

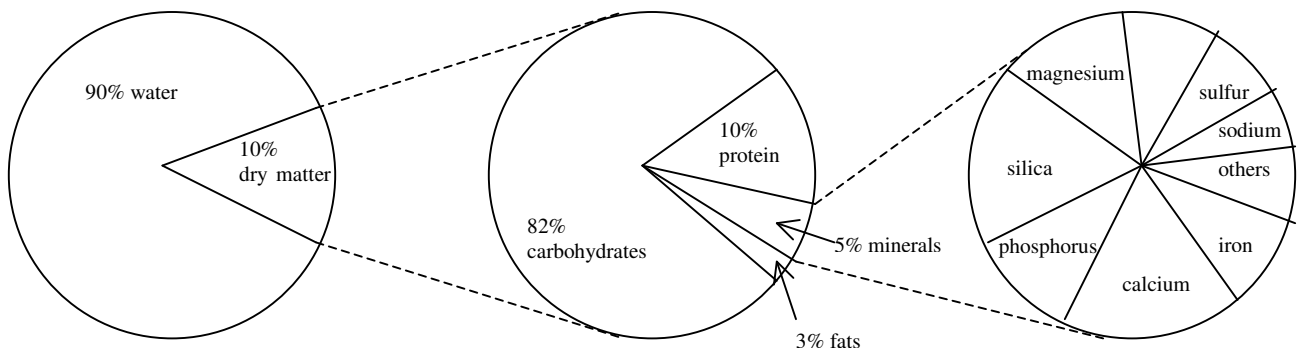
## Soil Dynamics in a Nutshell

(A synopsis of the January 24<sup>th</sup> Soil Seminar at the 1987 Winter Driftless Bioregional Gathering)

“Man, despite his artistic pretensions, his sophistication, and many accomplishments, owes the fact of his existence to a six-inch layer of topsoil and the fact that it rains.” Anonymous

Unlike the bare rocks from which all terrestrial life has sprung, the soil is composed of a complex web of interrelated physical, chemical, and biological phenomena. All animal life is dependent, either directly or indirectly, upon the ability of plants to synthesize organic compounds from light, water, air, and the various minerals derived from rocks. The survival of many species of plants which can be used as food or feed depends on the ability of these plants to grow and reproduce in a specific environment. For the most part, plants are composed of air, water, and sunshine with only 5% of their dry weight made up of the minerals from the soil. But this 5% is of critical importance to the nutrition of the plant, its health, its growth, its reproduction, and the subsequent health of its consumer.

### Plant Composition (approximate percents)



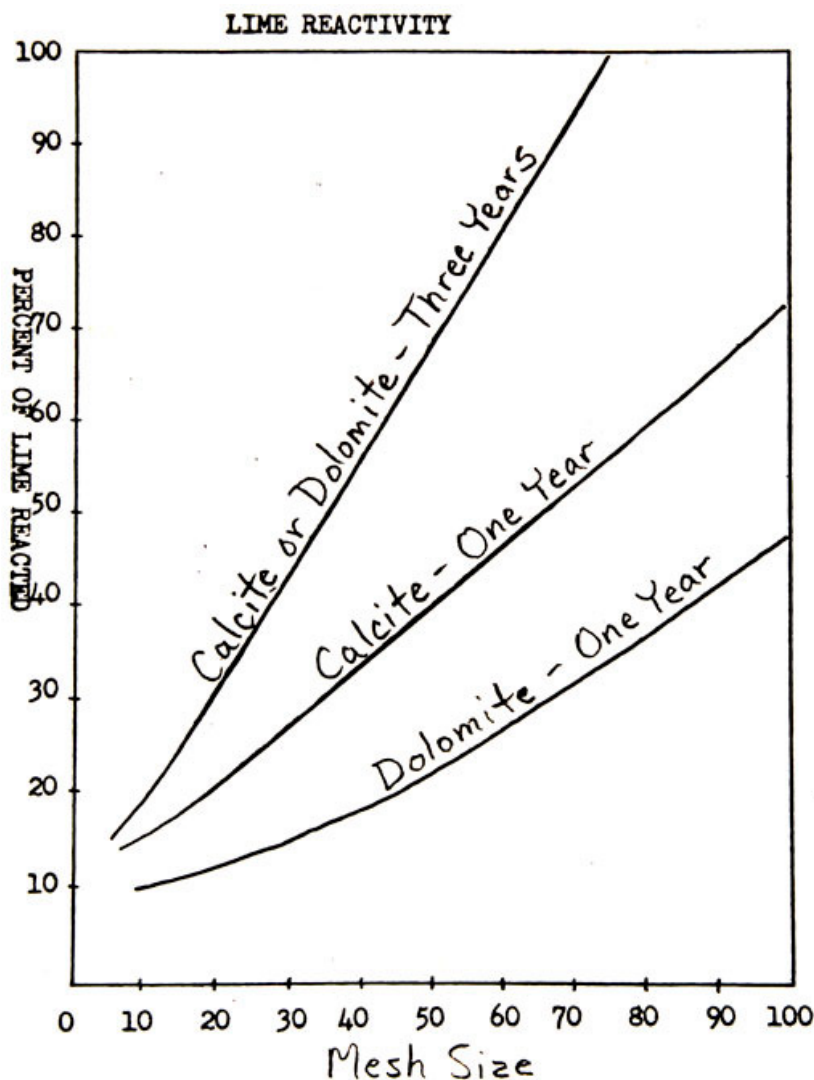
The soil in which plants grow consists of particles of rock made smaller through the erosive action of wind and water, the climatic effects of freezing and thawing, the chemical reaction of weak acids in rainwater with the minerals in the rock, and the biochemical activity of micro-organisms as they use more complex chemical reactions to extract from the minerals what they need for food. As an example of the rock particle sizes we're talking about in soils, imagine that a piece of coarse sand is 15 to 30 feet across. At this scale, fine sand would be 3 to 7.5 feet, and silt, which embodies much of our bioregion's soil, would be a mere 0.75 to 18 inches in size. Clay, the smallest type of soil particle, would range from 0.00025 to 0.75 inches at this scale.

### Particle Size Comparisons

Type	Actual Size	In Expanded Scale
Coarse sand	0.5 to 1.0 mm	15 to 30 feet
Medium sand	0.25 to 0.5 mm	7.5 to 15 feet
Fine sand	0.1 to 0.25 mm	3 to 7.5 feet
Very fine sand	0.05 to 0.1 mm	1.5 to 3 feet
Silt	0.002 to 0.05 mm	0.75 inches to 1.5 feet
Clay	0.00000072 to 0.002 mm	0.00025 to 0.75 inches

The size of soil particles has a tremendous bearing on that soil's ability to hold water or allow it to percolate downward during times of excess and upward during a drought. The larger particles allow water to move quickly downward but have little ability to draw water upward by capillary attraction. Smaller particles are packed together more tightly with less space between them, and this not only slows movement downward but also improves the upward capillary flow. As water moves down, air is drawn into the soil above it, so particle size also affects the ability of soils to exchange gases with the atmosphere. Also, a soil that *drains* more quickly, especially in the spring, will *warm up* more quickly as sunlight and warm air heat it. This is because water *holds* more heat than air, and *requires* more energy to heat it to the same temperature.

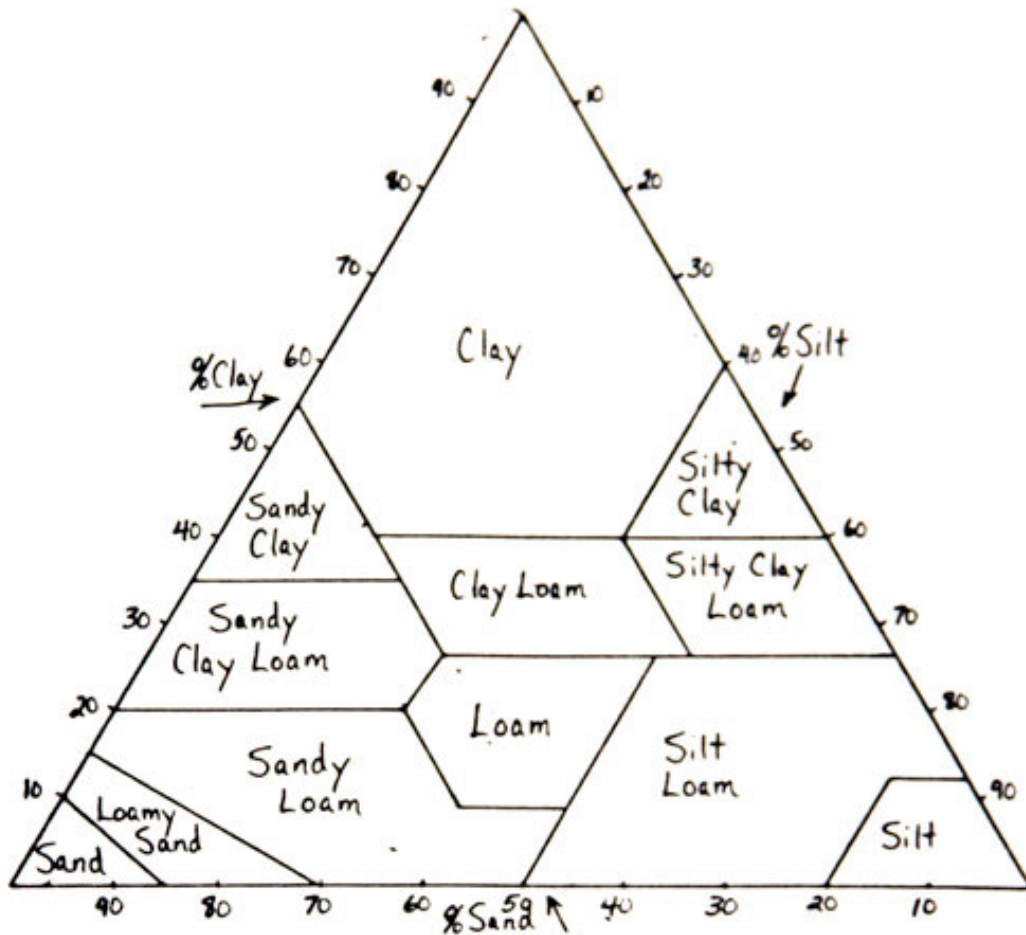
Particle size also influences the *rate* at which elements are chemically removed from minerals. As an example, this chart shows the typical amount of calcium and magnesium carbonates (lime) that are chemically reacted with a soil in one to three years.



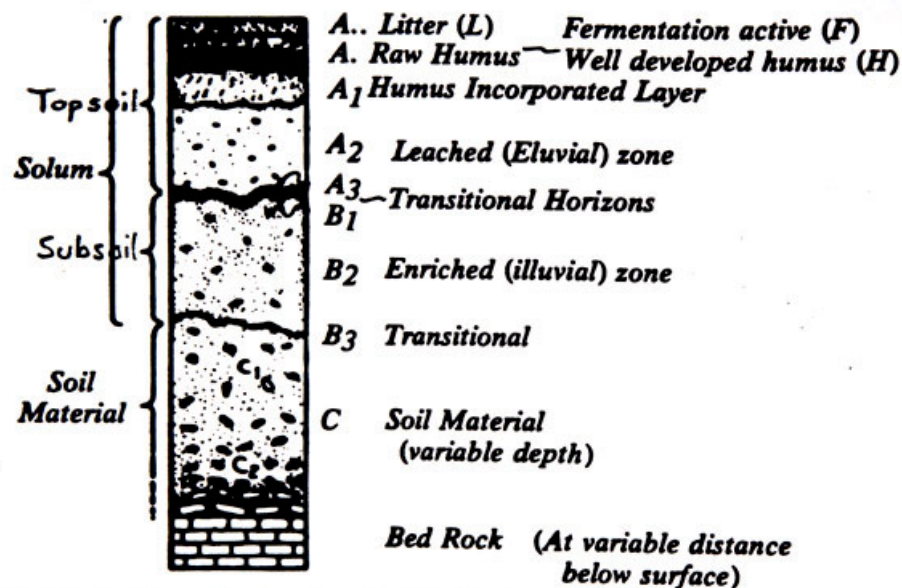
As you can see, a particle that passes through a screen with 10 wires per inch will take many more years to release its stored mineral nutrients than a particle passing 50 wires per inch. As a particle gets smaller its rate of chemical reaction accelerates. And even though many growers use dolomitic lime because its blend of calcium and magnesium raise pH more using less material, calcitic lime reacts more quickly at any particle size. The chart shows the reaction

rate for lime, which is relatively quick to break down. Soil particles such as silt break down much more slowly. The eventual destination of much mineral breakdown is clay, with a typical clay increase of 10 pounds per acre per year in my bioregion.

A soil's particular combination of sand, silt, and clay can be characterized using a soil texture chart. The chart is read by following the arrows in the indicated direction from the listed percents of each particle type. For instance, a soil with 80% silt, 15% clay, and 5% sand would be called a silt loam.



Besides these strictly mineral components, nearly every soil has at least some residue of plant or animal remains on its surface or deeper down. This residue is called *organic matter*. As a soil begins to be colonized by microbes and plants, and as their organic remains build up on the surface after their demise, the soil begins to be constructed from the “parent” materials upward. Later, after this material has been decomposed more fully and has mingled with and sifted downward through the inorganic soil particles, the soil deepens and is constructed from the surface downward. In this way living topsoil is formed from the seemingly lifeless rocks.



**An ideal soil profile showing all of the horizons usually distinguished.**

When organic matter is decomposed beyond recognition of its original source it is called *humus*. The percentage of humus varies widely but its formation is of utmost importance to increase a soil's water and nutrient holding capacity and its ability to support healthy crops. Depending on the climate, rainfall, the balance of mineral elements, and the microbes and plants that grow in and on it, a soil will build its reserves of total organic matter to an equilibrium level. At this level the production of humus from organic matter equals its breakdown into plant-available nutrients. For our bioregion the percent of total organic matter centers around 4.6%. Before we go into the details of how to both improve humus formation and feed our crops from the breakdown of humus, we need to study some of the chemical processes that are involved.

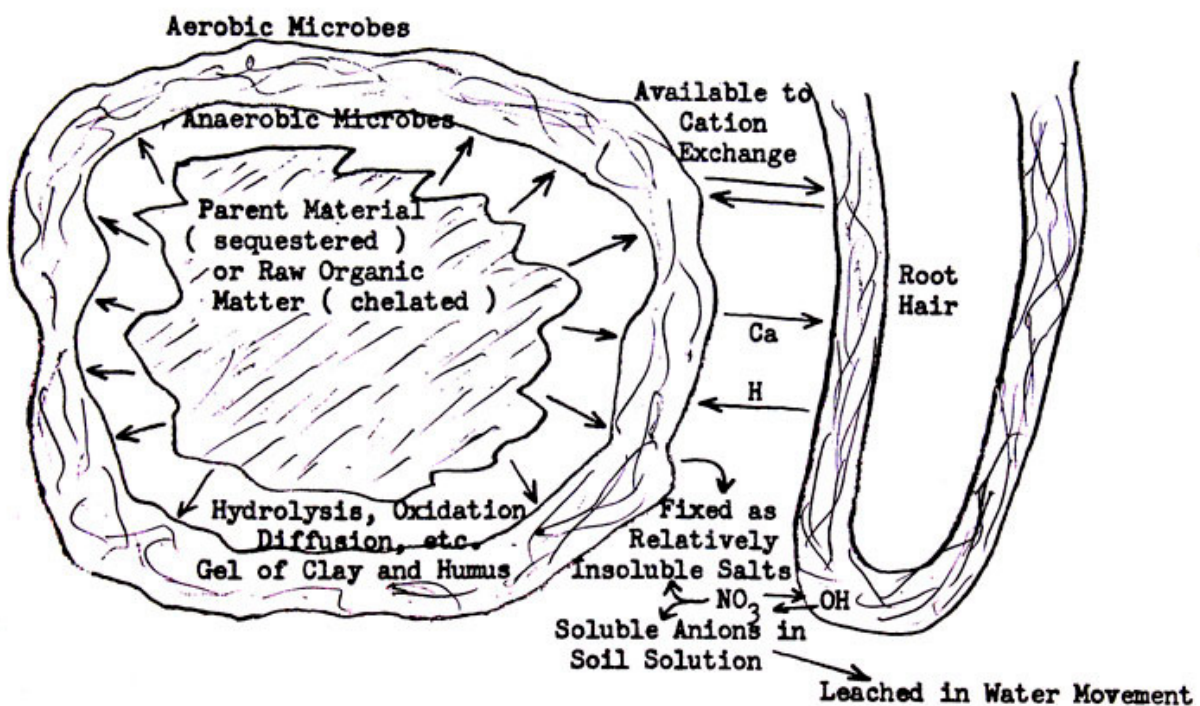
### Relative Salt Hazards of Fertilizers

Fertilizer	Formula (NPK)	Salt Index
Anhydrous Ammonia	82-0-0	47.1
Ammonium Nitrate	34-0-0	101.7
Ammonium Sulfate	21-0-0	69.0
Urea	45-0-0	72.7
Pressurized Nitrogen Solution	41-0-0	78.3
Sodium Nitrate	16.5-0-0	100.0
Calcium Nitrate	15-0-0	52.5
Superphosphate	0-20-0	7.8
Triple Superphosphate	0-45-0	10.1
Monoammonium Phosphate	11-55-0	26.9
Diammonium Phosphate	18-46-0	29.0
Potassium Nitrate	13.8-0-46.6	73.6
Potassium Sulfate	0-0-54	46.1
Potassium Chloride	0-0-46	116.3
Sul-Po-Mag	-	43.2
Calcium Sulfate (Gypsum)	-	8.1
Calcitic (Calcite) Lime	-	4.7
Dolomitic (Dolomite) Lime	-	0.8

First, let's define some terms. A chemical *element* is one of the 100 or so separately identifiable substances that can't be further purified. A *compound* is composed of two or more elements. Normally an element is *electrostatically balanced*, with the positive charges in the nucleus of its atoms matched unit-for-unit with the negatively charged electrons orbiting them. However, under certain conditions, a number of atoms will *ionize*, losing or gaining electrons from its outer, reactive *electron shell* and obtaining a net negative or positive *charge*. Charge is the opposite of chemical *valence*. An atom with *too many electrons* in its outer electron shell is called a *cation*, and it is *positively valenced or negatively charged*. And an atom with *too few electrons* in its outer electron shell is called an *anion*, and it is *negatively valenced or positively charged*. These ionized atoms, or *ions*, attract their electrostatic opposites forming compounds called *salts*. Salts can be more or less *soluble*, or dissolvable, in water. Highly soluble salts, such as potassium chloride, are easily leached downward through a soil during heavy rains. Highly insoluble salts, such as rock (tricalcium) phosphate, are extremely resistant to leaching by water, requiring the action of acids to increase their solubility. Salts can build to toxic levels in a soil, restricting the root penetration of plants and endangering young seedlings by drawing water away from their rootlets.

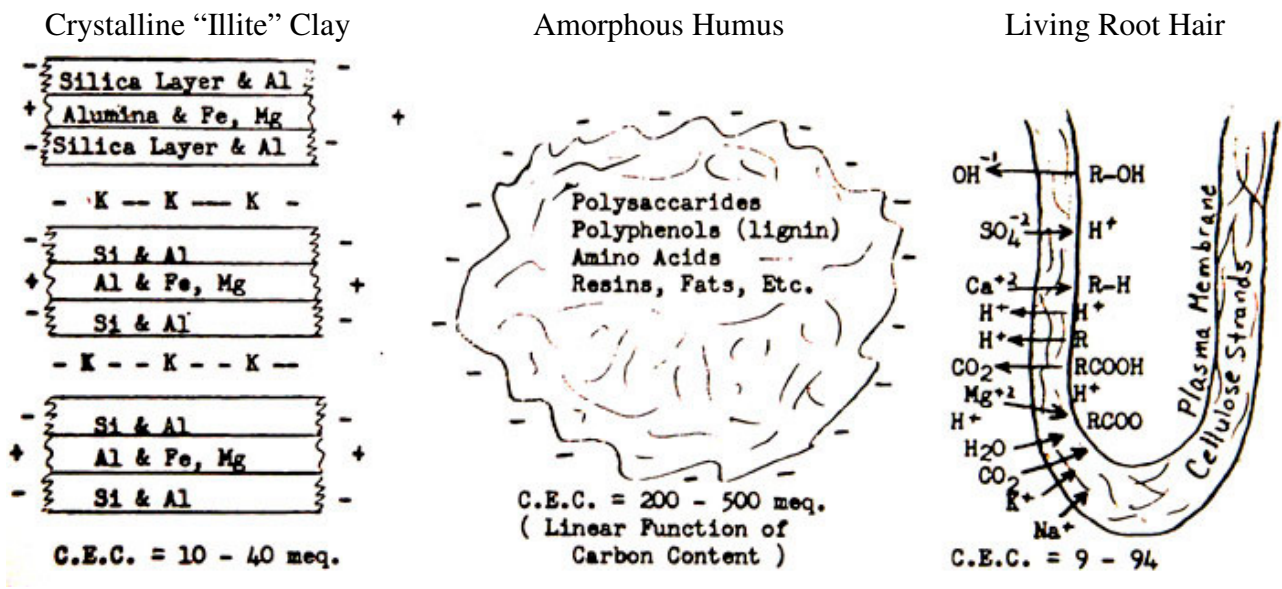
Ion Type	Valence	Charge	Characteristics
Cation	+	-	Fixed in clay layers
"	+	-	Adsorbed Electrostatically
"	+	-	Exchangeable as ions
"	+	-	Chelated in proteins
Anion	-	+	Exchangeable as ions
"	-	+	Chelated in proteins
"	-	+	Absorbed in pores of humus
"	-	+	Soluble in water

### Nutrient Movement



The mineral elements found naturally in soils usually are not very water-soluble. The *chelated* form of a mineral element, found in plants, microbes, and complicated organic chemical compounds, is a prisoner to a much larger *molecule* (a complex compound). An example is a type of protein called an enzyme. Chelation derives from the Greek word for “claw”, which aptly describes an enzyme’s ability to select and grab the specific element it prefers.’ *Sequestered* elements are by definition ‘set apart from’. Usually they are locked in as part of a crystalline mineral that is highly resistant to breakdown. An example is the silicon found in sand and silt as silicon dioxide. *Exchangeability* is a function of ions. The *cations* (pronounced KAT-eye-ons) are *adsorbed* and exchanged from their storage sites on clays and humus by electrostatic substitution for other cations. The *anions* (pronounced ANN-eye-ons) are exchanged from the water surrounding soil particles and *absorbed* into humus. *Absorption* is the mechanical holding of nutrients like a sponge. *Adsorption* is the electrostatic bonding of nutrients. *Available* nutrients are those that a plant root can easily obtain. Fixed nutrients are those that are not easily obtained either because they have formed a highly insoluble salt or because they are tightly bound to particles of clay. In order to better understand the electrical properties of soils let’s look at the chemical structure of our bioregion’s most common clay, illite.

### Soil Colloids



Clays are formed in crystalline layers of aluminum oxides and silicon oxides. Illite has two alumina layers surrounding a silica layer, and is referred to as a 2:1 type clay. It differs from other 2:1 clays in two important respects. First, illite doesn’t shrink or swell very much with changes in moisture. This is because some silicon ions with a charge of -3 are substituted for the -4 charged aluminum ions in the outer sheets, leaving a net valence of -1. This gets balanced by potassium ions, also of -1 charge, which get lodged between the clay layers, holding the sheets apart at a constant distance, resistant to the shrink/swell of moisture changes. The other big difference is the substitution of iron and magnesium ions for the silicon normally found in the middle layer, making illite a more chemically diverse class of clays rather than an exact species with a rigid formula. The practical outcome is that our region’s soils often show a lack of easily available potassium and sometimes also a lack of iron, especially when the local, parent minerals are low in either element.

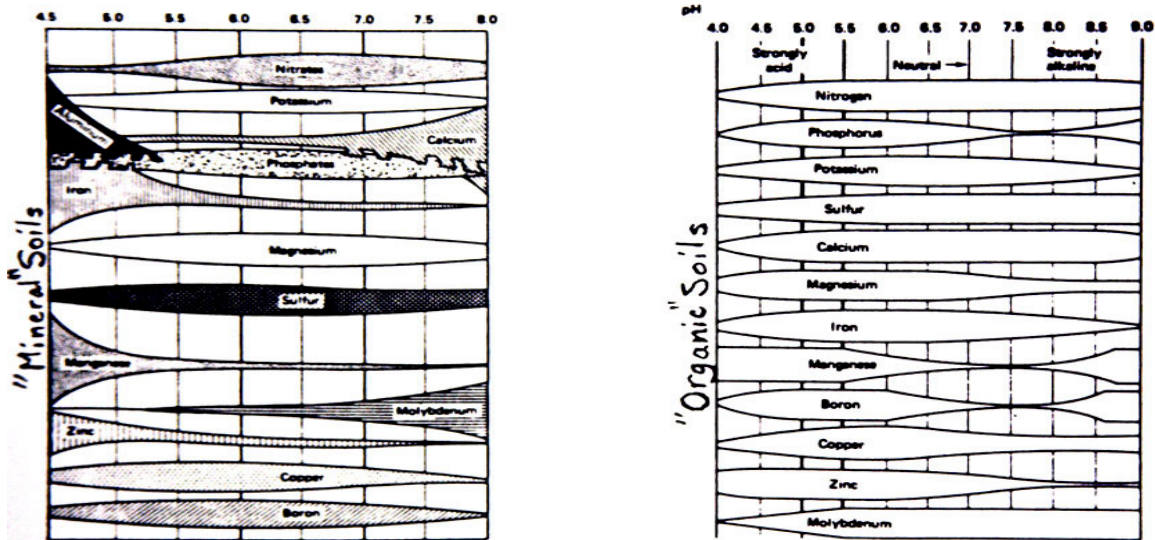
The term “*colloid*” is derived from the Greek word for glue. Colloidal materials are those which are extremely small, with a huge surface to volume ratio, and which carry an electrostatic charge capable of holding ions by adsorption. Note that the valences on illite clay are mostly negative, making them ideal storage sites for positive-valence cations. But the edges of the middle sheet have a positive valence, making them slightly capable of adsorbing anions. Clay is referred to as negatively valenced since it has many more negatively valenced exchange sites than positive. This is measured by a unit called “*C.E.C.*” (*Capacity for Exchangeable Cations* or cation exchange capacity).

As you can see in the colloid comparisons, humus has no rigid crystalline form. It is composed of a complex and highly variable combination of rings and cyclic chains of atoms called polyphenols, polysaccharides, etc. Humus has almost no positive valences and almost all negative ones, giving it an enormous C.E.C. when compared to clay. This makes humus not only vitally important in holding nutrient cations in the soil, but also helps to hold the tiny clay particles in the topsoil when they might otherwise sift slowly downward through the soil layers. It does this because of the difference in C.E.C. Humus sees clay as being comparably positive in valence and attracts it as if it were a cation, forming an association called the *clay-humus colloid*.

The thin strands of cellulose that surround a root cell form the third type of colloid. Different plant species have characteristic root valences and C.E.C.’s but these can vary from minute to minute as the plant’s requirements for cations and anions change during the day. Plant roots exchange *hydrogen ( $H^{+1}$ )* for cations and *hydroxyl ( $OH^{-1}$ )* for anions. They also excrete and absorb carbon dioxide ( $CO_2$ ) and take in oxygen and water through the root surfaces. A soil’s oxygen content is vitally important in a root’s ability to obtain nutrients, especially potassium.

In order to start the process of nutrient movement some element has to ionize to create an imbalance of electrostatic forces. This “prime mover” of chemical reactions is hydrogen. According to one theory, the flow of the Earth’s magnetic field through water initiates the ionization of a small fraction of a given unit of water into hydroxyl ( $OH^{-1}$ ) and hydrogen ( $H^{+1}$ ) ions. In water with a pH of 7.0 the concentration of these ions is equal, but when hydrogen ion concentration increases tenfold the pH drops to 6.0. A hundredfold increase yields a pH of 5.0, and so on. If the concentration of hydroxyl ions increases tenfold the pH rises to 8.0, and so forth. The pH of water surrounding soil particles has a powerful effect on nutrient availability and storage.

### Nutrient Availability and pH



In these charts, the vertical width of each band indicates the relative availability of each nutrient at different pH's. As you can see, in soils with less than 10% organic matter (called "*mineral soils*") the optimum pH for balanced nutrient availability is between 6.0 and 7.0. When organic matter levels exceed 10% (on "*organic soils*") the optimum pH drops to a more acidic level. A pH of 5.8 is considered optimum at 15% organic matter, and it drops to 5.2 at 20%. Clearly pH is not the sole factor in determining nutrient availability if the optimum pH can change.

The capacity for exchangeable cations, C.E.C., was mentioned previously. Its unit of measurement is "milligram equivalents of hydrogen per 100 grams of soil". In other words, one one-thousandths of a unit of hydrogen is being compared to 100 units. This comparison yields a factor of 1:100,000 (1/1000 divided by 100 = .00001, or 1/100,000). Notice the term "equivalent", or "equal valence". To determine the C.E.C. of a soil we must compare the total weight of hydrogen in it, or the weight of other cations that have replaced hydrogen, based on equal valence.

### C.E.C.: Capacity for Exchangeable Cations

### Ideal Cation Saturations

Element	Atomic Weight		Valence					Milliequivalent Constant (meq.k)	(on "mineral soils")	
Hydrogen	1	/	1	=	1	x	20	=	20	5 – 15%
Calcium	40		2		20		20		400	60 – 75%
Magnesium	24		2		12		20		240	10 – 20%
Potassium	39		1		39		20		780	2 – 7%
Sodium	23		1		23		20		460	0.5 – 2%
Ammonium	18		1		18		20		360	up to 3%

To do this we need to know which cations replace hydrogen, what their valences are, and the weight of a standardized quantity of soil. A one acre parcel of air-dried mineral soil, six and a half inches deep, weighs about 2 million pounds. If we compare 2 million with the milliequivalent (meq.) factor of 100,000 the result is a multiplier of 20. To determine the number of pounds of each cation that would totally saturate an acre of 1 meq. topsoil we simply divide each atomic weight by its respective valence and multiply the result by 20. As you can see, hydrogen may be tiny in terms of weight but its charge-to-weight ratio, and its resulting activity in the soil, is enormous. You may also notice that the activity of calcium is lower than that of magnesium. In fact, three units of magnesium have the same ability to raise pH as five units of calcium. But the ratio of calcium to magnesium in lime isn't just important in terms of pH.

Through experiments with plants and the various soil microbes, an optimum range has been found for the balance of these major cations. Calcium turns out to be the "prince" of nutrients in that it is needed far more than the others are to ensure well-constructed plant, animal, and microbial cells. The others are needed in lesser amounts but, just as we saw how the 5% of minerals in plants plays such an important role, elements in smaller quantity have a disproportionate role in determining the availability and use of the more predominant elements. The balance of cations mainly influences the reproductive health of living organisms while the balance of anions mostly affects vegetative growth.

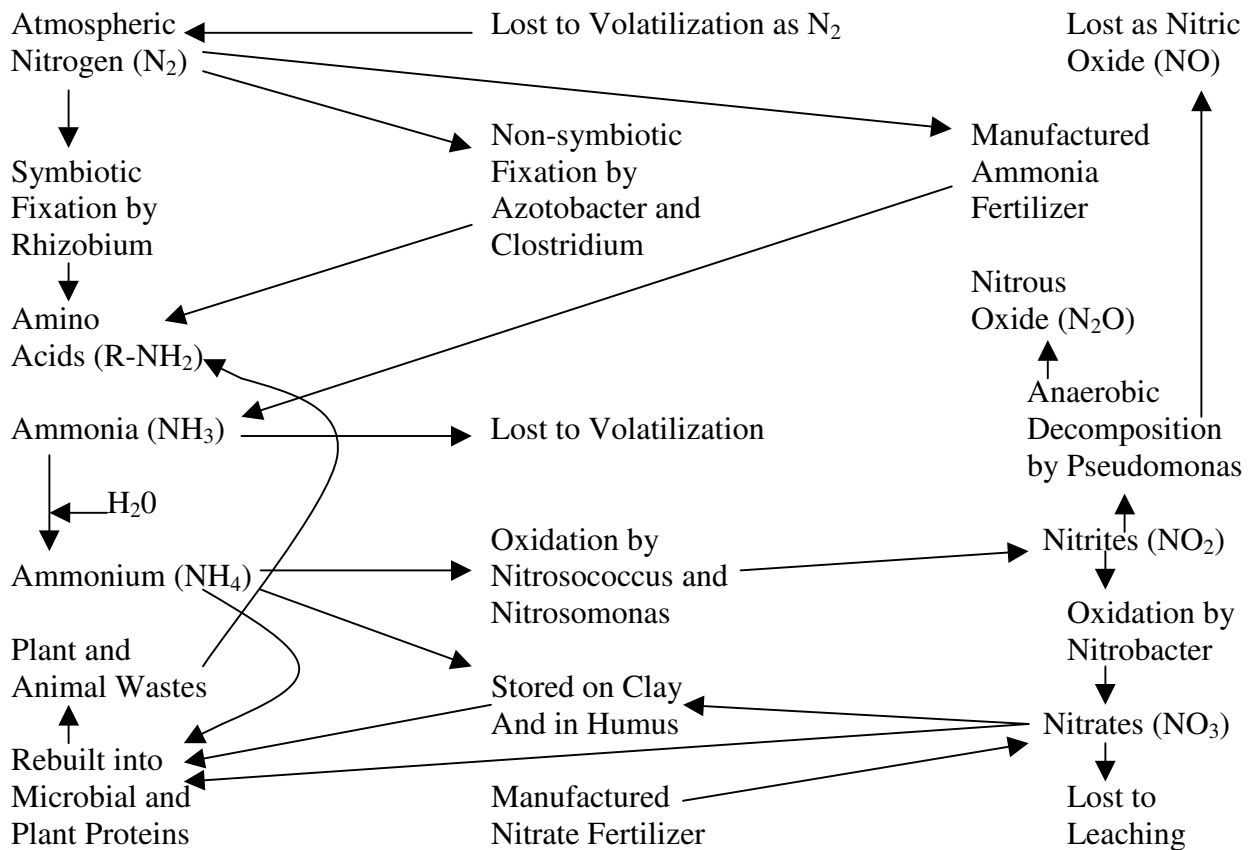
Cation ratios govern the ability of both plants and microbes to reproduce. So a proper balance ensures both a system for stabilizing the equilibrium of the countless species of competing microbes, and for stabilizing the peaceful coexistence of microbes and plant roots. Many crop diseases are the result of normally friendly (symbiotic) microbes becoming unfriendly (parasitic) due to an imbalance or lack of nutrients or organic matter. Since microbes

always feed first, then make the plant-available nutrient byproducts that grow our crops, feeding the soil, not just the crop, is very important. It becomes important for our crops first because it allows plants to survive and thrive, and secondly because it fosters the uptake of a balanced diet that will guarantee the crop's ability to reproduce in the form of seeds, tubers, fruits, etc. A plant that can successfully reproduce makes a terrific food source for animals, including humans.

There's no need at this point to get bogged down in all of the details of what each nutrient does for plant and microbial nutrition. This information is available from a number of other sources. But we've seen how nutrients move in the soil, how they're stored, and how they're exchanged. To better understand why certain nutrients are available at some times but not at others we need to look at some of the nutrient cycles to see the ways in which nutrients interact.

First let's look at a nutrient which doesn't typically originate in soil minerals. It comes from the atmosphere. It's converted into available forms and stored mostly in the bodies of microbes. Nitrogen availability is of primary concern to many growers, yet how many of them know what's really involved in producing the nitrogen that plants can use?

### The Nitrogen Cycle



By studying the nitrogen cycle chart you can see that just applying an ammonia or nitrate-based fertilizer won't guarantee a steady supply to your plants. It can be lost back to the atmosphere, leached away in heavy rains, grabbed by nitrogen-starved microbes, or it can even languish in an unavailable form due to waterlogged soil or the lack of a particular nitrifying bacteria. Many farmers have learned the hard way that the over-application of nitrogen can destroy a soil's tilth, as soil microbes attempt to balance their high-nitrogen diet by burning up high-carbon humus. In addition, applied nitrogen in moderate to high levels actually causes

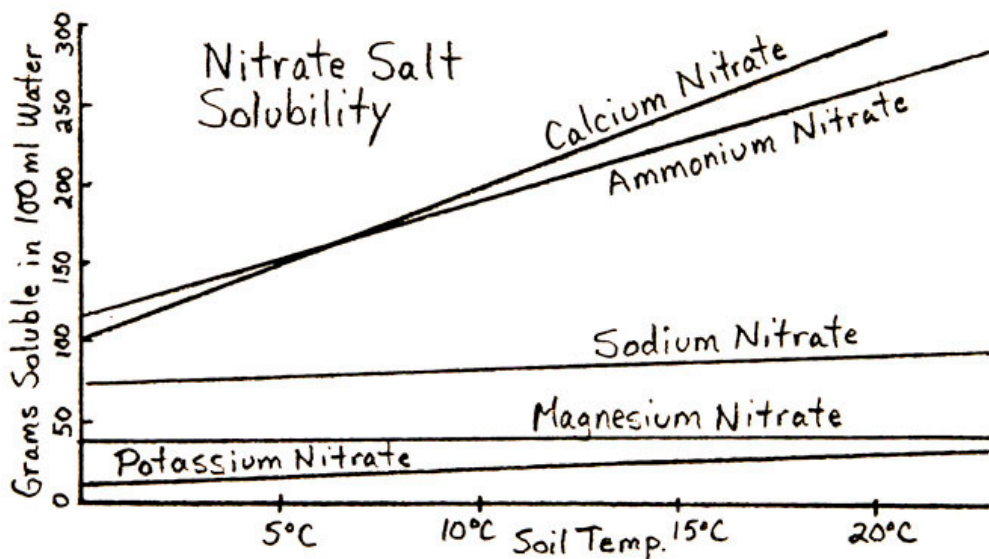
nitrogen fixing bacteria to become dormant, shutting down a soil process that can supply up to 170 pounds/acre of nitrogen under favorable conditions.

### Estimated Nitrogen Release (ENR) Per Year by Soil Type

% Organic Matter	Clay Loam	Silt Loam	Sandy Loam
0 - .3	0 - 30	40 - 50	50 - 55
.4 - .7	30 - 40	50 - 60	60 - 70
.8 - 1.2	40 - 50	60 - 70	70 - 80
1.3 - 1.7	50 - 60	70 - 80	80 - 90
1.8 - 2.2	60 - 70	80 - 90	90 - 100
2.3 - 2.7	70 - 80	90 - 100	100 - 110
2.8 - 3.2	80 - 90	100 - 110	110 - 120
3.3 - 3.7	90 - 100	110 - 120	120 - 130
3.8 - 4.2	100 - 110	120 - 130	130 - 140
4.3 - 4.7	110 - 120	130 - 140	140 - 150
4.8 - 5.2	120 - 130	140 - 150	
5.3 - 5.7	130 - 140	150 - 160	
5.8 - 6.2	140 - 150	160 - 170	
6.3 - 6.7	150 - 160		
6.8 - 7.2	160 - 170		

The breakdown of humus also supplies a sizable quantity of nitrogen each year in the form of ammonia. The quantity released is based on the soil's organic matter level, its soil type, its temperature, water availability, and how well it's aerated.

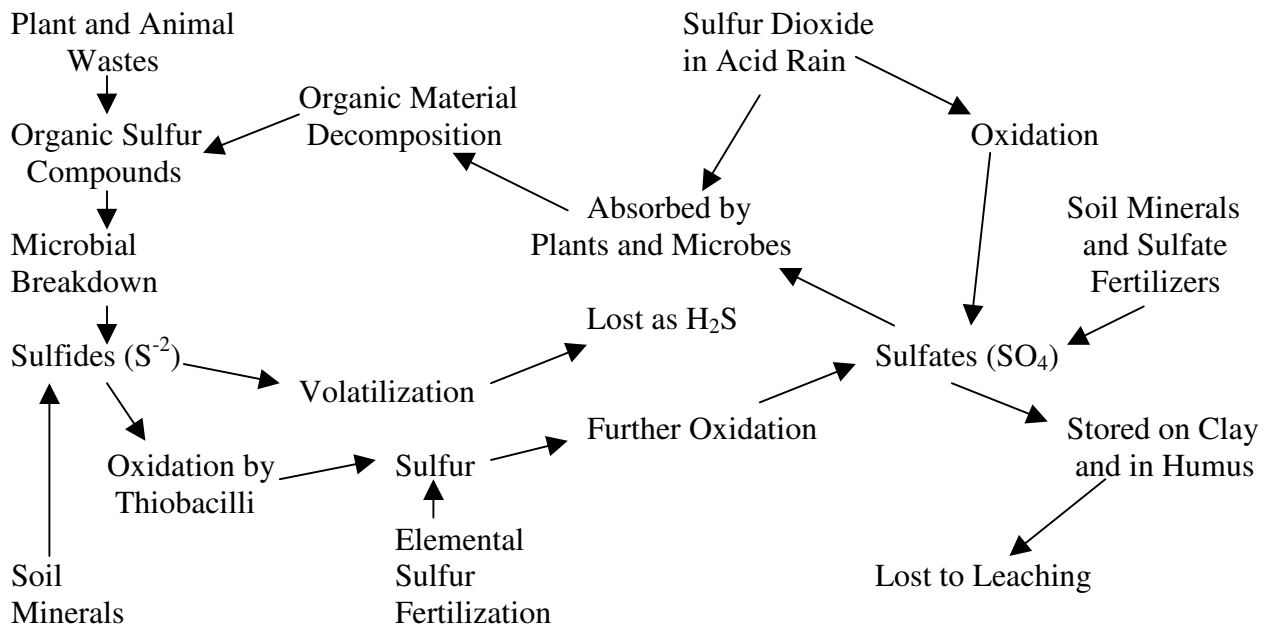
Another factor to consider when managing nitrogen levels is water solubility. Anionic nutrients such as nitrogen rarely exist in a purely ionic form like  $\text{NO}_3$ . They exist mainly as a protein-bound chelate or a soluble salt, combined with a cation such as calcium, magnesium, etc. It's important to know just how soluble each salt is if you're trying to maintain a proper cation balance.



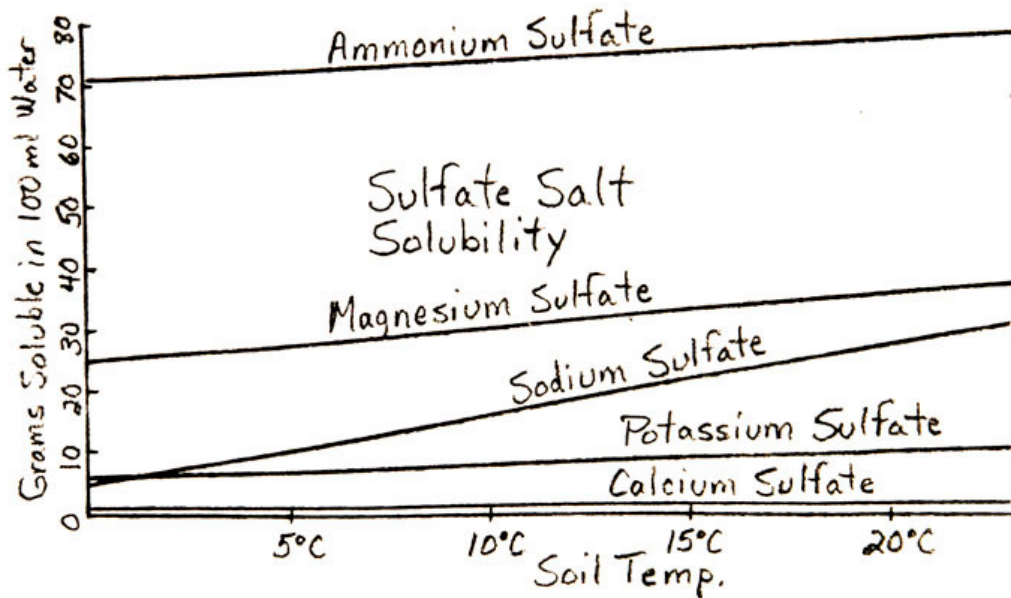
As you can see from this chart, when nitrates are generated and released by microbes, or when they are supplied in fertilizers, calcium and ammonium combine with the nitrates to form extremely soluble salts. This means that a heavy rainfall can leach away much of your soil's calcium and its reserve nitrogen ( $\text{NH}_4$ ) if nitrate levels are excessive. The calcium/nitrate balance and carbon/nitrogen balance are both vital to the healthy growth of crops and the sustenance of microbes. The most cost-effective and ecological approach to nitrogen availability is to monitor calcium levels using a soil test, apply the right form of lime when it's needed, and to avoid routine nitrogen fertilization. When a soil's other nutrients, pH, and organic matter levels are in balance, Nature will supply the nitrogen in its proper form, in the right amount, and exactly when it's most needed.

Sulfur exists in both mineral and organic forms in most soils. Some regions get more sulfur through the burning of coal in factories and power plants. Some regions, especially where I live, lack both an adequate mineral supply and the industries that supply it in the form of "acid rain".

### The Sulfur Cycle

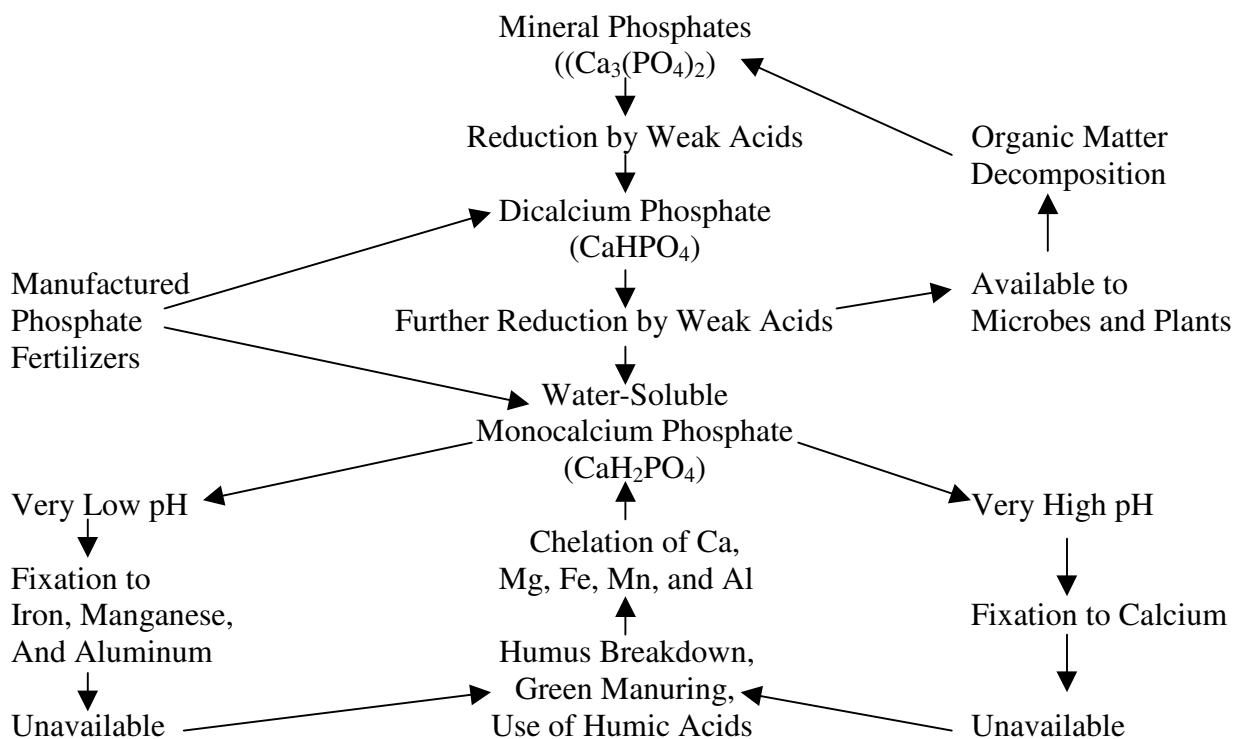


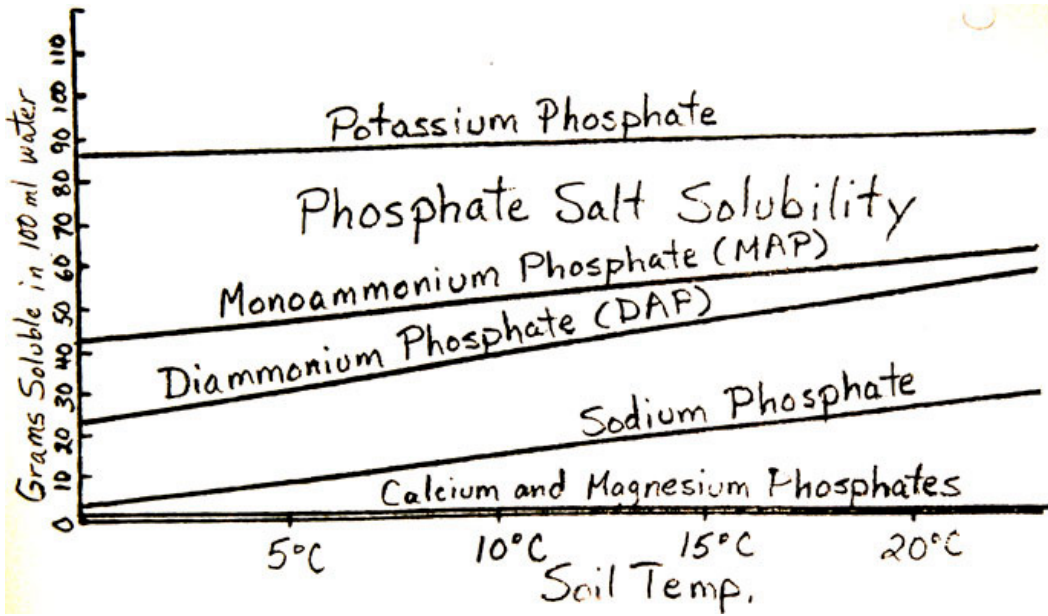
As you can see there are three major sources of applied sulfur. Crop residues and animal manures can supply some, but if these sources are low in sulfur, and the animals consuming crops grown from them get no other sulfur supplements, these sources merely recycle a depleted store. Sulfate containing fertilizers such as ammonium sulfate, superphosphate, and gypsum can supply quite a bit but in a form that is easily leached away if rainfall is heavy. Pelleted elemental rock sulfur is slowly weathered by rain and converted to sulfates by a species of soil bacteria. In this process the supply matches the demand since hot, moist weather that accelerates weathering and microbial activity also increases plant growth and sulfur uptake. Another factor favoring sulfur in its rock form is the fact that you only need to apply it once every three or four years. Yearly application is required with organic or sulfate forms.



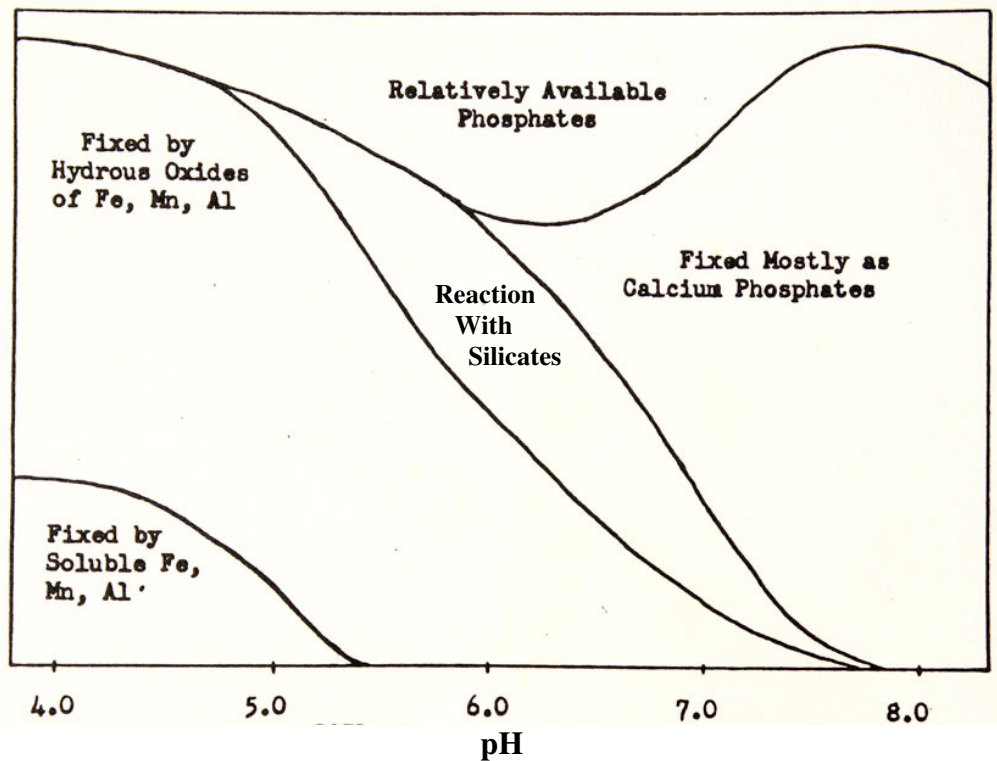
Using this solubility chart you can see why soil consultants recommend sulfur as a cure for high magnesium or high sodium soils. These cations react with the sulfate anion to form moderately soluble salts that can be leached away by rainfall. But notice too that ammonium sulfate is even more soluble. So leaching away excessive cations with sulfur can be a double-edged sword. Moderate sulfate levels are important as they assist nitrates in the job of building complete proteins both in crops and microbes. But too much sulfate will cause a situation where stored nitrogen (ammonia) can easily be lost to leaching, especially when soils are cold and temporarily have less demand for either sulfur or the nitrates derived from ammonia. By using sulfur wisely a balance can be achieved. But by using sulfates routinely, in excess or at the wrong time, you can do more harm than good.

### The Phosphorus Cycle





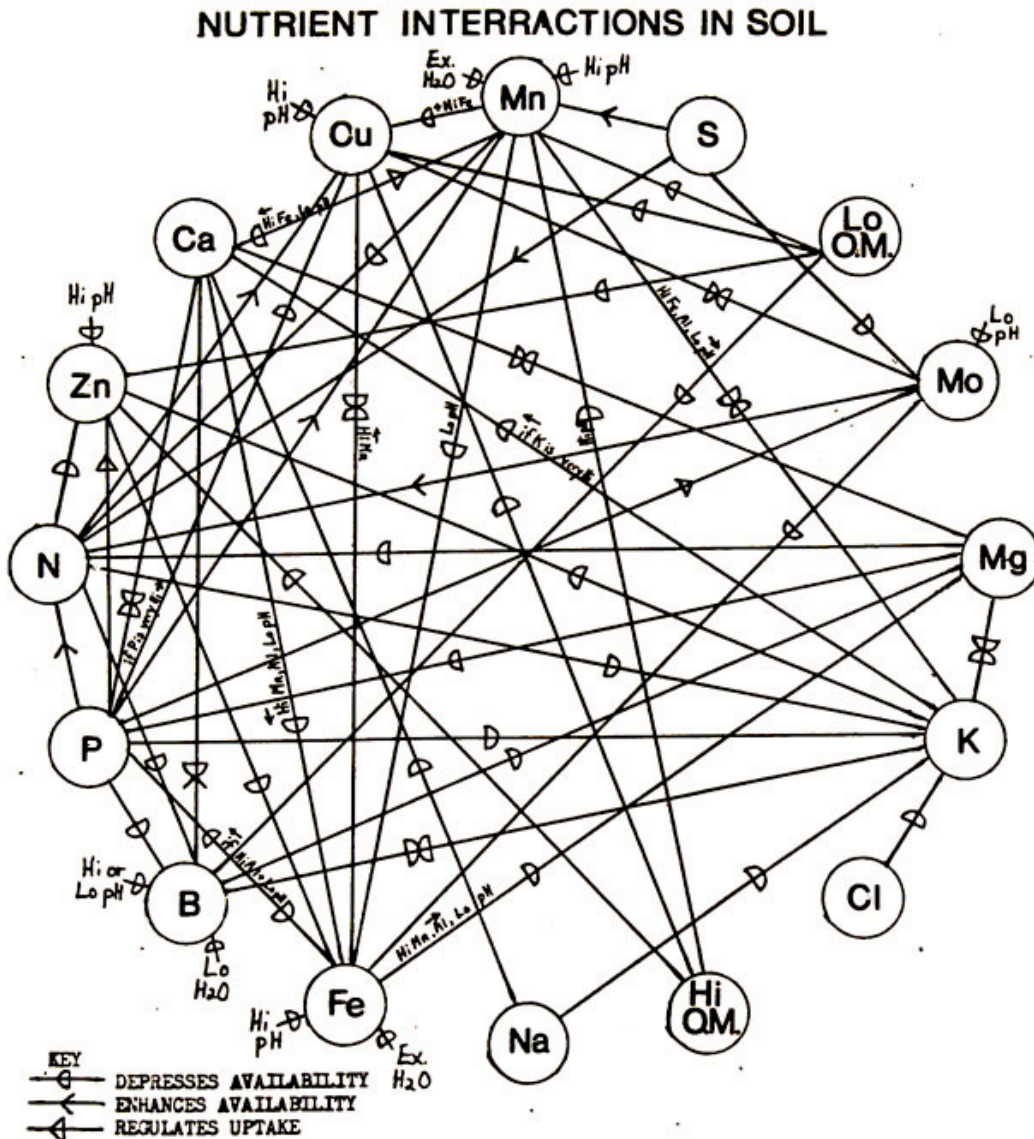
**Phosphorus Availability in the pH Range**



In the chart above the relative height of each area shows its phosphorus availability at each pH.

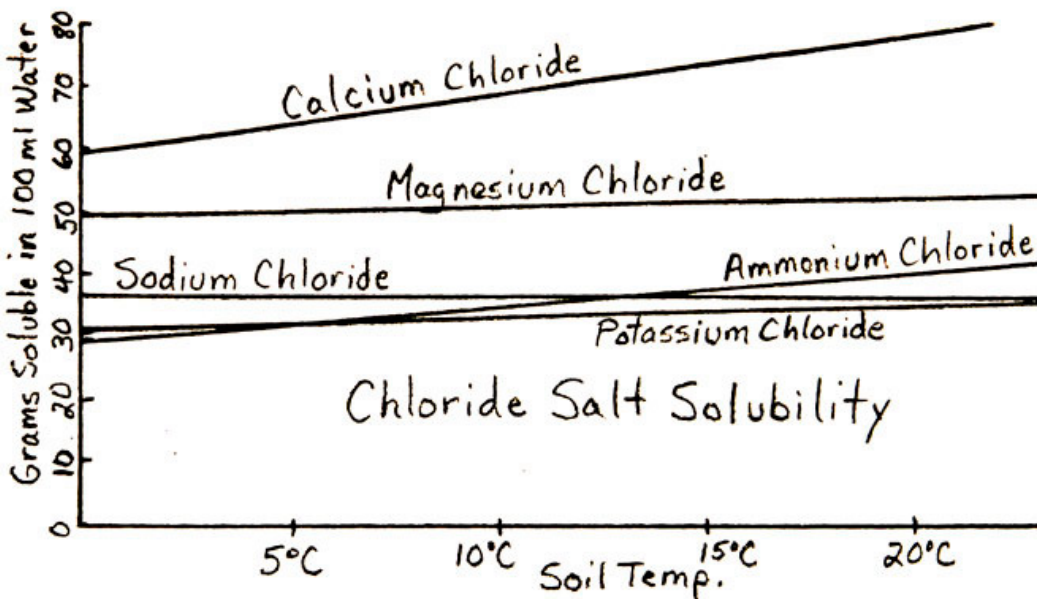
The availability of phosphorus is perhaps the most vexing problem in all of plant nutrition. The grower who applies the more water-soluble forms of phosphorus, found in ammoniated phosphates, "extra soft" (sodium) phosphates, and the "superphosphates" (0-20-0 and 0-46-0), supplies an initial massive dose of this highly necessary anion. But soil conditions can quickly and easily rob plants of the steady diet they need, converting the more soluble phosphates into various fixed forms. The grower who relies on "hard" and "soft" forms of rock phosphate is no less at the mercy of the soil's nutrient balance. A continuous supply of available phosphate can only be obtained if attention is paid to nearly all of the factors influencing nutrient availability in general. This includes proper management of pH, cation ratios, anion ratios, humus supply, water availability, and appropriate tillage. Any weak links in the chain will lower the phosphorus availability, even if soil tests indicate that the soil testing solvents can withdraw it. Once again, it's by cooperating with Nature that we learn to cut our costs of production and supply our crops with the diet they need, when and how they need it.

To get an idea of just how complex Nature's workings are, let's look at what I usually refer to as "the Soil Consultant's Nightmare".



An excess of one nutrient can increase or decrease the availability of other nutrients. These nutrients can then affect the availability of others, and so on, until a new equilibrium is reached. As you can see, the “shotgun approach” of applying just a few nutrients, often in a highly purified form, just doesn’t measure up as either efficient or appropriate management.

While we’re on the subject of purified forms, note that chlorine lowers the availability of potassium. This only touches the surface of the mischief caused by an excess of chlorine. Soils actually need only one pound per acre of it to produce a crop containing 4000 pounds of dry matter. This translates to about 5 pounds per acre for most crops. But when a grower applies potassium chloride (0-0-60, “kalium”, or muriate of potash), which is about 50% chlorine, enough of this microbe-toxic salt goes down to completely sterilize a soil for weeks. This shuts down all of the microbe-dependent nutrient cycles, ensuring dependence on nitrogen, phosphorus, and sulfur containing fertilizers.



Also, note the solubility of the various chloride salts. Is it any wonder that crops and animals suffer calcium deficiency symptoms when potassium chloride is routinely used as a potash source? Calcium and magnesium chlorides are preferentially leached away, making more frequent liming an absolute necessity.

If we can just back off from practices that limit the soil’s natural ability to grow crops we can begin to see balanced fertility at work. Nature can buffer some of our mistakes by shuffling the availability of nutrients and by activating dormant weed seeds that will concentrate nutrients in low supply. Nature tries to tell us that soils are faltering when weed growth exceeds the growth of a chosen crop or when crops get “recycled” by insects and disease. But how many growers actually stop to listen?

Let’s take a look at the kind of management that helps Nature build, balance, and maintain vibrant soils. The theories of soil management can be divided roughly into three schools: the offensive, the defensive, and the cooperative. The offensive school advises quick, simple, low-cost methods of obtaining a crop measured only by its yield. These are commercial, conventional, commodity crops like “#2 Yellow Dent”. The methods employed fail to take into

account the balance of life in the soil, the soil's tilth, the balanced availability of nutrients, the resulting nutritional value of the crop, or the subsequent health of the crop's consumer.

The defensive school is characterized by the heavy application and careful conservation of organic matter, the maintenance of an adequate economic yield, the management of crop predators within acceptable limits using fairly non-toxic means, and the careful regulation of the forms of soil amendments deemed acceptable. These are commercial Organic crops. They are surely a step up in terms of pesticide residues, crop nutrition (usually), soil health, and sustainability of methods. Especially of merit is this system's elimination of anhydrous ammonia and high chlorine salt fertilizers that deplete humus and kill microbes. What it lacks is the commitment to a full understanding of Nature's processes and the possibilities that exist for working, not simply to conserve the best in mediocrity, but to build vibrant biological fertility.

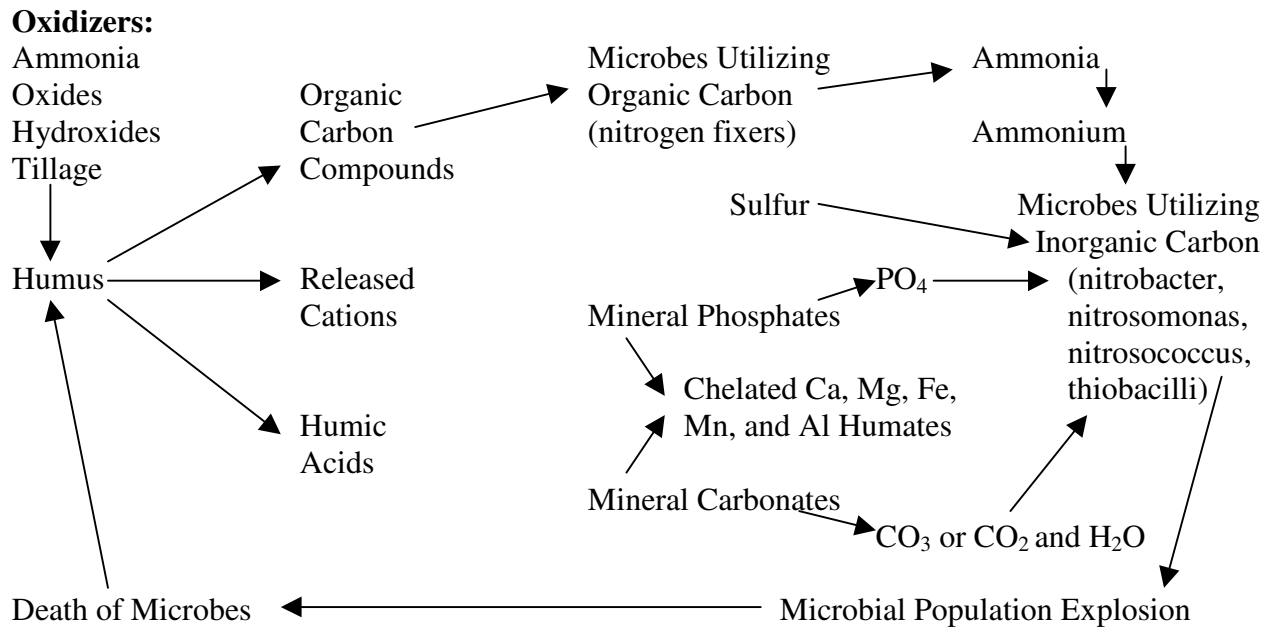
Let's look at two more charts that can help to explain what I'm getting at.

### Properties of Oxidation and Reduction

Oxidation	Reduction
Emission of electrons	Acceptance of electrons
Yielding oxygen or accepting hydrogen	Yielding hydrogen or accepting oxygen
Requires oxidizable material	Requires reducible material
Lowers energy of oxidizable material	Raises energy of reduced material
Increased in warm, dry soils	Increases in cold, wet soils
Lowers organic matter and humus levels	Raises total organic matter levels
Raises pH (more alkaline)	Lowers pH (more acidic)
Caused by tillage, green manuring, fresh rainfall	Caused by heavy mulching, no-till, and waterlogging

The cooperation between humanity and Nature begins with the building and maintenance of humus, not just total organic matter. The offensive school would have us believe that the loss of humus is the gain of the grower, since the breakdown of humus releases stored nutrients. The defensive school recognizes the importance of humus but lacks an economically viable strategy designed to help create it. The fact is that *some* humus must be sacrificed (yes, actually burned, in the process of slow biological oxidation) in order to create *more* humus. Highly reduced soils typically have poor drainage, low temperatures, and nutrient imbalances that lead to a build-up of organic matter but very little finished humus. Highly oxidized soils are typically dry, overheated, and unbalanced, leading to both a near total loss of humus and a lack of organic-matter-producing plants or microbes. A soil in which humus oxidation occurs to a *moderate* extent has the capability to rebuild itself, provided the microbes have a readily available source of mineral carbonates (such as lime). Of course some soils are so depleted in both humus and organic matter that *any* humus oxidation would lower the soil's Cation Exchange Capacity so much that leaching of cations in a heavy rain would be uncontrollable. In these soils the addition of mined humates or concentrated humic acid is necessary.

## Humus Building – A New Strategy



Little is written about this process in standard agronomic texts but, then again, soils don't read. The process begins when some type of oxidizer gets added to a soil (tillage adds to the effect). Typical oxidizers include quicklime, slaked lime, wood ashes, and ammonia (NH<sub>3</sub>). Ammonia is released in a soil when organic matter breaks down. Both green manures and aerobic animal manures readily release ammonia. When it reacts with ionized water it grabs hydrogen to become ammonium (NH<sub>4</sub>). The leftover hydroxyl (OH<sup>-</sup>) remains and becomes a major assailant of humus. The hydroxyl ion makes the humic acids in humus much more soluble. These acids react with relatively insoluble compounds such as lime, rock phosphate, and other fixed phosphates to produce chelated cations, available phosphates, and carbonates. When combined with nitrogen from nitrogen fixing bacteria and sulfates released by thiobacilli, the soil microbes that build humus have a complete diet of anions. If the cation balance is correct and the micronutrients are in adequate supply a microbial population surge occurs. And as these microbes exceed their food supply, and either die or become dormant, the supply of humus derived from the bodies (protoplasm) of these microbes increases dramatically. On well-balanced soils an increase of one-percent organic matter per year is common. This translates to 20,000 pounds of protoplasmic humus built in just one growing season!

All of this organic carbon is produced without having to add tons of manure, compost, mulch, or other shipped-in biomass. It's built in place by a natural process that's much more efficient than humans could devise. All the soil asks is that we stop applying toxic fertilizers, supply the minerals that are in short supply to help achieve a chemical balance, then ignite the soil building process by releasing some of the stored humic acids. What we get in return includes not only increased humus and phosphorus levels, but, with the type of clay found in my area, the increased release of stored potash. Remember the potassium stored between the illite clay layers? Increased ammonium levels cause a substitution of ammonium for potassium in the clay. Also, when carbonates, phosphates, and hydroxides increase, the solubility of their respective salts of potassium increase markedly. And we get all of this without adding any of the so-called "cheap" potash fertilizer that would ordinarily destroy this process.

Can you see now why the debate over “Which recipe of routine maintenance fertilizer is best?” is more than a bit misguided? Without any knowledge of the nutrient balance in your unique soil how can you intelligently choose the materials and methods that will benefit that soil? Unless we take into account more of the complexity of natural processes we miss the possibilities for healing our often-ravaged soils. To study Nature is to be frequently humbled. But rather than burying our heads in the sand or plodding onward in battle with the Earth, let’s move forward to build our soils, heighten our understanding, and develop our intuition and sense of wonder. Let’s work as true stewards of the Earth we’ve been given!