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 (2): 185-193, 2006
ISSN 1680-5194

Strategies for Improving Crops' Use-Efficiencies of Fertilizer Nutrients in Sustainable Agricultural Systems

Ezekiel Akinkunmi Akinrinde
Department of Agronomy, University of Ibadan, Ibadan, Nigeria

Abstract: 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. Plants can be exposed to wide range of stress factors like toxicity of aluminium and manganese, low pH, limited availability of nutrients (phosphorus, calcium, magnesium, molybdenum and zinc). The genetic potentials of improved cultivars (selected and bred to adapt to acid soils as a strategy to ameliorate these conditions) could further be enhanced by optimum nutrition. This contribution explored the effectiveness of other 'tools' for improving the efficiency of use of native and applied nutrients in the face of increasing fertilizer costs (arising from price subsidy removal in most developing and underdeveloped nations of the world) and the general environmental contamination and/or pollution hazards. In the final analysis, liming as well as the use of vesicular arbuscular mycorrhiza (VAM) fungi and chemical growth substances were particularly highlighted.

Key words: Acid infertility factors, sustainable agriculture, vesicular arbuscular mycorrhiza fungi

Introduction

Prior to the advent of shifting cultivation system of farming, tropical and sub-tropical soils could guarantee sustainable production of important arable/field and permanent/tree crops (maize, *Zea mays*; cowpea, *Vigna unguiculata*; soybean, *Glycine max*; cassava, *Manihot species*; yams, *Dioscorea species*; cacao, *Theobroma cacao*; oil palm, *Elaeis guineenensis*; rubber, *Hevea brasilensis*; and lots more) without external input of nutrients. Currently, however, there is problem of widespread nutrient deficiency, which limits crop uptake, growth and yield due to fixation of nutrients in soils. Most of the plant essential nutrients, especially phosphorus (P) and potassium (K) occur in complex forms in the soil and substantial proportions may be transformed into fixed states, making them relatively unavailable for plants to absorb. More so, most of the soils are acid ($pH \leq 5.5$) in nature; having high aluminium (Al), iron (Fe) and manganese (Mn) ions levels that readily fix nutrient elements in the soils. Soil acidity is common in all regions where precipitation is high enough (about 1500 mm or more) to leach appreciable amounts of exchangeable bases from the surface of the soil (Conyers, 1986). A review of the literature (Oluwatoyinbo *et al*., 2005) showed that acid soils cover about 17 million hectares of land (representing about 18% of total land area) in Nigeria. The Ultisols and Oxisols, particularly have problems associated with Al toxicity, low nutrient status, nutrient imbalance and multiple nutrient deficiencies (Sanchez *et al*., 1997).

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 (Akinrinde *et al*., 2005). The challenge has been to develop sustainable agricultural systems that will reverse the soil acid infertility and consequently boost crop production in such areas.

According to Akinrinde and Okeleye (2005), crops have become so expensive to produce that nutrient deficiencies should not be allowed to limit their yields. However, this goal is far from reality. The use of fertilizers (e.g. phosphates) is beyond the reach of peasant farmers due to procurement difficulties, especially in both under-developed and developing countries of the world. This necessitates research to investigate scientific techniques that can be used to improve nutrient supply to crop. To make fixed nutrient ions available in soil for absorption by plants' roots, the soil could be limed and/or inoculated with vesicular abuscular mycorrizal (VAM) fungi. Chemical growth regulators could also be used to improve the uptake of nutrients and, hence the productivity of the crop. The association between VAM and plants may either be direct or indirect, and are especially believed to be effective in soils with low nutrient (particularly P) availability. The objective set-up for this report was to explicitly explore the causes and implications of soil acidity as well as highlight the effectiveness of the available options for improved activation of fixed soil nutrients in the quest to ensure their availability to crops and guarantee sustainable agricultural development.

Soil acidity, causes and implications: Acid soils have been identified in about 30% of the world's ice-free land area (Haynes and Mokolobate, 2001), occurring in the northern cold temperate belt and the southern tropical belt (Von Uexkull and Mutert, 1995). Agriculture is practiced as semi-subsistence farming in the latter belt, where unlike before, increasing population pressures no longer permit reasonable fallow periods, but forces farmers to manage soil fertility in order to maintain productivity (Myers and De Pauw, 1995). Economic and logistic reasons make it difficult for the resource poor farmers to apply high rates of fertilizer P and / or lime. This situation calls for the development of other practicable alternatives. A number of workers have shown that the addition of green manures and animal wastes to acid soils can reduce Al toxicity and increase crop yields (Berek *et al.*, 1995; Hue, 1992; Haynes and Mokolobate, 2001). Incorporation of organic residues can increase P uptake and crop growth on P deficient soils (Hue *et al.*, 1994). Roots of some crop species (including *V. unguiculata*) have also been reported to have the capability of developing certain adaptation mechanisms (exudation of exudates, protons, bicarbonates, ecto-enzymes, or association with micorrhiza or cluster root formation) in acid soil conditions in order to solubilize sparingly soluble P forms (Neumann and Martinoia, 2002; Obigbesan *et al.,* 2002).

In recent times, industrial pollution, resulting in leaching with acid rainfall, and nitrification following applications of nitrogenous fertilizers have further aggravated acidification problem and caused it to be of more concern (Haynes and Mokolobate, 2001). Deficiencies of nutrients (such as P, Ca and Mg) coupled with the presence of phyto-toxic substances (like soluble Al and Mn) are responsible for fertility limitation of acid soils.

According to Abruna-Rodriguez *et al.* (1982) poor growth in acid soils could be related directly to Al saturation (the percentage of effective CEC occupied by exchangeable Al). The element is 15% of the earth's crust and together with silicon makes up the lattices of primary and secondary clay minerals. It is, therefore, of great significance in soils though its solubility is quite low in neutral and alkaline soils on which it has no effect on plant growth. In acid soils, Al toxicity limits plant growth due to series of chemical factors and interactions such as the toxicities of H, Al and Mn (caused by increased concentration of each of these elements), deficiencies of Mg, Ca and K (due to decreases in macro nutrient cation concentration), deficiencies of P and Mo (due to decreasing solubility) as well as general nutrient deficiencies, drought stress and increased nutrient leaching that causes root growth inhibition and impairment of water and nutrient uptake (Marschner, 1991).

The low P status of highly weathered acid soils is also worrisome as large amounts of fertilizer P need to be applied in order to raise the available P to an adequate level (Sanchez and Uehara, 1980). This is because such soils contain large quantities of Al and Fe hydrous oxides that have the ability to adsorb P onto their surfaces and much of the added P is 'fixed' instead of being made available for crop use. The general nutrient deficiency, drought stress and increased nutrient leaching cause root growth inhibition as well as impair water and nutrient uptake. The toxicity of Al is among the most widespread ion-toxicity problems or stress conditions in plants and is the major limitation to crop performance on acid soils prevalent in tropical climates. As such, in combination with general nutrient (particularly P and Ca) use efficiency, Al tolerance is a fundamental trait for plants to fit into sustainable systems of crop production on acid soils (Foy *et al.*, 1974; Baligar and Fageria, 1997). The use of this integrated approach of combining the use of acid tolerant genotypes with the optimization of nutrient cycling in soil is a focal point for the improvement of food production in humid tropical Africa and the sub-humid Brazilian savannah cerrado (Sanchez, 1997). The restriction of plant growth by excess soluble Al in acid soils may arise from either the direct inhibition of nutrient uptake or disturbance of root cell functions (Kochian, 1995). The tolerance to high Al concentrations by indigenous plants of acid soils can be due to the mechanisms of Al exclusion from root cells and/or intrinsic tolerance to the element (Cuenca *et al.*, 1990). Aluminium accumulator plants are mostly woody plants in tropical acid soils (Haridsan, 1982; Osaki *et al.*, 1995; Geoghegan and Sprent, 1996) and can contain more than 1,000 mg Al kg^{-1} dry matter.

Soil nutrient availability: Cheng *et al.* (1999) indicated that up to 98 % of P and K might be unavailable for crop use, resulting in low yield of crops. The amount of a specific fertilizer material required to raise soil nutrient level by one unit depends on the soil group and is determined largely by the exchange capacity (cation exchange capacity, CEC for cations and anion sorption capacity, ASC for anions) and the soil bulk density. Thus, for P, the higher the soil P retention the more the amount of fertilizer P that would be required to increase the available (Bray-1) P by one unit. This is, of course, the reason why higher capital P inputs are required during the developmental phase on an acid soil, relative to say, a soil of almost neutral reaction.

Phosphorus: The total P contents of most Alfisols and Ultisols are known to be low (ranging from 68 to 788 mg kg^{-1}) (Bates and Baker, 1960; Enwezor and Moore, 1966; Udo and Uzu, 1972; Udo and Dambo, 1979). On the whole, Ultisols contain more total P (about 430 mg kg^{-1}) than Alfisols with average content of 189 mg kg^{-1}. The higher values for the Ultisols may be due to the higher contributions from organic matter, which is higher in Ultisols than in Alfisols.

The generally low total-P in these soils may be attributed to the low amounts contained in parent materials from which they have been formed. The total P amounts in Alfisols and Ultisols are low compared with the high values found in Entisols, Oxisols and Inceptisols formed on alluvium basalt and shale (Ibedu, 1982).

Total P gives indication of total reserve of the nutrient in the soil but it is a poor indicator of the availability level since most of the P may be fixed. The soil P status is therefore more readily assessed from the relative abundance of the different forms. The soil P is found in two major forms, the organic and inorganic forms.

The organic fraction is important in the tropics as it readily mineralizes to release available P for the plant. In contrast, inorganic P forms may be fixed and made unavailable to plants. In hydromophic soils where decomposition rate of organic matter is low, organic P may also not be considered significant in contributing to P availability.

The organic P is related to organic carbon and total P in Alfisols and Ultisols (Udo and Dambo, 1979), indicating the contribution of organic P to total P content in these soils. Tisdale and Nelson (1956) also showed that almost in all cases, the organic P/Organic C ratio is less than 200, a situation that would lead to mineralization of organic P and eventual release of available P in organic matter.

The chemistry of organic P in the soil is rather complex. The relative abundance of the various forms depends on such factor as pH, activities of ions like Al, Fe and Mn, and the presence of sesquioxide, calcium carbonate and the degree of weathering of the soils. Inorganic P may exist in soil as discrete minerals like fluorapatities or as hydrophophates such as dufrenite, wavellite, strengnite and variscite. It may also occur as oxides of Fe and Al, which readily adsorb P from soil solution, especially in acid soils.

The nature of P compounds in the soil determines the relative abundance of aluminium bound P (A1-P), calcium – bound P (Ca), Iron – bound P (Fe-P) and occluded P (OCC-P). The first three are regarded as active P as they are the main sources of the readily available P. The OCC-P is P occluded within the oxides of Fe and A1 that is largely unavailable to plants. The Ultisols have higher percentages of active P and lower amounts of occluded P than Alfisols. This is an indication that Ultisols have a higher fraction of total P in the available form than the Alfisols. This is attributable to the fact that higher acidity of Ultisols favours the formation of Al –P relative to Fe-P. The Al-P has been found to be more available than Fe-P for upland crops in acid soils (Smith, 1965) since Al-P has the lower rate of crystallization than Fe-P (Juo and Ellis, 1968). Thus, in the final analysis, the Ultisols have more available P than Alfisols.

Estimation of available phosphorus: Attempts have been made to evaluate critical P-levels in soils based on different soil testing methods. Results indicted that for both greenhouse and field experiments, critical levels are approximately the same for Alfisols and Ultisols; being between 10 and 17 mg kg^{-1} with an average of about 12 mg kg^{-1} (Udo and Uzu, 1972).

In general, most virgin Ultisols have values above the critical range while majority of Alfisols have values below it, arising from the higher amounts of active organic P in the former then in the latter.

Forms of potassium ions in soil: There are four pools of K in soils – They are soil solution K, exchangeable K, fixed or non-exchangeable K and K within the lattice of some primary minerals.

The amount of each fraction varies, depending on cropping history, as well as chemical fertilizer or organic manure application.

According to Golakiya *et al.* (2001) soluble-K content of some calcerous soils in India ranges between 0.03 and 0.21cmol kg^{-1} soil, whereas exchangeable K varies from 0.03 to 2.00 and non-exchangeable or fixed K varies from 0.32 to 21.7. Warren and Johnston (1962) found for a particular soil type that for soils with exchangeable K above 170 mg kg^{-1}, about 15% of the exchangeable K is water – soluble.

Potassium ions released from the exchangeable and non-exchangeable pools replenish the ones that might have been either removed by plant uptake or leached into the subsoil. The release of K from both pools to the soil solution, can take place concurrently. The most important thing, however, is for the K in the soil solution to be replenished so as to meet the crop demand. When there is surplus K in the soil solution (especially following the addition of fertilizer) the element is transferred to the exchangeable and non-exchangeable fractions through exchange and fixation processes.

Johnston and Mitchell (1974), observed that K^- from the non – exchangeable pool was twice the amount taken from the exchangeable fraction, suggesting that there was an equilibrium between the K in the exchangeable and non exchangeable pools. Nevertheless, it was proposed that the ratio of K released from these two fractions might differ based on the type of clay minerals and their degree of weathering. It is also possible that K in the non – exchangeable pool is of importance for crops (e.g. potato) with restricted root systems. The smaller the root density, the higher should be the concentration of K in the soil solution to sustain a particular K uptake rate (Johnston and Krauss, 1998). Cheng Mingfang *et al.* (1999) estimated the rate of K to be 5 to 9 mg K kg^{-1} soil per minute from the exchangeable fraction and only 0.1 to 0.5 mg K kg^{-1} soil per minute from the non – exchangeable fraction in soils from North China. Thus, the more the plant depends on K released from the non – exchangeable fraction the lower would be the yield assuming that only small amounts of K are in this form. The K concentration in the soil solution also depends very much on the K saturation of the exchange complex and on the nature of the clay minerals (Mutscher, 1995).

Effect of liming acid soils: Liming is an ancient agricultural practice for rehabilitating acid soils. It continues to be accepted as an essential step to effective agricultural production in several areas of the humid tropics. The overall effects of lime on soils include among others, increased soil pH, Ca and Mg saturation, neutralization of toxic concentrations of aluminium, increase in pH dependent CEC resulting in absorption and hydrolysis of Ca^{2+} (Mg^{2+}), increase in P availability and improved nutrient uptake by plants (Nicholaides *et al.*, 1983; Oguntoyinbo *et al.*, 1996). Kamprath and Foy (1971) reported that liming effect on P availability of highly weathered soils varied from favourable to detrimental. Liming to pH 7, however, drastically reduced P uptake from acid, aluminous Latosols. Neutralization of exchangeable Al reduced by 50% the P fertilizer required for optimum growth on North Carolina soils. However, liming had an effect on P uptake when initial pH was 5.8. Very little response was obtained from 80 ppm P for Oxisol in Natal, until liming neutralized exchangeable Al. Similar result was obtained with an Oxisol from Colombia (Amasiri and Olsen, 1973).

In an incubation study, Lelei *et al.*, (2000) reported that there was significant difference between lime, TSP, urea and control. In descending order, N mineralization was as follows: lime > control > TSP > urea. Likewise, P mineralization followed the order: TSP >control > lime > urea. They concluded that liming and P application enhanced soil N and P mineralization, respectively while urea retarded both.

Lime application was reported to induce significant difference in nodule dry weight and grain yield with small response obtained from shoot dry matter production compared to control in soil with pH of 3.7 (IITA, 1978). This was attributed to the ameliorating effect of lime on the soil.

Labios *et al.* (1995) while testing varying levels of inorganic fertilizer in combination with or without organic fertilizer, reported no significant difference in grain yield due to fertilizer levels for 3 cropping seasons. However, there was significant difference on yield due to varietal effects for the first and second year. He concluded that an alternative to full application of inorganic fertilizer would be to combine half the recommended fertilizer rate plus organic fertilizer, since same yield is obtained with less fertilizer input. He stated that this combination could sustain the nutrient required by the maize plant. This would translate to higher output from low fertilizer input and also, the soil quality will be improved with increase in soil microbial activity.

Liming in combination with other materials: Wambeke (1992) reported the inefficiency in liming alone to obtain plant response in nutrient deficient soils. In a liming experiment, Morrison *et al.* (1989) reported double control yield of 1000 kg ha^{-1} maize for soils with high organic matter and lime while plots with fertilizer plus lime treatment, had 3-4 times yield of lime plus organic matter plots.

Friensen *et al.* (1982) found that lime applications at low rates were required to sustain yield. Lime application at the rate of 0.5 t ha^{-1} powdered Ca $(OH)_2$ was reported to maintain near maximum maize yield for two years after lime application while lime applied at the rate of 2 t ha^{-1} Ca $(OH)_2$ could sustain yield for over five years. Leaching loses of Ca in lime treated plots after 3 years of lime application were attributed to the presence of acidifying N fertilizer as most of the Ca migrated with $NO_3^-$and Cl^- anions, but no pH change was reported Wambeke (1992).

For several crops, liming results in some chemical changes in the soil such as, increase in pH effective cation exchange capacity (ECEC), and exchangeable Ca, decrease in toxic elements for example Al^{3+} and Mn^{2+} and changes in the proportion of basic cations in CEC sites. Available results on the effect of liming on soil physical attributes are controversial.

Vesicular arbuscular mycorrhizal (VAM) fungi and supply of nutrients to crops: For more than two decades now, investigations have increasingly revealed the role of symbionts like VAM fungi. Besides being noted for guaranteeing the availability of plant nutrients (especially phosphates) in soil and subsequent plant roots' absorption of the nutrients (Sieverding, 1981), they are also known in the biological control of root pathogens, and the improvement of drought tolerance of plants (Osinubi *et al.*, 1992) and increasing crop yield (Taiwo and Adegbite, 2001).

Mycorrhiza is a term used to denote the unique structure formed by the interaction of the roots of higher plants and the fungal mycelium (Tate, 1995). The vesicular-Arbuscular mycorrhiza (VAM) is formed by certain fungal species of the family endogonaceae identifiable by their characteristic spores and structures formed on the external hyphae, which can initiate mycorrhiza associations (Werner, 1992). Mycorrhiza is found throughout the world, and is known to be beneficial to plants. They commonly associate with almost all plant species of agricultural importance. VAM are of the highest spread, and occur on more plant species than any other mycorrhiza (Werner, 1992).

Vesicular arbuscular mycorrhizal (VAM) infection enhances the uptake of nutrients (especially phosphorus) by crops (Osinubi *et al*., 1992; Atayese and Laisu, 2001). However, Harley and smith (1983) reported that P uptake still depends on the soil phosphorus content.

Smith (1965) compared the increase in plant growth that was due to phosphate and cation uptake in mycorrihizal and non-mycrrhizal clover (*Triphium subternaeum*) and observed improved growth in plants with VAM but with low P supply. The roots of VAM treated plants were able to exploit a greater volume of soil resulting in the release of a greater amount of phosphate into the soil solution. Mycorrhiza can, therefore be taken as ensuring nutrient uptake from the available nutrient pool. Smith (1965) concluded that mycorrhiza fungi directly increased the rate of phosphate uptake by roots over a range of soil phosphorus level, even when mycorrhiza growth has seized.

Significant higher nitrogen concentrations have also been reported in mycorrhiza inoculated plants than in non-mycrrhizal plant, suggesting that VAM hyphae can use N forms that are less available to non- mycorrhizal plants (Taiwo and Adegbite, 2001). Mycorrhizal infection may also increase the rate of nodulation and N-fixation by rhizobium in leguminous plants (Akobsen and Jensen, 1992).

Vesicular arbuscular mychorrhiza (VAM) fungi are also believed to be capable of increasing the uptake of other nutrients, except K (Harley and Smith, 1983). Benthtenfalray and Franson (1989) observed that inoculating apple plants with VAM fungi was able to correct Zn deficiency. On the other hand, Arines *et al.* (1990) observed that VAM inoculation depressed the uptake of Mn by red clover plant roots, thereby reducing the likelihood of Mn toxicity. This may be attributed to enhanced-P nutrition of the mycorrhiza-inoculated plants. VAM infection has also been shown to improve water relations to *Faidberbia albida* seedling (Osinubi *et al*., 1992) and weed cover (Atayese and Laisu, 2001). Increased biomass production by VAM inoculated-plants has also been reported (Mosses and Hayman, 1977; Taiwo and Adegbite, 2001). They obtained highly significant correlation between dry matter production and percent mean infection of mycorrhizal plants relative to non-mycorrhizal plants.

Role of chemical growth substances in crop production: The need for efficient use of fertilizer nutrients by crops has also necessitated studying the relationship between plants' hormonal regulation and absorption of nutrients for growth and yield. Such studies could assist in developing new fertilizer types for the various major essential nutrient elements. Kim *et al.* (2003) reported a significant yield increase of tuber crops due to gibberellic acid, megiquant chloride and trinexapac ethyl applications. Ancymidol and chlormequat also increased rice grain yield while plant height was reduced at half-life but not at maturity (Akinrinde, 2006). Growth promoting diazotrophs were similarly noted to enhance growth and development of crops by transferring fixed N or by improving uptake of nutrients through nodulation or hormone linked phenomena in inoculated plants (Biswas *et al*., 2000).

The naturally occurring organic substances, which are usually produced in glands, effective at low concentrations and which may be active at sites far from their origin are referred to as 'hormones' while the term 'growth regulator' include all naturally occurring and synthetically produced substances that may be used to increase or decrease plant growth and development (Janick, 1979). Plant growth retardants (often called gibberellins) control shoot growth by in the production of gibberellins that are responsible for cell elongation of and leaves (Barrett *et al*., 2004)

Growth hormones participate in both genetic and environmental control of growth and differentiation (Wareing and Phillips, 1970). The pattern of distribution of growth hormones in the plant is controlled by the intercation of environment and genetic factors (Wareing and Phillips, 1970). They may be either growth inhibitors or promoters, depending on the site of action as well as their concentrations. The auxins, cytokinins, gibberellins, abscisic acid and ethylene are known. Auxins are the growth hormones produced in virtually, all higher plants, especially in the meristematic tissues of stem and root apices, young developing leaves, flowers and fruits (Wareing and Phillips, 1970). The highest rate of auxin biosynthesis is in the shoot apical region. Auxin is transported downward, causing a concentration gradient in various plant parts. Janick (1979) found that the concentration of auxins correlated with the inhibition and stimulation of growth as well as differentiation of organs and tissues.

Auxins are known to influence growth of plants in various ways such as cell enlargement and elongation, phototropism, geotropism, apical dominance, abscission of plant parts, flower initiation and development, root initiation, fruit set and growth, tuber and bulb formation, and seed germination. Commercially synthesized auxins are used to initiate adventitious roots from cuttings. Indole-butyric acid, indole-proprionic acid and naphthalene acetic acid are examples of synthetic auxins applied to the bases of stem cuttings to stimulate the initiation of adventitious roots (Hartman *et al*., 1981).

Another synthetic auxin, (2, 4-dichlorophenoxyacetic acid, 2, 4-D), is commonly used as a selective herbicide against broadleaf weeds. Some auxins are also used to increase fruit set. The use of 4-chloro-phenoxyacetic acid to increase blossom and fruit set in tomatoes has also been successful. Auxins are also commonly used in tissue culture procedures to initiate rooting in explants or callus (Hartman *et al*., 1981).

Gibberellins are a group of naturally occurring plant hormones causing cell enlargement and division, which leads to stem internode's elongation. They have a dwarf reversing response, allowing certain dwarf cultivars to grow to normal height. They affect many developmental processes, particularly those controlled by temperature and light like seed and plant dormancy, germination, seed stalk and fruit development (Janick, 1979). Gibberellins are used commercially to increase fruit size of some seedless grape varieties. They are applied at fruit set or shortly thereafter. They also promote male flower initiation in cucumbers when pollen is wanted for hybrid seed production and may overcome the cold requirement for flowering of some perennial plants (Hartman *et al*., 1981).

Hartman *et al*. (1981) also found out that Cytokinins primarily promote cell division but they also influence cell enlargement, tissue differentiation, dormancy, phases of flowering and fruiting and retardation of leaf senescence (Hartman *et al*., 1981).

Cytokinins and auxins may interactively affect tissue differentiation. A high auxin cytokinin ratio stimulates root development, whereas very low ratios stimulate bud development and their equal concentrations results in undifferentiated tissue or callus (Janick, 1979). Cytokinins are not commonly used in agriculture; but commonly used in tissue culture to induce shoot development (Hartman *et al*., 1981).

Ethylene is a gas that diffuses readily throughout the plant. It is produced in meristematic tissues, ripening fruits, senescing flowers and fruits and germinating seeds. The cuticular coating of the plant tends to prevent losses from the plant (Hartman *et al*., 1981).

Synthetic ethylene-releasing compounds such as ethephon have several valuable commercial applications. Ethephon is used to ripen bananas, pineapples, melons and tomatoes, and when applied as a pre-harvest spray, it promotes uniform ripening of apples, cherries and pineapple. It is used to increase the production of female flowers on cucumbers, which develop fruits and increase yields. High concentrations of ethylene may be harmful to plants, inducing leaf abscission and hastening senescence of flowers and fruits (Hartman *et al.,* 1981).

Abscisic acid interacts with other hormones in the plant, counteracting their growth-promoting effects. It inhibits rather than stimulates plant growth. Abscisic acid promotes dormancy in seeds and is involved in leaf and fruit abscision. The abscisic acid content of leaves increases following water stress, where it induces closure of the stomata (Hartman *et al.,* 1981). Abscisic acid is expensive to synthesize and no commercial applications are as yet in use.

Generally, greenhouse growers and nurserymen commonly use growth retardants in managing plant growth. Many synthetic compounds are available to dwarf plants, increase branching and manage flowering to produce compact flowering plants in a timely manner. Use of growth retardants is specific by species and desired result.

The effects of the interaction between the essential nutrients (indigenous to soil or applied by fertilizers) and hormones have also been enumerated (Hartman *et al*., 1981). The nutrients can influence the functioning of hormones and vice versa. For example, calcium has a positive influence while N has a negative influence on plant hormones. Similarly, hormones can speed up plant's metabolism and cause chemical fertilizers to be efficiently used, implying that less fertilizer would be needed when hormones are adequately supplied. Given appropriate combinations of nutrients and hormones, growth and yield of crops influence would be much better. Hormone treatment of seed and plants, therefore is perhaps even more important than hybrid seed development. The full genetic potential of existing seed is achieved and yields are vastly improved. It is important to note that the cutting down of macro nutrients, as presently being used, will result in savings that offset the expense incurred in hormone treatment and micronutrient supply. Improved yields will more than compensate for the expense and efforts expended.

Micro nutrients and hormones are naturally occurring elements and compounds. Thus, the use of these elements and compounds are environmentally safe and highly desirable. It is important to note that hormone use in plants is not similar to indiscriminate use of hormones in Poultry Production. The hormones suggested for use with plants are only those that would be normally produced by the plant itself.

Conclusion: In the face of increasing fertilizer costs, finite resources as well as environmental contamination and/or pollution hazards, the use-efficiency of applied nutrients should be improved. Possibilities for the improvement include liming of acid soils, use of vesicular arbuscular mycorrhiza (VAM) fungi and use of chemical growth substances. The mechanism for the activation of fixed nutrients (particularly P and K) by mycorrhiza fungi needs to be further dissected. Crop response to the interaction effect of lime and fertilizers in acid soils and the relationship between crop uptake of the various essential nutrients and the natural (internal) or synthesized (external) plant hormones should also be evaluated.

Acknowledgement

Literature references from Adebusayo Onanuga supplied useful information on PGRs and VAM fungi.

References

Abruna-Rodriguez, F., J. Vicente-Chandler, E. Rivers, J. Rodriguez, 1982. Effect of soil acidity factors on yields and foliar composition of tropical root crops. Soil Sci. Soc. Am. J., 46: 1004-1007.

Akinrinde, E.A. and K.A. Okeleye, 2005. Short and long term effects of sparingly soluble phosphates on crop production in two contrasting Nigerian alfisols. W. Afr. J. Appl. Ecol., 8: 141-150.

Akinrinde, E.A., O.S. Bello, K.O. Ayegboyin and L. Iroh, 2005. Added benefits of combined organic and mineral phosphate fertilizers applied to maize and melon. J. Food Agri. Environ., 3: 75-80.

Akinrinde, E.A., 2006. Growth regulator and nitrogen fertilization effects on performance and nitrogen-use efficiency of tall and dwarf varieties of rice (*Oryza sativa* L.). Biotec. (accepted for publication).

Akobsen, J.I. and E.S. Jensen, 1992. Hyphal transport of 15 N-Labelled nitrogen by vesicular arbuscular mycorrhizal fungus and its effect on depletion of inorganic soil N. New Phytol., 122: 281-282.

Amasiri, A.S. and B.O. Olsen, 1973. Liming as related to solubility of phosphorus and plant growth in an acid tropical soil. Soil Sci. Soc. Am. Proc., 37: 716-721.

Arines, J.J., 1990. Effect of VAM fungi on Mn uptake by red clover. Agri. Ecosys. Environ., 29: 1-4.

Atayese, M.O. and M.O. Laisu, 2001. Arbuscular mycorrhizal fungi, weeds and earthworm interactions in the restoration of soil fertility in the Guinea Savannah region of Nigeria. Moor J. Agri. Res., 2: 103-109.

Baligar V.C. and N.K. Fageria, 1997. Nutrient use efficiency in acid soils: Nutrient Management and Plant use Efficiency. In: Moniz, A. C., Furlani, A. M. C., Schaffert, R. E., Fageria, N. K., Rosolem, C. A. and Cantarella, H. (eds.). Plant- Soil interactions at low soil pH: Sustainable Agriculture and Forestry Production. Brazilian Soil Science Society, Campians, Brazil, pp: 75-95.

Barrett, J.E., C.A. Bartuska, J.B. Million, R.K. Schoellhom, D.G. Clark and T.A. Netl, 2004. The development of plant growth regulators for nursery and greenhouse crops. Quarterly reports on plant growth regulation and activities of the plant growth regulation Society of America (PGRSA), 32: 40.

Bates, J.A.R. and T.C.N. Baker, 1960. Studies on Nigeria soil. J. Soil Sci., 11: 25-26.

Berek, A.K., B. Radjagukguk and A. Maas, 1995. The effect of different organic materials on the alleviation of Al toxicity in soybean on a red-yellow podzolic soil. In: Date, R A; Grundon, N J; Rayment G E; Probert, M E (eds) Plant-soil interactions at low pH: Principles and management, pp: 579-584. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Bethtenfalray, G.J. and L. Franson, 1989. Manganese toxicity alleviated by mycorrhizal in soybean. J. Plant Nutr., 12: 953-970.

Biswas, J.C., J.K. Ladha and F.B. Dazzo, 2000. Rhizobia Inoculation improves nutrient uptake and growth of lowland rice. Soil Sci. Soc. Am. J., 64: 1644-1650.

Cheng Mingfang, Jin Jiyun and Huang Shaowen, 1999. Release of native and non-exchangeable soil potassium and adsorption in selected soils of North China. Better Crops Int., 13: 3-5.

Conyers, M., 1986. The relationship between average annual rainfall exchangeable aluminum in soils of South Eastern New South Wales. Aust. J. Exp. Agri., 26: 587-590.

Cuenca, G., R. Herrera and E. Medina, 1990. Aluminium tolerance in trees of a tropical forest. Plant Soil, 125: 169-175.

Enwezor, W.O. and A.W. Moore, 1966. Phosphorus status in some Nigerian soils. Soil Sci., 102: 322-328.

Foy, C.D., H.N. Laferer, J. Schwartz and J.W. Fleming, 1974. Aluminium tolerance of wheat cultivars related to region of origin. Agron. J., 66: 751-758.

Friensen, D.K., A.S.R. Juo and M.H. Miller, 1982. Residual effects of lime and leaching of Ca in a kaolinitic Ultisol in the high rainfall tropics, Soil Sci. Soc. Am. J., 46: 1184-1189.

Geoghegan, I.E. and J.I. Sprent, 1996. Aluminium and nutrient concentrations in species native to central Brazil. Soil Sci. Plant Anal., 27: 2925-2934.

Golakiya, B.A., J.D. Gundalia and K.B. Polara, 2001. Potassium dynamics in the soils of Saurashtra. Poster at the IPI-PRII International Symposium on the "Importance of potassium in nutrient management for sustainable crop production in Inida", 3-5 December, 2001, New Delhi, India.

Haridsan, M., 1982. Aluminium accumulation by some cerrado native species of central Brazil. Plant Soil, 65: 265-273.

Hartman, H.T., W.J. Flocker and A.M. Kofranck, 1981. Plant Science Growth, Development and Utilization of Cultivated Plants. Prentice-Hall, Inc., pp: 676.

Harley, J.L. and S.E. Smith, 1983. Mycorrhizal Symbiosis. Academic Press, London.

Haynes, R.J., M.S. Mokolobate, 2001. Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanisms involved. Nutrient Cycling in Agroecosystems, 59: 47-63.

Hue, N.V., H. Ikawa and J.A. Silva, 1994. Increasing plant-available phosphorus in an Ultisol with yard-waste compost. Commun. Soil Sci. Plant Anal., 25: 3291-3303.

Hue, N.V., 1992. Correcting soil acidity of a highly weathered Ultisol with chicken manure and sewage sludge. Commun. Soil Sci. Plant Anal., 23: 241-264.

Ibedun, M.O., 1982. Phosphorus status of some saline and non-saline hydromorphic soils from the Niger Delta of Nigeria. Unpublished M.Sc. Thesis Department of Agronomy, University of Ibadan, Ibadan, Nigeria.

International Institute of Tropical Agriculture ,IITA, 1978. Annual report II 5A, Ibadan, Nigeria.

Janick, J., 1979. Horticulture Science. W.H. Freeman and Company, San Francisco, pp: 608.

Johnston, A.E. and A. Krauss, 1998. The essential role of potassium in diverse cropping systems: Future research needs and benefits. *In*: Johnston A. E. (Ed) "Essential Role of Potassium in Diverse Cropping Systems'. International Potash Institute, Basel, Switzerland, pp: 101-120.

Johnston, A.E. and J.D.D. Mitchell, 1974. The behavior of K remaining in soils from the Agdell experiment at Rothamsted, the results of intensive cropping in pot experiments and their relation to soil analysis and the results of field experiments. Rothamsted Experimental Station Report for 1973, Part 2, 74-97.

Juo, A.R.S. and B.G. Ellis, 1968. Chemical and physical properties of iron and Aluminium phosphates and their relation to phosphorus availability soil Science Soc. Am. Proc., 32: 216-221.

Kamprath, E.J. and C.D. Foy, 1971. Lime-fertilizer-plant interactions in an acid soil. In: Fertilizer Technology and Uses. Olsen, R.A., T.J. Army, J.J. Hanway and V.J. Kilmer (Eds.). Soil Sci. Soc. Am., Madison, Wisc., pp: 105-151.

Kim, S.K., S.C. Lee, B.H. Lee, H.J. Choi, K.U. Kim and I.J. Lee, 2003. Bulbil formation and yield responses of Chinese yam to application of Gibberlic acid, mepiquat chloride and Trinexapac-ethyl. J. Agron., 189: 225.

Kochian, L.V., 1995. Cellular mechanisms of aluminium toxicity and resistance in plants. Plant Mol. Biol., 46: 237-260.

Labios, R.V., J.D. Labios, M.Q. Esguerra, L.L. Tamisin and R.C. Cambaya, 1995. Conservation farming for small holders to sustain corn productivity. In: World Congress on Conservation Agriculture, Aug., 11-15, Vol. II: 121-123.

Lelei, J.J., B.O. Mochoge and R.N. Onwonga, 2000. Effect of lime, urea, TSP on nitrogen and phosphorus mineralization in an acid soil during incubation. Afr. Crop Sci. J., 8: 327-336.

Marschner, H., 1991. Mechanism of adaptation of plants to acid soils. Plant Soil, 134: 1-20.

Mosses, B. and D.S. Hayman, 1971. Plant growth responses on VAM in Unsterilized field soils. New phytologist, 70: 29-34.

Morrison, R.J., P. Gangaiya and Y.W. Sing, 1989. Amelioration of soil acidity and the impact on the productivity of some highly weathered "Fijian soils" in soil management and small holder development in the Pacific islands, IBSRAM Proceedings, No. 8, Bangkok, Thailand.

Mutscher, H., 1995. Measurement and assessment of soil potassium. IPI Research Topics No. 4 (revised version), International Potash Institute Basel, Switzerland, 102 pp.

Myers, R.J.K., E. De Pauw, 1995. Strategies for the management of soil acidity.

Neumann, G. and Martinoia, 2002. Detection of root-induced Al-complexation by Aluminon staining in *Lupinus lutus*. Trends in Plant Sci., 7: 162-167.

Nicholaides, J.J., P.A. Sanchez and S.W. Buol, 1983. Proposal for the Oxisol-Ultisol. Network of IBSRAM. Raleigh, North Carolina State University, pp: 16.

Obigbesan, G.O., G. Neumann and V. Roemheld, 2002. Root growth responses and rhizosphere pH changes by cowpea genotypes grown in a phosphorus-deficient acid soil. Paper presented at the Annual Conference, Deutsche Gesellschaft fuer Pflanzenernaehrung. Weihenstephan, 2002.

Oguntoyinbo, F.I., E.A. Aduayi and R.A. Sobulo, 1996. Effectiveness of some local liming materials in Nigeria as ameliorant of soil acidity. J. Plant Nutr., 19: 999-1016.

Oluwatoyinbo, F.I., M.O. Akande and J.A. Adediran, 2005. Response of okra (*Abelmoschus esculentus*) to lime and phosphorus fertilization in an acid soil. World J. Agri. Sci., 1: 178-183.

Osaki, M.S., C. Sittibush and T. Nuyim, 1995. Nutritional characteristics of wild plants grown in peat and acid sulfate soils distributed in Thailand and Malaysia. In: Vijarsorn, K., Suzuli, K., Kyuma, E., Wada, T., Nagano, Takai, Y. (eds.). A tropical swamp forest ecosystem and its green gas emission. Nodai Research Institute, Tokyo Univ. of Agric., Tokyo.

Osinubi, O., O.N. Bakare and K. Mulongoy, 1992. Interaction between drought stress and vesicular arbuscular mycorrhiza on growth of faid herbia Albida (Syn Acacia albida) and Acacia nilotica in sterile and non sterile soils. Bio. Fert. Soils, 14: 159-165.

Sanchez, P.A. and G. Uehara, 1980. Management considerations for acid soils with high phosphorus fixation capacity. In: Khasawneh F. E., Sample E. C, Kamprath E. J.(eds) The role of phosphorus in agriculture, pp: 263-310. Am. Soc. Agron. Madison, Wisconsin.

Wambeke, A.V., 1992. Soils of the tropics. Properties and Appraisal. Mcgraw-Hall Incorporation, pp: 163-173.

Sanchez, P.A., 1997. Changing tropical soil fertility paradigms: from Brazil to Africa and back. In: Moniz, A. C., Furlani, A. M. C., Schaffert, R. E., Fageria, N. K., Rosolem, C. A. and Cantarella, H. (eds.). Plant- Soil interactions at low soil pH: Sustainable Agriculture and Forestry Production. Brazilian Soil Science Society, Campians, Brazil, pp: 19-28.

Sanchez, P.A., E.R. Stoner and E.D. Pushparajah, 1987. Management of acid tropical soils for sustainable agriculture. Proceeding of IBSRAM Inaugural workshop. Bangkok Thailand, pp: 107.

Sieverding, E., 1981. Ecology of VAM fungi in tropic agro system. Agri. Ecosys. Environ., 29: 369-390.

Smith, A.N., 1965. The supply of soluble phosphorus to the wheat plant from inorganic soil phosphorus. Plant and Soil, 23: 314-316.

Taiwo, L.B. and A.A. Adegbite, 2001. Effect of arbuscular mycorrhizal and Braadyrhizzobium inoculums on growth, N_2 fixation and yield of promiscuously modulating soybean (Glycine max). Moor J. Agri. Res., 2: 110-118.

Tate, R.L., 1995. Soil micro biology. John Wiley and Sons Inc. NY.

Tisdale, S.L., W.L. Nelson, 1956. Soil fertility and fertilizer. Macmillan New York pg 74.

Udo, E.J. and F.O. Uzu, 1972. Characteristics of phosphorus absorption by some important agricultural soil of Nigeria. Soil Sci., 120: 212-218.

Udo, E.J. and V.I. Dambo, 1979. Phosphorus status of the Nigerian coastal Plain sands. J. Agri. Sci. Camb., 93: 281-289.

Von Uexkull, H.R. and E. Mutert, 1995. Global extent, development and economic impact of acid soils. In: Date, R A; Grundon, N J; Rayment G E; Probert, M E (eds) Plant-soil interactions at low pH: Principles and management, pp 5-19. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Wambeke, A.V., 1992. Soils of the tropics. Properties and Appraisal. Mcgraw-Hall Incorporation, pp: 163-173.

Wareing, P.F. and I.D.J Phillips, 1970. The Control of Growth and Differentiation in Plants. Pergamon Press Ltd., New York, pp: 303.

Warren, R.G. and A.E. Johnston, 1962. Rothamsted Experimental Station Report for 1961, quoted in Syers, 1998.

Werner, D., 1992. Symbiosis of plants and microbes. Chapmen and Hall London.