PJN
ISSN 1680-5194

PAKISTAN JOURNAL OF NUTRITION

ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
Mob: +92 300 3008585, Fax: +92 41 8815544
E-mail: editorpjn@gmail.com

Pakistan Journal of Nutrition 5 (4): 387-397, 2006
ISSN 1680-5194

Issues of Optimum Nutrient Supply for Sustainable Crop Production in Tropical Developing Countries

E.A. Akinrinde
Department of Agronomy, University of Ibadan, Ibadan, Nigeria

Abstract: "Sustainable agricultural development" has become an international "agenda", gaining tremendous recognition in developing countries, though originally coined for use in developed nations. Crop yield, farm profit and environmental sustenance are of major concern as majority of humid and sub-humid tropical soils have "marginal fertility". Yet, plant nutrition is the most singular factor-controlling crop yields. Marginal lands require external inputs to ensure optimum nutrient supply, demanding growers' awareness of plant *hunger* signs to solve nutritional troubles and sustain productivity on farmlands. This entails multifaceted problems that are of great significance in plant production development in tropical developing countries. Agricultural production needs to be intensified on the basis of progressive social concepts though fertilization (particularly with mineral compounds) is still in its incipient stage in many countries. Indeed, the problem of optimizing nutrient supply to crops remains unsolved even in some countries that boast of intensive crop production and high-level agricultural research. This report considered the plant symptoms that are of significance to the identification of nutritional ailments and their causes. Solutions for reversing them and enhance crop productivity and sustainability were proffered. Guaranteeing optimum nutrition to tropical crops demands advanced level of knowledge about soil-plant systems and on the associated soil and climatic characteristics. Necessary information must be made available to growers apart from promoting discussions of this important and complex problem with (and among) scientists in the region.

Key words: Sustainable crop production, acid soil infertility reversal, marginal lands, yield building and protecting factors, developing and under-developed countries

Introduction

Food security is a major issue in tropical developing nations of the world as a result of unreliable rainfall, marginal soil fertility and low input level, causing declining crop yields. About 80% of most administrative regions of tropical developing countries depend on agriculture for their livelihood and the estimated incidence of poverty at 69% (International Fund for Agricultural Development, 2003) makes them one of the poorest regions in the world. According to Braimoh and Vlek, (2006), food production (increasing at 2% annually) has not kept pace with population growth (annual increase of 3%). The associated per capita deficits in most agricultural produce are among the highest in the world. Thus, net cereal imports are extraordinarily high. For example, in northern Ghana such imports increased from 1.5 million tons in 1967 to 12 million tons in 1997, and projections indicate that the region will require about 27 million tons of cereal imports to satisfy demand in 2020 (Rosegrant *et al*., 2001). The implication is that importation might subsequently become economically unfeasible to ameliorate food shortages. Evidently, increased agricultural production is the major avenue for guaranteeing food security. This is usually accomplished in sub-Saharan Africa by expanding land area under cultivation, but due to increasing pressure on available land, agricultural intensification has been reduced. The alternative is to increase yield on existing agricultural land, rather than expanding it. This, of course, call for efficient soil management to guarantee food security.

Over the years, issues surrounding sustainable development have received increasing attention among scientific workers, governments and policy-makers in virtually all the nations of the world. It involves the provision of adequate food (feed and fibre supplies), profitable system for the producer and responsible safeguards for the environment. According to Shi (2004), the trend in crop production has been to assist farmers who are continuously faced with multiple challenges, as they must be efficient in order to remain in business while their production systems must be sensitive to environmental concerns. These requirements are in addition to the usual challenges and hazards of weather, pests and uncertain markets.

Tropical and sub-tropical soils support important crops such as maize (*Zea mays*), cowpea (*Vigna unguiculata*), soybean (*Glycine max*), cassava (*Manihot species*), yams (*Dioscorea species*), cacao (*Theobroma cacao*), oil palm (*Elaeis guineensis*), rubber (*Hevea brasilensis*), etc. Maize is, however, the most important food crop cultivated by the smallholder farmers, contributing about 20% of calories to the diet (Braimoh and Vlek, 2006). The deficiency of essential nutrient elements is a crucial problem that limits uptake of the nutrients, growth and yields of crops. Plants are believed to need about 16 essential nutrient elements for normal growth. Some of the nutrient elements occur in complex forms in the soil and substantial proportions may be transformed into fixed states, making them relatively unavailable for plants to absorb.

The issues pertaining to the optimisation of nutrient supply as aid for reversing nutritional troubles and insurance to sustainable crop production in tropical developing countries need to be dissected. In this report, the concept of "sustainable crop production system" would be considered prior to the discussion of the symptoms associated with the identification of crop nutritional ailments. Thereafter, the practical solutions for reversing them and guarantee crop productivity and sustainability would be provided.

Sustainable crop production systems: The major crop controllable factors include the *yield building factors* (water management, plant nutrition, tillage management, hybrid/variety selection and precision planting) and the *yield protecting factors* (market strategy, harvest management as well as disease, insect pests and weed control).

Sustainable farming practices demand less water. By 2025, most developing countries are predicted to face water shortages (Ngandwe, 2006). Rainfalls are usually of high intensity, seasonal and significantly differ between growing seasons (Andreini *et al*., 2000). Yet, the mono-modal rainfall pattern that is typical of moist savannah agro-ecological zone of some of the areas, results in growing seasons that last for 5 or 6 months. In most cases, Alfisols account for up to 80% of the land area while a large proportion is inherently poor in exchangeable cations. According to Braimoh and Vlek (2004), some soils (classified as *Typic Plinthqualf, Rhodic Paleustalf and Typic Plinthaquept* by Soil Survey Staff, 1994) were formed from sandstone parent materials in the region have effective cation exchange capacity (ECEC) that are as low as 4.4 cmol kg^{-1}, and with organic C 1.2%, total N 0.05% and available P 8 mg kg^{-1} (Braimoh and Vlek, 2004). In spite of this, the associated farming systems are characterized by very small external inputs as inorganic fertilizers.

To worsen the situation, the pressure on land (usually exemplified by crop grower-cattle herdsmen) in most of the developing countries has drastically increased with increase in population. In practice, there are the traditional common property systems (land tenure and ownership) that enable village heads to allocate land for specific household needs, except in circumstances permitting preferential allocation to large-scale commercial farmers. Even then, land previously farmed by a household but left to fallow to restore its fertility may be given to a different household when land is scarce. Similarly frustrating is the fact that in several administrative areas, vegetations (e.g. grasses) contributing very little litter (and hence adding insufficient soil organic matter) for soil fertility restoration have been replacing the rotational fallow system that used to last about 8 years in the savannah woodland areas. Some of these areas have been "food baskets" and global best producers of specific farm produces (Policy, Planning, Monitoring and Evaluation Division, 1991), the yields of which have declined in the last few years. In most of the moist savannah agro-ecological zones, marginal soil fertility coupled with low fertilizer inputs, erratic rainfall pattern, and fallow period reduction usually result in crop failure that makes feeding the growing human population problematic and a bottleneck to rural development. Thus, the chronic food insecurity, manifesting in low food consumption as well as malnutrition and high mortality rates (International Fund for Agricultural Development, 2003) has necessitated measures to increase crop yields and guarantee reliable food supply.

Recently, Braimoh and Vlek, (2006) assessed the impact of soil and management variables on maize yield in a 5400-km^2 area in Northern Ghana by producing a soil quality index that was combined with social data and related to maize yield in a bid to identify the major constraints to the production of the crop. They identified soil quality index, fertilizer use, household size, distance from main market, and the interaction between fallow length and soil quality index as yield determinants. The soil quality-fallow interaction effect on yield, being negative, indicated the influence of soil litter and N immobilization.

Griffith (2006) noted that plant nutrition is the most singular factor controlling crop yields. Yet, a large proportion of soils in the humid and sub-humid tropics are highly degraded and weathered, heavily leached and have limited capacities for supplying plant nutrients and for holding enough moisture needed for high productivity. Bello and Akinrinde (2005) had referred to such farmlands as 'marginal' lands, most of which are always in danger of erosion, drought and low structural stability and compaction. They have lost their ability to support the required biodiversity either through natural catastrophes and / or human destructive activities (Ojating, 1997). Farmers in most of the developing countries might continue to crop the marginal lands in as much as increasing population growth and tendency to use agricultural lands for housing, roads, industry and other human activities prevail.

Higher yields reduce unit costs because fixed expenses, such as those for land and machinery, do not change with yield and are spread over more tons of yields. Unit cost of production is a farmer's best single indicator of profit potential. As unit costs drop, there is a built-in protection factor against a fall in market price or when weather conditions may not allow an established yield goal to be achieved. According to Griffith (2006), "Sustainable Crop Production System" is a term often used to describe a management philosophy that will be adopted by those farmers who are going to remain as the future producers of human food, feed and fibre. This philosophy includes the implementation of crop management strategies that provide adequate, high quality food, feed and fibre supplies that are produced economically, and with the added responsibility to safeguard the environment. It is the combination of productivity and responsibility that most accurately describes the term "Sustainable Crop Production Systems." Sustainable systems start with the adoption of Best Management Practices (BMPs). Once in place, BMPs lead to Maximum Economic Yields (MEY) and together they lead to sustainability in economical and environmental terms (Griffith, 2006). Farm profits increase with higher yields for the simple reason that the unit cost of production declines as MEY is approached.

Table 1: Role of the essential nutrient elements (adapted from Barker, 1999)

Macronutrients

Nitrogen (N):

- Nitrogen is a part of all living cells and is a necessary part of all proteins, enzymes and metabolic processes involved in the synthesis and transfer of energy.
- Nitrogen is a part of chlorophyll, the green pigment of the plant that is responsible for photosynthesis.
- Helps plants with rapid growth, increasing seed and fruit production and improving the quality of leaf and forage crops.
- Nitrogen often comes from fertilizer application and from the air (legumes get their N from the atmosphere, water or rainfall contributes very little nitrogen).

Phosphorus (P)

- Like nitrogen, phosphorus (P) is an essential part of the process of photosynthesis.
- Involved in the formation of all oils, sugars, starches, etc.
- Helps with the transformation of solar energy into chemical energy; proper plant maturation; withstanding stress.
- Effects rapid growth.
- Encourages blooming and root growth.
- Phosphorus often comes from fertilizer, bone meal, and super phosphate.

Potassium (K)

- Potassium is absorbed by plants in larger amounts than any other mineral element except nitrogen and, in some cases, calcium.
- Helps in the building of protein, photosynthesis, fruit quality and reduction of diseases.
- Potassium is supplied to plants by soil minerals, organic materials, and fertilizer.

Calcium (Ca)

- Calcium, an essential part of plant cell wall structure, provides for normal transport and retention of other elements as well as strengthening the plant. It is also thought to counteract the effect of alkali salts and organic acids within a plant.
- Sources of calcium are dolomitic lime, gypsum, and super phosphate.

Magnesium (Mg)

- Magnesium is part of the chlorophyll in all green plants and essential for photosynthesis. It also helps to activate many plant enzymes needed for growth.
- Soil minerals, organic material, fertilizers, and dolomitic limestone are sources of magnesium for plants.

Sulfur (S)

- Essential plant food for production of protein.
- Promotes activity and development of enzymes and vitamins.
- Helps in chlorophyll formation.
- Improves root growth and seed production.
- Helps with vigorous plant growth and resistance to cold.
- Sulfur may be supplied to the soil from rainwater. It is also added in some fertilizers as an impurity, especially the lower grade fertilizers. The use of gypsum also increases soil sulfur levels.

Crop nutritional troubles: It is necessary that the grower be conversant of the basic (rudimentary) knowledge of plant nutrition. According to Mengel and Kirkby (1987), an element is not essential unless *its deficiency prevents the plant from completing the vegetative or reproductive stages of its life cycle*, *its shortage or deficiency is specific for the given element, being corrected only when the same is applied* and the element must be directly involved in the nutrition of the plant; its effect being not as a result of an eventual correction of unfavourable physical, chemical or microbiological conditions in the soil or in the culture medium.

Mere chemical analysis of plants is usually not enough to establish which elements are essential since many of them that are absorbed do not have a significant role in plant; soils being extremely complex.

Sixteen chemical nutrient elements (non-mineral and mineral) are usually referred to as essential for a plant's growth and survival. The Non-Mineral Nutrients (hydrogen, H; oxygen, O; and carbon, C) are found in air or water and during photosynthesis, plants utilize solar energy to convert carbon dioxide (CO_2 i.e. C + O) and water (H_2O i.e. H + O) into starches and sugars, which are plants' food. Photosynthesis (manufacturing things with light) involves plants' acquisitions of C, H, and O from air and water that can be hardly controlled by crop growers (Barker, 1999).

The 13 mineral nutrients, originates from soil and dissolved in water for plant roots' absorption but are not always enough for a plant to grow healthy. Hence, fertilizers are used to augment the available soil nutrients. The mineral nutrients are required in large doses, referred to as Macro nutrients (including the primary ones: N, P, and K as well as the secondary ones: Ca, Mg, and S) or needed in minute amounts, referred to as macronutrients (B, Cu, Fe, Cl, Mn, Mo, Co and Zn). The major nutrients are usually deficient in soil since plants use large amounts for their growth and survival while the secondary nutrients are usually enough such that fertilization is not always needed (Barker, 1999). Besides this, large amounts of Ca and Mg are added when lime is applied to acidic soils and S is usually found in sufficient amounts from the slow decomposition of soil organic matter, an important reason why grass clippings and leaves should not be thrown away.

Table 1 continued

Micronutrients

Boron (B)
- Helps in the use of nutrients and regulates other nutrients.
- Aids production of sugar and carbohydrates.
- Essential for seed and fruit development.
- Sources of boron are organic matter and borax

Copper (Cu)
- Important for reproductive growth.
- Aids in root metabolism and helps in the utilization of proteins.

Chloride (Cl)
- Aids plant metabolism.
- Chloride is found in the soil.

Iron (Fe)
- Essential for formation of chlorophyll.
- Sources of iron are the soil, iron sulfate and iron chelate.

Manganese (Mn)
- Functions with enzyme systems involved in breakdown of carbohydrates, and nitrogen metabolism.

Molybdenum (Mo)
- Helps in the use of nitrogen
- Soil is a source of molybdenum.

Zinc (Zn)
- Essential for the transformation of carbohydrates.
- Regulates consumption of sugars.
- Part of the enzyme systems which regulate plant growth.
- Sources of zinc are soil, zinc oxide, zinc sulfate, zinc chelate.

The deficiency of any of the essential nutrient elements usually results in specific nutritional ailments, exhibition of unmistaken signs of hidden hunger and reduction in crops' growth and yield (Obigbesan, 1978; Akinrinde, 1987; Hochmuth *et al.* 2004).

Plant analysis assists in diagnosing nutritional problems or potential problems in the crop from which the samples are taken, i.e., the current crop. Potential problems can be circumvented, particularly if they are discovered early in the crop (before bloom) cycle by routine leaf analyses. Indeed, the ability to identify visual deficiency, sufficiency and toxicity plant symptoms is one of the major assets in modern crop production. Concise information on the nutrient elements is provided in Tables 1 - 3.

A major soil property affecting the availability of these nutrients is soil pH, a measure of soil acidity or alkalinity. Macronutrients tend to be less available in soils with low pH while micronutrients tend to be less available in soils with high pH (Fig. 1).

Lime can be added to the soil to make it less sour (acid) besides supplying calcium (Ca) and magnesium (Mg) for plants to use. Lime also raises the pH to the desired range of 6.0 to 6.5. In this pH range, nutrients are more readily available to plants, and microbial populations in the soil increase. Microbes convert nitrogen (N) and sulfur (S) to forms that plants can use. Lime also enhances the physical properties of the soil that promote water and air movement.

Optimum nutrient supply: The wide range of multifaceted problems associated with an optimum nutrient supply to crop plants is related to fundamental questions of crop production that are of current interest to all developing countries trying to increase food production. However, the complexity of biomass production could be appreciated from the fact that the factor limiting the photosynthetic rate is not just light but the non-optimum CO_2 levels, temperatures as well as water and nutrients supplies. The relevance of plant nutrition could be seen in its being a major pillar of metabolic physiology. There is no reaction of the primary and secondary metabolism that is not influenced by one or several mineral nutrient elements. It is important to know how these processes actually proceed and how increased light use efficiency can increase productivity. Currently, it is known that yield increase can be achieved through fertilization.

Results of plant nutrition research on the supply of adequate amounts of nutrients to plants have shown clearly that optimum plant yields through the provision of additional amounts of plant nutrients is yet to be achieved in most of the tropical developing countries (Enzmann *et al.*, 1983). Hence, it is good to focus on the relations between the transformation and availability of nutrients in tropical and subtropical soils, the fertilization effects on soils and plants in different locations in tropical regions, and the methods of determining the soil and plant nutrition levels as an essential basis, ascertaining nutrient supply levels and determining fertilizer requirements.

Of course, there are other areas of interest. Nowadays, developments in plant nutrition are not based on the discovery of more essential plant nutrients but by application of knowledge acquired in the past coupled with the extension thereof by specific research work. A

Table 2: Summary of the role of macro nutrient and associated deficiency symptoms of plants

Macro nutrients	Deficiencies	Remarks
Nitrogen (N) - Part of proteins, enzymes, chlorophyll, and growth regulators.	Reduced growth, yellowing (chlorosis), reds and purples may intensify with some plants, reduced lateral breaks.	Excess will yield all leaf and stem growth, with little fruit.
Phosphorus (P) - Role in fat, carbon, hydrogen, and oxygen metabolism; respiration and photosynthesis.	Reduced growth, colour may intensify foliage turning brown or purple in some plants; thin stems, loss of lower leaves, reduced flowering.	In very acid or alkaline soils, phosphorus will be unavailable.
Potassium (K) - Important in starch formation, sugar translocation, water relations, disease resistance, chlorophyll development, and tuber formation.	Reduced growth, shortened internodes, marginal burn or brown leaf edges, dead spots in the leaf, reduction of lateral breaks, and tendency to wilt readily.	Large amounts of potash are needed by most plants.
Magnesium (Mg) - Part of chlorophyll, enzyme activator, important in energy utilization.	Reduction in growth; yellowing between veins, also can occur with middle or lower leaves; reduction in seed production.	Interferes with calcium uptake if used in excess.
Calcium (Ca) - Important in cell wall structure, cell division, enzymes, and as an enzyme activator.	Inhibition of bud growth, death of root tips, cupping of mature leaves, weak growth.	Too much calcium will result in high pH, causing many of the micro nutrients to become unavailable to the plant.
Sulphur (S) - Part of protein, amino acids, vitamins, important in respiration.	Symptoms are a general yellowing of the affected leaves of the entire plant.	Up to 10 pounds of sulphur per acre can be discharged by acid rain to the soil each year.

dynamic approach resulting in interdisciplinary methods being increasingly used for research studies has been established. Nutrient cycles in agricultural systems of utilization of land, new theories of within soil nutrient migration and plant nutrient uptake have continued to receive growing attention.

Important problems like the effects of nutrient supply upon soil fertility, integrated crop farming and location-dependent use of yield-increasing methods of farming have similarly been governing research efforts. Interdisciplinary approaches have also been providing the basis for an efficient utilization of tropical soils by the use of programmed agricultural ecosystems.

Decisive data on securing of soil fertility at economically feasible cost, especially in humid tropical regions and in irrigation-salinised soils in arid and semi-arid regions are, however, lacking.

Fertilizers as key to food crisis in Africa: Very recently, agricultural experts, ministers and policy makers gathered in Nigeria at an Africa Fertilizer summit called on their various governments to improve farmers' access to fertilizers across the continent so as to help solve food shortages (Brahic, 2006). The New Partnership for Africa's Development, NEPAD (2006) organized the event with the goal of rapidly increasing chemical and synthetic fertilizer use in Africa and creating an action plan for doing so.

It was stressed that while too much fertilizer can be a problem, too little fertilizer is equally problematic, as it means soil nutrients are not replenished. When farmers plant the same fields season after season and cannot afford to replace nutrients taken up by their crops, the soil is literally mined of life (Odhiambo, 2006). This has depleted African soils, making them less able to sustain plant life and has led to increasing water scarcity and the spread of deserts. Africa's soils are being stripped of nutrients so fast that 75 per cent of farmland is now severely degraded. From 2002-2004, about 85 per cent of African farmland lost more than 30 kilograms of nutrients per hectare per year. In Angola, Burundi, Congo, Guinea, Rwanda and Uganda, annual losses were more than 60 kilograms per hectare.

Fertilizer use is lower in Africa than anywhere else, amounting to less than ten per cent of the global average. Fertilizers cost two to six times more in Africa than elsewhere - a price that is too high for most farmers there. African farmers use on average eight kilograms of fertilizer per hectare of land each year, compared to 350 in China and 420 kilograms in Holland. Unless African farmers boost their use of fertilizer significantly, they will struggle to produce enough food for the continent. The summit heard that 'micro dosing' (placing the equivalent of a bottle cap of fertilizer near a plant) could improve yields, especially in the dry Sahel region directly south of the Sahara. By applying minimal amounts of fertilizer precisely where they are needed, farmers could both raise their profits and help to rebuild the soil. The summit in Nigeria was aimed at identifying ways to cut fertilizer costs and encourage investment in fertilizer manufacturing within Africa.

It was resolved that access to fertilizers should be made easier and more affordable by calling on governments to declare fertilizer a strategic resource that is not taxed when it is imported or when it moves from one African country to another.

Another call was to the African Development Bank to provide loans to improve the transport infrastructure that is needed to get fertilizer to farmers. It was declared that fertilizers should be accepted as a product that can make money while loans are very appropriate financial mechanisms as the supply chain that is put in place can end up paying back the loan.

The summit also encouraged Africans to produce more fertilizer themselves since the continent has an ample supply of the rock phosphate needed to make its phosphate component. Nevertheless, the summit attracted criticism from a campaign in favor of organic farming by the International Federation of Organic Agriculture Movements, arguing that chemical fertilizers are known to break down natural cycles, creating a dependence on chemicals.

Environmental impact of fertilization: The overall responsibility of science should not be overlooked while dealing with the various problems that are of current interest. Evidently, population explosion and the ever-increasing expenditure on food production require that progress be made in the development of agricultural sciences.

The differences between the world system and the struggle for peace and progress as well as the establishment of a social system providing decent living conditions for all human beings will in the final analysis, be decided by the developmental level and the utilization of knowledge acquired in the natural, agricultural, and engineering sciences plus the Marxian laws concerning human societal development.

The role of mineral fertilization in increasing agricultural production, the association of mineral fertilization and intensification, optimal nutrient supply / optimal fertilization, the relationship between soil nutrient supply capacity and plant nutrient demand, the role of soil nutrient supply capacity dynamics and plant nutrient demand together with factors influencing the role of fertilization in solving problems of development in tropical developing countries should be of concern to all and sundry. It is obvious that success would be attained only by planned fertilizer application that is based on knowledge of nutritional requirements of particular crops and of the ways in which the soil can supply such nutrients.

The attainable performance level can be forecast from the yields obtained in countries already practicing intensive plant production. It might, however, remain elusive in the face of non-systematic nutrient supply by fertilization (mineral / organic / organo-mineral). From experience, fertilization could be responsible for over 50% of the yield increase in intensive plant production. The relationship between fertilizer use and yields shown in Fig. 2 manifests the role of mineral fertilization (Enzmann *et al*., 1983).

Constraints of fertilizer use in the tropics: Traditionally, growers in most tropical countries rely on shifting cultivation for the restoration of soil fertility via organic matter build-up during the fallow period. Rapid increases in population and urbanization have shortened the fallow period and led to decline in soil fertility and crop productivity (Aweto, 1981). Yet, the dependence on chemical fertilizers has reduced as a result of their high costs and the adverse effects on soil properties (Parr, 1974).

In view of these problems, there is need to develop a strategy for maintaining soil fertility using local materials as advocated by FAO (1994). Thus, the restoration and rehabilitation of degraded soils to an acceptable level of productivity can be accomplished by the application of both on-farm and off-farm sources or organic wastes that are of considerable importance in the maintenance of soil tilth, fertility and productivity (USDA, 1978). In addition, they protect the soil from water and wind wash, thereby preventing nutrient loss through erosion and leaching (Parr *et al*., 1989).

The invention of chemical fertilizers has allowed man to raise soil productivity higher than could be attained under the natural climax vegetation. Many studies of various crops have shown significant yield advantages while applying inorganic fertilizers. However, excessive application of mineral fertilizers has been reported to have deleterious effects on crop growth and yield increase. Reliance on chemical fertilizers to increase crop yields has generally led to a decrease in soil organic matter and an increase in soil erosion (Dorna *et al*. 1996).

The use of mineral fertilizers alone has not been able to solve the problems of crop production in the tropics due to the adverse side effects of continuous application of acidifying fertilizers (e.g. sulphate of ammonia) on acid soils as revealed from the work of Agboola *et al*. (1975). It was revealed that a research field subjected to 10 years of continuous maize and cowpea cropping and with regular use of NPK fertilizers resulted into a situation where about 75% soil organic matter was lost and exchangeable K reduced by 13% and P content was reduced to one half of the original value. Continuous use of relatively high rates of N fertilizers on kaolinitc Alfisols, especially under cereal monoculture, can reduce soil pH

Table 3: Micro nutrients, their role, causes of deficiencies (in soils and hydro / soil less mediums) and solutions

Micronutrient and role in plants	Causes of Deficiency	Deficiency symptoms	Solution
Zinc, Zn (immobile)-aids plants size, vegetative parts, maturity, formation and activity of chlorophyll, drought tolerance. Essential in enzymes, growth hormones, low auxin levels cause stunted leaves and shoots. Parts affected by a zinc deficiency are young leaves and petioles. Excess of Zn is very rare, but when it does happen it can cause wilting and in worse cases, death.	High pH, Low organic matter, High Phosphorus levels in the soil, and or lack of nitrogen. Zn, Fe and Mn deficiencies may occur together; they get locked out due to unfavourable pH. - Soil Zn gets locked out at pH 4.5-4.7, 7.5-9.5 and absorbed best at pH 5.0-7.0 - Hydro and Soil less Mediums Zn gets locked out at pH 5.7-8.5 and it is absorbed best at pH 4.0-5.5. Best range for hydro and soil less mediums is 5.0 to 6.0.	- Occurs mainly in newer growths. - Spotting and bleached spots (chlorosis) between veins, often similar to Fe and Mn deficiency symptoms (without the little leaf symptom). - Small crops, short shoots, cluster of small-distorted leaves near tips. -Inter-venal yellowing, with overall paleness. - Pale or greyish yellowing between veins: rosette, weak and dramatically reduced yield. - Inter-venal chlorosis in small, narrow distorted leaves at the ends of shortened shoots and shortening between internodes. Leaf margins are often distorted or wrinkled.	- Chemical / Organic fertilizers containing K. (Mix at ½ strength for chemical nutrients to avoid nutrient burn!) - Zinc sulphate, zinc chelate, zinc oxides or buried galvanized nails, without the sharp point to prevent roots' damage). - Slow acting Garden Manure e.g. Green sands, Cottonseed Meal. Too much chemical nutrient additions and / or organic (hard to burn plants) can be flushed with 2 times as much plain water as the size of the pot e.g. a - 5 gallon pot needs 10 gallons of water to rinse out the soil good enough to get rid of excessive nutrients.
Iron, Fe (Immobile)-Component of plant enzymes - Important in electron transportation while photosynthesis is happening... - Reacts with many components of nutrient solutions, causing nutrient lockup e.g. Addition of much Fe without adding enough P can contribute to P deficiency, so watch out how much Fe and P your fertilizers have. - Fe is difficult for plants to absorb as it moves really slowly in plants. Harder for outdoor plants to absorb in hot weather. Young leaves and Petioles are mostly affected.	pH imbalance can make Fe insoluble. Too much Fe can cause a problem that looks like a pH imbalance, Brown spotting on the top leaves, mainly fan leaves. Can affect whole plant. Fe Toxicity is rare for pH < 5.5. -Over watering, pests, nematodes, not enough drainage. High pH, Soils with low iron, High Phosphorus, Excess Zinc, manganese or copper. -Gets locked out of soil at pH 2.0-3.5, absorbed best in soil at pH 4.0-6.5 -Gets locked out of Hydro and Soil less Mediums at pH 2.0-3.5, absorbed best at pH 4.0- 6.0. Best range for hydro and soil less mediums is 5.0-6.0.	Leaves turn pale yellow along growing shoots, while veins remain dark green. Tissue between veins becomes pale or white, mimicking Mg deficiency, but not yellow, iron has white whereas yellow is for Mg deficiency. -Starts with lower and middle leaves, new leaves, becoming completely lacking in chlorophyll, but little or no necrotic spots. Chlorotic mottling on new leaves starts near leaflets bases; middle of leaves have yellow marks.	-Chemical / Organic fertilizers having K in them (mix at ½ strength when using chemical fertilizers to avoid nutrient burn!). -Foliar spray with chemical fertilizer containing Fe or rusty water. Other supplements with Fe in them e.g. Iron chelates, Ferric oxide, Ferrous oxide, Ferrous sulphate (for fast absorption), Greensand and Cottonseed Meal (slowly absorbed); Garden Manure (for medium absorption). Manure is most common organic Fe source. With excess addition, (it is hard to burn your plants when using organic), flush soil with twice as much plain water as the size of the pot

Sulphur, S (Immobile) -Important in root growth, chlorophyll formation and plant proteins. Like Fe, S moves slowly in plant, hotter temperatures making it harder to absorb. Unlike iron, S is distributed evenly throughout the plant. -Important in vegetative growth. -Too much S causes plants to be small along with size of leaves, and with leaves being brown and dead looking at the tips. Excess sulphur can look like salt damage with restricted growth and dark colour damage.	-Gets locked out of soil growing pH 2.0-5.5, being best absorbed at pH 6.0-9.5 Gets locked out of Hydro and Soil less Mediums at pH 2.0-5.5, best absorbed at pH 6.0- 9.5.	First sign - pale young leaves. Leaves' growth remain slow; leaves can get brittle and stay narrower than normal. Leaves can be small and mutated, along with buds on top of flowering plants dieing off. Plant can be stunted; younger leaves and new growth turn yellow. Unlike Mg deficiency (where signs start from leaves' tips, S deficiency signs starts from back of leaves on forward to the middle. Stems become hard, thin and may be woody. Plants may show orange and red tints rather than yellow. Stems increase in length but not in diameter. Leaves become stiff and brittle like glass and fall off. Parts affected are: Whole plant, young leaves, leaf veins.	- 1-2 teaspoons of Epsom salt per gallon of water until condition improves. -Any Chemical / Organic fertilizers containing S in them (mix at ½ strength when using chemical fertilizers to avoid nutrient burn!) -Other S supplements are: Rain water, Ammonium Thiosulfate (fast absorption), Garden Sulphur, Sulphate of Potash, and Gypsum. Caution: Addition of gypsum to an acid soil (pH < 5.5) can have bad effect on plants by affecting absorption of aluminium that is toxic to plant roots.
Manganese, Mn (Immobile) - Helps enzymes break down for chlorophyll and photosynthesis production; works with plant enzymes to reduce nitrates before producing proteins. Too much Mg in soil causes Fe deficiency. The blotchy leaf tissue is caused by insufficient chlorophyll synthesis. Plants seem to have very weak vigour due to excess Mn.	-Soil pH > 6.5, High Fe soils, Low N soils, Dry weather and compacted soil. -Gets locked out of soil at pH 2.0-5.0, best absorbed at pH 5.5-6.5. -Gets locked out of Hydro and Soil less Mediums at pH 2.0-4.5, best absorbed in Hydro and Soil less Mediums at pH 5.0-5.6. Best range for hydro and soil less mediums is 5.0 - 6.0.	-Young leaves have spotted (mottled) yellow and / or brown areas. -Dead (Necrotic) yellow spots form on top leaves; lower older leaves have grey specks and / or spots. - Yellowing of leaves with leaf veins staying green. - Production of a chequered effect. As plant gets newer growths, it'll seem to grow away from the problem, making young leaves. -Brown spots on top of leaves; severe areas of the leaves turn brown and wither. Parts Affected by Mg deficiency are: Young leaves.	-Foliar feed with chemical fertilizers containing Mn, or mix with water and wet your plants with it. -Any Chemical / Organic fertilizers having Mg. (mixing ½ strength when using chemical fertilizers to avoid nutrient burn!) -Others are Mn chelate, Mn carbonate, Mn chloride, Mn dioxide, Mn oxide, Mn sulfate, and (all fast absorption). -Garden Manure, Greensand (medium / slow absorption).

and seriously reduce soil fertility (Jones, 1976; Nnadi and Arora, 1985; Pierri, 1989; Juo *et al.*, 1995) Acidification occurs mainly through the loss of exchangeable bases (Ca, Mg. K) during leaching or in Al hydrolysis and nitrification. Thus, in a long term experiment conducted on kaolinitc alfisol in Nigeria, Juo *et al.* (1995) reported that the rates of decline in soil pH and exchangeable Mg under three cropping systems with application of chemical fertilizers (NPK) were continuous maize with NPK without residues >

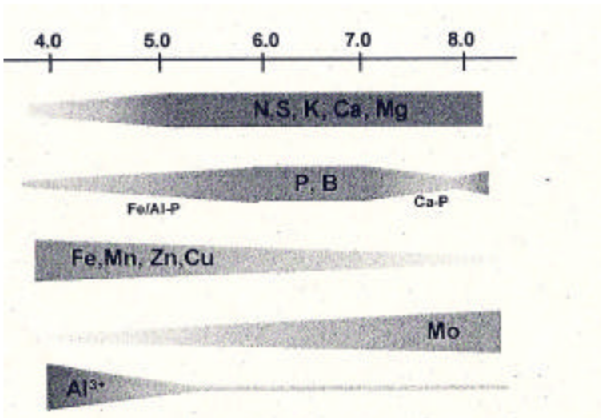

Fig. 1 Influence of the pH-value on the availability of mineral nutrients for plants

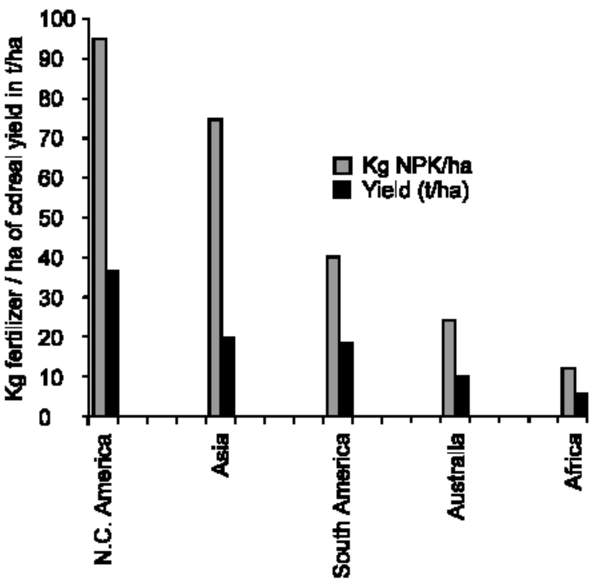

Fig. 2: Consumption of fertilizers and the corresponding cereal yields in different parts of the world (Source: Enzmann *et al.*, 1983)

continuous maize with residues mulch > maize/cassava intercropping. In the developing countries, fertilizers tend to be expensive to the farmers. High prices force the farmers to reduce the amount of fertilizer per hectare since the use of fertilizer depends on the value/cost ratio (Russel, 1947).

In Nigeria, the high prices of fertilizer brought the energy crisis, cost on input and transportation from urban to rural/farm areas, import restrictions and scarcity discouraged farmers from using inorganic fertilizer (Agboola and Omueti, 1982). Fertilizer use at excessive rates has been known to have deleterious effects on crop growth. Examples are the lodging of small grains and the low sugar content from excessive N. Nutritional disorders involving such trace elements as Zn and Fe have also occurred from excessive B (FAO, 1992). Furthermore, chemical fertilizer demonstrates a lethal effect when in contact with a living thing like the worms. Heavy use of N fertilizer is known to be inimical to the activity of symbiotic N fixing organisms such as *Rhizobium sp*. Indeed, fears are being expressed about the contribution of N fertilizer to environmental problem of N pollution of the earth's atmosphere with its oxides resulting in the greenhouse effect (FAO, 1994). However, the environmental effects of the movement of chemicals out of the soil and into the groundwater and of by-products released into the atmosphere need to be looked into critically, particularly as it affects the ecosystem (Kumazawa *et al.*, 2002; Sarka and Siegh, 2002).

Government's withdrawal from the purchase, distribution and acquisition of mineral fertilizers in the 80s led to a sharp drop in fertilizer use (Kwannashie *et al.*, 1977). In recent times, average rates of fertilizer use in Nigeria are about 12 kg nutrients per ha of arable land. Figures of other West African countries are lower (FAO, 1998). In addition to high cost, poor transportation and marketing infrastructure, sabotage and economic crunch, fertilizer availability has been faced with antecedent high prices where available making it to be out of the reach of poor farmers. Manyong *et al.* (2000) in their survey found that less than half of the recommended rate of 120 kg N/ha was applied by farmers in the Northern Guinea Savannah due to problems of availability and cost. Long usage of ammonium sulphate fertilizer has acidifying effect on soils. It is well established that 1 kg of nitrate fertilizer required 1.75 kg calcium carbonate for neutralization (Lombin *et al.*, 1991).

The physico-chemical natures of savannah soils of Nigeria make it imperative for nutrient supplementation in crop production. However, the non-availability and high cost of inorganic fertilizers make the introduction of organic fertilizer to farming a welcome idea.

Organic fertilizers improve soil water holding capacity as well as the CEC and nutrients are released slowly to crop plants. Organic inputs have a number of effects on nutrients availability. They add new organic matter to the soil and contribute to the maintenance of physical fertility, and result in better soil moisture status. Two main functions of organic content in soils are the supply of nutrients and increase in the organic matter content of soils. During the decomposition and mineralization process, part of the residue-carbon ends up in more recalcitrant form, which contribute to the organic matter pool. The significance of organic based fertilizers as suppliers of nutrients to plant growth is determined by the rate of nutrient release; the higher the rate of nutrient release the less the soil organic matter. The slow or gradual release of nutrients by organic fertilizers is called the additive effect of organic fertilizers. This is in contrast to inorganic fertilizers that release nutrients rapidly and may fit the plant demand during the crop growth (Jansen, 1993).

It is almost impossible to meet the crop demand with inorganic fertilizer alone; hence, the use of organo-mineral fertilizer (O.M amended with mineral fertilizer like N.P.K. 15:15:15) to provide as many nutrients as possible through organic fertilizer and complementing it with inorganic nutrients added to the fertilizer. The use of minerals only in the highly weathered soil that has a low C.E.C. has a negative effect on organic matter. Crop yield gradually declines with its continuous use. With a combination of organic and mineral supplements, the organic fertilizer can exhibit its long residual effect and add organic matter to the soil (Palm *et al.,* 1997). The organic fertilizers can improve the efficiency of added mineral fertilizer (Blandari *et al*., 1989).

The optimal combination for effective organic fertilizer addition to soil for good crop growth and development depends on many facts including climate, as well as the chemical and physical properties of the soil. Local available resources to plant (nutrients), the quality of plant residues, nutrient requirement of planted crops, the socio-economic situation of the farmer and the quantity of fertilizer that is readily available to farmers at the required time.

Agboola and Obatolu (1990) reported that composts and farmyard manure constituted the principal sources of nutrients to crops before the advent of inorganic fertilizers and till the early 60's. Similarly, the concept of organo-mineral fertilizer (OMF) is not entirely new. With the present shortage of mineral fertilizers coupled with the total removal of subsidy (since 1997) on them in Nigeria, the quest for sustainable agricultural production is to combine the use of organic and mineral fertilizers.

Conclusion: Sustainability of crop yields, farm profits and environments may forever be attractive while plant nutrition will continue to be a significant factor controlling sustainable crop production systems. Crops are so expensive to produce that nutrient deficiencies should not be allowed to limit their yields. This is far from reality. Acid infertility factors limit crop growth and yield as well as soil productivity in highly weathered soils of humid and sub-humid regions of the world due to deficiency of essential nutrient elements. In using external inputs (chemical fertilizers in particular), ability to discern crop nutritional troubles is a crucial weapon employed through the growers' understanding of signs of hidden hunger. The use of chemical fertilizers (e.g. phosphates) is beyond the reach of most peasant farmers due to procurement difficulties, especially in developing countries of the world. As such, integrated use of different sources of fertilizer nutrients could increasingly become fashionable. However, the level of farmers' awareness of the yield determining (or limiting) factors needs to be improved upon in the various administrative regions of the tropical developing countries if crop production will be sustained and food deficit drastically reduced. This, of course, assumes that the usual discussions among relevant scientists will continuously be encouraged so as to further dissect the important and complex problem of optimum nutrient supply.

References

Agboola, A.A. and C.R. Obatolu, 1990. The use of organic materials to improve the quality of organic matter. Tech. Humid Tropics, CRIN, Ibadan, Nigeria. 2nd African Soil Conf.

Agboola, A.A., G.O. Obigbesan and A.A.A. Fayemi, 1975. Interrelation between organic and mineral fertilizer in the tropical rainforest of Western Nigeria. In organic material fertilizers F.O Bulletin, 27: 337-351.

Agboola, A.A and J.A.I. Omueti, 1982. Soil fertility problem and its management in tropical Africa. In: Proc. Of the Int. Conf. on land clearing and development, 161-162. IITA, Ibadan, Nigeria.

Akinrinde, E.A., 1987. Assessment of the electro-ultra-filtration (EUF) technique for the determination of available soil nutrients. Ph.D Thesis, University of Ibadan, Ibadan, Nigeria.302pp.

Andreini, M., N. van de Giessen, A. van Edig, M. Fosu and W. Andah, 2000. Volta Basin water balance. ZEF Discussion papers on Development Policy No 21. Center for Development Research, Bonn, Germany.

Aweto, A.O., 1981. Organic build-up in fallow soil in some parts of South-western Nigeria and its effect on soil properties. J. Bio-Geog., 8: 64-67.

Barker, A.V., 1999. Plant Nutrients: Deficiency Symptoms. In: Laboratory, Problem Set, and Examination Manual. University of Massachusetts, Amherst, Mass.

Bello, O.S. and E.A. Akinrinde, 2005. Degradation characteristics and management of marginal lands in Nigeria, Africa. J. Soils and Sediments, 5: 125-126.

Blandari, A.L., K.N. Sharma, M.L. Kapur and D.S. Rana, 1989. Supplementation of Nitrogen through green manuring for maize growing. J. Ind. Soc. Soil Sci., 37: 483-486.

Brahic, C., 2006. Fertilizers: 'Key to food crisis in Africa'. SciDev.Net. http://www.scidev.net/ News/ index. cfm (accessed on 20 June 2006).

Braimoh, A.K. and P.L.G. Vlek, 2004. Impact of land cover change on soil properties in northern Ghana. Land Degradation and Development, 15: 57-64.

Braimoh, A.K. and P.L.G. Vlek, 2006. Soil quality and other factors influencing maize yield in northern Ghana. Soil Use and Management. 22: 165-171.

Dorna, J.W., M. Sarranotnio and M. Allebig, 1996. Soil health and sustainability. Advances in Agronomy, 56: 22-45.

Enzmann, J., H. Mutscher and K.J. Michalski, 1983. The role of mineral fertilization and problems of an optimal nutrient supply to tropical crops from the view point of increasing plant production.

F.A.O., 1992. Conversion and rehabilitation of African Land F.A.O. A document presented at F.A.O Regional Conference AIC/90/410/57001, Rome.

F.A.O., 1994. Soil management for sustainable Agriculture and Environmental Protection in the tropics. Land and Water Development. Division Food and Agricultural Organization of United Nation. Visle delle Terme di caracalla, Rome. 00100 Italy. Design, editing and production by words and publication. Oxford. United kingdom.

FAO, 1998. F.A.O. Plant production and Protection Paper.

Griffith, B., 2006. Efficient fertilizer use: Maximum economic yield strategies. http://www.kmag.com/assets/pdf_files/efu/mey.pdf (accessed 9/2/2006).

Hochmuth, G., D. Maynard, C. Vavrina, E. Hanlon and E. Simonne, 2004. Plant Tissue Analysis and Interpretation for Vegetable Crops in Florida. http://www.orst.edu/ dept/ infonet/soilfert.htm (accessed on 5 June 2006).

International Fund for Agricultural Development, 2003. IFAD in Ghana. International Fund for Agricultural Development, Rome.

Jansen, B.H., 1993. Integrated nutrient management: The use of organic and inorganic fertilizers in the use of plant nutrients for sustainable food production in sub-sahara Africa. Van Reuler, H. and Prins, W. H. (eds), pp. 53-68, Ponson.

Jones, M.J., 1976. New recommendation for Nitrogen fertilizers in the Northern States Savanna Agric. Newl 16: 67-73.

Juo, A.S., R.A. Dabiri and K. Franzhiebbers, 1995. Acidification of kaolinitic Alfisol under continuous cropping and Nitrogen Fertilization in West Africa Plant and Soil, 171: 245-253.

Kumazawa, K., K. Yagi, Y. Hosen Cai, F. Ellis, I.M.C. Taggart, M. Roelcke, Zhu and A.R. Mosier, 2002. In: Nitrogen fertilization and nitrate pollution in groundwater in Japan: Present status and measures for sustainable agriculture. International Workshop on Nitrogen fertilization and the environment in East Asia countries, Tsukuba, Japan, 5-6 February 2001. Nutrient cycling in Agroecosystem 2002, 63: 2-3, 129-139.

Kwannashie, M., Garba and I. Ajinlima, 1977. Policy modelling in Agriculture. Testing the response of Agriculture to adjustment policies in Nigeria. AERC Research paper 57 Africa Economic Research Consortium Nairobi, Kenya.

Lombin, L.G., J.A. Adepetu and K.A. Ayotade, 1991. Complementary use of organic manure and inorganic fertilizer in arable crop production. In: Lombin *et al*., (eds.) Organic fertilizer in Nigeria agriculture: Present and Future. Proc. National Organic Fertilizer Seminar held at Kaduna, Nigeria, 26-27 March, 1991, pp. 146-162.

Manyong, V.M., J. Smith, G.K. Webster, S.S. Jagtap and B. Oyewole, 2000. Macro characterization of Agricultural Systems in West Africa. An overview resource.

New Partnership for Africa's Development, NEPAD, 2006. Meeting Africa's food challenge. SciDev.Net. http://www.africafertilizersummit.org/ (accessed on 20 June 2006).

Ngandwe, T., 2006. 'Conservation agriculture' boosts yields and incomes. SciDev.Net. http://www. scidev. net /News/index.cfm

Nnadi, L.A. and Y. Arora, 1985. Effect of nitrogen sources on crop yield on crop yield and soil properties in the savanna In: B.T. Kang and J. Vanderteide (eds.), pp: 223 - 234.

Obigbesan, G.O., 1978. Nutritional problems in root crop production in a tropical country - Nigeria. Journal Beitrage trop. Landwirtsh. Vet. Med., 16: 289-297.

Odhiambo, Z., 2006. African soils being 'mined of life'. SciDev.Net. http://www.scidev.net/News/index. cfm (accessed on 20 June 2006).

Ojating, I., 1997. Role of forestry, folklore, traditional / customary institutions, beliefs and taboos in management and utilization of marginal lands in Nigeria. Proc. SSSN Conf. Sokoto, pp: 23-26.

Palm, C.A., R.J.K. and S.M. Naridwa, 1997. Combined use of organic and inorganic nutrient sources for fertility maintenance and replenishment In: Replenish soil fertility of Africa, R.J Burch, P.A. Sanchez and F. Calroun (ed.) SSSA Special publication 55, 193-217. SSSA, ASA; Washington.

Parr, J.F., R.I. Papendick and D. Colacicco, 1989. Recycling of organic easte for sustainable Bio Agric. 3: 115-130.

Parr, J.F., 1974. Chemical and biological consideration for land application of agricultural and municipal wastes in: organic material as fertilizers. Soil Bulletin F.A.O., 27:227 - 247.

Pierri, 1989. Fertilizer desterres de savanes. Ministered cooperation CIRAD. Paris, France.

Policy, Planning, Monitoring and Evaluation Division, 1991. Agriculture in Ghana: Facts and Figures. Ministry of Food and Agriculture, Accra, Ghana.

Rosegrant, M.W., M.S. Paisner, S. Meijer and J. Witcover, 2001. Global food projections to 2020: emerging trends and alternative futures. International Food Policy Research , Washington, DC.

Russel, M.B., 1947. Method of Measuring soil Structure and duration. Soil Sci., 68: 26-35.

Sarka, A.K. and R.P. Siegh, 2002. In Importance of long-term fertilizers use for sustainable agriculture in Jharkhand. The second International Congress on balancing Food and Environmental Security – A continuing challenge, New Delhi, India, 26-30 November 2002 Fertilizer News 2002; 47: 107 -117.

Shi, T., 2004. Operationalizing sustainability: An emerging eco-philosophy in Chinese ecological agriculture. J. Sustainable Agri., 24: 113-131.

Soil Survey Staff, 1994. Keys to soil taxonomy, 6^{th} edn. USDA-SCS, Government Printing Office, Washington, DC.

USDA, 1978. Improving soil with organic wastes report in response to section 1461 of the F.A.O act of 1977 pp: 95-173.