

Nutrient Quantity or Nutrient Access?

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Nutrient Quantity or Nutrient Access? A New Understanding of How to Maintain Soil Fertility in the Tropics

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Introduction

In order to achieve high levels of agricultural productivity in the tropics at the lowest possible economic and ecological costs, we need to properly understand the relationship between nutrients in the soil and crop productivity. For this to happen, the current understanding needs to change. The conventional view of the relationship between soil nutrients and crop productivity in the tropics is leading to both damaging agricultural policies and inefficient and damaging farm-level practices. There is no need to use the huge quantities of chemical fertilizers that are so often recommended. In fact, often times the use of such fertilizers is unnecessary, expensive and harmful to the environment, especially because farmers often stop using organic matter when they use chemical fertilizers.

Much of the theory described here was originally developed by Drs. Artur and Ana Primavesi. For a much more in-depth analysis of the chemical and biological issues described in this article, the best book at present is Ana Primavesi's *The Ecological Management of the Soil* (unfortunately this book is currently available only in Spanish and Portuguese). This article will discuss the conventional concept of soil fertility and some of its shortcomings; a new conception of soil fertility; and how the new theory can be put into practice.

The Conventional Concept of Soil Fertility

Soil fertility is more than the soil's content of available nutrients. For the purposes of this article, we will use the definition of soil fertility presented in Anthony Young's book *Agroforestry for Soil Conservation*: "soil fertility...is the capacity of soil to support the growth of plants, on a sustained basis, under given conditions of climate and other relevant properties of land."

The traditional concept of soil fertility to a large extent sees fertility as a reflection of the overall quantities or concentration of nutrients in the soil. According to this concept, as long as enough nutrients are present, soil pH is within a certain range, and cation exchange capacity (CEC) is high enough to hold nutrients, there is good soil fertility. The basic idea is that the soil operates like a bank: add nutrients repeatedly, over a long period of time, and they will gradually build up like a savings account, increasing the soil's fertility and therefore crop productivity. We will refer to this idea of soil fertility as the Nutrient Quantity Concept (NQC).

In most books on soil properties and management (the majority of them written by proponents of the NQC),

little attention is paid to organic matter or soil biology. Rather, sources and quantities of nitrogen (N), phosphorus (P) and potassium (K) dominate the discussion. As a result, most recommendations to restore soil fertility and improve food production in the tropics rely on the application of chemical fertilizers.

First, a short explanation for the benefit of the layman: crops are capable of absorbing some nutrients that exist in the soil at levels of less than 0.2 parts per million, while other nutrients are often difficult to absorb at 100 times that concentration. (Ahn) Thus there is actually little relationship between a plant's physical ability to absorb a nutrient and the nutrient's concentration in the soil. Also, plants do not absorb the various nutrients primarily according to the levels present in the soils, but rather in accordance with the plants' own needs, and in ratios between the nutrients that are relatively stable for each species or variety of plant, regardless of the supply of the nutrient in the soil. Thus, the Nutrient Quantity Concept is really saying that, other conditions being adequate, the growth or productivity of any plant will depend

The Nutrient Access Concept of Tropical Soil Fertility

To illustrate the Nutrient Access Concept of soil fertility, we start out with an experiment reported in Ana Primavesi's *The Ecological Management of the Soil*. In this experiment, crops were grown in four hydroponic solutions. The solutions were as follows:

- 1) A normal concentration of nutrients for maximum maize plant development was used, and replenished every 4 days.
- 2) Twice the normal concentration was used and replenished every 4 days.
- 3) The normal solution was diluted 50 times and also replenished every 4 days.
- 4) The normal solution was diluted 50 times, but was replenished every 2 days.

Plant growth (measured in grams of dry weight) was less in the second case than in the first. Plant growth in the third case was also less than in the first. But in the fourth case, plant growth was slightly better than in the first. Even when the nutrient solution was 1/50 what the traditional Nutrient Quantity Concept would have seen as optimal, the plants grew equally well, as long as the solution was replaced frequently enough and the roots could access the nutrients.

Crop growth above a certain extremely low concentration does not depend on the concentration of nutrients. Instead it depends on the plant roots' constant access to the nutrients, even when these nutrients exist in very low concentrations. What is needed is a constant supply of a small but well-balanced amount of nutrients over time, and the unobstructed access of plant roots to these nutrients.

This experiment shows that the relationship between concentrations or overall quantities of nutrients and plant growth is, above a certain minimum concentration, altogether nonexistent. As long as plants enjoy the right conditions of nutrient balance, accessibility to nutrients, and a constant resupply of nutrients, the relationship between the concentration of nutrients in the soil and its productivity is either zero (i.e. there is no relationship) or negative (i.e. more concentrated nutrients reduce plant productivity).

These results are more relevant to tropical soils and farmers than to temperate-zone soils and farmers for several reasons:

- 1) Tropical soils tend to have lower concentrations of nutrients and fewer cation-exchange sites (lower ability to hold nutrients).
- 2) The ambient heat of the tropics makes it difficult for plants to create enough osmotic pressure to absorb nutrients from highly concentrated solutions. Limited concentrations of nutrients are often better.
- 3) Most farmers in the tropics work by hand or animal traction, so they can micromanage the soil by hand and create different microenvironments. In some of these microenvironments, nutrients are more accessible.
- 4) Resource-poor farmers can't afford to over-fertilize. And they often lose more nutrients than temperate-zone farmers because of high rainfall, steep slopes, or factors of soil chemistry.

Rather than emphasizing the concentration of nutrients in the soil, the new concept emphasizes the access of plant roots to soil nutrients. We will refer to this concept as the Nutrient Access Concept of soil fertility. Here are the main claims of this concept:

Maximum plant growth can best and most cheaply be achieved in the tropics by:

- 1) the constant supply of soil nutrients (most inexpensively achieved with fairly low concentrations)
- 2) a healthy balance between the nutrients
- 3) maximum access of plant roots to these nutrients (e.g. the maintenance of good soil structure and/or mulches)

The Adequacy of the Nutrient Access Concept

Can the Nutrient Access Concept explain the phenomena mentioned above better than the Nutrient Quantity Concept could? For one thing, the Nutrient Access Concept admits that high levels of

productivity can be achieved through high concentrations of nutrients in developed nation agriculture, and even in highly capitalized plantation agriculture on the best soils of the tropics. This is true in many circumstances, especially in cooler climates, when soils are compacted or optimal soil structure has otherwise been damaged, when CEC is high and when farmers are well-capitalized.

However, where soils have very low CEC's, where soil organic matter is or could be abundant and cheap, where capital is scarce, and/or where temperatures are high, the Nutrient Access Concept points to agricultural practices of a radically different kind from those presently used.

Many farmers, in southern Brazil and scores of other countries, have realized competitive yields at relatively low cost on very "low potential" soils, with more positive long-term ecological impact than agriculture done according to the Nutrient Quantity Concept.

Thus the Nutrient Access Concept could reduce significantly the costs of producing competitive yields in the tropics. It also confronts the present unjust discrimination against those farming on so-called "low potential" soils. In fact, with fairly small, inexpensive applications of highly accessible nutrients, these soils can produce harvests several times their present levels. The "potential" of the soil depends more on the proper management of the soil than it does on the addition of large quantities of very expensive nutrients.

The Nutrient Access Concept also calls into question efforts to subsidize huge quantities of expensive chemical fertilizers to African nations that are already practically bankrupt. Such proposals are based on the Nutrient Quantity Concept. Adoption of the Nutrient Access Concept would force a major rewrite of these proposals, gearing them instead toward the goal of increased yields through higher levels of biomass production, soil structure improvement and mulch-based systems.

In addition, the Nutrient Access Concept can explain very adequately those observed phenomena mentioned previously, which the traditional theory cannot explain:

Green manure/cover crops. Rather than depending on high concentrations of chemical nutrients, yields in gm/cc and agroforestry systems depend on the fixation of N and the recycling of large amounts of organic matter which makes the P and other nutrients in soils much more soluble (i.e. chemically available), and places most of these nutrients near the soil surface, where they are easily accessible to plant roots.

SRI yields. With the SRI methodology, the soil is aerated and plants grow almost six times more roots per plant. This means they can access many more nutrients in the soil.

West African kitchen gardens. The organic matter thrown out of kitchens daily maintains a small, steady supply of nutrients.

Regeneration of tropical soils. The regrowth of forests or grasslands maintains or improves soil structure so that on newly cleared land, crops can more efficiently access the low concentrations of nutrients. Organic matter on or near the soil surface (from years of fallow) supplies nutrients in small quantities.

Rainforests. Good soil structure and mulches are maintained, so that trees can access the small amounts of nutrients that are constantly being supplied by the breakdown of soil organic matter. Trees with deep roots and lots of feeder roots can capture many nutrients even though they are present only in low concentrations.

Slow-release chemical fertilizer. The benefits of slow-release chemical fertilizer are much more understandable based upon the Nutrient Access Concept rather than upon the Nutrient Quantity Concept.

Of course these explanations are very simplistic. Plants' access to nutrients is a very complicated phenomenon which involves a large number of factors. These include soil temperature, soil organic matter levels, pH, soil chemical properties, the presence of compaction layers, and nutrient positioning and equilibrium. All of these factors are in turn affected by the activity of hundreds of thousands of microorganisms in every teaspoonful of soil. Nevertheless, the Nutrient Access Concept seems to come much closer to explaining the overall sum or average of all these varied and mysterious processes than does the Nutrient Quantity Concept.



Figure 1. The techniques associated with the Nutrient Access Concept can result in dramatic changes. Left is a bare, eroding piece of land. To the right is the same piece of land only two years later. Photos from Roland Bunch.

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Before, a bare hillside



2 years later

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Putting the Nutrient Access Concept Into Practice

The Nutrient Access Concept can most easily be put into practice through the copious use of organic matter. Organic matter supplies low to medium concentrations of nutrients, almost always in well-balanced quantities. Organic matter also by its very nature has a slow-release mechanism, allowing the nutrients to become available to plants over a period of several months or years. And lastly, soil organic matter can gradually improve soil structure, both directly (through the provision of binding materials to improve flocculation) and indirectly (by feeding earthworms and other soil organisms which also improve soil structure) (Minnich).

The best way to apply organic matter is to apply it either to the soil surface or, during the period of transition (from fertilizer-based to mulch-based agriculture), within 20 cm of the surface. During the first year or two of a transition into mulch-based agriculture, soil compaction below the surface is a serious limiting factor. After the first year or two, virtually all the organic matter should be applied to the soil surface.

The Nutrient Access Concept does not necessarily support a totally organic approach. But it suggests a greatly reduced use of chemical fertilizers in the short run. In the long run, it suggests use of chemical fertilizers only to replace nutrients not supplied by organic matter and nitrogen fixation.

Based on the Nutrient Access Theory, the following Five Principles of soil management have begun to be used around the world in small farmer agriculture:

1) Maximize organic matter production. Organic matter production can be increased by a) intercropping of crops or gm/cc's with annuals or tree crops; b) establishing two- to four-story fields and gardens; and c) growing trees or gm/cc's on wasteland or during the dry season. Watering/irrigation can help increase organic matter production in dry areas. It is best to produce biomass on site.

2) Keep the soil covered. Covering the soil will help to reduce both weed growth and the heating of the soil. The latter can accelerate soil organic matter burnout, reduce crop growth rates, and cause the death of beneficial organisms in the soil. By maximizing biomass production and keeping the soil covered, the need to let land lie fallow can often be eliminated. Keeping the soil covered reduces the decomposition rate of soil organic matter, which means the provision of nutrients to the soil will last longer and be more constant, even if mulches tend to lose a certain amount of N to volatilization.

3) Use zero tillage. In order to be effective, this technique should be used in the presence of a maximum production of biomass, so that the supply of nutrients and good soil structure can be maintained. Systems with plentiful biomass production can remain highly productive over decades, as a whole series of gm/cc and agroforestry systems have proven.

Often zero tillage cannot be practiced the first or second year of the transition. But the populations of organisms that naturally till the soil increase rapidly as soil organic matter levels increase and soil becomes covered. (Scientists have shown, for instance, that earthworms alone can move more soil/ha/year than is moved with one ploughing using a tractor-pulled moldboard plough.) (Minnich)

In the conventional textbooks, zero tillage is linked with a major increase in the use of herbicides. However, if the soil is kept covered through an adequate use of gm/cc's and agroforestry, most small-scale farmers will find they never, or only rarely, need to use herbicides.

Tillage damages soil structure and increases the rate of soil organic matter burn-out. It also exposes the soil (i.e. violates the principle of keeping the soil covered) and removes or incorporates the mulch, which violates the fifth principle below.

4) Maximize biodiversity. This principle is primarily important in maintaining the systems' long-term sustainability. It can also be very important in maintaining the balance of nutrients required by the Nutrient Access Concept (Primavesi).

5) Feed the crops largely through the mulch. Many humid tropical soils are not very hospitable environments for crop roots because of their low pH (below 5.0), their aluminum toxicity and compaction layers. Crops will often grow much better if they can also access nutrients from a thick litter layer or mulch. Most feeder roots will likely spread immediately under or up into a mulch layer as long as it remains fairly moist. The impact of chemical fertilizers can also sometimes be greatly increased by being applied to the mulch rather than the soil.

Feeding plants through the mulch helps compensate for poor soil structure or less than ideal conditions of root growth. In poor soils, if nutrients are on the soil surface, plants will have better access to them

root growth. In poor soils, if nutrients are on the soil surface, plants will have better access to them.

Small farmers and NGO's have developed a number of simple ways that plants' access to nutrients can be inexpensively enhanced during the transition period. For example, Edwin Asante, of World Vision/Rwanda has developed a small farmer version of "precision planting" for potatoes. In this case, an 8-cm ball of organic matter, lime, and about one-fourth the normally recommended amount of chemical fertilizer are placed less than 0.5-cm directly below the seed. Yields in very poor soils with a pH of 3.5 have averaged 20 t/ha, as opposed to 9 t/ha without precision planting (personal communication, during field visit). In Honduras, Elías Sánchez developed a type of strip tillage or in-row tillage (locally called "minimum tillage" or "labranza mínima") which concentrates the organic matter in the crop row, where it is more accessible.

These Five Principles are the very same principles a humid tropical forest employs to maintain its high "productivity" for millennia, even on soils with very low CEC's. A tropical rainforest maximizes biomass production and biodiversity, keeps the soil shaded at all times, and feeds its plants largely through the litter layer. And, of course, no human beings have to plough a forest to keep it growing lush and green, century after century.

Additional Impacts of the Nutrient Access Concept

We can expect a few major results of the Nutrient Access Concept of soil fertility.

1) An increase in optimism about the plight of resource-poor farmers. Given the Nutrient Access Concept, even those farmers with heavily depleted soils should be able to increase their yields dramatically with very little investment other than that of more increased knowledge and the adoption of new agricultural techniques. Gm/cc's provide cheaper nitrogen than fertilizer factories, while zero tillage and cover crops can practically eliminate the comparative advantage provided by tractors.

2) More sustainable agriculture. With the use of the aforementioned practices, the world's agriculture will become a good deal more sustainable. Increased sustainability will come from the reduced use of chemical fertilizers (reducing groundwater and stream pollution, nutrient imbalances and soil acidification). It will also come from the positive impacts on the environment of increased biomass production, soil cover, soil organic matter and biodiversity, and the decrease of farmer dependency on increasingly expensive fossil fuels.

Full article with full references (20 pages total) available on request.

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