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Outlook on fertilizer use efficiency in the tropics

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Abstract. In this paper efficiency of applied fertilizers under tropical conditions is examined. Understanding of the fertilizer efficiency is particularly important for the developing countries mainly because there is need for enhancement of crop yields at a reduced cost. Many of the soil, plant and climatic factors of the tropical regions that contribute to the efficiency of the applied fertilizers have been discussed. Many of the tropical soils are acidic in nature and in these soils efficiency of applied fertilizer is relatively poor, mainly because plant roots are unable to grow and function to their fullest extent in utilizing the soils available nutrients. To enhance yield potentials there is need for understanding of interaction between crop species and soil and climatic variables. Incorporation and adoptation of a suitable application time can greatly enhance efficiency of urea form of nitrogen. Research findings in tropical soils have shown that an initial broadcast application of P and subsequent band treatment is more effective than either method of application alone. Current crop yields in tropical countries are far below the known yield potentials. Such low production potentials are attributed to the lack of suitable crop germplasms and understanding of improved agronomic practices. Intensification of research activities in fertilizer use efficiency in tropical countries is suggested.

Introduction

Increase in the yield could be best achieved by adopting high yield potential varieties and supplementing soils with required plant nutrients and water. Most soils of the world are deficient in N and P and many in K. Specific soils are also deficient in one or more micronutrient. These nutrients must be applied as fertilizers to exploit yield potentials of crop plants.

Oxisols and Ultisols are the predominant soil types of tropics and they cover approximately 51 percent of the area. They are mainly in South America, Africa and certain areas of Central America and Southeast Asia. These soils are highly weathered, well-drained, and are acid with low base status and available P. These soils are not used extensively for crop production mainly because of their high acidity and low fertility. The level of the essential plant nutrients is low because of intense leaching the lack of primary

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minerals. In these soils using the crops that are tolerant to soil acidity does not solve the problem of crop production, because reserves of Ca, Mg, K and P are so meager that few crops will entirely deplete the available forms of these nutrients. Crop production on these soils seems possible only with proper soil amendments, crop management practices and suitable genotypes that are tolerant to the existing adverse soil conditions.

FAO [14] estimates that of all the energy used in agriculture in developed countries, 35% is needed to produce fertilizer and of this most is needed for fixing atmospheric nitrogen. In the U.K. only 3% of the national energy is used on farms; whereas, in the developing world 64% of the energy is used for making fertilizers of which nearly all is used for nitrogen manufacture. Not only is there a need to minimize the use of fossil fuels used in making N fertilizer, but these fossil fuels are becoming scarce and extremely expensive for the lesser developed countries (LDCs). Even if supplies are available, the relative cost of importation and transportation has increased because of the competition and the higher cost of energy involved.

The efficiency of added N is of the order of 50% or lower and efficiency of added P fertilizer is 10% or less. The K fertilizer efficiency is somewhere between 20 to 40%. In tropics large N losses are attributed to ammonium volatilization, leaching and denitrification. Losses of potassium is mostly by leaching. Losses of P from tropical soils (mainly by erosion) are very meager, but P is fixed by adsorption on amorphous (non-crystalline) Fe and Al oxides and hydroxides and are tied up preventing immediate availability to crops. However, some residual P will become usefull later. To avoid N and K losses by leaching these nutrients have to be applied in split doses. Application of fertilizers when crops are at their active state of growth helps to reduce losses from soil by reducing buildup in the soil. Considerable efforts need to be devoted by agronomists to improve the nutrient use efficiency by plants, particularly N. Even a 10% increase in efficiency would alleviate the need for a great amount of fertilizers. In enhancing efficiency of applied fertilizers it is essential to approach the problem on many fronts, namely: (1) increasing the efficiency of crop plants to absorb and utilize the nutrients; (2) reducing or utilizing existing fertilizer materials in a way to improve their efficiency either by rate or method of applications; (3) use of fertilizer reaction modifiers such as nitrification and urea hydrolysis inhibitors, or use of slow release fertilizers; (4) correcting the soil acidity or alkalinity by amendments so that crops and soil microbial populations are at their greatest potentials and (5) exploiting the nature of interaction of soil essential elements and crop growth.

Fertilizer efficiency

1. *Efficiency and its implications*

The term efficiency is defined by Barber [6] as "the amount of increase in yield of the harvested portion of the crop per unit of fertilizer nutrient applied where high yields are obtained."

Many soil, plant and climatic factors contribute to the efficiency of applied fertilizer in crop lands. In addition, the nature of fertilizer materials and their methods of use also affect their availability. Efficient fertilizer use on many tropical soils apparently still presents severe and unresolved problems. Compared to temperate regions recovery of fertilizer nutrients by crops in tropical soils is lower. Production of fertilizers is becoming more expensive because of a decline in supply of raw materials coupled with rising costs of natural gas and naptha, rising construction costs and absence of new processes for N_2 fixation that use less energy than the Haber-Bosch process [28]. At the present time we know very little about the kind of fertilizers that are efficient for tropical soils or how the existing fertilizer material can best be used on these soils. So far, attempts have been made to transfer fertilizer technology developed for temperate agriculture, directly to the tropics. Evidence is mounting so that tropical farming can benefit from technology specifically developed to meet its own needs. It is time that LDCs face up to this task and intensify their research activities in this direction as these countries currently are investing huge sums of money either by importing or manufacturing their own fertilizer needs.

2. *Parameters of fertilizer efficiency*

It is essential to look into the basic mechanisms governing the efficiency of applied fertilizers to farm lands. The fertilizer efficiency situation in tropical farming is more complex than in temperate regions. This is due mainly to climatic factors like high temperature and intense rains in short periods that are coupled with highly weathered, highly permeable soils with low ion retention (exchange) capacity. Fertilizer efficiency in tropical farming is governed by, a) soil factors, b) efficiency of crops, c) climatic factors, d) nature of fertilizer materials, e) practices of fertilizer application, f) fertilizer efficiency modifiers – amendments.

a. *Soil factors*. Soil factors have a large influence on the transformation, fixation (adsorption) and leaching losses of N, P and K. Among the soil factors are its texture, proportion and amounts of clay (expanding, non expanding and amorphus material), organic matter content, the cation exchange capacity, the concentration of ions on the exchange complex, the capacity of soil to release or renew the levels of exchangeable ion or to fix ions, soil pH, soil moisture, soil temperature, soil aeration and soil compaction [1,2,6,27].

Barber [6] records three important soil parameters which are responsible for the rate of supply of nutrients from the soil to the root: diffusion coefficient, nutrient concentration in soil solution, and buffer capacity. The diffusion coefficient is the most important factor and its magnitude is influenced by volumetric water percentage, the tortuosity of the diffusion path and the buffer capacity. By increasing the water content of soil, we reduce tortuosity and increase volumetric water content, thereby increasing the diffusion coefficient. Efficiency of fertilizers therefore can be enhanced by increasing soil water content within the limits of water holding capacity. If the water content exceeds water holding capacity, loss of plant nutrients by leaching will occur. Reduction of buffer capacity increases the rate of diffusion. Fertilizing the soil will increase the concentration of ions in soil solution and thereby decrease the buffer capacity. But if such alterations in buffer capacity are not done properly, ions in soil solution may be subjected to leaching in situations where water flow through the soil is intense.

Ultisols and Oxisols occupy extensive areas in the tropics. The clay fraction of these soils is dominated by iron oxides, gibbsite, kaolinite aluminum-chlorite and amorphus oxides of iron and aluminum. The largest amounts of applied P are fixed by amorphus hydrated oxides of iron and aluminum followed by gibbsite, geothite and kaolinite [20].

Fine textured soils containing vermiculite and montmorillonite or smectite clays will have more K than soils predominant in kaolinitic types of minerals, which are more weathered and low in K. Soils with a large proportion of vermiculite fix considerable amounts of K. Under such circumstances it is advisable to apply large amounts of K to obtain the desired soil test. Such fixed K is subsequently released to present or succeeding crops but the rate of release may be too low for high levels of production.

Organic matter content of soil has an influence on the exchange capacity of soil. Organic matter will help in adsorption of ions but the strength of adsorption is much less than clay minerals. In tropical soils fairly large amounts of organic matter are present when the lands are cleared for cultivations from natural vegetation. The surface layer of dark red latosols of the Cerrado region of Brazil after clearing native vegetation have organic C content as high as 3.5 percent. Greenland [16] reported a substantial decline in soil C in African Savanna with subsequent cultivation. Before clearing the surface soil C ranged anywhere between 0.8 to 2.9%, but after 2 years of using the local cropping method, it dropped to 0.7 to 2.0%. However, with intensive cultivation methods, the drop of soil C was to about 0.6 to 1.6%. Similarly in Brazilian Cerrado with advancing cultivation soil C drops from 3.5 to less than 2% and is believed to stabilize at this level under normal conditions. However, the influence of long range farming effects on soil C is yet to be known.

In acid soils the efficiency of applied nutrients is relatively poor, mainly because plant roots are unable to grow and function to their fullest extent and secondly because acid soils have low cation exchange capacity, which makes them poor adsorbers of added nutrients; thereby, such nutrients are subject to loss by leaching. Amendments such as liming material not only reduce the toxic levels of Al and Mn but also supplement soils with Ca and Mg which are in short supply for normal crop growth. In acid soils denitrification and leaching losses are much higher; whereas, in high pH alkaline soils ammonium voltilization is a primary concern.

Soil aeration is a vital component for active root growth and its function. Changes in the oxidative and reductive state of soil have an influence on the availability of plant nutrient. Similarly soil temperature plays a dominant role in growth and function of plant roots and availability of plant nutrients. Soil aeration and temperature largely influence the efficiency of applied nutrients by influencing on the plant, soil parameters, and microbial activities in the soil.

b. *Efficiency of crops*. Barber [6] states that if we can get the crops to absorb a higher proportion of the nutrients added as fertilizer, we will certainly increase fertilizer efficiency, provided environment is not a serious plant growth constraint. The mechanism that is involved in adsorption of nutrient will have an influence on the efficiency with which plants recover nutrients from soil. Mengel [25] stated that crop response to fertilizer application depends not only on the level of available plant nutrients in the soil but also related to crop morphology and physiology. Species or cultivars with a high growth rate generally respond more favorably to fertilizer application than those with low growth rate. The root occupies only about 1 or 2% of the soil surface volume, therefore the amount and proportion of applied nutrients that reach roots determine the efficiency of uptake. Hence the nutrient absorption efficiency is a factor comprised of the ability of the soil to supply and the capacity of plant to absorb. In the earlier section we have seen how soil parameters determine the amount of supply of nutrients to the growing plant roots. However, here we will emphasize plant parameters that are responsible for nutrient absorption and efficient utilization of available nutrients. Baligar and Barber [4] have listed the following plant factors that influence nutrient absorption: (1) Ion influx rate; (2) Root radius; (3) Rate of water uptake per unit of root; (4) Root length, and number and length of root hairs; (5) The number of roots (root density) and (6) rate of root growth. These parameters describe the morphology of the root and the rate of nutrient uptake by the root. Modifying the plant in order to increase the rate of nutrient uptake per unit of root will increase nutrient absorption and therefore enhance efficiency of the plant. It is essential to modify the nature of root system either by plant breeding or by morphological changes induced by tillage and cultural practices etc. This calls for a multidisciplinary team approach to design a plant according to the need of the situation. At the present time we know little about variability among plants and their inheritance capacity with respect to root morphology and uptake characteristics. Different plant species have different absorption capacities and within a species varieties have exhibited a remarkable variation in uptake of nutrients [5, 8, 30, 35]. Such differences are attributable to the type of root system, surface area of the root and demand factor of the shoot. All these factors are in turn governed by genetic make up of the plant and environmental factors. Root density and root type will effect the efficiency of uptake of potassium and phosphorus that diffuse to the root. The greater the root density, the closer thay are together, and hence a higher proportion of the fertilizer will be close enough to a root for it to have a chance to intercept the diffusion path. Phosphorus uptake appears to be influenced by root hairs. Root hairs increase the area of the root absorption cylinder and thereby increase the probability to intercept the P diffusion paths. However, root hairs have little influence on K adsorption because the average distance of potassium diffusion in the soil is greater than the length of the root hairs. In his recent review Mengel [25] concludes that nutrient exploitation of soils by plant roots depends on root morphology and root physiology. Further he states that grasses generally have much longer roots than dicots thus the rate of K and P uptake per unit root length is lower than for dicots. Increasing plant population per unit area will within limits increase damand for available nutrients in the soil; which may reduce the probability of loss by leaching. An efficient plant is not only efficient in recovering nutrients but it should also be efficient in utilizing what it absorbs. In orther words, crops should recover higher portions of added nutrients and at the same time produce higher yields per unit nutrient absorbed [6].

c. *Climatic factors*. Availability, movement and uptake of nutrients are affected by climatic factors such as moisture and temperature conditions. Moisture and temperature enhance weathering of mineral matter and decomposition of organic matter. Such changes in soil bring alteration in microbial populations. The microbial population has tremendous influence in mineralization, immobilization and nitrification of soil nitrogen and other elements as well. Under excess rainfall in tropical countries, N and K might be subjected to loss by way of leaching. Evaporating water from soil might enhance volatilization losses of ammonia from urea type nitrogenous fertilizers. Temperature also influences root growth and function thereby affecting nutrient absorption capacity of the root system [29].

In tropical farming climatic factors like rainfall and temperature play an important role on nutrient efficiency. Rainfall leaches away the soluble nutrients like NO_3 and K. Water logging of lower areas cause denitrification of NO_3, and extensive evaporation during dry spells means ammonia losses. Under high temperature mineralization of soil organic matter, crop and animal waste is rapid and the rate of soil weathering is high. In tropical soils the reserves of plant nutrients are low and release of nutrients from organic and minerals is very rapid. Furthermore, these soils have low nutrients retention capacity. Under such circumstances regardless of whether nutrients are lost by leaching, volatilization or denitrification soil fertility is thus lowered.

d. *Nature of fertilizer materials*. Very little is known about the kind of fertilizer materials needed for tropical soil conditions. Soil of the tropics and subtropics are different from those of temperate regions. In addition the growing season and climatic conditions are also different, so they may need different types of fertilizers.

In some developing countries it is evident that prilled urea will be used as a major source of N in the coming years [19]. Since the common practice of N application in these countries is by broadcasting, volatile losses of ammonia from ammonium or ammonium forming fertilizers will result. Even when fertilizers are mixed with soil they can create another problem. When ammonium undergoes nitrification, hydrogen ions are released ($2NH_4 + 30_2 \xrightarrow{\text{nitrification}} 2NO_3 + 8H^+$). This is a source of acidity. In addition if NO_3 is subjected to leaching it will carry with it bases such as Ca, Mg and K from the soil, which are already in short supply in tropical soils. Experiments with corn in Brazil and Puerto Rico have shown that urea fertilizer is a better source of N than sulfur coated urea [17]. Leon and Fenster [23] report several studies in Colombia with phosphate rocks. The use of phosphate rock as a source of P for pasture production appears to be economically and agronomically feasible. McLean and Wheeler [24] have reported that 10 to 20% partial acidulation of phosphate rocks could enhance their performance as P sources to crops. Such treatment of phosphate rock is known to provide more soluble P initially while still maintaining the desirable characteristics of low cost and high residual value. Leon and Fenster [23] report that partial acidulation of phosphate rocks with H_2SO_4 did not give any encouraging result with the Florida and North Carolina phosphate rocks. They conclude that the low performance of these rock phosphate is associated with problems involved in preparation. There is a coating of phosphate granules with a thin layer of insoluble anhydrous or hemihydrate $CaSO_4$ that either occlude release of the P or prevent the physical contact of the phosphate rock with soil.

The ineffectiveness of phosphate rocks as compared to superphosphate is attributable to their low water solubility. Partial acidulation of finely ground phosphate rocks with H_3PO_4 (10–20% acidulation) has increased their effectiveness on crops. Recent studies by Mokwuney and Chien [26] have shown that in Nigerian savanna soils and an Oxisol of Colombia the water extractable P was higher where partially acidulated phosphate rock was added. Further they suggested that presence of phosphate rock, in partially acidulated phosphate rock form or in mixtures of concentrated superphosphate and phosphate rock, slowed down the immobilization of water soluble P by reacting with some of the acidity produced during monocalcium phosphate hydrolysis, thus reducing the amount of acid available to solubilize soil Al and Fe. Beneficial effects of rock phosphate appear to be maximized in soils with high Al saturation of the exchange complex and/or high P-sorption capacity. Such findings are especially encouraging news for large areas of tropics where deposits of rock phosphate are associated with acid soils and acidulation of these P materials with H_3PO_4 might be an answer to P deficiency problem of these soils. The P availability from phosphate rock depends on supply source. Some sources such as Curacao, Moracco, and North Carolina rock can equal super phosphate availability on acid soils and further phosphate rock also supplies Ca and several micronutrients.

e. *Practices of fertilizer application.* In tropical soils volatiles losses of ammonia and leaching losses of nitrate are common forms of N losses. Volatile losses could be minimized by incorporating ammonium form or urea-form N sources with soil. Grove [17] states that leaching appears to be the most probable mechanism of N loss in tropical highly weathered soils especially where intensity of rainfall is very high. One way to minimize such losses is to use slow release N materials and modify the application methods and time of application as well. Such an arrangement will permit greater N availability in soil when there is a greater demand by crops so there will be little extra N left in the soil which otherwise might be lost.

Given the dominance of urea, from a use and production standpoint, in developing countries IFDC has given more emphasis to methods of urea application. IFDC [19] reports several fertilizer placement techniques that could reduce N losses in rice fields. The efficiency of N fertilizer could be achieved by using Japanese mudballs or point placement of urea "super granules" (briquettes of 1 to 3g sizes) placed at 8 to 12 cm depth with a rate of one for every four hills of rice. Another method is to apply urea or ammoniacal – N in solution (mixed with water 1 : 1) by injecting it directly in a reduced soil zone of water logged soils which will restrict the ammonia volatilization and denitrification. In addition TVA's sulfur coated urea is being tried successfully on rice soils. The combination of deep placement and controlled release of N have promising features with increasing efficiency on rice soils.

Grove [17] cites several studies with N placement for temperate and tropical row crops. Greater N recovery and increased yeild of corn were resulted when fertilizer N was applied as a side dress than when it was broadcasted before planting. Proper timing of application holds the most promise for influencing the recovery efficiency of fertilizer N. The longer the applied fertilizer N remains in the soil the greater the chances of its being lost. So it is essential that most of the N be applied just prior to the crops maximum growth rate.

Soils of Brazil are mainly Oxisols and Ultisols (latosols and podzolic soils) dominated by kaolinite and iron and aluminum hydrous oxides. The cation exchange capacity is due mainly to organic matter and other pH-dependent charges developed on the mineral faction. Acidity is a common feature of most soils and so is the low base saturation. Phosphorus deficiency is wide spread and most soils fix P [34]. In order to increase the efficiency of applied P it is essential to satisfy the P fixing capacity of these soils first. Locally available rock phosphates may achieve this goal in these soils. Use of rock phosphate as a source of P in Brazilian acid soils has been reported [7, 12].

Braga [7] published a review of work done on rock phosphate use in Brazil. He concluded that in all these studies, rock phosphates had a positive effect on crop yields but they were less efficient than that of super phosphate. Such performance is believed to be due to the fact that rock phosphate was band placed and the levels of applications were low. Recent findings [22] have shown that rock phosphates have more beneficial effects when they are broadcasted and mixed well with the soil.

EMBRAPA [12] reports that on a latosol of Brazil, which was originally under Cerrado vegetation, rock phosphate (hyperphosphate from Morocco) gave efficient performance with pasture when it was broadcasted. An experiment conducted at CPAC, Brasilia with Brachiaria showed that both the thermophosphate (19% P_2O_5 with 18% P_2O_5 citrate soluble) and the hyperphosphate (Moroccan rock phosphate containing 30% P_2O_5 of which 25 percent is citrate soluble) materials were equal to super-phosphate (20 percent citrate soluble P_2O_5). The Araxa rock phosphate (28 to 30% of total P_2O_5 of which about 5% is citrate soluble) found in the Cerrado region did not show much promise in the first season; however, crop yields improved during the course of the experiments [22]. It was concluded from these studies that a combination of an initial broadcast and subsequent band treatment give better results on these soils; such methods were more efficient than either method of application alone. Other experiments at CPAC in Brasilia on method and rate of P application have shown that after four continuous crops of corn, the best economic rate of return was obtained with 320 kg P_2O_5/ha broadcast initially and 80 kg P_2O_5/ha banded for each of the following crops [22].

Olsen and Engelstad [31] quoting results from joint FAO/IREA investigations in the tropics indicate that for flooded rice, surface placement of P is superior to shallow or deep placement. Studies under humid West African conditions as reported by Kang and Juo [21] gave little or negligible benefits by localized P application, except at sub-optimal rates of applications.

Limited work on potassium placement is reported. Recently Dibb [11] reviewed K placement studies. He concludes that in general all of the K placement methods adopted fall somewhere on the continum between the two extremes. (1) Broadcast application and subsequent mixing with soil and (2) band application where K is in contact with less soil volume thereby maintaining a band of high concentration of applied K. Significant responses of small grains were shown with broadcast K applications whereas row crops showed good responses to band applied K at lower soil test levels. On soils having high K fixing clay, placement is more critical [11]. In tropical soils where leaching losses of K are great, split applications of K are preferred over the single applications practiced in temperate agricultural systems.

f. *Fertilizer efficiency modifiers.* As we have seen in the earlier section, increases in efficiency of applied fertilizer are related to soil conditions and plant growth (root) activities, including the ability of the soil to retain added nutrients in an available form for plant use and the ability of plants to absorb these nutrients from the soil at desirable rate. In orther words the availability and absorption should operate in such a way as to minimize the probability of nutrient losses.

In tropical countries soils are very acid with high amounts of exchangeable Al and sometimes Mn. These soils are very low in other essential elements which are required for normal plant growth. These soils are loose in structure, and are highly drained and have very little base (cation) exchange capacity. Liming of such soils produces a four fold change: (1) eliminates acidity and reduces toxicity of Al and Mn, (2) improves structure, Ca, P and Mo availability, (3) creates favorable conditions for bacterial nitrogen binding (symbiotic N fixation) and (4) reduces Mn, Zn and Cu availability [15].

Liming acid soils to neutralize aluminium helps to increase effective cation exchange capacity. Such increase in CEC might reduce the potential for leaching loss of K by reducing the concentration of K in soil solutions. However, if liming materials (Ca or Mg) are applied in forms other than carbonates or oxides this may cause more leaching of K because these two elements increase the number of cations competing for space on exchange complex. If the associated anion is chloride or sulphate (these are highly mobile) it might remove K from the soil [33]. Liming enhances the root growth by reducing the activity of Al and further providing a suitable pH range, as well as Ca and Mg which are essential elements for proper function of plants. To minimize or to avoid losses of nitrogen one needs to eliminate or reduce the presence of the chemical species i.e. NO_3 that might be subjected to loss. Two ways this could be achieved are by applying some chemical to retard the rate of nitrification or to apply slow releasing nitrogen fertilizer to soils so as to match availability of N to crop removal thereby, reducing chances of buildup of nitrate. Prasad et al. [32] and Hauck and Koshino [18] have discussed this subject in detail. Ureaform or amide, IBDU, are some of the slow releasing fertilizers commonly proposed. Sulfur coated urea has also been extensively tested with good results for rice on submerged soils. Many agricultural chemicals also have been applied with ammonium or ammonium forming fertilizers to reduce the rate of nitrification. The application of nitropyrin inhibits the Nitrosomonas bacteria activity, thereby keeping ammonium in soil for a considerable length of time in a form not subjected to loss by leaching.

Yield potentials

From Table 1 it can be seen that great yield potentials exist with respect to the important food crops of the world. Known yield potentials are five to seven times greater than achieved production. Average yields in developing countries are two or three times lesser than those in developed countries. Even in developed countries top yields obtained are less than half the proved practical potentials.

Table 1. Established yield potentials and yields of important crops for different regions of the world[a]

Regions	Corn	Wheat	Rice	Potatoes
		Tons/ha		
Established Potentials[b]	13.0	12.0	14.0	90.0
World	2.8	1.7	2.4	14.4
Africa	1.1	1.0	1.8	8.3
Asia	1.9	1.2	2.4	9.8
Europe	3.8	3.0	4.8	19.3
North America	4.5	2.0	3.7	23.0
Brazil[c]	1.6	0.7	1.5	9.7
Developed Region	5.0	2.2	5.7	21.7
Developing Region	1.3	1.2	1.9	8.5
Centrally Planned Economy	3.0	1.7	3.1	13.6
Average Yield In Country with large production	5.7[d]	5.2[e]	6.0[f]	37.0[e]

[a] From FAO, 1970–1976 [13] and Cooke [10].
[b] Experiments of farmers.
[c] Anuario Estatistico do Brasil, [3].
[d] U.S.A.
[e] Netherlands
[f] Japan

Average yields per hectare of corn, rice and potatoes in Brazil are par with average yields of developing countries, but these yields are eight to nine times less than known potentials and about two to four times less than average yields recorded in the developing countries. Known potentials for wheat are seventeen times larger than average yields of Brazil. Wheat yields of the Netherlands are seven times larger than yields in Brazil. Such differences are largely attributable to soil, climate, varietal and new improved farming practices. Cooke [10] states, "it does seem that experiments have not identified all the factors that control growth of crops in a field." Further he believes that when crop diseases and weeds are eliminated, as they can be, the remaining factors affecting yield are associated with the supply of water and nutrients, as affected by physical and biological conditions in the soil.

Yield can be seen as the product of genetical, cultural and environmental interactions. Development of genotypes which make better use of N and P would mean increasing the efficiency of applied fertilizers [35, 36]. Recent reviews on genetic factors on crop nutritional requirements have shown that crop plants could be improved for the efficient use of mineral elements even under mineral stress conditions [8, 35]. Environmental factors such as soil and climate are less controlled, but with the great improvements in hybrids and varieties enable us to bring positive interactions with cultural practices and environmental variables.

Cooke [9] states that "progress towards maximum yields in developed agrigultural will depend largely on exploiting interaction." This statement very well applies to less developed farming as well. In well weathered acid tropical soils nutrient deficiencies and imbalances of these nutrients are major problems. Lime applications helps in reduction of the amount of exchangeable Al but better growing conditions with liming are only realized with adequate P and Zn application [21]. Similarly greater benefits from N fertilization and liming of acid soils are achieved only under adequate phosphate fertilization. The maximum crop beneifts from N can be obtained only with the presence of sufficient P, K and water, Cooke [9] and Wagner [37] cite numerous studies where several crop species showed tremendous interactions with levels of N, P and K application and irrigation levels as well. Positive nitrogen and phosphorus interactions are observed on corn, soybeans and grasses. Positive P and K interactins are obtained on soybeans, corn and coastal bermuda grass. Added P without Zn on corn had negative effect on yield, as did the addition of Zn without P.

For many years low corn plant population was a factor in negative interaction and responses were not observed in short duration studies. Under high density plant population there is demand for more nutrients. High yielding varieties have high demands for nutrients. Large yield from such varieties are only possible by high application of major nutrients. Cooke [9] concludes that it is by exploiting the interactions of nutrients with each other, and with improved practices such as better varieties, irrigation, weed control, and disease control that yield have been raised dramatically in many countries in the last 30 years.

Conclusions

All developing contries are importing large quantities of fertilizer materials to boost their crop production capacities, so as to match their demand for food. Foreseen shortage of fossil fuel and natural minerals and energy involved in transportation have increased the cost of these fertilizer materials. Under tropical conditions the efficiency of applied fertilizer is very low. It is estimated that efficiency of applied N is less than 50%; for P it is less than 10% and for K it is somewhere around 40%. Currently we know very little on how to enhance the efficiency of these applied fertilizer materials. Technical knowhow developed from temperate regions for nutrient transformation is being applied to tropical regions. There is widespread evidence to show that tropical conditions are quite different from temperate regions so there is need for development of an extensive research undertaking in tropical countries to enhance fertilizer efficiency.

To enhance the yield potentials of crops we need to understand the interactions of climate and cultural practices. More than one element might be involved in obtaining maximum yield potentials. Selection of genotypes which are capable of growing in uncertain rainfall areas and which are capable of utilizing their environmental variables to the fullest extent is essential. So there is an enormous task ahead to achieve our set goals. There is a great need for intensification of basic research so as to achieve a breakthrough in increasing fertilizer efficiency.

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