Nutrient cycling

By Carlos Armenian Khatounian. Source: Dictionary of Agroecology and Education.

2025/02/19

Plant mineral nutrients

All living beings are mainly composed of three chemical elements: carbon (C), oxygen (O) and hydrogen (H). In plants, these three elements constitute around 95% of the dry matter, with H and O coming from water and C, from carbon dioxide in the air. In the remaining 5%, there are a number of other chemical elements, collectively called mineral nutrients. Among the mineral nutrients, three are needed in greater quantities, nitrogen (N), phosphorus (P), potassium (K). These are designated as primary mineral macronutrients, followed by calcium (Ca), magnesium (Mg) and sulfur (S), called secondary macronutrients. Plants also need, in significantly smaller amounts, boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), cobalt (Co), nickel (Ni) and zinc (Zn), which are called micronutrients. Silicon (Si) is also very common and is considered essential for some plants.

To grow and complete their cycle satisfactorily, plants need to be supplied with everything they need. As plants are fixed in the soil, all these nutrients need to be available where their absorption structures develop, particularly the roots. To be absorbed, nutrients must be dissolved in the soil solution that permeates the capillary spaces. From this solution, they pass to the roots and go up to the places where they participate in the physiology of the plant.

Soils from different regions contain different amounts of mineral nutrients, and may also contain toxic elements, such as free aluminum (Al). As plants are fixed by their roots to the soil, they have had to develop, throughout their evolution, mechanisms to adapt to the proportions in which mineral nutrients are present, and also strategies for coexisting with toxic elements.

For this reason, although they need the same mineral nutrients, plant species differ in the proportions of the elements they need. They also differ in their ability to extract nutrients from the soil and their tolerance to toxic elements. Therefore, plants that evolved in different environments, such as wheat on calcareous soils under a temperate semi-arid climate and rice on acidic soils in the humid tropics, developed different adaptations. As a consequence, they require different conditions to fully express their productive potential.

Particularities of the dynamics of P, K and N in the soil-plant system

Phosphorus

Mineral nutrients have very different chemical behaviors. Due to their importance, we consider the three main macronutrients here.

As a rule, P in uncultivated soil is essentially derived from bedrock, the original source for absorption by plants and incorporation into their biomass. When this biomass is decomposed, P is released into the soil solution in the form of phosphate anions. In this form, it reacts readily with cations, particularly aluminum and iron, in tropical soils. The phosphates formed with aluminum and iron are practically insoluble, so phosphorus becomes unavailable for most agricultural crops. This process is called phosphorus fixation. To avoid fixation, the released P must be readily reabsorbed by a growing plant, which requires active roots.

When phosphorus is applied as a mineral fertilizer, it undergoes the same fixation process, so that its use by the crop is normally only 5 to 10%. Fixed P can be put back into circulation by crops that have evolved the ability to extract it from these insoluble phosphates, such as cassava, pigeon peas, mucunas and fava beans.

P export by crops is normally on the order of a few tens of kg per hectare. As P concentrations in the soil solution are low, leaching losses are of little importance on the agricultural time scale. The most important route of P loss is soil erosion, in which P is associated with particulate matter, so erosion control is the main measure to prevent P losses.

Potassium

As for P, the original source of K is the soil bedrock. Released from the matrix, potassium appears predominantly as K^{+} cation, which forms very soluble salts, unlike P. After sodium (Na), K is the metal that forms the most soluble salts in water, and is therefore present in all plant liquids.

In the soil, clay minerals and humus form a chemical sponge with negative charges, which is capable of retaining positively charged ions, such as K^{+}, on its surface. In soil chemistry, this surface retention is called adsorption, and the adsorbed ions can later be absorbed by plant roots. Cation exchange capacity (CEC) is a measure of the soil's ability to retain positively charged nutrients.

As K has a strong affinity for water, intense rain can remove K from the leaves and take it to the soil, where it will be absorbed by the clay-humus complex. If the amount of water is very high, and the CEC is reduced, part of this K can be carried by rain or irrigation and descend to deeper layers of the soil with percolation water. This dragging with the percolation water is called leaching. If K is leached to a depth beyond the reach of the roots, it will be lost to the plant's mineral nutrition.

In humid climates, leaching usually leads to the loss of an important fraction of K. The deeper and denser the root system, the smaller this loss.

The export of K in the harvested product normally varies between several tens and a few hundred kg per hectare, depending on the type and quantity of harvested product. As K has a strong affinity for water, export is significantly lower in dry products, such as grains, than in wet products such as sugar cane, bananas or cassava.

Nitrogen

Unlike P and K, N in natural systems does not come from the soil's bedrock, but from the air, from which its gaseous form N_2 represents around 80%. Its incorporation into the soil can occur through electrical discharges and, above all, through the activity of organisms capable of converting its gaseous form N_2 in organic forms. This conversion is called “biological nitrogen fixation” (BNF). Note that the term “fixation” here has a different meaning than when it is used for phosphorus. Among the various biological N fixation systems, the association of legumes with bacteria, known as rhizobia, is the most common in agriculture.

After water, N is usually the factor that most quickly and visibly promotes plant development. Together with C, H and O, N is an integral part of proteins, which form enzymes, tools that mediate the entire metabolism of the living world, including photosynthesis. Once incorporated into the biomass of legumes, N will participate in the development of the plant. At the end of the cycle, part of it will be directed to the seeds, and part will remain in the plant remains that will be worked on by decomposers.

In a well-ventilated environment, the N in plant remains is converted into nitrate (NO_3^-), an anion with extreme affinity for water, so that, like K^+, it is subject to leaching. However, because it has a negative charge, nitrate is not retained in the exchange complex in the soil, so losses are very high, unless there is a root system dense enough to absorb it before it is leached. As land subjected to agricultural use goes through long periods without any vegetation, nitrate losses through leaching are usually very important.

Due to this chemical dynamic, replenishing N stocks in the soil was a natural requirement to recover the production potential of agricultural land throughout the history of agriculture. For this recovery, the main strategy was fallow or "rest", which required leaving the land out of cultivation for several years. With the invention of synthetic nitrogen fertilizers, long fallow periods could be dispensed with, and the land could be occupied year after year with agricultural crops. This was the reason why the 1918 Nobel Prize in Chemistry was awarded to Fritz Jacobus Haber, a German of Jewish origin who developed the chemical process of N fixation.

This process, adapted to the industry by Carl Bosch, is the same one used today to produce urea offered on the fertilizer market. Over time, the continued use of synthetic nitrogen fertilizers brought unforeseen problems, so that today synthetic nitrogen fertilizers are avoided in ecologically based agriculture and banned in *organic production*. But this subject is beyond the focus of this entry.

Returning to N dynamics, both urea and other synthetic nitrogen fertilizers are converted into nitrate if the environment is well ventilated, in the same way as N in plant residues, so leaching losses are equally important.

In addition to leaching, N can be lost from the system through other routes. When plant tissues containing N or nitrate itself are subjected to chemically reducing conditions, as is the case in environments covered by water and with abundant organic matter, N is converted into other chemical forms, especially into ammonia (NH_3) or nitrogen gas (N_2). Thus, in situations such as irrigated rice fields or lagoons for storing effluents from pig farms, the N contained in the material is lost to the atmosphere through volatilization.

Another form of loss is through animal urine. In systems with a high population of large animals, such as bovids, this can be the largest source of N losses. Animals concentrate the digested N in their urine, and, when urinating, deposit it in a small area, usually a circular spot less than one meter in diameter. In the center of the patch, the N concentration can exceed five hundred kg per hectare applied at once, which results in leaching because the pasture is not able to absorb that amount of N immediately.

In a drought situation, the loss of N tends to be even more significant. The high concentration of N in the form of urea, added to the K and Na present in the urine, creates a highly saline environment, so the pasture burns in the center of the patch. From the center to the edges of the stain, the salt concentration decreases; the pasture does not die, it is fertilized by N and irrigated by urine water, forming a bluish green halo around the burned center. In the burned center, urea is converted into NO_3^-, which accumulates there. With the return of rain, K and Na salts and NO_3^- are dissolved and descend into the soil profile with the percolation water.

The net result of this process is a loss of N from the system each time an animal urinates. This is the main way this nutrient is lost in pastures, and leads to continuous impoverishment. Farmers don't see this loss, and most agronomists don't know about it, but the impoverishment of the pasture is clearly perceived.

This continuous loss of N creates favorable conditions for the establishment of plants capable of performing NBF, particularly legumes, which replace the soil by removing N from the air. In conventional rotational grazing systems, replacement is done by applying urea each time cattle are removed from a paddock.

On land occupied by crop production, N subtractions are quantitatively high, either through export in the harvested product or through losses, especially through leaching. For this reason, the inclusion of legumes in crop rotation/intercropping is essential in ecologically based systems.

At this point, the reader has probably realized that the chemical dynamics of N are complex, and that its proper management requires much greater study and planning than that of other nutrients. There are no tips. This entry is just a stimulus to prepare a management plan suitable for your production system, starting with the simplest and going up to the required level of complexity.

Comparing the movements of N, P and K in ecosystems, it is evident that, on the agricultural time scale, only N presents regular inputs, which justifies speaking of “cycling”. For P, K and all other nutrients, on the agricultural time scale, what is actually observed is a movement from land to sea. This movement is a flow of losses, which need to be somehow compensated by human action in permanent agricultural systems. In the topics that follow, we try to better understand these movements to reduce losses, and thus reduce the need for replacement.

Mineral nutrient cycling in natural and agricultural systems

Mineral nutrients are in constant and complex movement and require the farmer to understand them well to manage them effectively. These movements are due to the chemical characteristics of each nutrient, natural factors such as climate and fauna, and human interference. For ease of explanation, we divide these movements into three categories: natural, automatic, and intentional cycling.

Although the term cycling may be inappropriate from the point of view of the natural phenomenon, it is appropriate to draw the reader's attention to the need to reuse all locally and regionally available materials to direct them towards optimizing plant production.

Natural cycling of mineral nutrients

At every point on the planet's surface, the natural vegetation present there is fully adapted to the growing conditions in that location, since any poorly adapted species is eliminated by another with better adaptation. Each plant germinates, grows, reproduces, and to do so it carries out photosynthesis to generate biomass, capturing CO_2 from the air, and water and mineral nutrients from the soil. Dead, the plant is decomposed, the CO_2 returns to the air and the mineral nutrients return to the soil, where they will be absorbed again by another growing plant. This process occurs continuously in natural ecosystems and is an essential part of the functioning of nature.

By producing biomass through photosynthesis, from water and CO_2, the plant absorbs and incorporates mineral nutrients, which become part of its structure. The biomass produced is a source of food for herbivores and decomposers, and, when decompose, it releases mineral nutrients simultaneously with the release of CO_2 and water. Nutrients move up from the soil to the plant, and then down from the plant to the soil. Thus, in natural ecosystems, *mineral nutrient cycling is coupled to biomass cycling and nutrients move predominantly vertically*. This is the "natural" cycling of mineral nutrients.

Automatic cycling of mineral nutrients

In environments managed by humans, the same processes of photosynthesis, absorption of mineral nutrients, production and decomposition of biomass occur. *However, in the operation of the agricultural production system there ends up being an intense horizontal displacement of the biomass produced, off the land, and part of this biomass is exported as an agricultural product.*

Furthermore, agricultural land tends to remain bare or with little vegetation during the off-season, so nutrients can be lost through erosion and leaching. For these reasons, cycling on agricultural land involves much more losses, so nutrient replacement becomes a necessity, including in ecologically-based agriculture. In this situation, the big question is how to minimize losses, to minimize the need for replacement.

In systems where animals are raised, biomass and mineral nutrients are moved from the areas where their food grows to the spaces where they deposit their waste, concentrating there. A part of the land is fertilized at the expense of the impoverishment of another part. Retreats, mangroves, pigsties and chicken coops are spaces for the concentration of mineral nutrients. These nutrients have no use in production as long as they remain in this space, because the constant presence of creations prevents the development of plants. For this reason, the way in which manure will be collected and transported to vegetable production areas deserves special attention from the farmer.

In intensive animal production systems, to feed birds or pigs in a 1,000 to 2,000 square-metre shed, two to four hundred hectares of soybeans and corn are needed for a year. This means that the biomass harvested from these hundreds of hectares will have to pass through a very narrow funnel, so any losses in this funnel are very relevant.

One of the most common forms of displacement of mineral nutrients in agricultural systems, and which often goes unnoticed, is their concentration in the vicinity of the farmer's house. The farmer brings firewood for his stove, then throws the ashes somewhere nearby. Also brings corn to the animals, who are treated and dispose of their waste there; brings fruits, vegetables, straws, the residues of which end up remaining there. As a result, over time, the surroundings of the home become richer in nutrients and biomass.

This movement that occurs as a result of the operation of the property, usually without the farmer noticing, is called automatic cycling. It occurs, above all, horizontally, impoverishing the spaces for vegetable production and enriching the spaces where animals are concentrated and the surroundings of the house.

Intentional Cycling of Mineral Nutrients

When the farmer applies manure, plant residues, ash, etc. in the plant growth environment it is *intentionally* directing the movement of nutrients to points in the system that are of interest. Ideally, intentional cycling enhances the use of nutrients present in the system, whether pre-existing or introduced, and optimizes their use for the biological and economic production of the system.

The collection of waste from plant and animal production to apply to gardens and plantations is part of this intentional cycling. But there is great potential to improve the use of nutrients in the system. Realizing this potential requires, as a starting point, that the farmer identifies the opportunity, and then adjusts the management and/or structuring of the system in order to capture the benefits.

The use of manure is often low, due to the difficulty of collecting it. To improve this use, facilities must be designed with the use of manure collection in mind and management must take into account the pattern of elimination of urine and feces. The most difficult situation for manure collection occurs when animals are raised completely free range. And the easiest when they are kept completely closed. On the other hand, completely free-range farming requires much less work and food, as the animals seek to meet their needs on their own, while closed farming depends entirely on human care.

However, there are also intermediate situations. Getting birds used to sleeping inside a chicken coop makes it possible to collect the manure produced during the night. A flock of 20 to 30 chickens, the usual number in production for farmers' domestic consumption, can generate enough manure for a vegetable garden measuring 50 to 200 square metres, sufficient to supply a family with vegetables throughout the year. Similarly, collecting large or small cattle at night makes it possible to use the manure produced relatively easily until the next morning.

Characteristics and care of manure

As a starting point, it is necessary to conceptualize what the term “manure” means. When cattle or horse manure is collected in a pasture, mangrove or retreat, the material essentially consists of feces with different amounts of moisture and stages of decomposition. Feces are the undigested fraction of food, rich in cellulose, and impregnated with small amounts of mineral nutrients (N, P, K, Ca, Mg, etc.) that the digestion process was unable to extract.

When animals are kept confined, on impermeable floors, and with bedding, the term manure is used to designate the mixture that includes, in addition to feces, bedding material and urine. In this case, its chemical and biological composition and dynamics are different. Firstly, there is the bedding material, such as wood shavings, peanut shells, rice husks, straws, etc. Secondly, there is urine, a solution to which the animal's body directs waste from its metabolism, particularly the end products of the digestion of nitrogenous substances and surpluses of water-soluble salts, especially K from forage and Na from table salt. Unlike the nutrients in feces, which only become available to plants over weeks or months as they are broken down by microorganisms, the nutrients in urine are readily available. The main nitrogenous compound in urine is urea, so diluted urine has effects on plants similar to those of urea of industrial origin. Pure urine is very saline and can kill plants.

Pig excrement follows the same pattern as cattle excrement, with feces acting slower than urine. However, as pigs' diet is mostly made up of plant tissues rich in starch and proteins, mainly grains, their feces decompose much more quickly than those of herbivores, whose main component is cellulose fibers. As in the case of cattle, the best use of nutrients in pig excrement is obtained with waterproof flooring and high bedding made of cellulosic material (wood sawdust, wood shavings, chopped straw, etc.). With the pigs' constant rooting, urine and feces end up mixed with the bedding material.

Over time, this material becomes moistened, so it needs to be removed before it turns into a paste that makes the animals dirty. The material removed is a mixture ready for the development of thermophilic bacteria, so that, when accumulated in a pile, it heats up immediately. This heating is very beneficial from a health point of view, because it eliminates the propagules of pathogenic organisms common to pigs and humans. This elimination is more efficient the more times the pile is turned.

The time to replace the litter varies with the relationship between the moisture absorption capacity of the material used and the amount of moisture excreted by the animals in feces and urine. As a reference, a 20 cm layer of sawdust in a 3 x 3 square metres bay is enough for a weaned litter for one to two months.

From a nutritional point of view, pigs and chickens are fed the same types of products, which would make one think of manure with similar characteristics. However, there are two particularities in the chickens' digestive system that make their manure different: the gizzard and the uric acid. In birds, food fragmentation occurs in the gizzard, a differentiation of the stomach, with powerful muscles, which reduces the ingested material to a much finer paste than pigs' teeth can make. Birds and reptiles experienced a very dry environment during their evolutionary past, which induced a system for eliminating nitrogenous waste in a water-insoluble compound, uric acid. Thus, while mammals need a lot of water to eliminate urea, birds do not waste water to eliminate uric acid. In a plaque of chicken droppings, the feces is the larger, darker plaque, and the uric acid is the light, comma-shaped part on top of the plaque. This clear comma is the equivalent of pig and cattle urine.

The finer fragmentation and the presence of uric acid make chicken excrement richer in N and decompose much faster than pig and cattle feces. Therefore, if there is moisture, chicken excrement is quickly attacked by bacteria that break down uric acid into water, carbon dioxide, and ammonia (ammonia gas). The strong, pungent and toxic odor from chicken sheds is precisely due to the volatilization of ammonia.

To make good use of N from chicken excrement, the material must be quickly dehydrated, which can be achieved with dry litter. When poultry manure is stored moist and pure for composting, most of the N is lost as ammonia, so the tanned product is a good source of P and K, but not N. N losses are lower in dry manure.

As it is more concentrated, pure poultry manure must be used with more care, so as not to harm the plants. In vegetable gardens, it is not advisable to go beyond one to two liters of dry material per square meter of bed. Comparatively, poultry manure presents fewer concerns for human health than pig manure.

An issue that always arises on this topic is the use of human excrement as fertilizer material. Effectively, this material has been used for thousands of years in rice-centric agricultural systems in the East, while in the West it remains taboo.

From the point of view of its composition and health risks, human excrement is very similar to pig excrement, and the same considerations apply. Composting human feces sanitizes the material, making it safe as a fertilizer material. Human urine is much easier to collect than that of any other animal, and can be used as a source of N for any crops. The care is just to dilute it in water, to avoid salinity, with a 1:10 dilution being well tolerated by most crops.

In the East, human excrement has traditionally been applied directly to crops, particularly in rice trays, without composting. This results in widespread environmental contamination by organisms present in human feces. To overcome this inconvenience, Eastern people, particularly the Chinese, drink boiled water, in the form of tea, and the vegetables undergo some type of heat treatment before being consumed.

Biomass decomposition and composting

In the operation of an agricultural production system, there are always important movements of biomass horizontally, and part of this biomass may end up piled up at certain points in the system. This material will be affected by organisms of varying sizes, resulting in a dark, friable product with a pleasant smell, with high fertilizer potential.

When the stacked material is rich in substances that are easily attacked by microorganisms, such as simple carbohydrates and nitrogenous compounds, and the stack is ventilated, rapid heating occurs to just above 60°C. This heating selects thermophilic bacteria, which become the main decomposers. The battery heating is not uniform; it occurs in a cap below the surface of the pile. On the surface, there is a lack of water, and in the center, there is a lack of aeration. After a few weeks, the cap cools down, because the material present there that can be attacked by thermophilic bacteria has been exhausted. If the pile is turned over, it heats up again, as the material from the outside and center of the pile, redistributed, feeds back into the shell. Thus, the more frequent the turning, the faster the decomposition and the more effective the heat treatment on the entire mass of the pile. The material resulting from this process is called compost, it has high fertilizer, restructuring and soil recolonizing potential.

When the pile is made up of predominantly cellulosic materials with a low N content, such as cereal straw, senescent tree leaves and sawmill waste, heating does not occur. There is a lack of food for thermophilic bacteria. In this case, decomposition will involve other organisms, will occur cold, and much more time will be needed to reach the fertilizer material, similar to compost. A much greater variety of organisms will work on the material, similar to what would occur on forest litter. In this case, the elimination of pathogen propagules is less efficient because there is no heat treatment.

The dynamics of N, P, and K follow different patterns in piles, regardless of whether decomposition occurs cold or hot. N is always lost, whether in the form of volatilized ammonia or leached nitrate. While you can try to reduce losses, stopping them completely is impossible. P remains in the material, with losses being very small. The behavior of K is a function of the amount of water that percolates through the pile. As K is very soluble, the percolation water carries it to the soil below the pile, concentrating it there.

The joint result of these processes is a change in the proportion between the nutrients N, P and K. Compared to the material placed in the pile, the finished compost is proportionally richer in P and poorer in N and K. For K, the depletion is greater the more water has percolated through the pile.

As a result, the continued application of compost increases P levels in the soil, but not N or K. The same phenomenon of increasing P levels occurs with any other form of biomass application, although at a slower rate.

Ashes

Of the dry biomass of plants, as a reference, 95% is made up of C, H, and O, with the remaining 5% made up of mineral nutrients. From a chemical point of view, burning means reacting with oxygen, so that the elements present in the biomass are converted into oxides. Oxides that are gaseous volatilize, as is the case with carbon dioxide (CO_2), water (H_2O) and sulfur oxide (SO_2). The oxides that are solid remain at the burning site, and are collectively called ash, the main ones being calcium (CaO), magnesium (MgO), potassium (K_2O) and silica (SiO_2). The proportions between these oxides depend on the type of biomass burned.

Silica is an inert material that, in liquid form, forms glass. In sugar cane straw, 70% of the ash is silica, so that glass stones are formed in the mill furnaces. Unlike silica, calcium, magnesium, and potassium oxides are very reactive. When moistened, they form the respective hydroxides, with a strongly alkaline reaction. Therefore, when they are applied to the soil, they not only provide nutrients but also correct acidity. When applied to plants, they prevent fungal attacks, which, in general, prefer acidic environments. Furthermore, K is the element with the greatest protective effect, contributing greatly to plant health.

For these reasons, ash is a valuable resource, the use of which deserves special attention in the production system.

Nutrient cycling, household consumption and food security

A privileged space for vegetable production, but little used, is the area around the house, to which we allude in automatic cycling. In addition to biomass and mineral nutrients, there is greater availability of work and water. Biomass, mineral nutrients, work and water make this environment the area with the greatest production potential in most agricultural systems.

But this space tends to be little used, due to a failure to perceive this potential, and due to the presence of loose creations. Farmers realize that chickens and pigs raised indoors do not produce as well as free-range ones, and so they are reluctant to close them. But loose creations prevent the full use of the production potential of the house's surroundings.

An alternative to reconciling the use of production potential with free-ranging livestock is to fence off an area close to the house and cultivate it intensively. To fertilize this area, all waste brought into the vicinity of the house is consciously directed, converting this part of automatic cycling into intentional cycling. The proximity to the house allows any small amount of available time to be transformed into vegetable production. A small part of the area, at the farmer's discretion, can receive vegetables that require irrigation.

An area measuring 1,000 to 2,000 square metres, with 20 to 100 square metres of irrigated land, located and managed in this way, can supply most of the food for a family of three to five people throughout the year. In the non-irrigated part, you can grow products such as cassava, green corn, popcorn, peanuts, pumpkins, beans, sweet potatoes, okra, ginger, peppers, etc. In the small irrigated fraction, kale, cabbage, lettuce, carrots, green beans, green onions, head onions, etc. can be produced, depending on the season and region. The surroundings of this area and the fence itself are a privileged space for plants such as pigeon pea and climbing plants, such as priest's ear (*Dolichos lablab*), broad beans, passion fruit, chayote, etc. In the personal experience of the person responsible for this entry, one hour of work per day may be enough to run an enclosure of this type, depending on the dimensions and complexity of the cultivated plants and the knowledge and skill of the people involved.

An overview

In light of the varied aspects brought to light in this entry, it is understood how and why the organization of the property and the management of crops and livestock affect the use of mineral nutrients available in the production system.

In ecologically-based agriculture, a significant part of success lies in the farmer's knowledge of how each nutrient behaves, so that the existing amounts of each nutrient can be used in the best possible way. For example, making efforts to avoid potassium losses under biomass piles, managing livestock in order to optimize the use of manure and regulating the destination of waste material brought to the residence to fertilize the area.

Knowledge enhances the use of nutrients, even when they are in limited quantities. This does not mean, however, that the incorporation of fertilizer material, chemical or organic, from outside the system is undesirable. A soil poor in phosphorus, as is usual in Brazil, can produce cassava, rice and pigeon pea well, for example. But if it is fertilized with this nutrient it can produce a greater variety of crops. Similarly, the application of limestone to neutralize free aluminum can expand the range of cultivable species in the system.

In the last two decades, there has been a notable expansion in the use of rock powders, in addition to traditional limestone and natural phosphates. Rock powder, applied appropriately, can promote soil remineralization, increasing the flow of nutrients circulating in the system. The so-called “chemical” fertilization can also contribute in the same direction.

However, the central point of this entry is to draw the reader's attention to the processes involved, so that, whatever the size of the nutrient stock in the system, the farmer has the elements to manage it as efficiently as possible.

To find out more:

With the aim of allowing the reader to fly higher and at the same time delve deeper into the subject, we comment below on three works, without the intention of exhausting the subject.

[1] JENKINS, J. *The humanure handbook.* White River Junction, VT, Chelsea Green Publishing, 1999. 301p. It is a practical and humorous text by a self-taught composter, who since the late 1970s has been composting his own family's excrement and using the compost to produce food.

[2] KHATOUNIAN, C.A. *The ecological reconstruction of agriculture.* Botucatu: Editora Agroecológica/ Instituto Agronomico do Paraná, 2001. 345p. Basic text on ecologically based agriculture, which has served as an anchor for the structuring and management of production systems oriented towards this paradigm. Based on the author's first-hand experience.

[3] NOVAIS, R. F. *et al.* (ed.) *Soil fertility.* Viçosa (MG): Sociedade Brasileira de Ciência do Solo, 2007. 1017p. Book organized by the Sociedade Brasileira de Ciência do Solo (Brazilian Society of Soil Science), covers a wide spectrum of aspects of soil chemistry, nutrient dynamics and mineral nutrition of plants.

Source: Republished from the book "Dictionary of Agroecology and Education", 1st edition: September 2021. Editora Expressão Popular LTDA / Translated from Portuguese and edited by ROOTS. Available at: https://www.epsjv.fiocruz.br/sites/default/files/dicionario_agroecologia_nov

---