerals. If you want to mix your minerals to a 12 depth", for example, multiply the lbs/ac by 2 (12/6), and apply double the minerals.

- **If lime has been applied in the last 3 years**: There is likely free calcium in the sample. Lab results may read high in calcium; and if so, the calculated TCEC will be high.

  Conduct a fizz test, as described on page 223 of "The Intelligent Gardener", and check for (calcium) carbonate. It's the free calcium that messes up the soil test.

There can be free calcium carbonate in the soil sample from many sources. Here's a list of possible indications:

- **Check for free calcium:** To check look for one of these conditions:
  Ca% of TCEC is more than 79% or
  Ca% of TCEC is more than 71%, and pH is higher than 7.45

  If one of these conditions is met, your soil may be calcareous. Conduct a fizz test, as described on page 223. If it is positive, we'll discuss your options at the end of this section.

- **Acid soil loving crops:** If you are growing blueberries, rhododendrons, potatoes or other such plants, you may not want to use these worksheets. This method balances the elements in the soil, resulting in a slightly acidic pH. Your acid loving plants may do well in balanced soil, but if you are trying for low pH, don't use these worksheets.

- **Very acid soil**: pH is less than 5.0. Manganese and/or aluminum toxicity is possible. Even if you need manganese, better to wait until the pH comes up to add any.

  Don't expect to grow much right away. Apply the recommended amount of lime as soon as possible. If you can't wait at least six months between applying the lime and applying any other minerals, you could lose some of those additional minerals. Though it will do no harm applying everything at once, you may be wasting money. Adding so much lime is going to incite turbulent and unstable conditions in your soil. During the next several weeks, the calcium part of lime will displace other cations while the carbonate part of lime will raise the pH.

- **Pastures:** These recommendations are for growing nutrient dense food, not for pasture. Aside from the expense of bringing large areas up to these levels, herbivores are very sensitive to changes in taste. Mineral application limits are much lower for pastures. Consult an analyst experienced in pasture management.

- **Your soil is already balanced:** Usually this happens after a few years of soil mineralization. Your soil settles to a point where the plants are growing very well. You don't want to disturb this equilibrium, or lose valuable (cation) nutrients. You want to add only enough of the sulfur anion to grow a good crop — 45 to 70 lbs/acre.

  In these worksheets, we target an initial ratio of 68% Ca to 12% Mg. We want to keep the Mg low, because it is hard to get rid of Mg once it is in. Also, we put the Ca at the high end, so it will displace excess cations. These initial targets work very well in practice.

  If your ground is sandy, you will want more Mg and less Ca. If you have clay soil, you will want less Mg and more Ca. If you have achieved equilibrium and your plants are growing very well, the Ca:Mg ratio you actually have is more important than a theoretical ratio. There are actually broad ranges of balanced Ca:Mg ratios. Ca% + Mg% should equal 78% to 82%. The Ca% can be between 60 and 70%. The Mg% should be between 10% and 20%.

  When your soil is mineral-balanced, it's time to really focus on the biology. Keep your organic matter below 30%; 5% is a nice number where summer is hot; 8 to 9 % is a good number where summers are coolish, such as in the Maritime northwest.

  Finally, if your soil is otherwise balanced and you have excess Ca, don't try to fix it; leave it alone.

- **Sodium is too high:**
  Na% is more than 4%:
  Irrigate deeply (spread at least 4 inches of water), resample and retest. If sodium is still high, consult a soil analyst.

- **Boron is too high:**
  B is more than 4 ppm:
  Consult a soil analyst.

- **Manganese is too high:**
  Mn is more than 400 ppm and pH is lower than 5.5
  Manganese toxicity is possible where soil pH is < 5.5
  Consult a soil analyst

- **Copper is too high:**
  Cu is more than 40 ppm
  Consult a soil analyst

- **Zinc is too high:**
  Zn is more than 100 ppm
  Consult a soil analyst

- **TCEC is too low:**
  TCEC is less than 2.5
  Consult a soil analyst

Which worksheet should I use?

Note: To save space throughout, we may use these symbols: > greater than and < less than.

If your pH is less than 7.0, (< 7.0), use the Acid Soils Worksheet.

If your pH is more than 7.0, (>7.0), use the Excess Cations Worksheet.

If you have fizzy soil, we recommend a test specifically for calcareous soils. The Soil Science Society of America recommends a neutral potassium chloride extractant for calcareous soil as it does not dissolve any calcium carbonate but only extracts available Ca and Mg. Other tests include the elevated ammonium acetate pH 8.2 or 8.5 tests. If instead of testing you want to make an educated guess, you have a choice:

> If the soil is fizzing as a result of recent lime or gypsum, use the Excess Cations or Acid Soil Worksheet, depending on your pH. Roughly 1/3 of the applied lime becomes adsorbed each year, so subtract a portion of the Ca from the Ca results and recalculate* the TCEC. These worksheets will balance your soil over time. They may add Ag Sulfur, and eventually you'll end up with a slightly acid pH.
>
> If your soil is barely fizzing, you will likely be able to get to a balanced soil. Use either the Excess Cations (usually) or Acid Soil Worksheet (very rarely). First, you will need to adjust the Ca test results downward and recalculate * the TCEC.
>
> If the soil fizzes and pops and bubbles, you have a strong reaction. If the pH is higher than 7.45, along with a high Ca% you may have calcareous soil. Enquire locally — these are limestone based; you don't add Ag Sulfur to these soils. Nothing you can do will change their pH more than a little bit. Go to the Calcareous Soils Section, after the other two worksheets.

Calcareous soils can be very productive, but require special handling.

*You might want a soil analyst to help recalculate the TCEC. Here's the theory; the soil test is accurate except for the calcium, and as we calculate the TCEC using the calcium, the TCEC is inaccurate too. Gauge how much the soil fizzes. Drop the calcium number to at least the calcium target (TCEC*400*0.68), thereby adding no calcium. Then, drop the TCEC number. Many of the mineral recommendations scale with the TCEC, so dropping the TCEC reduces the mineral recommendations. We rarely go below half the originally stated TCEC; reducing it by 1/3 the originally stated amount is usually safe.

When amendments cannot be dug in…

Our worksheets assume a 6" soil sample depth, and that the amendments can be dug in. If you cannot mix the minerals into the soil, as in an orchard, you can safely apply the amendments at half the rate of the 6" recommendation, fertilizing to a 3" depth. However, at least one very experienced analyst recommends applying the whole 6" amount. In subsequent years gypsum will help carry the minerals downward to a certain extent, so it is best to plan on applying part of any calcium requirement the second or third year, as gypsum. If you can, apply a mulch to cover the minerals, and let the roots grow into the mulch.

If you can't mix the minerals in, stratification will be an issue, especially if water is limited. Subsequent soil tests should be at different depths, from 1" to 6".

Before applying the amendments….

The first time you mineralize, apply 10 lbs/1000 sq ft Azomite or Kelp for trace minerals. In a large area, apply what you can afford. Quantities can be reduced in subsequent years. Or, you may substitute foliar feeding with liquid kelp when leaf stomata are open, about every 2 weeks.

Many farmers prefer to lime in the fall, and add the other minerals in the spring. If this is not possible, all the minerals can be mixed together and applied at the same time.

Blend all minerals with compost or humates before applying, if possible. We especially recommend mixing phosphorus sources (rock phosphate and bone meal) and manganese with vermicompost, well-made active compost or humates (such as New Mexico leonardite) before applying. These especially need a bioactive soil to be available to plants.

Humates are high CEC fossilized organic matter, associated with coal seams. They adsorb minerals onto their surface, and hold them so they are readily available to plants, a sort of chelation. Gently misting the humates before mixing with dry minerals encourages the minerals to connect with the humates. Humates are available as finely crushed rock or as micronized humates, for mixing with dry ingredients. Micronized humates are very fine particles which can also be applied with liquid fertilizers in a sprayer or through drip tape. It's the humate's surface area that counts, so a small package of very fine humates is as effective as a large bag of coarse material. Also, liquid humates are available which have been extracted with alkaline reagents. These are for mixing into liquid fertilizers.

Composted manure is a good source of phosphorus, potash, carbon, and sodium. It is a great substitute for rock phosphate and potassium sulfate, if your soil can stand the sodium usually accompanying manures. Compost is highly bio-active, and will provide a biological path for phosphorus assimilation when the ionic path is closed by high pH. Studies at Colorado State University (http://www.ext.colostate.edu/pubs/crops/00569.html) show rock phosphate is ineffective at high pH, but that manure and manure based compost are effective. And (or), here is a high P fish fertilizer you may want to try if you have a high pH soil: http://www.groworganic.com/pvfs-liquid-fish-2-4-0-2-gallon.html.

Rock phosphate and bonemeal are especially unavailable to the plants if the pH is over 7.5. Instead, use composted manure, or mix rock phosphate or bonemeal or bone char into an active compost pile, then dig in the finished compost.

Unless your compost is tested for mineral levels (such a test costs in the $150 range), you won't know how much to apply for P&K deficits. Make an educated guess, maybe spread a layer 1"thick, then re-test next year to see the compost's contribution to P&K.

Applying the amendments…

Dig all minerals into the top 6”.

Phosphorus is immobile. Mix well into the soil. Zinc is immobile. Mix well into the soil.

After applying the amendments…

When transplanting, it's nice to mix a tablespoon of bat guano with mycorrhiza into the soil immediately around the plant. This seems to make a big difference in my garden. Apply OMRI organic fish hydrosylate (E.B. Stone or equivalent) to young or leafy crops as needed. Do this about every 2 weeks when the soil is cold and doesn't release enough N.

All the anions (N, P, S and B) leach readily and are used in large quantities by growing crops. If a second crop is planted, side-dress or dig-in feathermeal at 20 lbs/1000 sq ft. In cooler climates use feathermeal at 30 lbs/1000 sq ft. Sulfur and nitrogen work together, so blend up to 10 lbs/1000 sq ft of gypsum with the nitrogen. If you know your boron levels are low from an earlier soil test, you can carefully add a bit of boron too.

Sometimes we end up having much less zinc than phosphorus in the soil because of our application limit on zinc. Phosphorus could be blocking the plant’s uptake of zinc if available phosphorus is greater than 10x available zinc by weight. If you suspect a zinc deficiency you can try foliar feeding zinc sulfate (heptahydrate is more soluble than monohydrate) at 1 tbsp. /gallon to see if you get a response. Better yet, use chelated zinc as a foliar.

Calculating NPK levels for purchased compost or fertilizer

It is possible to calculate what N-P-K you would like to see on purchased compost or fertilizer.

> Find the nitrogen deficit on page one of the worksheet. It is 200 lbs/ac in this example.
>
> Next, find the phosphorus deficit on the first page of the worksheet. Suppose our deficit is 98 lbs/ac. Look on page two of the worksheet. There is a phosphorus application limit of 175 lbs/ac. (If our deficit were greater than our application limit, we would use the application limit.) Convert the 98 lbs/ac phosphorus to phosphate by dividing by 0.44. Our phosphate deficit is 223 lbs/ac.
>
> Then, find the potassium deficit, also on the first page of the worksheet. In this example, it is 97 lbs/ac. (Check on page 2; there is an application limit of 200 lbs/ac elemental K. If our deficit were greater than our application limit, we would use the application limit.) Convert the 97 lbs/ac from potassium to potash by dividing by 0.83. Our potash deficit is 223 lbs/ac.

So, our soil needs 200-223-117 lbs/ac of total nitrogen, phosphate, and potash.

Divide all the numbers by the same number, in this case 100.

2-2.23-1.17 Make it 2-2-1.That’s the fertilizer ratio you are looking for. You would use 100 lbs/ac of this blend.

You can multiply all 3 numbers by a convenient number again, in this case 3: 6-6-3. This is the same ratio; you would use 33 lbs of this blend.

A word about Nitrogen…

If you are an organic grower and are new to using feathermeal or seed meals you are in for a pleasant surprise. If your garden is small and needs to be very productive you will be delighted with the response. In this photo, you can see how a generous application of nitrogen (along with some boron and gypsum (calcium sulfate, for the sulfur)) can change a garden:

Both Veronica Broccoli plants were grown in mineral balanced soil, but the plant on the left received a fall application of feathermeal, gypsum, and boron. ALL the minerals need to be present for great results.

Most chemically fertilized gardens have too much sudden nitrogen, and as a result, too many bug problems. Most organic gardens aren't fed enough nitrogen to be really productive.

Soil test results do not usually include nitrogen, as soil nitrogen levels can change even before test results are returned. Nitrogen availability is temperature dependent, and in in the nitrate or nitrite (anion forms), subject to leaching. So, nitrogen requirements are best judged by gardeners and farmers, not soil tests. Shades of green and growth rates are important clues, revealing if sufficient nitrogen is available. Slow growth or a yellowish-green color indicates a nitrogen deficiency. Sulfur deficiency in particular looks like a lack of nitrogen, but we always add sufficient sulfur for the season.

Nitrogen applications are very powerful. They are like stepping on the garden growth accelerator. You want to be sure everything is in tune, and all the other minerals are present and available before ramping up nitrogen applications. In an ecosystem, it is the scarcest resource that limits growth. If your plants lack water, or other minerals, don't apply lots of nitrogen.

Nitrogen applications are not without their downside. Nitrogen stimulates soil microbes, and they eat carbon. If you are going to apply nitrogen for growth, you need to supply carbon as well. Organic nitrogen sources come with their own carbon, which helps, but is insufficient to cover the entire amount lost. Soybean meal has a C:N ratio of 5:1. Feathermeal's ratio is 4:1. The lower the ratio, the more effective the nitrogen source (this is because some of the nitrogen is tied up digesting the carbon in the fertilizer). But, the higher the ratio, the more carbon will be pulled from the soil to run the microbe machine. If you are going to add concentrated nitrogen, you also should add carbon as mulch or compost. If you don't, the carbon in your soil will be converted into microbe fuel. When the microbes die, they become plant food, often as nitrates. The nitrates that aren't used by the plants can be lost by leaching or to the air.

In my own garden I want to grow the best quality (nutrient dense) food I can. My secondary goal is the production of fresh and preserved vegetables, year-round. So, my gardening is skewed toward quality and efficiency, without too many other constraints. My limitation is labor — I do all the vegetable gardening myself. For me, it makes sense to run the garden with the accelerator pretty much wide open. By adding nitrogen, I can plant closer together and get a larger harvest from a smaller area. This makes mulching and weeding easier. Honestly, I like harvesting quantities of large, great tasting vegetables. But, this strategy is not for all circumstances. If you space your plants further apart you will get fewer but larger vegetables. You won't need as much nitrogen. Your plants will be more drought tolerant. Your plants can maybe live on less applied water, as they will be drawing moisture from a larger area. Determining nitrogen application rates requires understanding your garden's limits to growth, and some real thought about what you are trying to accomplish in your garden.

The nitrogen application rates we recommended are approximate. Application recommendations are calculated at a 100 lb/acre Nitrogen rate, which in the case of 12% N feather meal, is 800 lbs/acre. This is a good level of nitrogen for tomatoes and root crops, which don't need lots of nitrogen. I wouldn't exceed 100 lbs/acre for these plants. In a mixed vegetable area, the usual strategy is to apply 100 lbs/acre nitrogen to the whole area, then more to those plants that need more. In cool climates always apply at least 100 lb/ac N as seedmeal or fishmeal in the spring.

Squash, all brassicas, corn, lettuce, and other nitrogen lovers can use 200 lbs/acre, assuming the other minerals are present. And if you want huge plants, you can add even more. But, I wouldn't go above 300 lbs/ slow release organic N under any circumstance. Establish a background, slow release nitrogen level, and supplement with foliar or liquid or solid quick release nitrogen as needed, especially when the soil is cold. If you get aphids, you have used too much nitrogen. Spray them off with water, and use less nitrogen next time.

Application rates for chemical nitrogen are well understood, with corn requiring up to 200 lbs/ac, and potato growers using up to 300 lbs/ac. But, there are problems with using chemical nitrogen. High chemical nitrogen levels can cause lower nutrient density and create “funny proteins”. This doesn't happen with organic sources of nitrogen. Organic nitrogen sources do not act at all like chemical nitrogen — compare the intense green and growth response of 200 lbs/ac chemical nitrogen to an equivalent application (1600 lbs/ac) of feather meal. The chemical nitrogen is much faster-acting than the feather meal. The feather meal is very, very slow release, and can sustain your plants throughout your growing season, unless you are in a very hot climate.

Here is an Ag industry chart originally titled Plant Food Utilization. These numbers are supplied by fertilizer dealers — possibly they represent the maximum amounts of chemical fertilizer which can be applied to various crops. We include these numbers to show the wide relative range of nitrogen and other nutrients used by different crops:

Vegetables		Relative Plant Food Utilization Nutrients (lbs/ac)					
Crop	Yield	Nitrogen N	Phosphate P_2O_5	Potash K_2O	Magnesium Mg	Calcium Ca	Sulfur S
Cabbages	35 T	270	75	247	36	84	65
Cantaloupes	175 cwt	65	20	115	12	30	10
Celery	75 T	380	165	750	60	195	105
Cucumbers	20 T	180	58	340	50	160	32
Lettuce	20 T	120	40	200	14	56	16
Onions	30 T	180	80	160	18	46	55
Potatoes	25 T	265	100	500	45	70	24
Spinach	6 T	60	18	36	6	15	5
Sweet Potatoes	15 T	155	70	310	25	18	24
Tomatoes	30 T	200	60	340	35	66	42
Turnips	5 T	64	14	70	5	27	9
Apples	500 bu	88	38	160	20	50	20
Grapes	12 T	102	36	156	18	36	26
Oranges	30 T	290	60	350	42	250	30
Peaches	600 bu	96	40	120	24	90	21

*Partial listing from: A&L Laboratories Agronomy Handbook. Highly Recommended. www.**al-labs-west**.com*
A&L credits The Potash and Phosphorus Institute, The Fertilizer Institute, California Fertility Association.

Excess nitrogen on lots of acres is a pollution problem. This is unlikely to occur on organically farmed land, because of cost constraints if nothing else. In a small backyard vegetable garden, the cost of organic nitrogen is not so much a concern, and the environmental impact of unused nitrogen from such a small area is minimal. Still, it is certainly worth capturing any residual nitrogen left after the vegetable garden and growing a nice cover crop.

You have lots of choices for organic nitrogen. There are quick release sources for cold soil, both liquid and solid. I like to mix a tablespoon of quick release high-nitrate bat guano into the soil below transplants. Other quick release options are fish meal, blood meal, or fish fertilizer. There are slower release sources like seed meal.

Cottonseed meal is a nice addition to alkaline soil since it is an acidifier. Soybean meal has a more neutral pH. Then, there is the slowest of all, feather meal. Feather meal is my preferred source for nitrogen. I special order it in 50 lb sacks from our pet supply store or farm feed store. The seed meals are often available from the same sources, sold as animal feeds.

Feather meal, being sold as a feed does not have a nitrogen figure on the label. Instead, it is labeled as (up to) 88% protein. The protein in seed meals corresponds to the nitrogen in feeds in this way: 100 lbs of nitrogen = 625 lbs of protein. Feather meal 88% protein/6.25 = 14% Nitrogen.

There is another source of organic nitrogen, which you may already have. The organic matter in your soil will slowly release nitrogen to your plants. Here is how to calculate your estimated nitrogen release (ENR): Take your organic matter percent (OM %) and assume 15 to 25 lbs per acre of nitrogen will be released for each percent. So, if you have 5% organic matter, as recommended by lots of garden writers, something like 100 lbs/ac of nitrogen will be released during the growing season — enough to grow low demand vegetables. But most of this release happens during the warmest summer months. N will be released more rapidly in hot climates, less in cooler climates. This is all very approximate, OM% test results can vary widely, like 2X, when we send the same soil sample to the same lab. If you want to minimize purchased nitrogen, you can have a lab do a CO_2 burst (Solvita) test. This will tell you more exactly how much nitrogen to expect from your organic matter.

Compost is another source of nitrogen; if it contains chicken manure it can be quite powerful. But, most "compost" is more of a proto-compost – the components are still identifiable, and it is best used as mulch. If unfinished "compost" is dug into the garden it can tie up nitrogen until it finishes. This is exactly what we do not want when adding nitrogen fertilizer. I keep my proto-compost on the surface, under a thin layer of straw, which keeps it moist. The plants seem to love it, maybe because it is such a nice home for microbes. By the end of the growing season, it has turned into a thin layer of humus, ready to contribute to next year's crop.

Sulfur….

Understanding how much of the major base cations (Ca, Mg, K, Na,) to apply is relatively straightforward. Understanding how much sulfur to apply is a bit more complex.

Sulfur has three functions:

1) It is attached to other critical minerals. Potassium, manganese, copper, zinc, iron, and some sources of magnesium and calcium are all sold as sulfates. If we are applying these critical minerals, we are applying sulfur too. Let's make this our first principle: Always apply as much sulfur in sulfate form as needed to carry these important elements.

Always keep track of how much sulfur is going into the soil, but never limit these important elements because of their sulfate component. The sulfate form of sulfur doesn't do any harm to our friends the microbes, but the elemental form of sulfur does set them back for a short time. So, we limit Ag Sulfur to less than100 lbs/ac.

2) A certain amount of sulfur is necessary to grow a crop. How much? Good question. Gary Zimmer says at least 25 lbs/ac, but he likes to see 30 to 40 lbs/ac. Bill McKibben, who works with the same Logan Labs tests we use, targets 40-50 (TCEC < 10) or 60-80 lbs/ac (TCEC > 10). Let's use Bill's numbers, 45 or 70 lbs/ac, depending on TCEC. Sulfur is a necessary nutrient; it works with nitrogen and enables plants to form complete proteins (some amino acids contain sulfur).

3) Sulfur is a powerful tool for removing excess cations. Sulfur in the sulfate form never stays around in the soil for long because all sulfates are readily soluble so excess cations attached to sulfate leach out easily. Excess sulfate, being an anion, combines with the base cations sodium, potassium, magnesium, and calcium; it also

combines with manganese, copper, zinc, and iron. Then, these sulfates are leached by rain or irrigation. This can be a good thing, if you need to remove excess cations in order to balance the soil. But if balance has been achieved, excess sulfur will remove cations you would rather keep, and thereby decrease the fertility of your soil.

So, in figuring how much sulfur our soil needs, we will consider these three parameters:

We will apply whatever sulfur is required to carry the sulfate forms of important minerals into the soil. We will supply at least enough sulfur to grow our next crop, and apply additional sulfur when there are excess minerals in the soil.

To determine if the soil needs extra sulfur to remove excess cations, look at the major base cations, Ca, Mg, K, and Na. See if any of them exceed our ideal percentages.

Ca < 70% and Mg < 18% and K < 120% of target K and Na < 2.5%

Another way to look at whether the soil is balanced is to look at the pH.

If our pH is high, we want to apply more sulfur to acidify the soil. Conversely, if the pH is low, we don't want to apply more than is necessary — we don't want to further acidify an already acid soil. So, we can define high pH and low pH as:

High pH > 7.2
Low pH < 6.0

If you have a high pH, you have excess cations. If your pH is low, you are lacking some cations.

This pH test is useful in finding a middle ground for our sulfur application target, as we shall see.

We are going to establish three targets for sulfur, depending on how many excess cations we want to strip, if any. Some of these numbers are linked to the TCEC, so they appear as ratios of other elements. But, they don't have any intrinsic relationship to these other elements. The ratios are just a convenient way of getting the sulfur target into the right ballpark. Sometimes it is necessary to have a maximum, to keep from applying too much to high TCEC soils, as in the 432 lbs/ac limit below. Also below, you will recognize McKibben's number as the *minimum* target, necessary to grow a crop.

No Excess Cations:
If pH is less than 6.0
Or
(Ca < 70% and Mg < 18% and K < 8%and Na < 2.5%):
Then if TCEC <10, TARGET S=45 lbs/ac. TCEC>= 10, TARGET S=70 lbs/ac.

Excess Cations:
If pH > 7.2
Then TARGET S=Mg/2, or 432 lbs/ac, whichever is less
(This is a range of 101 to 432 lbs/ac, depending on TCEC)

Some Excess Cations:
If pH is between 6.0 and 7.2
And
The soil does have excess cations

NOT Ca < 70% and/or Mg < 18% and/or K < 120% of target K and/or Na < 2.5%):
Then S=P/3
(This is a range of 101- 132 lbs/ac, depending on TCEC)

Here's a shorthand version of what we have done to establish the sulfur target:

Target S = Target Mg/2 or 432 lbs/acre, whichever is smaller, if the pH is >7.2. If the pH is <6 or there are no excess cations (Ca<72%, Mg< 23%, K<120% of target and Na < 3%), then for TCEC's less than 10 the target is 45 lbs/ac and 70 lbs/ac for TCEC's >= 10. All other cases target P/3 lbs/ac.

Those are the sulfur targets. Except for one more thing. We have another source of sulfur we haven't talked about yet. Gypsum. And, whether to use lime or gypsum to supply any calcium the soil needs. This is pretty simple, really. Here's what we want to do:

No Excess Cations:
Use lime, not gypsum, to get the pH up

Excess Cations but calcium is deficient:
Use gypsum, not lime, to strip the excess cations

Some Excess Cations:
Use gypsum, not lime, to strip the excess cations.

For reasons described elsewhere we always want to use lime to reach 60% calcium saturation. Then we can use gypsum, if it is called for.

Copper….

Copper is required by both plants and animals. Experts say it makes our vegetables taste better. So, our plants need copper; however, our soil life is easily injured by copper in the wrong form.

We include two copper sources on our worksheets. The OMRI organic farming standard is to use copper sulfate (25% Cu) to build soil reserves, when a soil or tissue test determines the soil needs copper. Our second option is an OMRI approved copper chelate, Biomin copper (4% Cu). Industry practice is to use the copper chelate as a foliar, only after a tissue test determines copper is deficient. The copper chelate is considered too expensive for farm scale soil applications; therefore no manufacturer's data is available for building soil reserves with copper chelate. The primary reason we include the copper chelate is because of the problems associated with copper sulfate.

Whereas the other major and minor minerals deserve care in handling, copper sulfate is a real problem. It can be absorbed directly through skin. When I used it, I mixed it with boron and applied it to the soil (not on the plants) as a spray, separate from the other minerals. That way I could be more careful with it. Copper sulfate does stabilize in the soil and loses its toxic properties. And, as copper is immobile in the soil, once there is sufficient stabilized copper you don't need to keep re-applying it.

If you are going to use copper sulfate, read the MSDS http://www.sciencelab.com/msds.php?msdsId=9923597.
You can compare the MSDS for Biomin Copper here:
http://www.jhbiotech.com/MSDS%20PDF/Biomin%20Copper.pdf

Copper sulfate is a powerful fungicide. Copper chelate will not harm our friends the fungi. In gardens, it is economical enough to build soil copper levels. In fields, it can be applied as a foliar or to the soil every year at low concentrations. It takes less to do more. University papers say it can be used at 1/6 the rate of copper sulfate, when used as a foliar spray. If you are working a large acreage, you will want a tissue test before spending your money on copper fertilizer. Copper is an expensive element to add to fields. Indeed, it is always better to get a tissue test before applying copper.

There are two major types of copper chelate on the market, one using EDTA, and one using citric acid. Only the citric acid copper chelate qualifies for OMRI certification.

Chelation means that the copper is surrounded by a ring of other atoms or molecules. This ring makes the chelated copper non-reactive compared to $CuSO_4$, and without fungicidal properties. The mechanism by which the plant can then access the copper is complex. There is strong chelation and weak chelation. Basically the citric acid is used as a sort of binder, and the outer ring is an amino acid which the plant wants to absorb. So, the citric acid chelated copper is readily available to plants.

Application rates for copper chelate can vary according to your circumstances. If you have a 4% copper chelate solution, just 3-4 tsp per 1000 sq ft every 4 to 6 weeks applied to plants provides sufficient copper. If you prefer to apply it to soil, use 4-6 tsp per 1000 sq ft. If you want to establish a soil reserve, you can bring the copper level up slowly up to 5 ppm (10 lbs/ac, 6" deep) by applying 2 lbs of elemental copper chelate at a time.

Here is a source for small quantities of chelated copper: http://leaftek.com/store/cart.php?m=product_list&pageNumber=&c=11&v=&id=&sortBy=&search=&shopByPrice=&viewAll=1&customListIds= Gallons are available here: http://rosecare1.stores.yahoo.net/biomincopper.html

The Biomin copper chelate is a liquid. The worksheets give copper recommendations by weight. You'll need to convert the worksheet results to liquid measurements:

4% Biomin Copper: 1 pint (16 fluid oz., 0.47 liters, weighs 1.2 lbs, 0.5 kg). Let's say you want to apply 2 lbs/ac copper, which at 4% is 2/.04 = 50 lbs copper chelate. 50 lbs/1.2 = 41.6 pints = 41.6/8 pints per gallon = 5.2 gallons.

In Australia, Biomin copper is available at a different concentration, not 4%.

Copper requirements are debatable. In a recent Acres article, Hugh Lovel summed up the situation nicely. "Though 2 ppm copper is generally considered adequate, 5 ppm gives more margin and 10 is not harmful unless the soil is extremely light with poor humus reserves." These are similar to the numbers Neil Kinsey gives us "Anything below 2 ppm copper means deficiency. Five ppm is excellent, but 10+ ppm is still not considered excessive."

Here are some estimates of copper requirements. These numbers are all based on Mehlich 3 extractions, and are expressed in lbs/ac (6" deep) of elemental copper, which are double the ppm numbers.

CEC	Four Expert Opinions on Soil Copper Targets			
10	16	16	8 to 16	5 to 7
15	23	19	8 to 16	7 to 11
20	31	22	8 to 16	7 to 11
Application Limit	7-10 lbs/ac	7 lbs/ac	2.5 lbs/ac	-

In our worksheets we are now targeting 6 to 10 lbs per acre of elemental copper per acre, with a 4 lb/ac application limit. It is wise to limit the per-application amounts of copper sulfate, so as to avoid setting back our soil life too hard. We set an application limit of 4.0 lbs per acre copper per year (16 lbs/ac copper sulfate). If you are using copper chelate, you can use less, so the application limit is 2 lbs/ac.

The values expressed as ranges are in a sense more realistic. In our own experience Mehlich 3 copper tests are not very repeatable. We have seen them vary by up to 40%. *Agricultural Laboratory Proficiency* (*ALP*) Program data confirms EDTA intra-lab copper test results vary by +- 20%. It is important to keep this in mind when building copper levels in your soil. Don’t over-react to the first test. Use sensible application limits.

Copper is one of the most immobile elements, and it is quite persistent. On our own land, this year's soil test showed a less-than-optimum level of copper. It was right on target last year. Where did it go? I don't think it went anywhere. The soil is producing like never before, the taste has exceeded what I would have thought possible, and the soil test results are showing good levels of about all the nutrients. The soil has settled into a great place. At this point I am thinking that we have reached a nice balance, and that if the soil test results don't match the targets, maybe something is wrong with the targets or the soil tests. At first, one learns soil analysis by following directions. Later, it becomes just another of many means to understand what the earth and the plants are telling us.

It is a very good idea to keep records of how much copper has been applied. Even if soil tests don't always show it, previous applications are almost certainly still around. According to two university bulletins, one should stop adding copper for any reason once 30 lbs/ac have been applied, so as to avoid copper toxicity. The Danish environmental standards mandate no more copper applications after 80 lbs/acre (US standards are higher). Sheep are particularly sensitive to copper. If you are grazing sheep, your copper targets will be much lower than anyone else's. If you are working in an orchard where copper might be applied as a fungicide, you will not need to apply any additional copper.

Not all crops require the same amounts of copper. These crops have especially high copper requirements: alfalfa, barley, blueberry, beet, broccoli, carrot, cabbage, celery, eggplant, flax, lettuce, oats, onion, parsnip, pepper, rye, spinach, sudangrass, tomato, watermelon, and wheat. And, soils respond to copper differently. Soils with lots of organic matter are likely to lock up soil applied copper, so with these soils it is better to apply copper as a foliar spray. Animals and plants have similar copper requirements. When manure is applied, it will likely have enough copper in it to avoid plant deficiency. However, fertilizing for optimum health is much different from fertilizing to avoid deficiencies. In the case of copper, though, these two boundaries are much closer than any other nutrient. Go slow when adding copper.

Sodium:

Na is required by plants in only very very small quantities, or not at all. It is never deficient. In fact, it is toxic to plants, and they will sequester it in their membranes. This maybe tastes great to animals, which require sodium and chloride in quantity. The alternative to applying salt to your soil is to get your salt out of a shaker.

We have changed our Na recommendation since the book was published. If you are in a humid climate you can add Na (in the form of sea salt) if you like without harm; up to 1 or even 2%. The trace minerals in sea salt might be just what your plants need. If you are applying sea salt for the trace minerals, you might want to investigate Sea-Crop. Sea-Crop is a salt water concentrate with most of the sodium removed.

If you were in an arid climate, as many are, adding Na is/can be harmful, as there is already too much in the soil and water. So, we have changed our default recommendation to 0% Na.

Salt is seasonal — in arid climates it rises in the summer due to transpiration, and sinks during the rainy season. In arid climates it may never be flushed away, unlike in humid climates. So, if you get a high sodium reading after a period of prolonged drought, it is possible you are seeing more sodium than is usual. In arid climates it is possible, even likely, that the irrigation water is a source of sodium. There is nothing like rain to lower sodium levels.

If you live in an arid climate, you really should have a salinity test run on your soil at least once. The test is usually called as an EC (electrical conductivity) test. Saline soils are not the same as sodic soils, though some soils are saline and sodic.

If your soil test shows lots of sodium (more than 3%) or high electrical conductivity, don't rush into remediation. Irrigate, resample, and retest. One can add lots of gypsum to the soil, then lots of water, to try to flush away the Na. But, you need to confirm this is really necessary. It's too big a remedy as the result of just one test. It'll take lots of nutrients with it. Also, you need a water test. Na is likely coming in with the irrigation water.

Different crops react differently to excess sodium. Even some varieties can be more salt tolerant than other varieties.

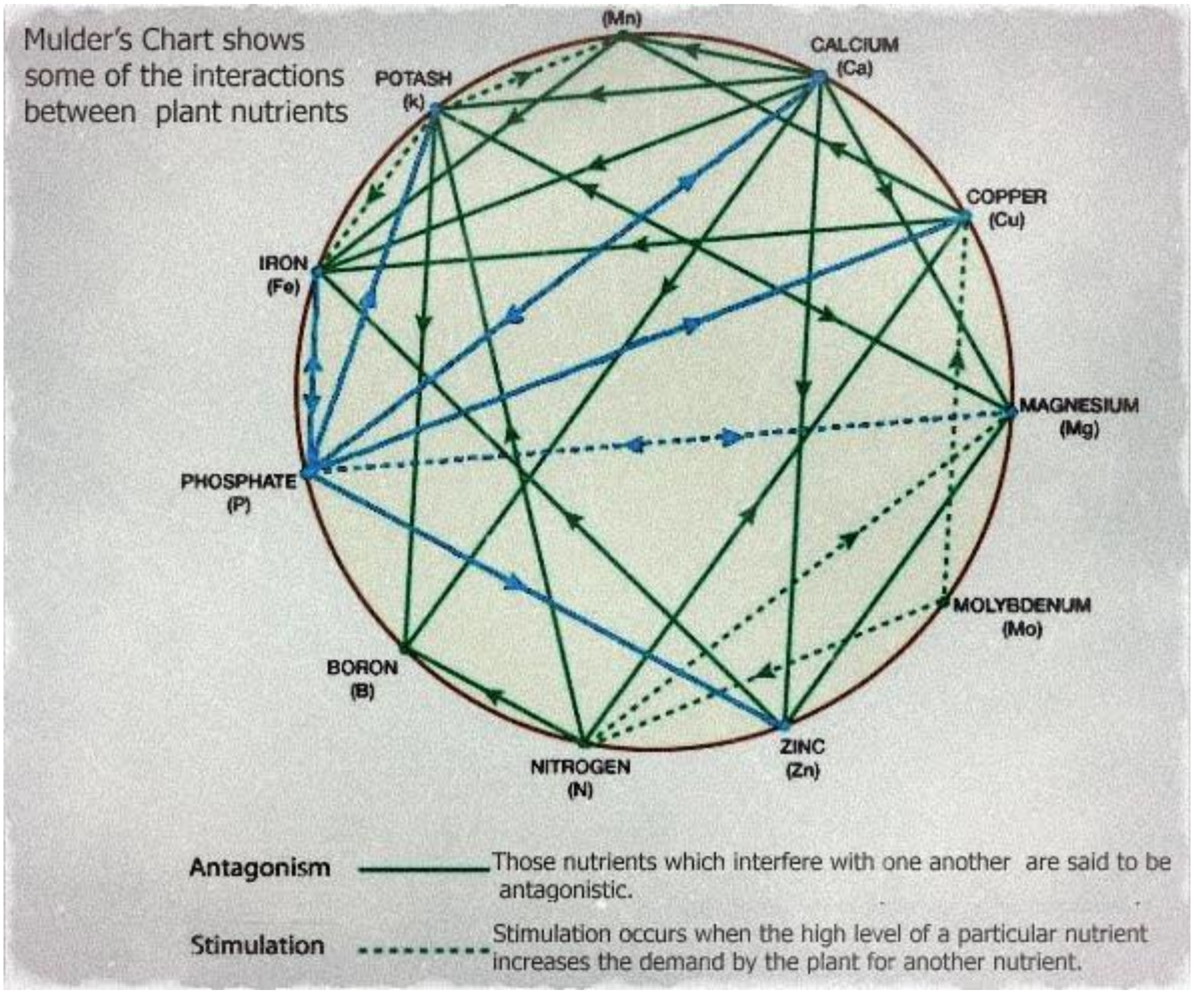
Dealing With Excesses:

Adding minerals which are deficient is relatively straightforward. If you have low pH soil, this is likely your situation. If you have high pH soil, as in an arid region, you have an excess of minerals. This is harder to deal with. First, avoid creating excesses. Measure your area carefully before applying minerals; be sure to add the appropriate quantity for your area.

If you do have excess minerals, the first thing that will happen is they will crowd out the hydrogen cations. The pH scale basically counts how many H^+ ions are available for interchange, so the pH measurement is high where there are excess cations. Yes, I know this sounds backwards, and it is. pH goes up when the H^+ count goes down.

The cation hierarchy is Ca>Mg>K>Na> H^+. Loosing those H^+ ions means losing a lot of ion mobility. Ion mobility makes it easier for plants to feed —plants basically exchange ions and bring minerals through their cell walls when they eat. Anyway, when there are excess cations and they are out of balance, it is much harder for plants to access nutrients, even if they are present.

When minerals are out of balance, an excess of one can block access to another. This is well illustrated in Mulder's chart:



Here are some of the most common practical interactions in table form:

Excess	Blocks
Nitrogen	Copper
Phosphorus	Sulfur, Zinc, in great excess Copper
Zinc	Phosphorus
Potassium > 7.5%	Boron
Potassium + Sodium > 10%	Manganese
Sulfur	Nitrate Nitrogen, Phosphorus, Molybdenum
Calcium or Phosphate	Iron

Source: Acres USA, October 2013, article by Neil Kinsey

Our worksheets are based on the idea that if the minerals are not in the soil they will not be in the plants. This is true. But, just because the minerals are in the soil does not mean they will necessarily be in the plants. Without good biological activity, plants may be unable to access the minerals in the soil. Soils with excesses can block plant's access to minerals.

When there are excesses we can try to balance the soil. We use the hierarchy Ca>Mg>K>Na> H^{+}. For instance, if there is excess K and low Ca, adding Ca will displace some of the K. It will also displace some of the H^{+}, Na, and Mg. Then, you re-test and see what happened. You can see this can be a long slow process.

Meanwhile, one needs to grow a garden or a crop. So, one turns to other tools. If the crop is large or the garden is not doing well, a tissue test is in order to close the knowledge gap between what's in the soil and what's in the plant. Then, missing nutrients can be supplied by foliar feeding. Another technique is to run brix tests. Using a refractometer, measure the brix of your plants. Apply a foliar spray. Measure the brix at the same time the next day. If the brix went up, you have discovered a way to supply a missing nutrient. What doesn't work so well is visual observation. You are much better off using a refractometer than just looking for a response. For instance, adding foliar nitrogen almost always makes the plants look better, but it can decrease the weight and nutrient density of the harvest.

While the Mehlich 3 test measures the loosely held minerals on clay and humus particles, the Morgan test and the saturated paste test measure the minerals in the soil solution. It's much more work, but if the plant can't access the minerals held on the clay and humus (let's call it CEC feeding) because of mineral imbalances, one can feed their plants through the soil solution. This is how hydroponics and most of commercial farming work.

If the CEC feeding vector is closed, there is yet another path whereby plants can feed. If the biological activity in the soil is increased enough, plants will live and grow as part of a very active biological system.

Compost:

The benefits of adding good compost (C:N ratio of 12:1 or less) are legion. However, if the leaves or stems are still discernible, it is better used as mulch than dug in. Good compost improves tilth, adds air to the soil, holds water, and fosters life in the soil. Mineral balancing only provides a great foundation for biology.

Change Summary….

Here is a summary of changes and improvements since the first edition of "The Intelligent Gardener — Growing Nutrient Dense Food"

Limit Ag lime to 8000 lbs/ac.

Minimum Ca target of 1900 lbs/ac for acid soils removed. Now just balance these low TCEC soils in the normal manner.

Changed Ca saturation limit up to which lime is applied from 62% to 60%
68% Ca and 12% Mg are defined as initial targets. As your soil balances, the Ca and Mg percentages can vary over a wider range

Ag Sulfur application limit changed from 110 lbs/ac to 100 lbs/ac.

Sulfur target changed from 100 lbs/ac.

Apply as much S in the sulfate form as needed to supply Potassium, Zinc, etc.

If your pH is over 7.4, always add 100 lbs/ac Ag S in addition to the sulfates.

Always be sure you have enough S to grow a crop – 45 to 70 lbs/ac. Add gypsum for sulfur (beyond the Ca target) if you need to — Ag S is slow to release, it's for next year's crop.

Potassium Target Levels for TCEC less than 7 changed — amount depends on TCEC

Note added — rock phosphate is ineffective at pH > 7.4

Low cut-off TCEC of 2.5 established. Soils with this low a TCEC need a different approach. They require frequent mineral applications.

Nitrogen (100 to 300 lbs/ac organic N) and Trace Minerals added to the worksheets.

Parameter for fizz testing (suspected calcareous soils) defined. Ca% of TCEC > 79% or Ca% of TCEC >71% and pH > 7.45, you may have calcareous soil.

Mg application limit explained, user determined after 2nd soil test.

Sodium target changed from 2% of TCEC to 0% of TCEC. Sea Salt no longer recommended in all cases — up to the user.

Danger levels of Na, B, Mn, Cu, Zn established.

For Boron target 2 lbs/ac if the TCEC is <=10, 4 otherwise.

Copper chelate discussed, copper sulfate is still the default for soil application. Copper target changed from ½ Zn to 5 ppm. Application limit changed from 7 lb elemental copper/year to 4 lb elemental copper ac/year for copper sulfate, 2 lbs ac/year for copper chelate.

Cobalt, Molybdenum, Selenium, and Silicon added to the worksheets. These are optional tests, popular in the NE USA. Added targets and materials for Co, Mo, Se, Si.

Aluminum deleted from worksheets. This cannot be deficient, nor can anything be done with excesses, except to raise pH.

Apply rock phosphate even if the calcium component in it exceeds the Ca target.

Changed Mn target to 0 for those soils with pH < 5.7

Added note for low TCEC soils: " Your TCEC is lower than 7.0 and therefore your soil does not hold nutrients well. Apply small amounts of fertilizer regularly"

Azomite or Kelp amounts can be reduced after the initial application.

Added calculation example converting lbs/ac elemental N-P-K to N-P-K on fertilizer

Omitted Logan Labs as a source for AA8.2 calcareous soil testing

Acid Soil Worksheet

Name
Plot or Field
Date of Test

Sample Depth 6 inches

TCEC:__________ **TCEC:** If TCEC < 7.0, your soil does not hold nutrients well. Balance the soil, but apply small additional amounts of fertilizer regularly. If TCEC is less than 2.5, it is too low. Don't use this worksheet.

pH:____________ **pH:** If pH is 7.0 to 7.6, go to the Excess Cations Worksheet. If Ca% of TCEC > 79% or Ca% of TCEC >71% and pH > 7.45 you may have calcareous soil. If it is calcareous, use the Calcareous Soil Worksheet.

OM%:__________ **Organic Matter %:** Target over 7% in cool climates. South of the Mason-Dixon Line target over 4%. Assume an approximate release of 15–25 lb nitrogen per 1% OM. Varies with temperature, moisture and air.

Element	**Actual Level**		**Calculating Target Level** Pounds per acre	**Target** Pounds per acre	**Deficit**
Nitrogen **N**	Unknown		100 to 300 lbs/ac Subtract N contribution of OM%. 15-25 lb Nitrogen per 1% OM	100 to 300	
Trace Minerals	Unknown		Apply 100 lbs/ac Kelp or 100 lbs/ac Azomite, or foliar liquids per label	100 first year	100 first year
Sulfur **S**	ppm	lb/ac	No limit on Ca,Mg,K,Fe,Mn,Cu,Zn in their sulfate forms. pH<7, TCEC<10: **S=45**, TCEC>=10: **S=70**		
Phosphorus **P**	P_2O_5	P =	**P = K (Target Level)** Calculate using actual P, not phosphate. P = 0.44 x P_2O_5		
Calcium **Ca**	ppm	lb/ac	**TCEC x 400 x 0.68 = Initial Target Level** If possible, apply agricultural lime in the fall and the balance of the amendments the following spring		
Magnesium **Mg**	ppm	lb/ac	**TCEC x 240 x 0.12 = Initial Target Level**		
Potassium **K**	ppm	lb/ac	**K is proportional to TCEC: see chart**		
Sodium **Na**	ppm	lb/ac	**Na = 0 lbs/ac** Sea salt to 1% is optional Salt Injury begins at about 3% of TCEC		
Boron **B**	ppm	lb/ac	**B = 2 lb/ac if TCEC below 10** **= 4 lb/ac if TCEC above 10**	Do not exceed 4 lbs/acre	
Iron **Fe**	ppm	lb/ac	**Fe = 100 lb/ac if TCEC below 10** **= 150 lb/ac if TCEC above 10**		
Manganese **Mn**	ppm	lb/ac	**Mn = 55 lb/ac if TCEC below 10** **= 100 lb/ac if TCEC above 10**		
Copper **Cu**	ppm	lb/ac	**If TCEC < 10, target 6 lbs/ac.** **If TCEC > 10, target 10 lbs/ac.**		
Zinc **Zn**	ppm	lb/ac	**Zn = 1/10 P (Target Level)**		
Cobalt **Co**	ppm	lb/ac	**4 lb/acre** (optional test, used in NE USA)		
Molybdenum **Mo**	ppm	lb/ac	**2 lbs/acre** (optional test, used in NE USA)		
Selenium **Se**	ppm	lb/ac	**1 lb/acre** optional test, used in NE USA)		
Silicon **Si**	ppm	lb/ac	**100 lbs/acre** (optional test, used in NE USA)		

Potassium Target Levels

TCEC	**Pounds**	**TCEC**	**Pounds**	**TCEC**	**Pounds**	**TCEC**	**Pounds**
3	190	13	350	23	459	33	519
4	210	14	365	24	463	34	523
5	225	15	380	25	475	35	527
6	240	16	390	26	481	36	531
7	255	17	400	27	487	37	535
8	270	18	410	28	493	38	539
9	290	19	420	29	500	39	543
10	310	20	435	30	507		
11	320	21	443	31	511		
12	335	22	451	32	515		

	One acre, six inch weighs	One hectare, 80mm deep weighs
1 meq Calcium	**400 lbs**	**400 kg**
1 meq Magnesium	**240 lbs**	**240 kg**
1 meq Potassium	**780 lbs**	**780 kgs**
1 meq Sodium	**460 lbs**	**460 kgs**

1 ppm = 1mg/kg = 2 lbs/acre = 2.24 kg/hectare

Garden Size: ___________________

	Deficit From other side of worksheet	**Application Limit** Per acre/year	**Material and Quantity to Add per Acre**	Amount for this area	**S**	**Mg**	**Ca**
Nitrogen **N**							
Trace Minerals	100 lbs first year						
Sulfur **S**		Unlimited Sulfates & 100 lbs Ag Sulfur					
Phosphorus **P**		175 lb/ac elemental P	Apply rock phosphate even if exceeds the Ca target.				
Calcium **Ca**		Limit Ag Lime to 8000 lbs/ac	If Ca below 60% of TCEC, use Ag lime to 60%				
Magnesium **Mg**		No more than 10% of target magnesium					
Potassium **K**		200 lb/acre elemental K	Consider reducing K if applying lots of compost Many compost sources contain significant K				
Sodium **Na**		50 lbs/ac sea salt					
Boron **B**		2 lb/acre elemental B					
Iron **Fe**							
Manganese **Mn**			Do not apply if pH < 5.7				
Copper **Cu**		4 lb/ac elemental Cu	2 lbs/ac (5.2 gal) application limit for 4% Biomin Cu				
Zinc **Zn**		14 lb/ac elemental Zn					
Cobalt **Co**							
Molybdenum **Mo**		0.75 lb/acre					
Selenium **Se**		10 grams/acre					
Silicon **Si**							
			Totals:				

	N%	P%	K%	S%	Ca%	Mg%
Fish Bone	4	8.8		0.06	19	0.03
Fish Meal	10	2		0.6	2.3	0.03
Crab Shell	3	1.5	0.025	0.02	23	1.3
Blood Meal	13	0.5				
Feather Meal	12		0.35	0.4	0.6	
Bone Meal[1]	3	13		2.5	12	0.3
Oilseed Meal	6	1.5	1			
Copra Meal	4	1	0.7			
Kelp Meal	1	0.3	2.5	2	2	0.7
Ag Lime					32-39	2
Dolomite					22	13
Gypsum				17	20.5	
Oyster Shell					36	0.03
Montana Hard Rock Phos[2]		1.3			29	
Calphos		8.8			20	
MAP	12	23				
K-Mag			18.2	22		11
Langbeinite			15.6	23		12
Greensand[3]		0.05	6	1.3	1.5-3.0	2-4
Ag Sulfur				90		

Magnesium Oxide	50%	Magnesium (Mg)
Sea Salt	35%	Sodium (Na)
Borax	10%	Boron (B)

Iron Sulfate	18% S	30% Fe
Manganese Sulfate	19% S	32% Mn
Biomin Copper	0% S	4% Cu
Copper Sulfate Heptahydrate[4] [blue]	12.5%S	25% Cu
Zinc Sulfate Heptahydrate[4,5]	17% S	35% Zn
Potassium Sulfate	17% S	42% K
Magnesium Sulfate Heptahydrate[4] (Epsom salts)	13% S	10% Mg
Cobalt Sulfate Heptahydrate[4]	11% S	21% Co
Sodium Molybdate Dihydrate[4]	0%	40% Mo
Sodium Selenate	0%	6% Se

[1] Bonemeal contains 5.7% sodium, and many trace elements.
[2] Hard Rock Phosphate is 1.5% available P and contains around 27% insoluble phosphate.
[3] Greensand contains 9% Fe, 50% Si, and many trace elements. More than half the potassium is insoluble.
[4] These hydrates are the commonly available forms
[5] Zinc Sulfate picks up moisture from the air; store in an airtight container

To calculate how much to apply, divide deficit by % available in an amendment, e.g. 4 lbs Zn deficit / 35% Zn in zinc sulfate = 11.4 lbs zinc sulfate to apply
To calculate how much of the other elements an amendment provides, multiply the amount to apply by the % available, e.g. 11.4 lbs zinc sulfate x 17% S = 2 lbs sulfur
To calculate amount to apply to your area, multiply by the fraction of an acre your area is, e.g. for 1000 sq ft, 11.4 lbs zinc sulfate * 1000 sq ft / 43560 sq ft/acre = 0.26 lbs
1 acre = 43560 sq ft = 4047 sq metres = 0.4047 hectares **1 pound** = 1 lb. = 16 ounces =0.45 kg = 454 grams

Excess Cations Worksheet

Name ____________________

Plot or Field ____________________

Date of Test ____________________

Sample Depth 6 inches

This worksheet is for Mehlich 3 audits with a pH above 7.0
If Ca% of TCEC > 79% or Ca% of TCEC >71% and pH > 7.45 you may have calcareous soil. Conduct a fizz test.

TCEC:_________ **TCEC:** Recalculate the TCEC if a fizz test is positive, but weak. If you have a strong reaction to the fizz test, go to the Calcareous Soil Worksheet. If TCEC < 7.0, your soil does not hold nutrients well. Balance the soil, but apply small additional amounts of fertilizer regularly. If TCEC is less than 2.5, it is too low. Don't use this worksheet. .

pH:___________ **pH:**

OM%:_________ **Organic Matter %:** Organic matter levels exceeding 5% are extremely helpful. Assume an approximate release of 15–25 lb nitrogen per 1% OM. Varies with temperature, moisture and soil air supply.

Element	Actual Level	Calculating Target Level Pounds per acre	Target Pounds per acre	Deficit Pounds per acre
Nitrogen **N**	Unknown	100 to 300 lbs/ac Subtract N contribution of OM%. 15-25 lb Nitrogen per 1% OM		
Trace Minerals	Unknown	Apply 100 lbs/ac Kelp or 100 lbs/ac Azomite, or foliar liquids per label	100 first year	100 first year
Sulfur **S**	ppm lb/ac	No limit on Ca,Mg,K,Fe,Mn,Cu,Zn in their sulfate forms. pH>7, **S=Mg/2** or 400 lbs/ac, whichever is less		
Phosphorus **P**	P_2O_5 P =	**P = K (Target Level)** Calculate using actual P, not phosphate. P = 0.44 x P_2O_5		
Calcium **Ca**	ppm lb/ac	**TCEC x 400 x 0.68 = Initial Target Level** If possible, apply agricultural lime in the fall and the balance of the amendments the following spring		
Magnesium **Mg**	ppm lb/ac	**TCEC x 240 x 0.12 = Initial Target Level**		
Potassium **K**	ppm lb/ac	**K is proportional to TCEC: see chart**		
Sodium **Na**	ppm lb/ac	**Na = 0 lbs/ac** Sea salt to 1% is optional Salt Injury begins at about 3% of TCEC		
Boron **B**	ppm lb/ac	**B = 2 lb/ac if TCEC below 10** **= 4 lb/ac if TCEC above 10**	Do not exceed 4 lbs/acre	
Iron **Fe**	ppm lb/ac	**Fe = 100 lb/ac if TCEC below 10** **= 150 lb/ac if TCEC above 10**		
Manganese **Mn**	ppm lb/ac	**Mn = 55 lb/ac if TCEC below 10** **= 100 lb/ac if TCEC above 10**		
Copper **Cu**	ppm lb/ac	**If TCEC < 11, target 6 lbs/ac.** **If TCEC > 11, target 10 lbs/ac.**		
Zinc **Zn**	ppm lb/ac	**Zn = 1/10 P (Target Level)**		
Cobalt **Co**	ppm lb/ac	**4 lb/acre** (optional test, used in NE USA)		
Molybdenum **Mo**	ppm lb/ac	**2 lbs/acre** (optional test, used in NE USA)		
Selenium **Se**	ppm lb/ac	**1 lb/acre** optional test, used in NE USA)		
Silicon **Si**	ppm lb/ac	**100 lbs/acre** (optional test, used in NE USA)		

Potassium Target Levels

TCEC	Pounds	TCEC	Pounds	TCEC	Pounds	TCEC	Pounds
3	190	10	310	16	390	23	459
4	210	11	320	17	400	24	463
5	225	12	335	18	410	25	475
6	240	13	350	20	435	26	481
7	255	14	365	21	443	27	487
8	270	15	380	22	451	28	493

Potassium Target Levels

TCEC	Pounds	TCEC	Pounds	TCEC	Pounds
30	507	34	523	38	539
31	511	35	527	39	543
32	515	36	531		
33	519	37	535		

1 ppm = 1mg/kg = 2 lbs/acre = 2.24 kg/hectare

Excess Cations Worksheet, page 2 **Garden Size:** ___________________

	Deficit From other side of worksheet	**Application Limit** Per acre/year	**Material and Quantity to Add per Acre**	Amount for this area	**S**	**Mg**	**Ca**
Nitrogen **N**							
Trace Minerals	100 lbs first year						
Sulfur **S**	pH > 7.4, always add 100 lbs/ac Ag S	Unlimited Sulfates; 100 lb Ag Sulfur	If excess Mg, K, or Na, use gypsum to satisfy any sulfur requirement. If excess Ca, use Ag Sulfur				
Phosphorus **P**		175 lb/ac elemental P	Apply rock phosphate if required, even if it exceeds the Ca target. Rock Phosphate above pH 7.4 is ineffective. Use composted manure, high P fish, or MAP				
Calcium **Ca**		Limit Ag Lime to 8000 lbs/ac	If Ca below 60% of TCEC (rare at this pH), use Ag lime to 60%				
Magnesium **Mg**		No more than 10% of target magnesium					
Potassium **K**		100 lb/ac elemental K	Consider reducing K if applying lots of compost Many compost sources contain significant K				
Sodium **Na**		50 lbs/ac sea salt max					
Boron **B**		2 lb/acre elemental B					
Iron **Fe**							
Manganese **Mn**							
Copper **Cu**		4 lb/ac elemental Cu	2 lbs/ac (5.2 gal) application limit for 4% Biomin Cu				
Zinc **Zn**		14 lb/ac elemental Zn					
Cobalt **Co**							
Molybdenum **Mo**		0.75 lb/acre					
Selenium **Se**		10 grams/acre					
Silicon **Si**							
			Totals:				

	N%	P%	K%	S%	Ca%	Mg%
Fish Bone	4	8.8		0.06	19	0.03
Fish Meal	10	2		0.6	2.3	0.03
Crab Shell	3	1.5	0.025	0.02	23	1.3
Blood Meal	13	0.5				
Feather Meal	12		0.35	0.4	0.6	
Bone Meal[1]	3	13		2.5	12	0.3
Oilseed Meal	6	1.5	1			
Copra Meal	4	1	0.7			
Kelp Meal	1	0.3	2.5	2	2	0.7
Ag Lime					32-39	2
Dolomite					22	13
Gypsum				17	20.5	
Oyster Shell					36	0.03
Montana Hard Rock Phos[2]		1.3			29	
Calphos		8.8			20	
MAP	12	23				
K-Mag			18.2	22		11
Langbeinite			15.6	23		12
Greensand[3]		0.05	6	1.3	1.5-3.0	2-4
Ag Sulfur				90		

Magnesium Oxide	50%	Magnesium (Mg)
Sea Salt	35%	Sodium (Na)
Borax	10%	Boron (B)

Iron Sulfate	18% S	30% Fe
Manganese Sulfate	19% S	32% Mn
Biomin Copper	0% S	4% Cu
Copper Sulfate Heptahydrate[4] [blue]	12.5%S	25% Cu
Zinc Sulfate Heptahydrate[4,5]	17% S	35% Zn
Potassium Sulfate	17% S	42% K
Magnesium Sulfate Heptahydrate[4] (Epsom salts)	13% S	10% Mg
Cobalt Sulfate Heptahydrate[4]	11% S	21% Co
Sodium Molybdate Dihydrate[4]	0%	40% Mo
Sodium Selenate	0%	6% Se

[1] Bonemeal contains 5.7% sodium, and many trace elements.
[2] Hard Rock Phosphate is 1.5% available P and contains around 27% insoluble phosphate.
[3] Greensand contains 9% Fe, 50% Si, and many trace elements. More than half the potassium is insoluble.
[4] These hydrates are the commonly available forms
[5] Zinc Sulfate picks up moisture from the air; store in an airtight container

To calculate how much to apply, divide deficit by % available in an amendment, e.g. 4 lbs Zn deficit / 35% Zn in zinc sulfate = 11.4 lbs zinc sulfate to apply
To calculate how much of the other elements an amendment provides, multiply the amount to apply by the % available, e.g. 11.4 lbs zinc sulfate x 17% S = 2 lbs sulfur
To calculate amount to apply to your area, multiply by the fraction of an acre your area is, e.g. for 1000 sq ft, 11.4 lbs zinc sulfate * 1000 sq ft / 43560 sq ft/acre = 0.26 lbs
1 acre = 43560 sq ft = 4047 sq meters = 0.4047 hectares **1 pound** = 1 lb. = 16 ounces =0.45 kg = 454 grams

Calcareous Soil Worksheet

Name
Plot or Field
Date of Test

Sample Depth 6 inches

This worksheet is for soils with a strong reaction to a fizz test, or for soils managed by the Tiedjens method.
No attempt will be made to bring the high pH down. Use the results of a pH 8.2 (or higher) AA soil test. Calculate the TCEC using the formula at the bottom of this page. Get a fertilizer recommendation from the lab to compare to this worksheet. Do not use Mehlich 3 or AA 7.0 lab results.

TCEC:__________ **TCEC:** If TCEC < 7.0, your soil does not hold nutrients well. Balance the soil, but apply small additional amounts of fertilizer regularly. If TCEC is less than 2.5, it is too low. Don't use this worksheet.

pH:____________ **pH:**

OM%:__________ **Organic Matter %:** Organic matter levels exceeding 7% are extremely helpful. Assume an approximate release of 15–25 lb nitrogen per 1% OM. Varies with temperature, moisture and soil air supply.

Element	Actual Level	Calculating Target Level Pounds per acre	Target Pounds per acre	Deficit
Nitrogen **N**	Unknown	100 to 300 lbs/ac. Subtract N contribution of OM%. 15-25 lb Nitrogen per 1% OM		
Trace Minerals	Unknown	Apply 100 lbs/ac Kelp or 100 lbs/ac Azomite, or foliar liquids per label	100 first year	100 first year
Sulfur **S**	ppm lb/ac	No limit on Ca,Mg,K,Fe,Mn,Cu,Zn in their sulfate forms. TCEC<10: **S=45**, TCEC>=10: **S=70**		
Phosphorus **P**	P_2O_5 P =	**P = K (Target Level)** Calculate using actual P, not phosphate. P = 0.44 x P_2O_5		
Calcium **Ca**	ppm lb/ac	**TCEC x 400 x 0.85 = Target Level**		
Magnesium **Mg**	ppm lb/ac	**TCEC x 240 x 0.05 = Target Level**		
Potassium **K**	ppm lb/ac	**K is proportional to TCEC: see chart**		
Sodium **Na**	ppm lb/ac	**Na = 0 lbs/ac** Sea salt to 1% is optional. Salt Injury begins at about 3% of TCEC		
Boron **B**	ppm lb/ac	**B = 2 lb/ac if TCEC below 10** **= 4 lb/ac if TCEC above 10**	Do not exceed 4 lbs/acre	
Iron **Fe**	ppm lb/ac	**Fe = 100 lb/ac if TCEC below 10** **= 150 lb/ac if TCEC above 10**		
Manganese **Mn**	ppm lb/ac	**Mn = 55 lb/ac if TCEC below 10** **= 100 lb/ac if TCEC above 10**		
Copper **Cu**	ppm lb/ac	**If TCEC < 11, target 6 lbs/ac.** **If TCEC > 11, target 10 lbs/ac.**		
Zinc **Zn**	ppm lb/ac	**Zn = 1/10 P (Target Level)**		
Cobalt **Co**	ppm lb/ac	**4 lb/acre** (optional test, used in NE USA)		
Molybdenum **Mo**	ppm lb/ac	**2 lbs/acre** (optional test, used in NE USA)		
Selenium **Se**	ppm lb/ac	**1 lb/acre** optional test, used in NE USA)		
Silicon **Si**	ppm lb/ac	**100 lbs/acre** (optional test, used in NE USA)		

Potassium Target Levels

TCEC	Pounds	TCEC	Pounds	TCEC	Pounds	TCEC	Pounds
3	190	13	350	23	459	33	519
4	210	14	365	24	463	34	523
5	225	15	380	25	475	35	527
6	240	16	390	26	481	36	531
7	255	17	400	27	487	37	535
8	270	18	410	28	493	38	539
9	290	19	420	29	500	39	543
10	310	20	435	30	507		
11	320	21	443	31	511		
12	335	22	451	32	515		

1 ppm = 1mg/kg = 2 lbs/acre = 2.24 kg/hectare

Calculating TCEC:

$$\frac{\frac{\text{lb/ac Ca}}{400} + \frac{\text{lb/ac Mg}}{240} + \frac{\text{lb/ac K}}{780} + \frac{\text{lb/ac Na}}{460}}{\text{(100- percent H+ - other bases)}} \times 100 = \text{TCEC}$$

In the case of case of calcareous soil, there is no H+, and other bases are usually about 4%

 Garden Size: ____________________

	Deficit From other side of worksheet	**Application Limit** Per acre/year	**Material and Quantity to Add per Acre**	Amount for this area	**S**	**Mg**	**Ca**
Nitrogen **N**							
Trace Minerals	100 lbs first year						
Sulfur **S**		Unlimited Sulfates 100 lb Ag Sulfur	Use required sulfates and gypsum. Do not use Ag sulfur.				
Phosphorus **P**		175 lb/ac elemental P	Rock Phosphate above pH 7.4 is ineffective. Use composted manure, high P fish, or MAP				
Calcium **Ca**		Gypsum: 2000 lbs/ac					
Magnesium **Mg**		No more than 20% of target magnesium					
Potassium **K**		100 lb/acre elemental K	Consider reducing K if applying lots of compost Many compost sources contain significant K				
Sodium **Na**		50 lbs/ac sea salt max					
Boron **B**		2 lb/acre elemental B					
Iron **Fe**							
Manganese **Mn**		10 lb elemental Mn					
Copper **Cu**		4 lb/ac elemental Cu	2 lbs/ac (5.2 gal) application limit for 4% Biomin Cu				
Zinc **Zn**		10 lb/ac elemental Zn					
Cobalt **Co**							
Molybdenum **Mo**		0.75 lb/acre					
Selenium **Se**		10 grams/acre					
Silicon **Si**							
			Totals:				

	N%	P%	K%	S%	Ca%	Mg%
Fish Bone	4	8.8		0.06	19	0.03
Fish Meal	10	2		0.6	2.3	0.03
Crab Shell	3	1.5	0.025	0.02	23	1.3
Blood Meal	13	0.5				
Feather Meal	12		0.35	0.4	0.6	
Bone Meal[1]	3	13		2.5	12	0.3
Oilseed Meal	6	1.5	1			
Copra Meal	4	1	0.7			
Kelp Meal	1	0.3	2.5	2	2	0.7
Ag Lime					32-39	2
Dolomite					22	13
Gypsum				17	20.5	
Oyster Shell					36	0.03
Montana Hard Rock Phos[2]		1.3			29	
Calphos		8.8			20	
MAP	12	23				
K-Mag			18.2	22		11
Langbeinite			15.6	23		12
Greensand[3]		0.05	6	1.3	1.5-3.0	2-4
Ag Sulfur				90		

Magnesium Oxide	50%	Magnesium (Mg)
Sea Salt	35%	Sodium (Na)
Borax	10%	Boron (B)

Iron Sulfate	18% S	30% Fe
Manganese Sulfate	19% S	32% Mn
Biomin Copper	0% S	4% Cu
Copper Sulfate Heptahydrate[4] [blue]	12.5%S	25% Cu
Zinc Sulfate Heptahydrate[4,5]	17% S	35% Zn
Potassium Sulfate	17% S	42% K
Magnesium Sulfate Heptahydrate[4] (Epsom salts)	13% S	10% Mg
Cobalt Sulfate Heptahydrate[4]	11% S	21% Co
Sodium Molybdate Dihydrate[4]	0%	40% Mo
Sodium Selenate	0%	6% Se

[1] Bonemeal contains 5.7% sodium, and many trace elements.
[2] Hard Rock Phosphate is 1.5% available P and contains around 27% insoluble phosphate.
[3] Greensand contains 9% Fe, 50% Si, and many trace elements. More than half the potassium is insoluble.
[4] These hydrates are the commonly available forms
[5] Zinc Sulfate picks up moisture from the air; store in an airtight container

To calculate how much to apply, divide deficit by % available in an amendment, e.g. 4 lbs Zn deficit / 35% Zn in zinc sulfate = 11.4 lbs zinc sulfate to apply
To calculate how much of the other elements an amendment provides, multiply the amount to apply by the % available, e.g. 11.4 lbs zinc sulfate x 17% S = 2 lbs sulfur
To calculate amount to apply to your area, multiply by the fraction of an acre your area is, e.g. for 1000 sq ft, 11.4 lbs zinc sulfate * 1000 sq ft / 43560 sq ft/acre = 0.26 lbs
1 acre = 43560 sq ft = 4047 sq meters = 0.4047 hectares **1 pound** = 1 lb. = 16 ounces =0.45 kg = 454 grams