Foundations of Eco-Agriculture

The Cation-Anion Connection

by Neal Kinsey

New terms now command entry into the eco-farmer's vocabulary — *cation, anion, exchange capacity, base saturation,* but all ultimately have to do with the clay of the soil and the electricity of nutrition, and how nutrients, or the lack thereof, govern everything from crop production to weed control.

A *soil colloid* is a particle of clay that has been broken down to the point that it can't be broken down any further. Such a clay particle (and humus) carry a negative charge, much like the negative post on a storage battery. Fertilizers must have a positive charge to be held to the soil colloid. Calcium and magnesium from lime compounds have this positive charge. So does sodium. Hydrogen, as a gas, also has a positive charge. Negative sites on a clay particle will attract and hold positives, according to our scientific conceptualizations. The more clay colloids in the soil, the more negatives there are to attract positively charged elements, much like a magnet. Positively charged elements are called *cations.* Negatively charged elements, such as nitrogen, phosphorous and sulfur, are called *anions.* Negative ions do not hold to the clay colloid.

The bottom line is that clay has a negative charge and the element being held on that clay has a positive charge. Most of the chemical reactivity of soils is governed by clay colloids. These colloids are extremely small and can't be seen with the naked eye.

We should point out that some laboratories do not actually measure the amount of clay in a soil. Some operators put it between their thumb and two fingers and rub it around as if to say, "Well, that feels like so much clay," and so they put that number down. If you start getting good, round numbers on a soil test, you can just about guarantee that they are simply estimating the exchange capacity. It is standard practice in Europe, and it is standard practice for a lot of soil-testing classes. Obviously, if you cannot see the colloid with the naked eye, how are you going to determine how much of it there is unless you involve sophisticated instrumentation? Colloids are plate-like in structure. These plates lie down on one another, very flat, forming the clay soil.

Colloids come from clay and organic matter. In other words, there is a *humus colloid* and a *clay colloid.* Both have negative charges. They are very small, much like dust or talcum powder. These smallest pieces of clay — along with humus — attract and hold nutrients, but they are also easy to lose. If you could collect the dust that the wind moves across a field and analyze it, you would find that it has the highest fertility of any part of the field. The most fertile part of the soil always leaves first, via either water or wind erosion. The longer erosion continues, the worse the soil gets.

The first thing to do for your land is to correctly measure the amount of clay and humus the soil has in it. Nothing less than a detailed analysis will answer the questions. The procedure to rely on is *atomic absorption.* Technicians use a flame and actually measure the atoms, as well as how much the atoms will absorb (this test shows a different color for each nutrient). This measurement has a name — *cation exchange capacity,* or CEC. As mentioned earlier, cations are nutrients with a positive charge. *Exchange capacity* is merely a measure of capacity of the soil to exchange nutrients. Whether the CEC is large or small, it affects the soil's capacity to hold nutrients such as calcium, magnesium and ammonia nitrogen, and it also affects the quantity of a nutrient needed to change its relative level in the soil. A light soil will hold less of everything. Consequently, it doesn't take as much fertilizer to get the right nutrient balance for total saturation — but that nutrient load can be lost or quickly taken up by cropping it. If you have an exchange capacity of, say, 5, that is a sandy soil for certain. It is not going to hold very much fertilizer. Another soil may have an exchange capacity of 10. It will hold twice as many pounds of nutrients as the soil with a CEC of 5.

As previously mentioned, the clay colloid has a plate-like structure. This plate may be hexagonal, square, chunky or blocky, but it basically maintains a plate shape of some type. All of the cations are attracted accordingly. For every plus charge there is a negative, or minus charge.

That is great as long as we have enough open negatives for the single plus-charged elements such as potassium, but when we start saturating a soil to achieve pH 7, not enough room will remain for weaker cations, and therefore additional nutrients with a single positive charge will not be easily positioned on the soil colloid. This is likely part of the reason why potassium will not be built up in clay soils when the pH is above 6.5.

We find that the nomenclature *total exchange capacity* (TEC) fits much better. "Cation exchange capacity" on a soil test means that the laboratory is measuring a certain part of the cation content. It may be measuring all, and it may not. We use the word *total* on our evaluations to assure the client that we are measuring *all* the cations that could have a major effect on the soil analysis.

Adsorbs is another term that needs to be added to every farming vocabulary, with special emphasis on the "ad." It means *held on the surface,* in this case on the surface of *the clay particle.* When a plant root releases its acids, an exchange between hydrogen and a cation nutrient takes place.

Sand has a low exchange capacity because it contains smaller amounts of clay and humus and holds less nutrients than other soil. Gumbo, on the other hand, has a high exchange capacity. A Florida sand used to grow leather leaf fern probably has a 3 or 4 exchange capacity. Some heavy clay soils have a 40 to 50 exchange capacity, or ten times more ability to hold nutrients. If you started out with nothing in either soil, it would take ten times more fertilizer to balance the high exchange capacity soil compared to the low capacity soil. That is why we have to measure the soil and mark the nutrient equilibrium or lack thereof. High-TEC soils therefore hold much larger amounts of fertilizer and moisture because they contain higher amounts of clay and humus.

Cation Exchange Capacity

The first order of business for the soil colloid . . . is to hold nutrients—nutrients that can be traded off as the roots of a plant demand them.

Almost all laboratories report cation exchange capacity, and they do this in terms of milliequivalents, or ME. If it helps, you can think of an electrician measuring in terms of volts and amperes, or a physicist measuring magnetic energy in terms of ergs and joules. The soil laboratory has its own lexicon. It expresses colloidal energy in terms of milliequivalents of a total exchange capacity, since soil colloids—composed of clay and organic matter—are negatively charged particles. Negative attracts positive. Cation nutrients are attracted and held on the soil colloids. Since anions are not attracted by the negative soil colloids, they remain free to move in the soil solution or water.

ME represents the amount of colloidal energy needed to absorb and hold to the soil's colloid in the top seven inches of one acre of soil 400 pounds of calcium, or 240 pounds of magnesium, or 780 pounds of potassium, or simply 20 pounds of exchangeable hydrogen.

— *Charles Walters,* Eco-Farm

To determine a soil's productive potential, then, *total exchange capacity* is the first thing we need to know. Then, after we know the capacity of the soil to hold plant nutrients, there is another portion of the test that goes hand-in-hand — the *base saturation percent.* The reason it comes second is because you simply can't establish the base saturations unless you know the exchange capacity. Base saturation teaches us that in each soil there is a specific percentage of nutrients that grows crops best, and that it is not the soil that receives the most pounds per acre that always delivers the best crop.

Anatomically, you use the pounds to get the percentages, and percentages tell how a soil is going to perform. Yield and quality are determined by the percentages, not the pounds. Thus our bottom line: base saturation percentage tells us what the soil is composed of in terms of cations — calcium, magnesium, potassium and sodium. It also tells us that the availability of these nutrients to plants generally increases with their percent saturation.

Magnesium and manganese are exceptions. A higher percent saturation of magnesium in a soil does not necessarily mean that this nutrient is more available. It is possible to get to the point where the percent of magnesium — as it goes up — actually makes *less* magnesium available to the plant.

Here is the optimum percentage base saturation of cations generally for most soils. The cation calcium should be 60 to 70 percent of the saturation of the soil. In other words, 60 percent of the minerals attached to the colloids should be calcium — on a light, sandy soil. On a heavy clay soil, 70 percent would be optimum. The correct number for magnesium should be between 10 and 20 percent. On a heavy clay soil, it would be better at 10 percent. The ideal is for calcium and magnesium to total 80 percent. In a high clay soil, 70 + 10 = 80, and in a light sand, 60 + 20 = 80. Very light sands below 4.0 TEC have to have even more magnesium in order to spoon-feed the plant. Heavy clays do not need that higher magnesium percentage. In fact, it is a detriment.

There is another side to this story. The nutrient side is perhaps not the most important side. The other side is the effect that calcium-magnesium have on the physics of the soil. A heavy clay soil needs to have more calcium. A light, sandy soil needs to have more magnesium because magnesium tightens the soil and pulls it together. The higher the magnesium content in a clay soil, the stickier it will be when wet, and the harder it will be when it is dry. Sodium can cause hardness, but magnesium is basically what gives stickiness to a soil. On the other hand, the higher the calcium, the looser it becomes, even to a point — if you overlime your soil — where needed moisture gets away. Increasing magnesium increases the amount of water held by that soil because magnesium attracts and holds extra water. The lighter the soil, the more important it is not to overlime and not to get too much calcium into that soil from whatever source.

Potassium should be at 3 to 5 percent. On grapes, cotton or woody plants, a better number would be around 7.0 to 7.5 percent. When you are at 7.5 percent potassium, the load will cut down on the available hydrogen in that soil. In short, there are tradeoffs. A soil with a deficiency is also a soil with too much of something else. We have to realize that if we build the potassium up to 7.5 percent, and we have 10 percent magnesium and 70 percent calcium, something else has to leave to make room. This will be the weakest link in the chain, namely, hydrogen, if the pH is below 7.0. Hydrogen should be between 10 and 15 percent of saturation. Hydrogen in this pH range gives a bit more acidity to the soil so that it will increase the availability of phosphate, potassium and other nutrients. These nutrients tend to tie up. With hydrogen, some acidity can be provided so the plants can better utilize them.

The other bases are 2 to 4 percent. We concentrate on these in the trace minerals tabulation rather than as a base saturation percentage. They are needed in minute amounts. No one I know has concentrated on them long enough to say, "We need this percentage of manganese, or this percentage of iron," and so forth.

The above inventory of figures (the base saturation percentages), then, tell a farmer how productive his soil is. If you have a heavy clay soil with 70 percent calcium and 10 percent magnesium, and the rest of the numbers fall in place, and you have a second soil with, say, 60 percent calcium and 20 percent magnesium, the 70 + 10 soil is going to outproduce the other one every time. If it is a heavy clay, the 70 + 10 equation has more of what contributes to the ideal situation for a clay soil — more calcium to keep it loose and less magnesium to hold it together, because clay soils are naturally tight. They have too little pore space. The problem in a clay soil is generally too much water occupying the available pore space. In a sandy soil, the problem is generally too much air. In soils with a TEC of less than 5.0, the 60 percent calcium and 20 percent magnesium saturations would be better. Thus we increase the magnesium in the sand in order to get the pore space out, and pull the particles together, and increase the calcium in a heavy clay to push the particles apart, causing them to aggregate in clumps in that soil.

True soil balance means determining and adding the proper amount of each nutrient. Fertility is the balance between elements. Not only is each element necessary individually, but a balance of all soil elements is necessary collectively. Every element works on every other one in an interdependent way. Adding too much of any nutrient means complexing some other nutrient needed for proper plant nutrition. Justus von Liebig is the fellow who gets credit for the concept of using N, P and K, meaning nitrogen, phosphate and potassium. He determined that there was a Law of the Minimum. He said that if you don't at least have this minimum, then your crop is going to suffer. That applies not just to N, P and K, but to all the other nutrients as well.

André Voisin, a member of *Academie d'Agriculture de France,* distilled his years of research into the "Law of the Maximum." This law states that if you put on too much of a given nutrient, it is going to tie up something else that is needed. He found that if you put on too much potassium, for example, it ties up boron. If you put on too much phosphorus, it ties up zinc and possibly copper. If you put on too much nitrogen, it ties up copper and sometimes some of the other elements, even zinc. If you put on too much calcium, it could tie up all the other nutrients, depending on their level of availability.

Thus our lessons fall into place. When the pH is 7 or higher, the exchange of hydrogen will be zero. As you come down the scale from a pH 7, then hydrogen begins to increase in direct proportion (as long as a water pH test is used to measure the phenomenon). If pH goes from 7 to 6.9, exchangeable hydrogen will go up by 1.5 percent. If pH goes from 7 to 6.8, exchangeable hydrogen will go up by 3 percent. For every 0.1 that pH is dropped, exchangeable hydrogen from pH 7.0 downward will go up by 1.5 percent until you reach pH 6.0.

When micronutrients are present in the soil in adequate amounts, and the soil has the right base saturation percentages, then they are most available, but not necessarily in adequate amounts. At the right percentages of calcium and magnesium — if the micronutrients are in that soil — they are going to be present in their most available form. Still, there are a tremendous number of soils that can be balanced in terms of all major nutrients, and be missing micronutrients in bare minimum amounts. They are in the deficient category even after we have done everything we can to balance the soil. It is not correct to say *balance the soil,* and micronutrients will take care of themselves. Some soils simply do not contain adequate minimum amounts of micronutrients. But if they are already there and tied up by excesses, they will be released as the excesses are brought under control.

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