# Nutrient Quantity or Nutrient Access?

## A New Understanding of How to Maintain Soil Fertility in the Tropics

By Roland Bunch

## INTRODUCTION

If we are to achieve or maintain high levels of agricultural productivity in the tropics, it is crucial that we properly understand the relationship between nutrients in the soil and crop productivity. This understanding is especially important if we wish to achieve such productivity at the lowest possible costs, both economic and ecological. **The thesis of this paper is that 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.** Of prime importance to small-scale farmers worldwide is that this conventional concept results in the consistent recommendation of the use of huge quantities of chemical fertilizers that are biologically unnecessary, economically extravagant and ecologically damaging. The ecological damage caused by chemical fertilizer in its own right is perhaps not that great. Nevertheless, if we include its indirect impact caused by the fact that most small-scale farmers reduce their use of organic matter (o.m.) once they start using chemical fertilizers, the indirect ecological damage brought about by chemical fertilizers in developing world agriculture and ecology is nothing short of breath-taking.

The present paper cannot delve deeply into soil chemistry and biology. For a much more in-depth analysis of the chemical and biological issues described herein, the best book at present (unfortunately available only in Spanish and Portuguese) is Ana Primavesi's <u>The Ecological Management of the Soil</u>. (Primavesi) Nevertheless, the present paper will describe, in general, a new conception of the fertility of tropical soils, and then, again very generally, ways in which that theory can be put into practice.

It should also be mentioned that much of the theory described in this paper was originally developed by Drs. Artur and Ana Primavesi. Furthermore, the Primavesis' theories have been widely validated by hundreds of thousands of small farmers in southern Brazil with the technical support of people such as Valdemar Hercilio (Salgado) de Freitas, Claudino Monegat and Ademir Calegari. Those of us trying to improve small farmers' productivity owe a deep debt of gratitude to these people.

## THE CONVENTIONAL CONCEPT OF SOIL FERTILITY

Soil fertility is not an easy concept to define, (Cresser) but for the purposes of this paper, we will use the definition of soil fertility presented in Anthony Young's book <u>Agroforestry for Soil Conservation</u>: "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." We choose this definition, rather than the much more limited one that takes into account only the soil content of available nutrients, because we agree with Young that the latter definition "leads to a myopic view of soil management, to the neglect of physical and biological properties." (Young)

The traditional concept of soil fertility basically maintains that fertility is largely a reflection of the overall quantities or concentration of nutrients in the soil. That is, plant nutrition is to be maximized primarily by ensuring that all the essential nutrients are present in the soil in significant concentrations. Therefore, if a farmer applies sufficiently large amounts of primarily chemical fertilizer, uses the right balance of NPK, and the soil has an acceptable pH and sufficiently high cation exchange capacity (CEC) to hold those nutrients in place, the farmer will have efficiently achieved good soil fertility.

The basic idea is that the soil operates like a bank: add more nutrients repeatedly, over a long period of time, and these nutrients will gradually build up, like a savings account, increasing the soil's fertility and therefore crop productivity. Although there are, of course, other factors that must be taken into account, primarily physical and chemical processes like leaching, soil pH, the soil's CEC and nutrient fixation, the basic idea is that the soil acts more or less like a static recipient of nutrients. Thus, the vast majority of the effort and experimentation of these traditional theorists have had to do with overall nutrient levels and their physical movement, mineralization and leaching within the soil profile. For the purposes of this paper, this idea of soil fertility will be called the Nutrient Quantity Concept.

The priorities of the adherents of this Concept are seen very clearly in the books they write on the subject of soil properties and management. A typical textbook, based on the Nutrient Quantity Concept--even one dealing with tropical soils-- dedicates three chapters (73 pages) to NPK, while not dedicating even a single chapter to either organic matter (o.m.) or soil biology. (Committee on Tropical Soils) Even a book published as recently as 1997 on soil fertility in Africa dedicates two long chapters (82 pages) to NP, and only a fraction of one chapter (8 pages) to specifically organic inputs. (Buresh) Other factors are mentioned in these publications, but chemical sources and quantities of NPK dominate heavily the entire discussion.

A common conclusion drawn from this conception by its proponents as late as 1997 is that in Africa "mineral fertilizers should be at the core of strategies to restore soil fertility and raise crop production." (Quiñones) Another major proponent of this conception wrote in 1994: "Some people say that Africa's food problems can be solved without the application of chemical fertilizers. They're dreaming." (Borlaug) The Financial Times goes on to write that the same author said that, "Sub-Saharan Africa had the lowest use of fertilizer in the world and soil nutrients were so low that other efforts to raise crop productivity would not be successful until fertility was improved." (Borlaug) By "fertility" being "improved," he is referring specifically to the application of chemical fertilizers.

First, allow me to include 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, in fact, 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 largely on the quantity and availability of the nutrient in the soil that is proportionately least adequate in relation to the total amount of that nutrient necessary for the plant to achieve maximum growth, and that in practice maximum crop growth should be achieved by having large enough reserves of these nutrients in the soil so that adequate quantities of them will exist in available forms. (Cresser)

## THE INADEQUACIES OF THE NUTRIENT QUANTITY CONCEPT

### Theoretical Inadequacies of the Concept

First, the Nutrient Quantity Concept, in its simplified, "banking" form, is very unrepresentative of what actually happens in the soil. Far more important for productivity than the total quantity of any single nutrient or group of nutrients is the chemical form in which it occurs, the depth in the soil at which it occurs, the kinds and numbers of macro and microorganisms that exist, the presence of soil compaction layers, and the equilibrium that exists between the nutrients, the pH of the soil, its moisture content, its organic matter content, its macro and microorganisms, its texture and structure, etc. Furthermore, these factors constantly impact on each other, creating a very complex and constantly changing environment within the soil, or, more accurately, a constantly changing complex of varying microenvironments within the soil. These factors may make it possible for a plant, in a particular time frame, to access a majority of the total store of a given nutrient in the soil, or much less than 1 % of the total store of that same nutrient.

In other words, the same nutrient that is in the same total concentration within two different soils may well be fifty to one hundred times more available to a plant in one of those soils than in the other. Obviously, the total amount of a nutrient in the soil is nowhere near as important in terms of the soil's fertility as is the <u>availability</u> of that nutrient to the plants growing on it.

Of course, the body of literature and scientific conclusions that have grown up around the Nutrient Quantity Concept, if taken in its total complexity, admits as much. The data of soil science, as a whole, take into account fairly well the fact that all the above-mentioned factors can affect fertility (although soil science could certainly be a good deal more aware of certain of these factors, especially the biological ones). In fact, quite surprisingly, the science built up around the Nutrient Quantity Concept in no way contradicts the very different conception of what is required to achieve soil fertility that will be described below.

Where the advocates of the Nutrient Quantity Concept of soil fertility have apparently gone wrong is in the conclusions they have made about soil fertility, based almost entirely upon only a certain, specific selection of these scientific findings. That is, the experiments, although heavily lop-sided in the dominance of their preoccupation with chemical fertilizers, do not necessarily support the Nutrient Quantity Concept any more than they support the concept presented below. What has apparently happened is that one particular fact has come to totally dominate people's thinking about soil nutrients. This is the fact that, in a uniform soil environment, the larger the total quantities of a nutrient that exist in a given soil, the larger will be the quantity of that nutrient that is in available forms. Even though there is ample proof that in a non-uniform soil, and in countless specific cases, this relationship does not exist at all, many conventional soil scientists continue to see this relationship as the most important single logical basis to soil fertility management. (See, for example, Cresser) To cite an extreme but very common example, even when the availability to plants of soil phosphorus is known to be as many as fifty times greater in an organic environment than in an infertile acid soil environment, the Nutrient Quantity Concept still leads virtually all conventional soil scientists to recommend applying additional chemical phosphorus to the acid soil rather than finding or creating an organic microenvironment within that soil in which to apply a much smaller dose of (organic or inorganic) phosphorus.

Thus, in a very few words, the Nutrient Quantity Concept does not differ from the concept to be presented below, in its scientific, experimental undergirding. Rather, the difference lies in the somewhat arbitrary decision to emphasize the relationship between total nutrient quantity and the quantity of nutrients available to growing crops, even though scientific evidence shows that this relationship is in most cases tenuous, at best, especially in the case of small farmers in the tropics.

A second major error of the Nutrient Quantity Concept is that it seems to presuppose that these nutrients are being more stable in the soil than their own research shows they actually are, especially where the CEC of the soil is quite low and/or erosion is occurring. The idea of building up nutrients in the soil would seem to presuppose that those nutrients will remain there over, say, twenty years or so. Yet virtually all of the N, much of the K, and even small amounts of the P applied as chemical fertilizers today, will not be there twenty years from now, even if no plants were using them. And on low CEC soils and erodible hillsides, the loss of even P can be considerable. In short, the farmers' "money" is constantly leaking out of the "bank". And, sadly, the more money there is in the bank, the more will leak out.

This assumption of the persistence of nutrients in the soil seems to be assumed, also, when conventional scientists criticize those who propose using large amounts of o.m. for maintaining soil fertility. Nutrient Quantity proponents worry at considerable length that organic inputs cannot maintain soil nutrient levels over the long term, and that they do not produce as much long-lasting humus as often as we all would like. (Buresh) They seem to forget that chemical fertilizers do not maintain the levels of most micronutrients, either. Of more importance economically, chemical fertilizers, as used by small farmers, do not maintain soil pH. (And even if farmers could, theoretically, avoid acidifying their soils with chemical fertilizers, the costs of liming or using the more expensive alkaline fertilizers is seldom included in economic analyses of the costs of chemical fertilizer use.) Of course, because of the leaking from the bank, chemical fertilizers, even when used in recommended quantities, may not achieve the long-term levels of total nutrients desired.

Thus, organic amendments are little different from chemical fertilizers in not being able to increase soil nutrient quantities dramatically over time in the tropics, especially under small farmer conditions. This is not to say we should give up on striving toward at least soil nutrient maintenance over the long run, but rather to say that the use of chemical fertilizers exclusively, in the case of small farmer agriculture, will very likely achieve no more long-term improvement in nutrient quantities than will the use of o.m. exclusively. Just as most small farmers often, but not always, lack the o.m. to increase stores of P, for instance, they also usually lack the cash (and often the profitability of chemical fertilizers on their depleted lands far from markets) to buy sufficient chemical fertilizer.

Furthermore, neither this paper nor most of those people who use low input agriculture oppose all use of chemical fertilizers. The replacement of some chemical elements in the soil (mostly P), under certain conditions, and in moderate amounts, is, for us, perfectly acceptable, if not desirable.

The third error of the Nutrient Quantity Concept is that its proponents have largely avoided taking into account the tremendous impact in tropical soils of such factors as their macro and microbiology, o.m. content, microenvironments and compaction layers.

Inadequacies in Practice

Based on these theoretical considerations, most conventional soil scientists have come to a series of extremely far-reaching conclusions. Among these, they have concluded that the best, most efficient way of improving the soil fertility of the developing world's resource-poor farmers is to apply tremendous quantities of NPK along with, perhaps, a small supplement of o.m. They have concluded that "low external input" technologies must inevitably lead to "low output" results. They have therefore further concluded that "ecological agriculture" is inevitably unproductive and has virtually no future. And finally, they have concluded that soils with very low CEC's, like those of most of West Africa, have very little potential for decent crop productivity. None of these conclusions is based on the scientific understanding we have of soils in its totality. And concrete evidence from tens of thousands of farms around the world, as well as from many scientific experiments, provides considerable evidence that not one of these conclusions is, in fact, accurate.

Thus, the Nutrient Quantity Concept is failing us. It is failing to lead us to proper conclusions about agricultural priorities. It is failing to predict what will happen if we apply a whole range of agricultural technologies that are now being tried in the tropics, and it is failing to help us understand a series of both natural and agricultural phenomena that we are observing. Above all, it is failing to lead us to promising new technologies that can provide tremendous benefits at low cost to poorer farmers within the tropics.

Let's look a little more closely at these failings. One of the main negative impacts of the traditional Nutrient Quantity Concept in tropical environments is that it has caused many scientists to dismiss ecological agriculture out of hand. It has become almost a mantra of some of these scientists that "low input agriculture is low output agriculture." After all, according to the Nutrient Quantity Concept way of thinking, if not much is put into the bank account, not much can be withdrawn. Thus a whole series of promising technologies for increasing agricultural productivity–mostly those which are included in approaches referred to as ecological agriculture or agroecology--have been largely ignored by the dominant members of the scientific community, (Anonymous; Pretty and

Hine) to the tremendous detriment of farmers in the tropics. In fact, millions of small-scale farmers in developing countries, representing well over 3 % of the total, have adopted ecological agriculture practices in just the last ten years, (Pretty and Hine) yet these practices are largely ignored by conventional soil scientists.

Another major negative impact of the application of this Concept is the claim that because many tropical soils have very low CEC's, they will never be able to produce large harvests. Because such soils cannot hold very many nutrients over a crop's entire life-span, it is said they will never be able to support maximum output. This conception of the dynamics of soil fertility has caused huge areas of the tropics to be written off as "low-potential" areas, where significant investments in agricultural development are therefore not advisable. (Mosher) As a result, hundreds of millions of people have been condemned to a not-so-benign neglect and perpetually low productivity. Since these people often were already among the poorest of the poor, this mistaken policy has aggravated already serious problems of economic injustice and downright hunger. And all because of a theory of soil fertility that is questionable at best.

Another factor that becomes extremely important for those of us who focus our work on the poorer farmers of the tropics is that the Nutrient Quantity Concept leads almost inevitably to an excessively high use of chemical fertilizers. The cost of chemical fertilizer very frequently represents the largest single cash cost of resource-poor farmers in the tropics. Yet experience in nation after nation has shown that for a much lower total expense, farmers can achieve the same or even higher yields. Furthermore, as the years go by, the use of most chemical fertilizers mine the soil of micronutrients, acidify the soil even more, and help to erode away, burn out, or simply fail to replace the soil's o.m. In time, these factors all work together to reduce the response that chemical fertilizers achieve in terms of productivity, to the point that, in many cases, there remains no net economic advantage to their use whatsoever.

Furthermore, the recent staggering increase in petroleum prices (from $ 12.00 a barrel to somewhere between $ 19.00 and $ 32.00 a barrel) is going to result in major increases in the real farm gate cost of fertilizers, both because of increased costs of production and increased transport costs. Thus, tens of millions of small-scale farmers for whom chemical fertilizer is presently economically advantageous will find that in the future that advantage will have largely or totally disappeared. Thus, it is extremely important that we all learn as much as we can about the technological possibilities that will still allow farmers to increase and maintain their productivity without depending so heavily on increasingly expensive chemical fertilizers.

An additional major problem of the traditional Nutrient Quantity Concept is that increasing observation, especially of ecological or low external input agriculture, is showing that the Concept's predictive abilities are seriously lacking. Crop productivity, in most such cases, is <u>not</u> basically, or even approximately, a factor of the overall amount of nutrients in the soil, or of the CEC of the soil. Very high levels of productivity are being achieved on soils that, according to the traditional Concept, could never produce such yields, and with applications of nutrients that are anywhere from one-half to one-tenth the quantities the Nutrient Quantity Concept would indicate are necessary. Recent scientific experiments with o.m. and fertilizer use in Africa, where scientists cannot explain with conventional theories the yields that were achieved, are typical. (Palm)

In what specific cases has the Nutrient Quantity Concept failed to predict present phenomena?

- The increases in yields achieved by the use of green manure/cover crops (gm/cc's) in system after system are greater than the conventional Concept would have predicted. With increases of only perhaps 100 kg of fixed N and no additional P or K, yields of maize crops have often doubled. (Buckles; Bunch and Lopez; Pretty and Hine, for example) Furthermore, yields of 2.5 t/ha have continued to be produced on relatively poor, humid tropical soils every year for 40 years, with no application of chemical NPK. Of course, what is happening here is due to biological, physical, and chemical dynamics within the soil, not just those of soil nutrients. Nevertheless, according to the Nutrient Quantity Concept, the levels of P, at least, should have become a major limiting factor years ago. Yet applications of chemical P on these soils still, after forty years, give no economic response. (Buckles)

Perhaps it should be added here that "green manure/cover crops" is a technology that is traditional in many tropical areas, but which have only been developed over the last fifteen years in Brazil and Mesoamerica and spread around the world largely by NGO's in the last five years or so. This technology, not to be confused with traditional "green manuring," grows biomass, often leguminous, intercropped with regular crops, under fruit trees, during the dry season, during frosty periods or on degraded soils too poor for cropping (i.e. on land with little or no opportunity cost), thereby **adding huge net** quantities of high-nutrient biomass *in situ* to agricultural systems and applying it to the surface where it is highly accessible to subsequent crops. (See Bunch 2001) "Dispersed trees" is another traditional practice around the world which has only recently been studied and promoted in Central America, but which apparently has tremendous potential for increasing biomass production in much of the lowland tropics.

-In Madagascar, hundreds of farmers are now using a System of Rice Intensification (SRI) that frequently achieves yields of 12 to 15 t/ha, and occasionally 18 t/ha, using only moderate amounts of compost and no chemical fertilizer on low CEC, acid soils (a classic case of "low potential soils"). (Uphoff) Yet the world's rice experts hold that the "biological maximum" for the rice plant is less than 10 t/ha. As one scientist has written, "yields for multiple varieties peak out at about 8 t/ha, even with high N applications, up to 200 kg/ha." (Ladha, et al.). Furthermore, even with applications of 200 kg/ha of N, N assimilation is considered to be the limiting factor for rice production. (Uphoff) In this case, the difference in yields between conventional rice and SRI rice is probably due to a whole series of factors, but whatever the reasons may be, the "low input agriculture is low output agriculture" attitude cannot come even close to explaining rice yields of 15 t/ha on these "low potential" soils with so little N introduced into the system.

- In the case of West Africa's very old, low CEC soils, books based on the Nutrient Quantity Concept claim good yields can only be achieved with major applications of chemical nutrients. (Avery) Yet around people's homes (admittedly on very small plots), African women frequently grow 4-mt-tall, 4 t/ha maize. How? Through the daily application of grey water and kitchen scraps from the household. And the soil is the same soil as in their fields a few mts away.

- The age-old, world-wide regeneration of soils by means of traditional slash-and-burn, or shifting agriculture, techniques cannot be fully explained by the dominant interpretation of the Nutrient Quantity Concept, either. Attempts have been made to somehow help the Concept explain this regeneration of the soil through the idea of nutrient pumping. But the amount of nutrients pumped by trees is frequently not enough to explain the renewed fertility. In many cases, there are precious few nutrients in the subsoil that the trees could pump, even if they were physically capable of pumping the required quantities. And, of course, the concentration of nutrients in the soils from which they are being pumped is only a fraction of what the Nutrient Quantity Theory would consider sufficient for adequate for plant growth.

Furthermore, I have personally asked West African farmers to show me which fields were ready to be "slashed and burned," and close to half of the indicated fields had no visible vegetation on them other than grasses. Certainly farmers whose food supply has depended for generations on their ability to accurately identify regenerated soils could not be mistaken half the time. And if grasses can regenerate soils by themselves, how can the Nutrient Quantity Concept explain this worldwide phenomenon?

- The biomass productivity of natural rainforests is also much higher than its CEC would allow under the traditional Concept. Interestingly enough, in this case, scientists who normally adhere to the Nutrient Quantity Concept freely admit that the rapid recycling of nutrients in tropical rainforests permits tremendous levels of biomass production in the presence of very low levels of nutrients and CEC's in the soil in general. Nevertheless, they have been largely unwilling to entertain the possibility that this same phenomenon of the rapid circulation of nutrients could be the basis of highly productive crop agriculture under similar conditions. Put another way, Nutrient Quantity proponents freely admit in the case of rainforests that "low input forests produce high output forests," yet they refuse to admit that the same principle might be applicable to agriculture in the very same environments. This use of one rationale for proven rainforest productivity while refusing to admit to the possibility of the very same process in agriculture would seem to represent a serious lack of logical consistency.

Nutrient pumping might seem to cloud the above issue somewhat. Nevertheless, many rainforests produce prodigious amounts of biomass above subsoils whose provision of nutrients, even under extremely efficient nutrient pumping, would be less than those nutrients added artificially under many "low external input" systems. We should also remember that the areas deep in the soil from which these nutrients are presumably "pumped," virtually always possess much lower concentrations of nutrients than do the soils above them. Therefore, even **with** nutrient pumping, natural forests provide clear evidence that sufficient nutrients for very high levels of biomass production are being extracted from soils with extremely low total concentrations of nutrients. Furthermore, low external input agroforestry systems also pump nutrients. Thus, the logic of the Nutrient Quantity advocates remains problematic at best.

-Chemical fertilizer companies are dedicating millions of dollars to research on "slow-release" forms of chemical fertilizer. This means, in effect, that the fertilizer companies themselves (which, not surprisingly, are among the most vociferous proponents of the Nutrient Quantity Concept) are admitting--through their actions, if not their words--that the overall quantity of nutrients available at any given time is not the primary issue in productivity.

Of course, one could argue that slow-release fertilizer is being developed because its ecological benefits will demand a sacrifice in productivity from farmers. Nevertheless, research on slow-release fertilizers has shown no such significant reduction in yields. Thus, the very development of this kind of fertilizer is an admission that, at least where this fertilizer is successful in terms of productivity, the constant supply of nutrients is more important than the total quantity available at any particular time.

Given the apparent inaccuracies and even logical inconsistencies of the traditional Nutrient Quantity Concept, it is time to develop a new, more comprehensive and accurate concept of soil fertility in the tropics.

## THE NUTRIENT ACCESS CONCEPT OF TROPICAL SOIL FERTILITY

### An Illustrative Experiment

To illustrate the new concept, I will first describe an experiment reported in Ana Primavesi's The Ecological Management of the Soil. (Primavesi) In this experiment, crops were grown in four hydroponic solutions. In the first solution, a normal concentration of nutrients for maximum maize plant development was used, and replenished every 4 days. In the second, twice the normal concentration was used and replenished every 4 days. In the third, the normal solution was diluted 50 times and also replenished every 4 days. And in the fourth case, the solution used was diluted 50 times the normal concentration, as in the third case, but was replenished every 2 days.

Plant growth (measured in grams of dry weight) in the second case was less than in the first. In the third case, as either theory would predict, the growth of the plants was 28% less than in the first. But in the fourth, quite surprisingly, the growth of the plants was slightly superior to that in the first case. That is, 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.

That is, crop growth above a certain extremely low concentration, does not depend on the concentration of nutrients. It depends, rather, on the constant access of plant roots to the nutrients, even when these nutrients exist in very low concentrations. The Nutrient Quantity Concept's remedy of increasing the concentration of nutrients by applying large amounts of chemical fertilizer misses the point almost entirely. What is needed is a constant supply of even a very 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).

So why is this fact more relevant to tropical soils and farmers than to temperate-zone soils and farmers? Very simply, tropical soils tend to have fewer cation-exchange sites, and therefore lower concentrations of nutrients. Because of this paucity of CEC, it is also much more difficult and costly for farmers to raise those concentrations of nutrients over the medium to long term. Second, the ambient heat of the tropics makes it difficult or impossible for plants to create the osmotic pressure to be able to absorb nutrients from highly concentrated solutions. (Primavesi) Therefore, plants in the lowland tropics often thrive better on more limited concentrations of nutrients (as was illustrated by the second case in the experiment above), as long as the remaining conditions are fulfilled.

Thirdly, farmers who work by hand or animal traction, can more easily micromanage their soils, creating varied microenvironments, in some of which nutrients are accessible, even if the total soil environment is deficient in accessible nutrients. And lastly, while northern farmers can often afford to fertilize their soils more heavily than need be for present purposes, resource-poor farmers in the developing countries just cannot afford to over-fertilize. Furthermore, in high-rainfall or steeply sloped areas, resource-poor farmers would lose more of those nutrients than do their northern colleagues.

### The Concept

The new concept of soil fertility emphasizes not the concentration of nutrients in the soil, but rather the maximization of the access of plant roots to soil nutrients. Thus I will herein call it the Nutrient Access Concept of soil fertility. The Nutrient Access Concept of soil fertility in the tropics posits the following:

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, and

3) maximum access of plant roots to these nutrients (i.e. the maintenance of good soil structure and/or mulches).

## THE ADEQUACY OF THE NUTRIENT ACCESS CONCEPT

Of course, the first question we must ask is whether the Nutrient Access Concept can explain the phenomena mentioned above better than the Nutrient Quantity Concept could.
First of all, the Nutrient Access Concept does not deny that heavy concentrations of nutrients can produce high yields in many circumstances, especially in cooler climes, and when soils are compacted or optimal soil structure has otherwise been damaged, CEC is high and farmers are well-

capitalized. It would tend to indicate that high-input agriculture is probably more expensive than it need be to achieve maximum productivity, but it does not deny that high levels of productivity can be achieved through high concentrations of nutrients in developed nation agriculture, and even highly capitalized plantation agriculture on the best soils of the tropics.

Where the Nutrient Access Concept does point to agricultural practices of a radically different kind is where soils have very low CEC's, where soil o.m. is or could be abundant and cheap, where capital is scarce, and/or where temperatures are high. But in these situations, very common in the tropics, would the Nutrient Access Concept be any more useful than the Nutrient Quantity Concept?

Adequacy in Practice

The Nutrient Access Concept has already led, in southern Brazil (Bunch, 1994) and small pockets of farmers in country after country, to competitive yields at relatively low costs, often on what were previously considered "low potential" soils, and with a much more positive long-term ecological impact than that of agriculture according to the traditional Nutrient Quantity Concept. (Pretty and Hine)

These experiences, plus the nature of the Nutrient Access Concept itself, would indicate that there is a good chance that this Concept could reduce significantly the costs of producing competitive yields in the tropics. For small-scale, poor farmers, especially on impoverished soils with low CEC's, the technology resulting from the Nutrient Access Concept could be a major life-saver, both literally and figuratively.

The Nutrient Access Concept provides absolutely no rationale for the present unjust discrimination against those farming on so-called "low potential" soils. Instead, it supports the idea that 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.

It would also call into question efforts to introduce and subsidize tremendous quantities of expensive chemical fertilizers to dozens of African nations already on the brink of bankruptcy. Presently, there is a lot of discussion about the possibility of bringing the "Green Revolution" to Africa. Proposals center on the idea that the World Bank and other major financial institutions should make a concerted effort to introduce and subsidize chemical fertilizers in Africa because of the perceived dangers of "soil nutrient depletion". (See IFPRI, SSSA)

These proposals, of course, fly in the face of increasing petroleum prices and a decade of Neoliberal efforts to reduce artificial governmental subsidies. But more basically, the perception that reduced levels of nutrients in Africa's soils will inevitably preclude high levels of production is, of course, based on the Nutrient Quantity Concept. Adoption of the Nutrient Access Concept would force a major rewrite of these proposals, orienting them instead toward the achievement of increased yields through higher levels of biomass production, soil structure improvement and mulch-based systems, rather than through the unsustainable use of billions of dollars of increasingly expensive chemical fertilizers.

Of course, even if we believed the Nutrient Quantity Theory, we have mentioned above that small farmers' lack of financial resources and the lack of their depleted soils' response to chemical fertilizers are a major an obstacle to maintaining or increasing soil nutrient levels with chemical fertilizers just as their lack of access to sufficient o.m. prevents them from doing the same with o.m. And with intercropped or dry season gm/cc's and/or dispersed trees, the former limitation may be much greater than the latter. If this is the case, someone must explain why, if African soil fertility is to be subsidized, it would be better to subsidize chemical fertilizers and rock phosphate to the total exclusion of subsidies of the dispersed planting of trees or of the price of green manure/cover crop grains.

Adequacy in Explaining the Observed Phenomena

The Nutrient Access Concept can explain very adequately those observed phenomena that the traditional theory cannot:

- Yields in gm/cc and agroforestry systems do not depend on high concentrations of nutrients. Rather, they depend on the fixation of N and the recycling of large amounts of o.m., which makes the P and other nutrients in the 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. Such systems can therefore produce good yields over long periods of time with low or no applications of additional nutrients (though eventually some nutrients, notably P, obviously have to be added to achieve sustainability).

- The SRI yields are achieved on very poor soils with only limited applications of compost because the rest of the technological package aerates the soil and makes the plants grow close to <u>six times more roots</u> per plant than does the conventional rice system, thereby allowing the plants to access many more of the limited nutrients in the soil. (Uphoff)

- West Africa's extremely poor soils with very low CEC's produce well near people's compounds because the o.m. thrown out of the kitchens maintains a small, steady supply of nutrients, and therefore low CEC's are sufficient to hold the nutrients necessary for a few hours or days until more nutrients are released from the next day's discarded o.m.

- The regeneration of tropical soils through fallowing does not occur primarily because large quantities of nutrients are brought to the surface and kept there. Rather, the large amounts of biomass deposited on the soil by the regrowth of forests or grasslands either maintain or, gradually and over a number of years, improve the soil structure, so that the newly cleared land allows crops to access much more efficiently the low concentrations of nutrients that exist in the upper horizons of the profile. Meanwhile, the organic matter on the soil surface or near it, produced during years of fallow, continues to supply nutrients in small quantities that can maintain reasonably high levels of productivity, at least for a year or two.

- Likewise, the same process maintains the impressive productivity of rainforests for millennia. Optimal soil structure and mulches are maintained, maximizing the access of the forest's trees to the few nutrients that are constantly being supplied through soil o.m. mineralization. And, to some extent, deeper tree roots, having a tremendous number of feeder roots like the rice under SRI, can capture large amounts of nutrients even in soil horizons with extremely low concentrations of nutrients.

In this last case, of course, the Nutrient Quantity people would largely agree with this analysis. What they cannot explain is how forests can grow so well on the basis of these very low concentrations of nutrients when, according to their Concept, low nutrient levels (i.e.. "low inputs"), in whatever part of the soil profile and of whatever origin, should result in the low productivity (i.e. "low outputs") of the entire system.

- Lastly, it is quite obvious that the research on, and benefits of, slow-release chemical fertilizer is much more understandable based upon the Nutrient Access Concept than upon the Nutrient Quantity Concept.

The above explanations are, of course, quite simplistic. Much more is happening in the soil than these explanations would indicate. Plants' access to nutrients, though certainly helped by applying the nutrients to the soil surface or together with o.m., or very near the seed, or by plants' growing in well-flocculated soils free of compaction layers, is a very complicated phenomenon which involves a large number of factors. These would include those of soil temperature, soil o.m. levels, pH, soil chemical properties, the presence of compaction layers, and nutrient positioning and equilibrium, all of which are in turn affected by the activity of hundreds of thousands of microorganisms in every teaspoonful of soil. Thus, nutrient access involves a whole series of dynamics which we only somewhat dimly understand as yet. **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.**

PUTTING THE NUTRIENT ACCESS CONCEPT INTO PRACTICE

It will be immediately evident to many people that the Nutrient Access Concept can most easily be put into practice through the copious use of o.m. O.m. can and does supply low to medium concentrations of nutrients, and almost always in well-balanced quantities. Furthermore, o.m., 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, though this mechanism is somewhat slower and sometimes problematic in improving the structure of heavily compacted soils, soil o.m. does serve to gradually improve soil structure. Soil o.m. does so both directly, through the provision of binding materials to improve flocculation, and indirectly, by feeding earthworms and other soil organisms, both macro and micro, which also improve soil structure. (Minnich)

Experience shows that the best way to apply o.m. in order to improve soil dynamics in these three respects, as well as to reduce costs, is to apply it either to the soil surface or, during the period of transition, within 20 cm of the surface. Although there is still some argument as to how the o.m.

should be applied to the soil the first year or two of a transition into mulch-based agriculture (when soil compaction below the surface is a serious limiting factor), experience tells us that after the first year or two, virtually all the o.m. should be applied to the soil surface. (See, for instance, Primavesi; MAG/DGP)

It should be mentioned here that the Nutrient Access Concept does not necessarily support the total discontinuation of the use of chemical fertilizer. While organic agriculture proponents may agree with this Concept, the Concept does not necessarily support a totally organic approach. What the Concept does do is open the door to a greatly reduced use of chemical fertilizers in the short run, and the gauging of their use in the long run more according to the replacement levels of net losses of nutrients for the purpose of sustainability (minus those nutrients supplied by o.m. and N fixation), rather than the much higher levels of use presently thought to be the only way to significantly increase productivity.

The Five Principles of Agriculture for the Humid Tropics

Based on the Nutrient Access Theory, an increasing number of institutions involved around the world in small farmer agriculture have begun to use some or all of the following Five Principles of soil management (Bunch, 1995):

1) Maximize o.m. production. Frequently, small-scale farmers can increase dramatically the amount of o.m. their fields produce while maintaining yields and only increasing costs slightly, if at all. In fact, many gm/cc and agroforestry systems reduce the amount of labor needed for controlling weeds, thereby increasing overall o.m. production while at the same time decreasing costs.

Increases in o.m. production can be achieved by using the intercropping of either various crops or gm/cc's with annuals or tree crops (as in dispersed tree systems), by establishing two- to four-story fields and gardens, and by growing trees or gm/cc's on wasteland or during the dry season. In droughty areas, an increased provision of water in whatever form can also result in greater levels of biomass production.

Obviously, the more biomass we produce in situ, the more we will have for applying to the soil, thereby making the provision of nutrients to the soil greater and more constant. If animals are present in the farming systems, they will also be more numerous and/or produce more manure per animal if they have more biomass to consume.

2) Keep the soil covered. Soil exposed to the tropical sun produces more weeds (which are another form of biomass, but may compete with crops and/or occasion a good deal of work). Unprotected soil also becomes very hot, causing a series of problems, including the more rapid rate of soil o.m. burn-out, the reduction in crop growth rates and the death of beneficial macro and microorganisms.

Shifting agriculture has been motivated in most places in the world by either declining soil fertility or increasing noxious weed growth. Once we maximize biomass production and keep the soil shaded, both of these problems are largely eliminated. The need to let the land lie fallow for years is thus also eliminated, as has been shown in country after country with the use of gm/cc's.

It is interesting to note that virtually all the systems of improved fallows or gm/cc's that farmers have developed on their own, have increased both soil cover and the overall production of biomass, as compared to the previous shifting agriculture systems.

Keeping the soil covered is obviously consistent with the Nutrient Access Concept because it reduces the decomposition rate of soil o.m., thereby making sure the provision of nutrients to the soil lasts longer and is more constant, even if mulches tend to lose a certain amount of N to volatilization.

3) Use zero tillage. Many traditional agriculture systems use zero tillage. However, these systems are often not very productive over time, because, in the absence of large amounts of soil o.m., nutrients are no longer constantly supplied to the soil and soil structure deteriorates quite rapidly. If, however, zero tillage is used in the presence of a maximum production of biomass, then both the supply of nutrients and good soil structure can be maintained. Thus, in contrast to many traditional zero till systems, those 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 as soil o.m. levels increase and the soil becomes covered, the populations of organisms that naturally till the soil increase rapidly, making further tillage by the farmer unnecessary. (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 very rarely, need to use herbicides.

Zero tillage has an important relationship to the Nutrient Access Concept, because tillage both damages soil structure and increases the rate of soil o.m. burn-out. Furthermore, tillage 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. Some gm/cc users report achieving slightly better yields with a mixed selection of gm/cc's. Nevertheless, this principle will find its primary importance not in the short run, but rather 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, with their pH's below 5.0, their aluminum toxicity and compaction layers, are not very hospitable environments for crop roots. Thus, crops will often grow much better if they can also access nutrients from a thick litter layer or mulch. In fact most, if not all, crops that grow in the humid tropics will spread the vast majority

of their feeder roots immediately under or even up into a mulch layer as long as it remains fairly moist. That is, they will feed much more readily from inside and immediately below the litter layer than from the soil itself.

Even the impact of chemical fertilizers can sometimes be greatly increased by being applied to the mulch rather than the soil. In Costa Rica, edible bean yields in the "frijol tapado" system, a traditional slash-mulch system, were not increased much at all above the traditional 500 kg/ha when chemical phosphorus was applied to the soil. However, yields rose two to three times traditional yields (to above 2 t/ha) when the inorganic P was applied directly to the mulch. Researchers in Africa have also noted that fertilizers applied to mulching materials are more efficient than when incorporated into the soil. (Thurston)

Basically, feeding plants through the mulch helps compensate for less than ideal conditions of soil structure or root growth, providing a supplemental source of readily available nutrients in small but constant quantities right at the soil surface, thereby making it less necessary for crops to develop huge root systems that extend deep into the soil profile. Obviously, plants' access to nutrients will be better if the nutrients are on the soil surface than if they are three feet below it, especially in impoverished, acidic soils with problems of aluminum toxicity.

These same rules may well apply not only to the humid tropics, but to the semi-arid tropics, as well. Reports from some semi-arid areas indicate that this is the case. Nevertheless, there still exist some doubts as to what extent crops can survive during, and recover after, the mulch has dried out completely due to the frequent droughts in such areas. Much more experimental evidence is needed in this case.

Small farmers and NGO's have developed a number of other simple ways that plants' access to nutrients can be inexpensively enhanced during the transition period. Edwin Asante, of World Vision/Rwanda, for instance, has developed a sort of small farmer version of precision planting for potatoes. In this case, an 8-cm ball of o.m., 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 impoverished 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 o.m. in the crop row, where it is more accessible. And Dr. Erich Raddatz is developing mycorrhiza strains that can double fruit production by increasing plants' access to nutrients. (Personal communication)

These Five Principles, apart from having proven themselves time and time again among small farmers around the world, are the self-same principles a humid tropical forest employs to maintain its high "productivity" during 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.

Thus, the sustainability of forest ecology over the millennia provides important evidence that tropical agriculture following these Five Principles should also be sustainable over long periods of time. The small amount of scientific research done on this issue so far tends to support this conclusion. (Buckles)

## ADDITIONAL IMPACTS OF THE NUTRIENT ACCESS CONCEPT

One major result we could expect of the Nutrient Access Concept of soil fertility would be an increase in optimism about the plight of resource-poor farmers. They are, by the conventional Concept, in serious, perhaps insurmountable, trouble. Their soils are increasingly depleted of nutrients. (Buresh; Henao) Furthermore, they have no hope of increasing their soils' nutrient supplies sufficiently with o.m., and they have far too little money to invest in chemical fertilizers, even if the impact of fertilizers on their impoverished soils were enough to cover the investment. To add insult to injury, the world's rich nations have now decided that somehow these unfortunate people are on a level playing field with rich European and American farmers, and therefore should have to compete with them without the assistance of protective trade barriers.

But 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 eliminate the comparative advantage provided by tractors. Whether most villager farmers will ever be able to compete with European or American farmers is still doubtful, but at least they should be able to produce enough for their own consumption to eat well. Although if conventional farmers in the First World persist in using increasingly expensive fossil fuels and chemical fertilizers at the present exorbitant rate, the poor just might be able to compete, after all.

A second impact of the Nutrient Access Concept would be that 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), from the positive impacts on the environment of increased biomass production, soil cover, soil o.m. and biodiversity, and from the decrease of farmer dependency on increasingly expensive fossil fuels.

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