ECHO Technical Note

AN INTRODUCTION TO SOIL FERTILITY

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Tanzanian farmers applying fertilizer to bean crop
Photo by Tim Motis

What's Inside

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Introduction

All plants need certain mineral elements for proper growth, development, and maintenance. The basic structure of all organisms is built of carbon (C), oxygen (O) and hydrogen (H). Plants obtain these elements from water (H_2O) in the soil and carbon dioxide (CO_2) in the air, so no input is required beyond being sure the plant has an adequate water supply to meet its needs. Turning the H_2O and CO_2 into organic building blocks, however, is a complex process that requires the assistance of at least 13 other elements.

Three elements, nitrogen (N), phosphorus (P), and potassium (K), are required in relatively large quantities and are referred to as **primary** or **macronutrients**. N is an important component of all protein, so is integral to the plant structure. P is a minor component of protein, but is integral to the molecules that control energy flow within the plant and is a component of genetic material. The role of K seems to be in maintaining the correct salt concentration in the plant sap. N, P, and K, in varying ratios, are the primary constituents of all chemical fertilizers. ***Depending on the fertilizer origin, their amounts present may be expressed as N, P_2O_5, and K_2O.***

Introduction continued…

Another group of elements are needed in lesser quantities, and are referred to as **secondary nutrients**. These include sulfur (S), calcium (Ca) and magnesium (Mg). S is another constituent of protein. Though less prevalent than N, it must still be present or the correct proteins cannot be formed. The primary role of Ca is in helping to bind cells together to form the plant structure. Without sufficient Ca, a plant tends to "fall apart." Mg is a component of the chlorophyll molecule, so without this ion the plant cannot harness light energy to create sugars and release oxygen (O_2). S can be obtained from S pollution in the air. (The detrimental effects of sulfur in the air usually outweigh the beneficial effects.) But with the reduction of S pollution in many parts of the world, it has become necessary to add S to fertilizers. Since the addition of Ca compounds is the primary method of pH control, maintaining pH at correct levels for plant growth usually ensures that adequate Ca is available for plant needs. Often Mg is also present in liming materials. If it is absent from these materials, however it can be added as Epsom salts ($MgSO_4$).

A third group consists of elements that are needed in very small quantities, and are referred to as **trace nutrients** or **trace elements**. The most noteworthy of these nutrients is iron (Fe). Fe in animals is the central ion of hemoglobin and without it O_2 cannot be transported to the cells. It has a somewhat analogous role in plants, being an integral part of the enzymes necessary for the formation of chlorophyll as well as some of the enzymes controlling oxygen use. Without sufficient Fe, C cannot be extracted from CO_2 and O_2 cannot be properly used in the plant. The yellow and red colors of most soils are caused by Fe compounds, so most soils possess enough Fe for plant needs. Problems can arise, however, in the ability of certain plants to extract the needed Fe. The fact that Fe gives the soil its color means that Fe remains behind while other more soluble elements are removed by leaching. Fe is least soluble in high pH (alkaline), dry soils and most soluble in low pH (acidic), wet soils. This means that a plant adapted to a wet acid soil may not be able to obtain adequate Fe in a moist to dry soil at near neutrality (pH of 7.0). Occasionally, rice grown in a low-iron paddy soil can become deficient in Fe due to precipitation of iron sulfide. This can be easily corrected by addition of old nails or other iron source to the soil.

The other trace nutrients are boron (B), manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo), chloride (Cl), and nickel (Ni). The trace nutrients are most commonly used in a variety of plant enzymes that control and facilitate the processes of growth and development. Some, particularly Fe, Mn, and Cu, are important in electron transfer reactions[1] within the plant. Since these nutrients are needed in only trace amounts, the majority of soils initially contain sufficient quantities for plant growth. In some cases, however, they may not be present or are present in such low amounts that a few years of removal in crops can deplete the nutrient to such an extent that the plant cannot obtain an adequate amount for proper growth and development.

It is often useful to develop devices for remembering lists of items. A device that I have found useful to remember the essential plant nutrients is: **C HOPKNS CaFe Mg B Mn CuZn Mo Cl Ni** (read: 'See Hopkins Café Managed by my cousins Moe, Cloe, and Nick').

In addition to the 16 elements required for all plants, a few plants may need additional nutrients. For example, rice and sugar cane require an adequate supply of silicon (Si) that stiffens the plant stems. Also, both corn and sugarcane require sodium (Na). A few plants require cobalt (Co) and others vanadium (V). Other elements may be needed by specific plants for proper growth and development. Nitrogen-fixing bacteria require cobalt, which means that a micronutrient benefit can be observed even when the plant does not directly use a particular nutrient.

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[1] Oxidation/reduction reactions are normal processes in the growth of both plants and animals. These reactions involve the transfer of electrons from one ion or molecule to another, and in many cases the transfer processes involve intermediary ions such as Fe, Mn, and Cu.

HOW DO I TELL WHETHER THE SOIL CONTAINS WHAT A PLANT NEEDS?

Soil testing is the most accurate method for determining whether sufficient nutrient is present. This is done before planting the seed so, if required nutrients can be added before the plant starts to grow. This ensures optimum conditions for maximum growth and development. While this method has major advantages in optimizing return, it does also have some disadvantages. First of all, a soil test must be interpreted. The soil is tested by chemically extracting the nutrients and determining how much is present. The next step is to interpret the results. Ideally, the solution used to extract the nutrients will remove the amount of soil nutrient that is available to the plant. Unfortunately, it is never an ideal world, so the best that can usually be expected is to find an extractant that will remove the nutrient in proportion to that available to the plant. The proportionality can differ in different plant species and in different regions of the world, or even in different soil types. It is therefore of little value to know how much element is removed without having some idea of the proportionality factor. Thus, it is necessary to conduct research that provides an estimate of plant growth response to fertilization as related to the amount of nutrient extracted. This is all costly, so worthwhile only if available financial resources are sufficient to purchase the fertilizer needed. While economists may teach that it is poor management not to optimize return, in many parts of the world financial resources for purchase of needed fertilizer are simply not available. In such areas it would be a waste of these limited resources to invest in soil testing, since the test itself can also be costly.

This said, it should be noted that there are several portable **soil test kits** available on the market. While many are rather expensive, they are convenient and for a large number of samples they can be less expensive per sample than sending the samples to a professional testing lab. Regardless of the cost, however, these test kits share the disadvantage of not being particularly accurate in reproducing testing laboratory results. In addition, the kits have usually been developed for use in a particular region and will often be even less accurate when used in other regions of the world. If they are to be used, the chemicals must be kept fresh and the results should be considered as only an approximation of the amount of nutrient available. A trained person can probably beneficially use one of these kits, but should invest time in some simple tests for plant response to fertilizer additions. In general, purchase of a test kit is not necessary. A major portion of their cost is usually a fancy package. With the help of a Soil Chemist trained users should be able, at a relatively lower cost, to assemble a kit usable for the region in which they are working and package it into an inexpensive tool box.

A second method of assessment is to **test for nutrients in young plants**. This method has the advantage of telling whether enough available nutrient is present to provide the nutrient in sufficient quantity to maintain healthy plants. It must still be interpreted, but databases now contain information on the concentrations of nutrients in healthy and unhealthy plants of most species. If no data are available on a particular plant, estimates can usually be made from data on similar species. While the plants may already be stressed due to insufficient nutrients, they are still young enough to benefit from addition of the nutrients found to be in short supply. This method, however, still has the possible drawback of being expensive. Relatively low-cost field kits are available for testing macronutrient concentrations in the plant sap, but like the soil test kits, these give only an estimate of nutrient sufficiency. Testing for the necessary trace nutrients usually requires the sophistication—and cost—of laboratory analysis. Due to cost, laboratory analysis is really only feasible for high value annual crops, but it can be both valuable as a diagnostic tool and economically viable for long lived perennials such as fruit trees.

A third method, which is probably the most practical in many areas of the tropics, is to simply be observant of **plant deficiency symptoms** and knowledgeable about what the symptoms indicate. The major drawback of this method is that by the time deficiency symptoms are observable, the plant is usually under severe deficiency stress and productivity will be impaired even if the nutrient is immediately added. On the other hand it costs nothing more than a little time to make observations, and immediate addition of the required nutrient may at least salvage some productivity. With the knowledge obtained, corrections can be made before planting the next crop.

WHAT DEFICIENCY SYMPTOMS SHOULD I BE LOOKING FOR?

Reading deficiency symptoms is, first of all, more of an art than a science. Many symptoms look similar and one symptom can mask deficiency of other nutrients. Also, correcting for deficiency of one nutrient may cause the plant to become deficient in another. One hundred and fifty years ago, Leibig, a famous German chemist, expressed what has been called "The Law of the Minimum." Essentially, it says that plant development will be controlled by whichever nutrient is most limiting to it. Thus, for example, maize plants may show nitrogen deficiency symptoms, so some nitrogen is added only to have the plants begin to exhibit phosphorus deficiency symptoms. In turn, this might be corrected and another deficiency symptom may become apparent. It may, therefore, take several years to discover and correct and balance all needs of the crop. Some generalizations can be made, but deficiency symptoms also differ widely with different species. One should become familiar with the specific deficiency symptoms of whatever crop is being grown. Given these notes of caution, let's look at some of the generalized symptoms (Bennett, 1996; Prasad and Power, 1997).

Just as a doctor can tell much about the health of a patient by observing visual symptoms, a farmer can tell much about the health of his crops by observing growth characteristics. First of all, he really needs to know what a healthy plant looks like. This is particularly important if a new crop or variety is being introduced, since not all healthy plants will look the same. With this background, nutrient deficiency symptoms can be more readily recognized. Some of the plant characteristics to examine are:

a. General Leaf Health. Do the old leaves near the base of the plant or branch and the new leaves near the growing tip look equally healthy, or nearly so?
b. Chlorosis — loss of green pigment. The leaves may be partially or wholly a very pale green or yellow. In severe cases the leaves may even become white.
c. Leaf Uniformity — does the interveinal area (area between the veins) look like the veins, or is there a substantial difference in color?
d. Necrosis — death. Are leaves dying, either whole leaves or sections of leaves?
e. Morphology — form and structure. Do the plant parts (leaves, stems, roots) look like they should? Many times a nutrient deficiency (or toxicity) causes a change in morphology. The roots may be stunted; stems may be unusually long or short between the branches; leaves may be stunted, curled, or dry and brown at the edge.

All of these characteristics are symptoms of an unhealthy plant unless they are known characteristics of a healthy plant. The same holds true for the following list of **nutrient deficiencies**:

Nitrogen: Deficiency is usually indicated by yellowing (chlorosis) of the midrib veins in the oldest leaves. If the deficiency is not corrected, the yellowing will gradually extend outward from the midrib; in severe deficiency the oldest leaves die. The plant's growing tip has priority for use of nitrogen, so if this nutrient is not available from the soil it will be removed from the oldest leaves, with N being extracted first near the midrib. Loss of N causes the leaf area to become yellow or chlorotic.

Phosphorus: The classical symptom of insufficient P in a plant is an abnormally dark green or crimson color that develops in the leaves, usually progressing from leaf tip and outer margin toward the midrib and stem. This will be most obvious in young plants, and as with N the symptoms first develop in the oldest leaves. Other symptoms include stunted growth, both of roots and upper plant portions, and delayed maturity.

Potassium: Deficiency of this nutrient will usually be shown by drying and bronzing of the leaf margins and curling of the leaves. In severe cases dead spots may appear in the leaves. Fruits may have a shorter shelf life.

Sulfur: Deficiency symptoms are similar to N, except that S is less mobile so the youngest leaves tend to turn yellow while the oldest leaves remain green. There may, however, be exceptions to these symptoms. Different plant species respond differently, but in general S deficiency is indicated by a pale yellow color and stunted, thin-stalked plants. Since symptoms are similar to those of N deficiency there is a tendency to assume N is in short supply. The symptoms, however, do not disappear with addition of N.

Calcium: This nutrient is immobile in the plant, so when insufficient calcium is available the terminal bud will fail to develop properly, causing young leaves to be distorted. In addition, in some plants dead spots will be found in the leaf mid-rib or in the stem. In maize, the tips of new leaves can be covered by a sticky substance that causes the leaves to adhere to each other, giving the plant a ladder-like appearance.

Magnesium: Deficiency symptoms are similar to those of N, but the veins tend to remain green, with the yellowing of the leaves occurring from the tip toward the veins, rather than *vice versa*. Brown and dead spots may appear on the leaf margins and tips.

Iron: This nutrient tends to be less mobile in the plant, so yellowing or whitening occurs in young, rather than old leaves. In severe deficiency in rice nurseries, direct seeded rice, or sorghum fields the entire plants may turn pale yellow to white due to interveinal chlorosis in the stem.

Boron: Also relatively immobile in the plant, deficiency of B will often result in death of the terminal buds. Other symptoms include rosette formation, flower or fruit shedding, poor quality root crops, and brown spot disease in the cabbage family.

Manganese: Mn deficiency symptoms are often not clear-cut, but will tend to cause interveinal chlorosis with the veins remaining green. In severe deficiency whitening and death of leaves may be observed. Melons, for example, seem to be susceptible to Mn deficiency. It may also occur on coconut palms, particularly in the spring months following a cold winter. When Mn deficiency does occur, symptoms tend to be most pronounced in the newest leaves of the plant.

Copper: Stunted growth and death of the terminal leaf buds can be associated with Cu deficiency, since formation and chemical composition of cell walls can be affected. Other symptoms sometimes observed are white leaf tips and narrowed, twisted leaves.

Zinc: Zn is a component of auxin, a hormone regulating plant growth, so insufficient quantity in the plant can lead to stunted growth. Pale to white coloration of young leaves may also be observed, such as white bud and white streaks in leaves of maize. Brownish red (rusty) discoloration of leaves in rice, known popularly as Khaira disease, is caused by Zn deficiency. Maize, beans, citrus, and rice are indicator plants for Zn deficiency.

Molybdenum: Deficiency somewhat resembles N-deficiency symptoms. Whip tail disease of cauliflower is associated with lack of sufficient Mo. This nutrient is particularly critical in legumes; it is an essential component of nitrate reductase and nitrogenase, thus important in turning atmospheric nitrogen into a useable soil nutrient.

Chloride: This nutrient is seldom deficient under field conditions; symptoms are most frequently observed under greenhouse conditions. When deficiency does occur it will often be indicated by chlorotic leaves and some leaf necrosis.

HOW DO I ASSURE THAT NUTRIENT SUPPLIES IN SOIL ARE MAINTAINED?

Whenever crops are harvested, nutrients are removed. These nutrients, as well as those lost by leaching, need to be restored in some way or agricultural sustainability may be threatened. Restoration can be accomplished in a variety of ways. Where financial resources are sufficient the lost nutrients may be replaced by adding commercial fertilizer. If animals are incorporated into the system nutrients may be at least partially replaced by spreading the manure produced. In a shifting agricultural system weathering of rock and accumulation in vegetation is relied upon to replace the nutrients. In many cases a combination of methods are used to maintain nutrient supplies. One of the helpful tools used in devising sustainable nutrient management strategies is the nutrient budget, which balances nutrient inputs to and exports from an area of interest. Nutrient balance studies provide quick findings, but they are usually based on short time-frame studies, and depend on various assumptions relating to system dynamics (Roy and Misra, 2002). The validity of the assumptions and the reliability of data can always be questioned, but at least this does provide some basis for estimating whether and the extent to which nutrients are being depleted. A simple nutrient budget model might be as demonstrated in Figure 1. This model is often expanded or contracted, depending on availability of data. At minimum the nutrient removed in the crop should be estimated and balanced by nutrient additions. Following are some data typical of that used in developing nutrient budgets.

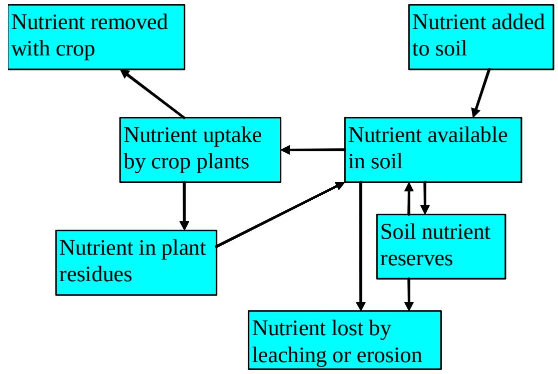

Figure 1. Simple nutrient budget model

The key to sustainable productivity is the replacement of nutrients removed from the fields with the harvested crops. Over time the nutrient removal can be substantial. Many tropical soils have a naturally limited supply of nutrients and the soils can be depleted quite rapidly in their ability to sustain additional crop growth unless provisions are made for replacing the nutrients removed. A few examples of nutrient removal with crops are found in Table 1 below.

Table 1. Nutrients removed via harvesting of some field crops in small holdings (Mueller-Samana and Kotschi, 1994).

Crop	*yield*	*N*	*P*	*K*	*Ca*	*Mg*
			kg ha^{-1}			
Maize (grain)	1100	17.1	3.0	3.0	0.2	0.2
rice (paddy)	1100	13.6	3.5	3.9	0.9	1.5
groundnuts (nuts)	550	28.5	2.4	3.0	0.3	1.0
(shells)	220	2.2	0.2	1.8	0.7	
Cassava tubers	11,000	25.0	3.0	66.0	5.9	
yam tubers	11,000	38.6	3.0	39.9	0.7	
banana	11,000	30.7	4.5	63.2	0.7	
cocoa (bean)	550	13.6	3.2	11.4		
(husks)	550	11.4	1.2	25.0		

It is important to retain and incorporate into the soil as much of the crop residues as possible. When crop residues are removed, nutrient loss can be considerable, since in many cases there may be more nutrients contained in the residues than in the harvested crop (Table 2). Burning can also result in substantial loss of nutrients, although at times the farmer must weigh the nutrient loss against the benefits of burning for disease and insect control, as well as for rapid release of contained nutrients.

Table 2. Average nutrient contents in selected crop residues collected in eastern and southern Africa (Palm et al., 1997)

	N	*P*	*K*
		kg t^{-1} (dry)	
Maize stover	6	<1	7
Bean trash	7	<1	14
Banana leaves	19	2	22
Sweet potato leaves	23	3.6	-
Sugarcane trash	8	<1	10
Coffee husks	16	4	-

The nutrient contents of manure can be quite variable, as indicated in Table 3. The variability in manure quality depends on animal diet as well as management. While there may be limited ability to affect manure quality by altering diet, manure management practices can greatly affect the amount of nutrients available for return to the soil. For example, the nitrogen content of urine is much higher than that of the solids, so urine retention becomes important. In general, the fresher the manure the greater the nutrient content per unit dry matter; storage time affects quality.

Table 3. Chemical composition of manure from a variety of West African sources (Tarawali et al., 2001).

Source of Manure	*N*	*P*	*K*
		kg t^{-1} (dry)	
Cattle	6 - 25	2 - 3	2 - 5
Sheep	14 - 23	2 - 11	- 14
Goats	14 - 22	4 - 7	-

The contribution of manure to nutrient needs on a small scale can be considerable, but on a country or continental scale manure produced will not meet the nutrient needs of all agricultural land. Various estimates, for example, have indicated that only about 10 percent of African nutrient needs can be satisfied through addition of manure (Tarawali *et al*., 2001). It is clear, then, that if resources are not available to purchase commercial fertilizer, production must be scaled to low intensity use of the land. As pointed out by Bunch (2002), however, low intensity does not necessarily mean low productivity in tropical areas. Cover crops and intercropping can be used effectively to maintain fertility. Continued productivity of the land can be facilitated by incorporation of legumes and other types of vegetative material in combination with rotation of cropping plots.

HOW CAN I ASSURE NUTRIENT SUPPLIES ADEQUATE FOR CROP GROWTH?

There has been much discussion over the years regarding the best way to “feed” plants. It must first be emphasized that plants are not animals, and the concept of “feeding” them can be forgotten. There is some evidence that in the case of a serious nutrient deficiency a plant may be able to absorb sufficient amounts of the nutrient through the leaf stomata to alleviate the deficiency symptoms, ***but with few***

exceptions all nutrients except C, H, and O enter the plant through the roots. Furthermore, most enter the root in only one or two forms. Thus, for example, no matter how N is added to the soil, it will likely enter the plant primarily as nitrate (NO_3^-) or ammonium (NH_4^+), and no matter the form in which P is added to the soil, it will enter the plant as phosphate (HPO_4^{2-} or $H_2PO_4^-$). No, feeding the plants is not the issue, but maintenance of the soil in a physical condition conducive to plant growth can be affected by nutrient management practices. ***In most cases the key to maintenance of good physical condition requires soil organic matter management.*** In the majority of soils organic matter forms the "glue" which binds small particles to form larger aggregates, thus decreasing the density of the soil and opening it to more ready movement of air and water. In some tropical areas iron can become the "glue", and these soils need special care to prevent destabilization, but even these soils can benefit by organic matter management. ***Inorganic fertilizers can be and have been successfully used to provide needed plant nutrients, but for maximum effectiveness soil management should include reincorporation of organic residues and should minimize stirring of the soil, which helps break down aggregates.***

This said, it is recognized that in subsistence agriculture, as practiced in much of the tropics, little or none of the plant nutrients will be added as commercial fertilizers. In these circumstances the cropping system becomes of utmost importance in maintaining fertility.

RELATIONSHIP OF CROPPING SYSTEMS AND SOIL FERTILITY

Farming systems everywhere, from the tropics to the breadbaskets of Europe and North America, are evaluated on the basis of their potential for maintaining adequate rates of growth in productivity over the long term. The traditional cropping system over much of the tropical regions was shifting agriculture. This system is sustainable only so long as the fallow period is sufficient for the land to reestablish a climax ecosystem, which allows replenishment of soil nutrients to approximately the levels existing prior to clearing for a few crop years. As population pressures increase, however, the pressure on the land also increases and the period of time the land is occupied by native vegetation is no longer long enough to reestablish a climax ecosystem. By the early 1990s, for example, true shifting cultivation had become rare in Africa, and the practice had more accurately become a bush-fallow system[2] (IITA, 1992). This system has been reasonably successful since it keeps a continuous layer of organic residues on the soil surface, thus protecting the soil from structural damage and erosion brought about by the high temperatures and torrential rains. As the need to produce more increases, however, a variety of alternative technologies have been proposed to replace the bush-fallow system. Any alternative must still manage the soil organic matter in such a way that it maintains and regenerates the productive capacity of the soil (IITA, 1992). It is thus necessary to find ways to maximize use of local sources of biological materials, which can be supplemented by fertilizers if they are available.

Proper management of soil organic matter is the single most important factor in maintaining soil fertility in tropical areas, since organic matter is the primary source of nutrients to the plants. Dick *et al* (2001) have indicated that increasing organic matter can also decrease phosphorus adsorption by the soil and increase phosphorus availability to plants. However, soil organic matter is very labile (breaks down quickly), and will be quickly lost when soil is aerated by cultivation. The loss of organic matter can be reduced by minimizing soil disturbance, but long term productivity can only be assured by a management program which includes additions of organic materials to the soil. Some organic material will be added to the soil when animal manure or other organic nutrient sources are used. Management of these materials will, however, be based on nutrient content and the amount of organic material added will

[2] Bush-fallow is still a type of shifting cultivation but rather than allowing the land to reestablish a climax ecosystem before again cutting, a year or two of cultivation is followed by only about 3 to 7 fallow years.

be inadequate for maintaining soil organic matter. The latter can only be accomplished by appropriate management practices.

The use of herbaceous legumes has been particularly effective in maintaining or even increasing soil organic matter. *Mucuna pruriens* var. *utilis*, *Desmodium heterocarpon, Mucuna pruriens, Centrosema pubescens*, *Psophocarpus palustris*, and *Pueraria phaseoloides* have been useful in management programs when quick ground cover is needed and they will increase the soil organic matter. In addition, all of these species have a positive effect on soil chemical properties (IITA, 1992). Some are better than others in raising the content of soil organic matter. *Psophocarpus palustris* and *Pueraria phaseoloides* contribute more than other legumes to soil organic carbon and total nitrogen (IITA, 1992).

Herbaceous legumes have been particularly effective in the live mulch management technique. In this system a food crop is planted directly into an established cover crop without tillage or destruction of the fallow vegetation. When used as live mulch, herbaceous legumes can yield up to 300 kg of nitrogen per hectare. Maize grown in the live mulch has shown little or no response to nitrogen fertilizer. In addition to supplying nitrogen, herbaceous legumes in live mulch suppress weeds, prevent erosion, and add organic matter to the soil. Live mulch using legumes has proved effective in minimizing the yield decline that is usually associated with continuous cropping in tropical soils. *Pseudovigna argentea* is a promising candidate for live mulch systems because it does not readily climb on stakes or smother other crops (IITA, 1992).

In the Americas, slash/mulch or “tapado” agriculture was the traditional practice. While burning the slash to obtain the nutrients in the ash was not unknown, farmers commonly cleared plots from the forest and planted crops in the resulting mulch. Rather than burning, they used the decomposing mulch as a source of nutrients. ***The decomposing slash appears to sustain soil fertility over the cultivation cycle better than does ash from burning*** (Thurston, 1994). The use of herbaceous legumes has also shown potential in combination with slash/mulch systems. Velvet bean (*Mucuna pruriens* var. *utilis*), for example, has produced around 30 T biomass ha^{-1} yr^{-1}, 90-100 kg N ha^{-1} yr^{-1}, and increased humus 0.5 in yr^{-1} (Holt-Giménez and Rubén, 1994). In addition to velvet bean, jack bean (*Canavalia ensiformis*), lablab or hyacinth bean (*Lablab purpureus* subsp. *purpureus*), alverjilla (*Lathyrus nigrivalvis)*, tropical kudzu (*Pueraria phaseoloides*) and scarlet runner bean (*Phaseolus coccineus*) have been successfully used in combination with slash/mulch (Bunch, 1994).

Alley cropping is another management system that shows a good deal of potential. In alley cropping arable crops are grown in “alleys” between hedgerows of planted, preferably leguminous, shrubs and trees. The hedges are kept pruned to prevent shading the companion crops. According to Escobar-Munera *et al* (1994) alley cropping increases organic matter content and associated nutrient content and cycling; it increases cation exchange capacity and soil moisture; it reduces soil temperature, weed seed emergence and soil loss. The prunings are a source of mulch, and the nitrogen in the clippings is supplemented with that fixed by living leguminous species in the hedgerow. The hedgerows therefore function similarly to the trees and shrubs in bush fallow, recycling nutrients, suppressing weeds, and controlling erosion on sloping land. *Leucaena leucocephala* and *Gliricidia sepium* appear to be the most promising woody species for alley farming in Africa (IITA, 1992). The biomass and nutrient yields of these species are presented in Table 4 and compared with two other species used as hedges. In Costa Rica *Erythrina poeppigiana* and *Gliricidia sepium* are used in alley cropping. In one study *Erythrina poeppigiana* produced up to 18.5 ton ha^{-1} yr^{-1} dry matter with a density of 280 trees ha^{-1}. At density of 555 trees *E. poeppigiana* produced a mean of 9.74 tons dry matter ha^{-1}, which translated to a nutrient input (kg ha^{-1} yr^{-1}) of 229 N, 23.2 P, 144.6 K, 77 Ca and 47 Mg (Escobar-Munera *et al*, 1994).

Table 4. Biomass and nutrient yields of four hedgerow species alley cropped with intercropped maize and cowpea in southwest Nigeria (Kang and Shannon, 2001)

Species	*Biomass yield*	*Nutrient yield* N	P	K	Ca	Mg	S	Mn	Zn
	t $ha^{-1}yr^{-1}$	kg $ha^{-1}yr^{-1}$						g $ha^{-1}yr^{-1}$	
Alchornea cordifolia									
prunings	3.89	86.8	7.0	38.9	20.8	6.8	4.60	1058	97
wood	1.33	8.7	1.5	24.3	12.8	1.7	—	266	21
Dactyladenia barteri									
prunings	2.11	28.0	2.7	19.3	5.9	3.7	2.11	125	38
wood	0.31	1.7	0.2	1.8	1.0	0.4	—	10	5
Gliricidia sepium									
prunings	5.75	226.0	14.5	160.0	72.0	25.0	10.35	431	115
wood	4.55	46.0	2.3	40.0	44.0	5.5	—	137	59
Leucaena									
leucocephala	8.37	301.0	19.3	156.0	67.0	36.0	24.27	594	209
prunings									
wood	5.62	28.6	1.7	33.1	18.0	3.9	—	225	51

SUMMARY

One agricultural missionary pointed out to me that when man abandoned the nomadic hunter/gatherer lifestyle in preference for a sedentary lifestyle cultivating crops it was done with an intimate knowledge of the conditions under which the plants grew and thrived. Thereby he attempted to duplicate those conditions in cultivated plots. There are “primitive” cultures that still cultivate the land using these principles, but they have been largely forgotten or ignored in much of the developed world.

We are able to grow healthy plants (hydroponically) in sterile sand or nothing but water — but at what cost? One of the biggest agricultural failures of the twentieth century was the attempt to export modern Western technology to societies still using sixteenth century (or earlier) technologies — the attempt, for example, to introduce grain combines when a scythe would have been an appropriate improvement over the sickle still used to harvest grain.

Similarly, it is easy to say that all a farmer needs to do is add fertilizer and he would harvest enough to feed his family with some left over to sell. However, if he has no resources and has been unable to adequately feed his family he will not be worried about feeding both his and some neighbor’s family. In a *Science* article, Foley, et al. (2005) have indicated that many modern agricultural practices requiring large applications of chemical fertilizers and the diversion of water to marginal lands are unsustainable. Bunch (2002) has also pointed out that fertilization of tropical soils can even be counterproductive, depending on the crop and the soil.

There is a need to return to an understanding of the conditions under which crops grow, particularly in the tropics. For many centuries slash-and-burn agriculture was successful because it depended on the vegetation, not the soil, as the primary nutrient pool. While it is not possible, nor even advisable, to return to this type of agricultural system, maintaining a vegetative cover over the soil is still a valid and vital cultural principle. Living plants accumulate nutrients and the debris becomes a slow release source of the nutrients to the crop. Together, the living and dead plant material both shade the soil and protect it from the eroding effects of rainfall. The final keystone element of sustainability is an awareness of the nutrients being removed with a crop. These nutrients do need to be replenished, whether by rock weathering, atmospheric input, or by fertilizer. Bunch (2002) correctly states that fertilizer addition is not bad, *per se*, but in tropical soils the nutrients should be added in the organic form. Farmers in the tropics have a variety of options for replenishing these nutrients in organic form, including manure, green manure and cover crops, plant residues and cuttings, etc.

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