John Phillips

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CONTENTS

THE PROSPECTIVE CONTRIBUTION TO AGRICULTURAL AND RELATED DEVELOPMENT THROUGH THE SOUND USE OF CHEMICAL FERTILIZERS

CONFERENCE ON THE
ECOLOGICAL ASPECTS OF
INTERNATIONAL DEVELOPMENT
AIRLIE HOUSE, WARRENTON, VA. DEC. 9-11, 1968

SUMMARY

The actual and the prospective use of chemical fertilizers in the tropics and subtropics of Trans-Saharan Africa is discussed against the background of the prime bioclimatic regions (Phillips), the great soil groups (D'Hoore) and selected agricultural features.

The experience gained by the Food and Agriculture Organization (FAO) - in its efforts to test the capacity of fertilizers for the raising of yield from the commoner staple crops - is encouraging and supports the views of many investigators in the Colonial services of earlier days. Given the requisite conditions and circumstances, the sound application of suitably balanced fertilizers produces considerable enhancement of yield - provided this is done with some knowledge of the particular ecosystem, in its widest sense: habitat to man.

Several effects of fertilizers detrimental to the soil and to the establishment and satisfactory growth of young plants are noted: all of these could be readily counteracted. The influences of fertilizer upon the ecology of forest and savanna are touched upon briefly: the literature is sparse and apart from some general features, the experience of the author does not record anything spectacular: the prime effects being a stimulation of growth or, where extreme pressure is exerted upon grass communities high in the succession, a replacement of later stages by pioneer ones. The now classic instance cited is an example of ecologic retrogression but also one of economic advance!

The "laterite" or "ferruginous crust" or "pea-ironstone" phenomena of humid/hot to warm bioclimates, cited by some as a warning against replacement of forest with derived wooded or grass savanna and by extensive areas fully exposed to insolation and direct impact by rain of high intensity, are in a sense linked with the use of fertilizer. The point is made that whilst exposure of these materials does indurate them, their accelerated formation through the removal of forest canopy and by the mechanized preparation, cultivation and fertilizing of the soil is unproven and unlikely.

The experience so far won is overwhelmingly in favour of the sound application of fertilizer, and that the few known instances of detrimental effects of these chemicals should be studied more intensively. It is stressed that in studying the chemical, biological and related influences of fertilizer, the economic and all other features of the ecosystem must be borne in mind.

ECOLOGICAL ASPECTS OF INTERNATIONAL DEVELOPMENT

THE PROSPECTIVE CONTRIBUTION TO AGRICULTURAL AND RELATED DEVELOPMENT THROUGH THE SOUND USE OF CHEMICAL FERTILIZERS

John Phillips

South Africa

BACKGROUND

I select a subject with which I have been associated, at various times, during my fifty years study of the ecological approach to the development of tropical and subtropical Trans-Saharan Africa. Particular interest has been expressed by the organizers in the ecological consequences of the use of chemical fertilizers in tropical soils.

The limiting of the scope and details of the subject to a discussion of studies "in depth" has, in a sense, circumscribed a discussion of a number of ecological principles and their application. Nevertheless, the subject outlined is sufficiently significant to stimulate a wide ranging discussion of both scientific and applied nature.

I confess that, by comparison with several personalities participating in the Conference, I am not qualified to present this subject. I am neither a chemist nor a pedologist but, merely, an ecologist who has worked on aspects of the fertility of some African soils and has taken an interest therein during the study of the economic prospects of certain countries in Asia and Latin America. I attempt, however, to present objectively the matter as I see it and trust this will stimulate those who know more about the physical, chemical and bio-chemical details to tear my views asunder.

One of the current foibles, in some circles commendably interested in the progress of the developing countries in the tropics and subtropics, is to accept subjectively the statement that the application of chemical fertilizers has ipso facto a detrimental effect upon the soils and also the indigenous and the exotic economic vegetation. This arises perhaps partly from the enthusiastic propaganda associated with the emotional tenets of what is known as the "muck and mystery" school. Its savants believe that whilst organic matter - glibly called "humus" - is capable not only of resisting the deterioration of but also of advancing the fertility of soils to a remarkable degree, the reverse effects accrue from the use of chemical fertilizers. Another reason may be that the detrimental influences of unwisely prescribed and applied chemicals are often widely advertised in some circles, whilst the greater bulk of the beneficial effect receives little publicity, other than in manufacturers' catalogues.

The effects, good and other, are indeed complex, with manifold combinations and permutations of variation according to the local climate, soil characteristics, indigenous vegetation, kind of crop, interplay of the animal factor and the method and the efficiency of preparation and husbandry of the soil, and other factors. It is therefore imperative to review - even in an amateur manner - both the encouraging and the puzzling aspects of the subject.

THE SOILS OF TRANS-SAHARAN AFRICA - A BRIEF REVIEW OF SOME OF THEIR PRIME CHARACTERISTICS IN RELATION TO THE ROLE OF CHEMICAL FERTILIZERS

The 15 million square kilometers (9 million square miles) of Trans-Saharan Africa could not be described satisfactorily in a short note, but I record several features which bear directly upon the role of fertilizers in the present and the prospective development of the utilizable portions of this vast terrain, for crop, livestock, forestry and wild game production. Relevant literature is growing apace but the non specialist could obtain a good background - in English - to the nature and distribution of the soils by consulting, inter alia, D'Hoore (1964), who compiled the soil map of Africa and prepared the explanatory monograph, under the auspices of C.C.T.A. (Commission for Technical Co-operation in Africa); the journal published earlier by B.I.S. (the Inter-African Bureau of Soils) an agency of C.C.T.A.;* in regard to the role of shifting cultivation in the husbandry and the deterioration of soils, the monograph by Nye and Greenland (1960); and the less specialized references contained in these publications.

(1) CERTAIN GREAT SOIL UNITS ACCORDING TO THE BIOCLIMATES OF TRANS-SAHARAN AFRICA

It should be borne in mind that the soils of the highly humid to humid to humid-subhumid tropical and subtropical forest bioclimates, those of the subhumid, subarid and arid wooded savanna (Phillips: 1959; 1961 - 1966; 1964; Aubréville 1948) and those of the subdesert are markedly different pedogenically,

* African Soils.

in physical, chemical and biological nature, resistance to disturbance and to exposure to insolation, and also in actual and potential productivity according to crop and soil husbandry. It is impossible to discuss these here, but reference to D'Hoore (op. cit.) Nye and Greenland (op. cit.) and Phillips (op. cit.) would help.

As it is imperative to study the soils as portion of the ecosystem: climate, physiography, geology, vegetation, animal life and man, I assemble some relevant information in the following table:-

GROUPS OF BIOCLIMATIC REGIONS (Phillips: 1959, 1961-1966, 1964)	GREAT SOIL UNITS (D'Hoore : 1964)	SELECTED PRIME AGRICULTURAL FEATURES
Highly Humid Forest, Humid Forest, Humid/Subhumid Forest - all at low and medium elevation, tropics and subtropics, but including the comparatively small, scattered Montane Forests in E., N.E., Central and West Africa. (An extensive group of bioclimatic regions: West and Equatorial Africa, with outliers in East Africa, Ethiopia and elsewhere: say 2.5-3 million square km.); appreciable portions now converted to Derived Wooded Savanna by shifting cultivation and other man-induced processes	A Ferrallitic Soils B Ferrisols C Alluvium D Hydromorphic Soils	A Strongly leached, low in nutrients, readily erodible on exposure; B less leached; C moderately to good in nutrients, moderate to great depth, highly erodible; D nutrients variable, texture and drainage poor, but amenable to management; responses to wise application of fertilizers:- A: fair to good, B: good to moderate to poor, C: moderate to excellen D: moderate to good, depending on drainage;

GROUPS OF BIOCLIMATIC REGIONS (Phillips: 1959, 1961-1966, 1964)	GREAT SOIL UNITS (D'Hoore : 1964)	SELECTED PRIME AGRICULTURAL FEATURES
		Removal of forest canopy and exposure of the soils to insolation and heavy, frequent rain deteriorates the physical characteristics through erosion, short period "baking" and induration of the surface.
Derived Wooded Savanna of the above bioclimates (Forest converted to Wooded Savanna, tall to short, with scrub and grass.)	Soils as above	In many parts soils are deteriorated by 2-3 years of shifting cultivation with resting periods 3-6 years; where rest is 10 to 15 years some rehabilitation of soils occurs; responses to fertilizer much as in above bioclimatic group, N, NP and NPK according to soil and crop; whilst short period cropping alternating with long period "bush fallow" permits a short period of re-use, steady physical and other deterioration occurs where cropping periods are more frequent and longer.
Subhumid Wooded Savanna and Mild Subarid Wooded Savanna. (The most extensive group of bioclimatic regions, about 3-fold that of the Forest; extensive north and south of the forests, with great arms in West Africa and large but interrupted extensions into Angola, Zambia,	A Chiefly Ferrallitic Soils B Ferrisols, but also C Fersiallitic (Ferruginous tropical soils) and D Vertisols locally	A Ferrallitic soils much leached, B Ferrisols somewhat less leached, C Fersiallitic soils slightly to moderately leached; nutrients low in A and somewhat higher in B and C;

GROUPS OF BIOCLIMATIC REGIONS (Phillips: 1959, 1961-1966, 1964)	GREAT SOIL UNITS (D'Hoore : 1964)	SELECTED PRIME AGRICULTURAL FEATURES
Tanganyika, Mocambique, - say 6 million sq. km.		Vertisols, depending on origin, nutrients fair; excellent to good to fair for agriculture; Responses to wise application of fertilizer; A: fair to good, B: moderate to good, C: good, depending on drainage, D: good to excellent, according to origin and topography (drainage)
Subarid to Arid Wooded Savanna north and south of the foregoing, with outliers in East and Southern Africa	A Fersiallitic Soils B Lithosols C Vertisols D Alluvium E Halomorphic Soils	A Much leached, B generally shallow, poor to fair, C nutrients fair, D moderate to good in nutrients, E saline Where rainfall is inadequate in amount and distribution, no crop production should be attempted other than incidental "catch" subsistence crops: fertilizing always hazardous and returns usually very poor; where rainfall more satisfactory, fair to moderate crops, except on halomorphic soils but moderate to good crops on alluvium; where supplementary irrigation is possible, careful

GROUPS OF BIOCLIMATIC REGIONS (Phillips: 1959, 1961-1966, 1964)	GREAT SOIL UNITS D'Hoore : 1964)	SELECTED PRIME AGRICULTURAL FEATURES
		fertilizing, according to soil (other than halomorphic) and crop may render application of N,NP and NPK economic; halomorphic soils require special treatment which cannot be discussed here; poor irrigation and unwise application of fertilizers produce brack conditions in soils near neutral to alkaline in reaction; climatic and soil characteristics call for special care in the use of fertilizers
Arid Wooded Savanna (also transition Arid Wooded Savanna to Sub-desert Wooded Savanna); 2.5-3 million sq. km.; extensive north of the above bioclimatic group and also extensive in NE Africa with large outliers in SW Africa and Botswana	Brown soils of arid and subarid tropics and subtropics	Generally too arid for cultivation, except on the occasional alluvial soils after rain; where irrigation has been developed, as on a small scale in West Africa, Sudan, East Africa, Horn of Africa, SW Africa, good management produces fair to good yields of cereals and cotton; Brown soils, better suited to extensive pastoral usage, but under irrigation produce sorghum, millet and cotton, but structure deteriorates with other than short usage; response to fertilizer fair to good

GROUPS OF BIOCLIMATIC REGIONS (Phillips: 1959, 1961-1966, 1964)	GREAT SOIL UNITS (D'Hoore : 1964)	SELECTED PRIME AGRICULTURAL FEATURES
	B Vertisols, C Lithosols, D Halmorphic Soils and, on sandy parent material, some Fersiallitic soils	B Vertisols, well drained, fertilized and otherwise managed, produce good yields under irrigation; Fersiallitic soils, in their better types, are also amenable to the same kind of management; the halomorphic soils are difficult to ameliorate, unless much water can be used for leaching salts; the Lithosols are commonly too shallow for irrigation
Subdesert Wooded Savanna an extensive strip north of the above group of regions, with smaller outliers in Kenya, Horn of Africa, SW Africa and South Africa	Variable desert and subdesert soils (sands, clays pavements and others, with halomorphic soils)	Useable under careful irrigation only; require the most skilful application of water and fertilizer
Highveld pseudopodsolic soils: South Africa, parts of Angola, Kenya: Subhumid to Subarid Wooded Savanna, in which open grassland is common, either through human agency or because of intensely fierce fires in the dry season	High pseudopodsolic soils (mainly subtropics, higher elevations, 1000-8000 m.)	Extensively and, locally, intensively grazed; liable to erode under heavy pressure by livestock and also when cultivated carelessly; where rainfall is 30 and more inches (750 mm), maize, sorghum, millet/and other annuals - yield well when suitably fertilized

GROUPS OF BIOCLIMATIC REGIONS (Phillips: 1959, 1961-1966, 1964)	GREAT SOIL UNITS (D'Hoore : 1964)	SELECTED PRIME AGRICULTURAL FEATURES
Ferruginous cuirasses, crusts and hardpan ("ouklip" in South Africa); main sector 5-20 deg. N. to 10-15 deg. W.; but also scattered in Forest and Wooded Savanna of various types in East, Central and Southern Africa; exceptionally well developed in Ivory Coast, Dahomey, Guinea, Upper Volta, Liberia, Mali, Niger, Senegal and Sierra Leone	Developed from rocks of various kinds, in various bioclimatic regions, but mainly where warm and humid; much ancient, so-called "fossil" laterite, pea-ironstone, "ouklip", exists in various parts of the sub-continent; soils with ironstone hardpan drain poorly: a perched watertable in the wet season but, in the dry, deficient in moisture; currently produced wherever forest and denser canopied Wooded Savanna is subjected to insolation	Where this material occurs under forest it is gradually softened and broken, the soil then exposed being suitable for tree planting and small scale subsistence cropping; in Wooded Savanna it is not much broken even under closer canopy; when broken by hand, the soil exposed supports hardy trees

(2) SOME FEATURES OF FOREST AND WOODED SAVANNA SOILS IN TRANS-SAHARAN AFRICA BEARING UPON THE PROSPECTIVE ROLE OF CHEMICAL FERTILIZERS

I summarize that the soils of Trans-Saharan Africa, whether bearing closed canopy forest or wooded savanna of varying degrees of crown density and stocking are, for the greater part, only moderately to poorly supplied with the prime nutrients required by annual subsistence and cash crops. For the needs of the indigenous vegetation - the mighty forest trees to the savanna grassland and petty herbs - more than enough organic and mineral nutrients exists to supply the needs of these relatively closely stocked plant communities.

Based on my review of the knowledge available some years ago (Phillips: 1959, 1961-1966, 1964), I summarize some of the relevant points, bearing in mind that there is wider variation according to the particular forest - bioclimatic region, whether highly humid or humid/subhumid and the particular wooded savanna region, whether subhumid, subarid or arid.

FOREST SOILS	SOILS OF THE WOODED SAVANNA
RAW AND DECOMPOSING ORGANIC MATTER	
Relatively abundant to moderate to slight, according to the bioclimatic subregion and type, usually more abundant than in wooded savanna; readily decomposes and disperses on canopy being removed from clearings more than a hectare; provides a good biochemical and physical setting for N,NP and NPK fertilizers.	Except in denser Subhumid Wooded Savanna and on locally moist soils, moderate to sparse to very sparse to absent - depending upon bioclimate, frequency and intensity of fire; where grass and shrub growth are fertilized, heavy vegetative growth produces more organic matter but this is readily lost where insolation and intensity of rain are high and mild subarid to arid conditions pertain; only locally and temporarily

FOREST SOILS	SOILS OF THE WOODED SAVANNA
	sufficient to provide a satisfactory setting for fertilizers.
NITROGEN	
Usually fair but becoming deficient after a year's exposure to insolation - as in shifting cultivation and complete clearing for mechanized or other "progressive" cultivation; Carbon:Nitrogen ration 10-12, W. Africa, much as for temperate farm soil. Return of N on recovery of canopy and stocking fair to moderate: e.g. Ghana, Gay, 160 lbs. p. acre/ann. (Greenland and Nye: 1964). Adequate for annual subsistence crops for 3-8 years after exposure, but, for economic production, addition of N imperative; increase of 50 to more than 100 per cent readily shown: such yields much higher than in savanna.	Relatively slight compared with forest soils under similar climates (i.e. in Derived Savanna) except where canopy and stocking are dense and fire has been long excluded; the more arid the bioclimatic type (from Subhumid, through Subarid to Arid Wooded Savanna), the lower the total and available N. C:N ratio 13-18 in Subhumid Wooded Savanna: West Africa; Return of N in Derived Savanna and Subhumid Wooded Savanna much less: 30 lbs. p. acre/ann. only (Greenland and Nye op. cit.) Usually adequate for subsistence crops at low yield but, for economic yield, N must be added; such yields may be economic in variable degree, depending upon bioclimate, crop and amount of fertilizer.
PHOSPHORUS	
Always adequate for forest needs - indigenous and exotic trees - in primary and secondary communities even on light soils, much leached; inadequate for annual crops where bioclimate is highly humid to humid and intensity of rain is heavy; where less humid and rain less intense and soils of heavier texture, leaching much less; P readily lost in shifting cultivation, where exposure is severe and is even more readily lost under "progressive" mechanized farming, where exposure to insolation and heavy rain is severe; secondary forest growth.	Deficiency is common and widespread - much less P than in forest in total and available forms (de Endredy and Quagraine: 1952; Nye and Bertheaux: 1957A, B, C; Vine: 1953); particularly limited where organic matter is lacking; much less accumulated P in upper soil horizon than in forest; much leached from lighter soils, due to "scavenging" action of iron oxides; addition of P and NP fertilizer essential where economic production is required; subsistence production much enhanced where P and NP are applied.

FOREST SOILS

SOILS OF THE WOODED SAVANNA

restores P, total and available; (Nye: 1952, 1954; Nye and Bertheaux: 1957A, 1957B); as organic P is related to organic C, the higher organic matter of the forests provides more P than in the wooded savanna; the addition of P and preferably of NP to forest soil under shifting and "progressive" mechanized cultivation is essential for continuing satisfactory yield

POTASSIUM

Status of total and exchangeable K fair in all but the highly humid bioclimates (vide map in Phillips: 1959, 1961,- 1966, 1964); provided; Reed: 1951, reports for Liberia - primary and secondary forest - that exchangeable K is relatively high; Kellogg and Davol (1956) report for the Congo a slightly lower exchangeable K in old Derived Wooded Savanna than in heavy forest; deficiencies reported in Nigeria (Benin), Ivory Coast and Dahomey, for oil palm by various workers; but Stephens (1953) and Nye (1954) report no response to K by maize under moderate rain in Ghana; application of K cannot be prescribed generally - detail depending upon the local conditions and the crop; (oil palm, maize, cassava, yam, rubber, lemon and coffees reflect some deficiency - depending on the soil and the rainfall).

Total and exchangeable K status higher in Derived Wooded Savanna and secondary forest than in primary forest (Nye: 1958, Nye and Stephens: 1957); this refers to Subhumid, Subarid, Arid and Subdesert Wooded Savanna; although K deficiency is local and infrequent, it is reflected in Subhumid to Mild Subarid Wooded Savanna by sisal, cassava, banana, sweet potato, potato, tomato, pineapple and citrus; groundnut responds to K in some circumstances, for instance in Senegal; application is not a natter of rote but should be guided by local conditions and the crop - and obviously by the adequacy of rain and soil moisture

LIME

FOREST SOILS

Where the pH is greater than 5.5, no responses are shown by maize to lime (Nye: 1952, 1954 and other workers), but on highly leached acid soils (pH 4.5) in S.E. Nigeria maize and yam respond (Vine: 1953); the addition of lime probably renders conditions more conducive for the development of nitrate; in the Knysna forests, S. Africa, lack of lime (pH 4-4.5) produces small boned livestock and induces decay in human teeth where no counter-measures are taken; application of fertilizer must be guided by local study, the crops concerned and, economically, by the transport costs for this bulky material.

SOILS OF THE WOODED SAVANNA

Sometimes lacking in Subhumid Wooded Savanna but/more often adequate in the Subarid, the Arid and the Subdesert bioclimates; infrequently an important limiting factor in the higher rainfall areas of the Subhumid Wooded Savanna - but sisal may make heavy demands, continuous cropping inducing acidification; application of fertilizer must be guided as noted for the forest.

TRACE ELEMENTS

FOREST SOILS

In West Africa, the Congo and elsewhere the detailed study of oil palm, coconut, coffee, citrus and rubber has thrown some light on the local significance of boron, copper, molybdenum, manganese and zinc, some times in association with P, Ca, K and Mg; more detailed study continues.

SOILS OF THE WOODED SAVANNA

Little is known about the role of these elements; only small responses (below 10 per cent) have been recorded in preliminary trials with copper, magnesium and molybdenum in Subhumid Wooded Savanna in West Africa (I.R.H.O. : 1952), manganese and boron having no effect; work continues

(3) DETERIORATION OF FERTILITY ON REPLACEMENT OF FOREST BY SAVANNA

This is an involved subject, the details depending on the circumstances of the bioclimatic subregion (kind of vegetation, humidity, rainfall, length of the ecologically dry season, temperature) the particular soil series, the degree and dimensions of the clearing of forest and the associated introduction of insolation and direct rainfall, the soil and crop husbandry and the duration of continuous cultivation. Available N and P decrease as the savanna replaces the forest, water relations alter - either becoming wetter or drier - and the microbiota are accordingly influenced. But we must be realistic: the forests throughout the world have steadily retreated before cultivation and livestock production but, provided sound conservation practices are consistently applied, it is probably better that some of the severely disturbed tropical and subtropical forests should yield place to well managed Wooded and Grass Savanna, capable of bearing crops and supporting livestock. Where suitable measures are not applicable the forest "shells" should be conserved and managed.

(4) THE NUTRIENT CYCLE

The concept of deeper rooted trees and larger woody shrubs absorbing nutrients from the whole of the solum and concentrating these in the upper horizon, through the normal processes of cast and decomposition of organic matter, has not yet been given sufficient attention. /(Kellogg & Davol: 1956, in the Congo; Greenland, Kowal and Nye working in my Department in Ghana: 1957-1959, devoted some detailed study to this (vide: Phillips:1959: Nye and Greenland: 1960).7

The phenomenon is worthy of more detailed investigation, as this might teach us more about the intimate actions and reactions characteristic of the interrelations of the habitat and the vegetation, that is of the ecosystem. This should in turn teach us more about how best to maintain the fertility of land deprived of deeper rooted woody growth. Here fertilizers might well be shown to be the only practicable substitute for natural renewal fertility, once deeper rooted vegetation is permantly removed, wholly or for the greater part, as it must be for any but shifting cultivation.

RECENT AND PROSPECTIVE USAGE OF PLANT NUTRIENTS IN AFRICA

In order to see this matter in perspective it is imperative to examine the recent and the prospective use of fertilizers, in approximate amounts, in Africa, Asia, the Far East and Latin America. For present purposes Australasia may be omitted.

According to the Food and Agriculture Organization (FAO: 1965), the total plant nutrients, largely in the form of N,P,K applied in the developing countries in the tropics and subtropics in 1959-1960 were:

Continent	Millions of Metric Tons
Africa	0.40
Asia and the Far East	2.53
Latin America	0.83
	3.76

The comparable World consumption was 28 million tons.

Clearly the total use in these continents was relatively small in relation to the vast terrain even if land unsuitable climatically, physiographically and edaphically be omitted.

By 1963/64 the total nutrients used in Africa had risen to 0.85 million tons, still only 4.3 per cent of the World total. Of this a fair proportion (0.3 million tons) was used in the mainly European owned land in South Africa.

Looking at the prospective usage (FAO: Parker: 1960) in Africa and the other two largely tropical and subtropical continents by 1980, we note that, whilst an appreciable increase is estimated as imperative to meet the anticipated food and other requirements for a population which will probably have doubled, at least, in relation to their dimensions in 1960, the tonnages even then would not really be very great:-

Continent	Millions of Metric Tons
Africa	8.6
Asia and the Far East, including Mainland China	20.0
Latin America	7.3
	35.9

This is not to belittle the vast amount of agricultural extension, community development or "self investment", organization, planning and financing demanded to translate these estimates into fact, but I wish to press home the still modest amount of prime nutrients which would be applied in Africa in comparison with the 70 million tons estimated to be the World need. FAO (1965) considers that whilst there will be a levelling of the consumption curves in Europe and the United States, those in the developing countries must rise rapidly if the demands for adequate food production are to be met for a population twice its present size. According to the figure cited above, the most striking increase by 1980 should be in Africa: about 21.5 times that in 1960!

EXPERIENCE GAINED RECENTLY BY FAO IN THE EXTENSION OF FERTILIZER IN THE TROPICS AND SUBTROPICS

For practical purposes, and merely as an example of what is being attempted and achieved, I invite attention to the work accomplished recently by a single international organization, FAO, through its Fertilizer Programme in the tropics and subtropics in West Africa.

Objectives of the FAO Programme

Let us consider the aims of the programme because these are a guide to its merits and weaknesses.

First, to promote the efficient use of fertilizers, so as to increase food supplies in deficient areas; to increase food supplies so as to lay a sounder foundation for livestock production; to increase the income of simple cultivators and peasant-type farmers, through the efficient use of fertilizers coupled with other improved soil and crop husbandry practices;

secondly, to assist governments to develop national programmes for the effective use of fertilizers and related practices, so as to increase production;

thirdly, to aid in extending sound information regarding the need for fertilizers and about their proper usage;

finally, to develop practical guiding principles as to the satisfactory usage of fertilizers in foreign aid programmes.

Means Whereby the Objectives Might be Achieved

Achievement is being sought by these means:-

(1) By conducting many fertilizer trials and demonstrations - on the land worked by the local farmers : not on experiment stations;

(2) basing the programme on results already gained by sound experimentation in the country concerned, wherever these exist in usable form;

(3) by applying, in principle, the 2^3NPK factorial design for simple trials and 3 and 4 plot demonstrations; by chosing the quantities, per hectare of nutrients, according to the economic minimum which would give relatively high increases in yield and, ensuring that the results could be achieved by local farming practice.

The Africa programme envisages work on maize, millet, sorghum, rice, wheat, groundnuts, beans, yams, cassava and pastures: emphasis is on food crops but cash crops, annual and perennial, are also included.

Results indicated

Commenced in 1961, under the guidance of FAO soil fertility specialists working in collaboration with local extension staffs, the programme had achieved the following broad results by 1965:-

For all crops and seasons in all the countries concerned, the simple mean increase in yield was 73 per cent, the regional means being:-
West Africa (Nigeria, Senegal, Ghana) 71 per cent;
Near East and North Africa, 56 per cent ... due to the limiting factor of adequate moisture;
Latin America 95 per cent. Most important is the fact that the Value/ Cost Ratio (VCR), that is the value of the increase in yield divided by the cost of the fertilizer used, generally increased. In West Africa for the best fertilizer treatments the results were:-

NIGERIA

Maize: mean increase in yield: 30 per cent,
VCR 1.8-2.4, (NPK);

Rice: mean increase in yield: 28-31 per cent,
VCR 2.1-3.6, (NPK and PK respectively);

Yams: mean increase in yield: 33-38 per cent,
VCR 4.5-7.5 (NP and NPK respectively).

SENEGAL

Rice: mean increase in yield: 35-61 per cent, according to the amount of N used:
VCR 5.2 and 4.5, when no subsidy was provided;

Millet: mean increase in yield: 65-79-87 per cent, with corresponding VCR's 4.4, 2.4 and 2.3, according to the fertilizer used: N,NP and NPK respectively and when no subsidy was provided;

Groundnut: mean increase in yield: 27-30 per cent,
VCR's 2.7-3.0, according to the strength of the NPK used, and when no subsidy was provided.

GHANA

Maize: mean increase in yield 62 per cent,
VCR 2.3 (NPK);

Rice: mean increase in yield 182 per cent,
VCR 7.5 (NPK);

Yams: mean increase in yield 51 per cent,
VCR 4.7 (P only).

General Comment

The few years experience summarized for West Africa indicate several features which earlier work by the local Departments of Agriculture and other investigators foreshadowed, and which promise well for the future:-

In the Humid to Humid-Subhumid Forests the main increase in yield is produced by N, but this is increased economically by the addition of P. By contrast, the boost by P is greatest in the wooded savanna (both Derived Savanna and also the Subhumid Wooded Savanna), but this is augmented by the addition of N. Addition of K to NP in a high proportion of trials increases yields, in both forest and savanna.

The largest economic increment in yield, following increased rates of application of NPK appears to be produced by the first 20 kg. ha. of each of the three nutrients. Whilst there is a further appreciable and and often economic increment between 20 and 40 kg., the resultant increment curve is much less marked when 40 and 60 kg. are applied. Applications above 60 kg. produce no better responses. This is partly due to the varieties of the specific crops grown and the standard of the soil and crop husbandry: when these practices are improved, larger amounts of fertilizer might well produce economic returns.

Deficiency symptoms observed after unbalanced fertilizer treatments demonstrate how low the available nutrient reserves are in some soils. Remembering this and endeavouring to avoid unbalanced and excessive treatments, it appears to be safe to advocate the use of fertilizers among small farmers, even when the traditional system (shifting cultivation) and methods of cultivation (cutlass or hoe) are employed.

From the trials conducted in these West African countries during the period 1961-65, the economic aspects were encouraging. Of 5,600 3 plot and 4 plot demonstrations, 80 per cent showed positive economic returns from at least one treatment, with an average VCR of 3.6, for the best treatment, whilst over 1,200 9 plot trials showed a 99 per cent positive economic return, with an average VCR of 7.3 for the best treatment.

It appears from a recent enquiry (July, 1968) made by me of FAO that the many trials and demonstrations conducted in the Fertilizer Programme in various countries have not yet suggested anything at all startling as to detrimental effects of fertilizers upon soils. It is admitted, however, that FAO's function is extension and not research.

SOME POSSIBLE DETRIMENTAL EFFECTS PRODUCIBLE BY FERTILIZERS

It would be unscientific to assume that the application of fertilizers could be considered wholly without detrimental effect under all bioclimatic and edaphic conditions, and irrespective of the knowledge and experience of the user. As experience in progressive farming circles in Britain, Europe, the United States, Canada, Australia, New Zealand and South Africa and elsewhere testify, mistakes in the application of fertilizers, in kind and amount, do produce detrimental effects. This being so, it is obvious that even more serious errors might be committed in the developing countries, where scientific, technical and practical experience is so slight by comparison.

I summarize some of the kinds of detrimental effects which should be expected and guarded against, so far as knowledge and practical supervision could ensure.

(1) Effect upon Germination

It is well known that various commonly applied fertilizers may reduce the per cent of germination of maize, wheat, sorghum, millets and other cereals, groundnut , other legumes and the seeds of a number of other crops.

In some instances the reduction in germination or in vigour of growth of the young seedling is produced through <u>osmotic</u> effects (for example, urea), in others through a <u>toxic</u> effect (ammonium salts and notably, in decreasing order, by anhydrous ammonia, ammonium nitrate, and ammonium sulphate). Urea, sodium nitrate, potassium chloride, ammonium nitrate, ammonium sulphate, potassium sulphate, triple superphosphate and "straight" or ordinary superphosphate may decrease germination for one reason or another. It is also evident that protection of the seed from direct contact with the fertilizer and avoidance of applying fertilizer during dry periods greatly reduce the risk. (Cooke: 1967:316 provides a useful review of this subject, citing work by Rader *et al*. (1943), Prianishnikov (1951), Gasser (1961) and Davies *et al*. (1964) upon cereals, sugar beet and other crops under temperate conditions - European, Russian and American. See also McVicar, Bridger and Nelson: 1963 re work by Allred: 1962 on diammonium phosphate.)

(2) Retardation of Growth of Seedlings

Retarding of the rate of growth of young roots and stems is linked with the fertilizers above noted and also with others.... when these are in contact with or very near the plant.

(3) "Scorching" of Young Growth

The top dressing of stands of cereals and of young or re-shooting pasturage with ammonium salts, notably ammonium sulphate and ammonium nitrate, induces "scorch" or "burn" of the foliage.

Careless application of ammonium sulphate to the roots of young coffee, tea, cocoa, oil palm, rubber and other plants also may produce "scorching" of the foliage and, indeed, result in death of part or whole of the plant.

Boron, excessively applied as a trace element where deficiency is suspected, may induce toxicity, reflected by a progressive necrosis, commencing at the tip or margins of the leaves, which later appear as if "scorched".

(4) Increase in Soil Acidity

The continuous application of ammonium sulphate - the commonest carrier of N used in the tropics and subtropics - may in time reduce greatly the pH of the soil solution: even the relatively low rate of application at 24 lb. per acre per annum, under an annual rainfall of 40 inches (1000 mm) considerably lowered the pH in Ghana (Ofori and Potakey: 1965). Examples are given also by Omar Toure (1964) in his survey of fertilizer studies in the Sudan Zone of West Africa (12th to 16th parallels, North latitude: rainfall 450 mm (16 inches) to 1000 mm (40 inches), June-October, in ferruginous soils, in Northern Nigeria, Senegal, Chad and Mali. (Equivalent to the Arid Wooded Savanna and the Subarid Wooded Savanna: (Phillips: 1959).) The phenomenon is also well known in East and Southern Africa.

Where soils are originally acid, repeated use of this fertilizer could in time make liming necessary - a condition sometimes almost impossible on a large scale because of the profound problems associated with the transport of this bulky material. (Vide: Haylett and Theron: 1955; Weinmann: 1950; Saunder: 1959).

(5) Nutrient Imbalance

Excessive or other unsound application of certain fertilizers may induce nutrient imbalance, examples being:-

On weakly buffered soils, common enough in the tropics and subtropics, the fixation of nutrient elements may be caused by excessive applications of the otherwise widely efficacious mixed fertilizer, NPK, as this could render zinc unassimilable and thus induce a zinc deficiency.

An excessive application of N will produce marked vegetative response accompanied by a reduced yield of fruit or seed. A common example is the large groundnuts devoid of kernels or with very small kernels, known as "pops".

It is noteworthy that ammonium sulphate decreases the total exchangeable bases, especially calcium and potassium and accordingly, inter alia, increases the acidity, as noted above. Experience of this is recorded from Puerto Rico, West and Southern Africa and elsewhere. (Henzell: 1962; Abruna et al.: 1958). Ammonium nitrate is also reported to exert a marked reducing effect upon exchangeable potassium in the lower horizons of red-yellow podzolic soils, in Georgia, U.S.A., the possible explanation being the accelerated uptake of potassium by the vigorous grass and an increased leaching (Abruna et al. 1961, Hentzel: 1964).

Potash applied in moderate quantity by itself might reduce organic carbon excessively, whereas a balanced application with either NP or with P alone would increase organic carbon.

Heavy dressings of phosphate, continued for some time, is reported to "fix" phosphorus in very insoluble form, in soils rich in free iron and aluminium oxides. Although examples of this "fixation" are reported from Hawaii, Australia and Africa, it is as well to remember the point made by Nye and Greenland (1960) that, within the wide scope of tropical soils, these should be considered to be in the minority.

The U.S. Plant, Soil and Nutrition Laboratory Staff (1965), in connection with the associated subject of the role of fertilizers in the nutritional quality of plants, has rightly noted, that whilst fertilizers may temporarily exaggerate an existing deficiency of elements essential to man and beast, the possibilities of such deficiency or imbalance must often be weighed against the certainty of hunger, if fertilizer be not applied! (Vide also Cook: 1967.)

If "fixation" of phosphorus be cited as a problem in some soils, the leaching of nutrients applied in bioclimatic regions of higher rainfall is another. Leaching occurs more often from light, sandy, acid soils with little structure, when excessive amounts of P are applied. This is particularly marked when superphosphate is used, the loss of phosphate from mineral rock phosphate being much less. Applying superphosphate to acid hydromorphic soils (sometimes wrongly termed "peaty" soils) also induces loss of soluble phosphorus by leaching.

Leaching of nitrate also occurs in light, structureless soils, the degree depending upon the form in which N is applied, and the amount, distribution and intensity of the rainfall. It is accordingly more marked in Humid Forests and Subhumid Wooded Savanna than in the drier bioclimatic regions.

Removal of the phosphate and the nitrate in itself might induce other chemical changes in the upper soil and where there is a semi-permeable or impermeable pan, of iron sesquioxide. The accumulation of nitrate and phosphate might also generate chemical reactions unfavourable to indigenous vegetation. The subject is involved and has not been sufficiently studied. Some interesting work has been done upon the leaching of phosphate from sandy soils in West Australia (Ozanne et al. 1961).

(6) Influence of Fertilizers upon Vegetation

There is little literature on this subject and, strangely, that cited often springs from work with which I was associated during the period 1932-1948, in the Highveld of South Africa, in the so-called "purple veld" near Johannesburg. (Induced Open Grassland: Subarid: Phillips: 1959.) In the early 30's my colleagues, Hall, Meredith and Murray, Glover and certain other of my students established a series of fertilizer and grazing trials on the higher stages of the grassland succession leading ultimately to Acacia-Other Species Scrub. Where regulated grazing was practised, the purple veld (Trachypogon-Tristachya-Other Species) responded nobly in vigour, volume and enhanced palatability to a balanced NPK fertilizer. Where further N - in the form of ammonium shlphate - was added and the resultant lush growth in the vicinity of gates, drinking points, salt licks and other sites on which cattle concentrated was taken with avidity, the higher stage grasses gradually gave way to those lower in the primary succession. These were

principally Eragrostis

and _Cynodon dactylon_, which in their younger stages are palatable and nutritious. Control camps showed, by contrast, growth of much less vigorous purple veld, whereas that heavily grazed but not well supplied with fertilizer (notably not with additional N), did not show reversion to the lower successional grasses.

Much later, Hall _et al_. (1955) described this work and at the same time Roux (1954) and Jong and Roux (1955) expressed the view that ammonium sulphate, sodium nitrate and sodium sulphate tend to repress the growth of the higher stage grasses, perhaps because these are very sensitive to even very low salt concentrations - it being argued that so-called "climax" species could not thrive until low concentrations of soil solutions are induced. There was the further thought that these species were also active in retarding, if not preventing, high concentrations through their checking nitrification.

Whatever the precise biochemical explanation may prove to be, my working view is that the heavy grazing, trampling and manuring by cattle of the lush "climax" grass communities, induced by the fertilizers, play a major role in this conversion of purple veld to intermediate-pioneer stages. There has been a tendency in the literature to miss this practical point.

Excessive distribution of ammonium sulphate on veld and established pasturage - particularly during the drier periods in the warmer season in Southern Africa - causes a "scorching", temporary or more lasting. Where the "scorch" is more severe, bare patches are formed and these in time are colonized by pioneer grasses such as Cynodon and Eragrostis and even by weedy forbs.

No work on either incidental or experimental fertilizing of secondary "bush" (forest or wooded savanna secondary wooded stages), of which I have knowledge, has recorded the effect of fertilizers upon the indigenous sub-shrub, large shrub and other woody growth. Incidental observation made by myself in Tanganyika, Rhodesia, South Africa and Ghana suggest, however, that apart from encouraging a lusher growth, no particularly significant responses have been shown. I do not suggest that a detailed quantitative ecological study would not show such responses, for instance the encouragement of certain species and the retardation and subsequent disappearance, through competition with others of more assertive nature.

Where wooded savanna carries lush grass, there is often a very marked response in vigour, height and volume, especially if N and P be added and but little visible result if P and K, either alone or together, be applied in the absence of N.

It is feasible that in forest soils the application of NPK and other fertilizers could affect the microflora and the microfauna. Incidental observations have shown that domesticated animals as well as antelope and buffalo are attracted to areas where fertilizer has been distributed - attracted probably by the bases. When sodium chlorate was used extensively in scrub control trials in South Africa about thirty years ago, my students were unpopular with the owners of cattle, sheep and goats because these animals were attracted by the sodium and accordingly suffered from severely blistered mouths, tongues and noses!

FERRUGINOUS CRUSTS, LATERITE, PEA-IRONSTONE, "OUKLIP" AND RELATED MATERIALS: THEIR SIGNIFICANCE FOR EXTENSIVE DEVELOPMENT OF CROP AND LIVESTOCK PRODUCTION

From incidental references and more particularly from the comments by White (1963) and McNeil (1964), it is clear that some apprehension about this group of materials exists in the minds of those interested in the conservation and management of the cultivatable and pastoral lands in the tropics and subtropics of Africa, Asia and Latin America. But it might be asked whether this has any bearing on our current theme of the role of fertilizers in the ecology of these regions. There seems a tendency to associate with prospective expansion and intensification of the formation of this kind of material, not only unsound policy and methods in the clearing of forest and closer canopied Subhumid Wooded Savanna and the disturbance of the soil and subsoil, but also later the associated extensive use of fertilizer. In order to put the matter into perspective I record several thoughts which might prove helpful to those who are perturbed.

Without considering the details of the nature, history of development and distribution of this group of materials, I draw attention to the following points:-

Laterite, ferruginous crust, cuirasse, pea-ironstone, "ouklip" (South Africa) and related material is essentially an iron-oxide-rich residual weathering product, derived from a wide range of rocks, weathering under strongly oxidizing and leaching conditions in the tropics and subtropics where the conditions are sufficiently humid and warm. The material contains variable proportions of hydrated iron, aluminium and, sometimes, titanium and kaolin, but is poor in silica due to leaching. Its structure may be crust-like to pea-like and the material, although sometimes relatively soft on opening up, hardens when dried.

Its distribution includes parts of India, Malaya, the East Indies, Australia, Cuba, Hawaii, equatorial and other parts of Africa, South America and a small part of the U.S.A. A "fossil" remnant occurs at Antrim, Ireland. Geologically old occurrences indeed are known in various parts and widely in tropical, subtropical and temperate - subtropical Africa.

It is important that the formation of the material is not precisely identifiable with any specific rock, geological epoch and method of development.

In Africa the group of related materials is estimated* to occur, in varying form, concentration and depth, in some 887,000 sq. km. north of the equator and 525,000 km. to the south thereof. The most locally extensive and intensive development is in Humid to Humid/Subhumid Forest and various forms of Derived Savanna and Wooded Savanna in the Ivory Coast, Dahomey, Guinea, Portuguese Guinea, Upper Volta, Mali, Niger, Liberia, Senegal and Sierra Leone, with extensive but less concentrated occurrences in East, Central and Southern Africa, in a wide range of the current bioclimatic regions. Largely developed in Tertiary times, the materials were considerably dismantled during the Pleistocene, from which the so-called debris is very widely distributed in many parts of Africa.

Its actual development appears to be restricted to humid, warm bioclimates, such as associated with forest in its various faciations, whereas seasonally humid and less humid climates appear to indurate the material. Today forest is considered to be active in "breaking" the crust where this is confluent or otherwise very well developed, whereas in the less humid Wooded Savanna this does not occur.

Subjection of the softer material under forest canopy to insolation tends to indurate the material. It is also clear that rainfall of higher intensity erodes the softer materials associated with the deposits under canopy. Erosion of ferruginous crusts and pea-ironstone deposits is much less evident in the less humid bioclimatic regions.

* D'Hoore : 1964

Some fear has been expressed that feckless introduction of insolation and the subjection of the soils of the Humid to Humid/Subhumid Forest bioclimates will induce erosion of land, in some measure protected by the crusts and subterranean hard pans. This may indeed be true but no quantitative impression has yet been gained.

Intensive, mechanized cultivation is suspect as likely to accelerate the erosion of land rich in this group of materials, the taking of "catch" crops of annual cash crops through the aid of fertilizers being associated, in the minds of some, with the works of the Devil!

I have lived with one form or another of "ouklip" in various parts for many years: I know about its tendency to produce perched water tables, its trapping water during the rains which is rapidly exhausted by vegetation during the earlier portion of the dry season, and its inevitable influence, when thick, to retard the development of good rooting systems, not only in annuals but also in perennials. I do not, therefore, under-rate the problems it sets to the cultivator, farmer, and even the forester! I do suggest, however, that its rapid "development" on the removal of forest cover is not established. Its induration under such circumstances does of course occur.

The use of fertilizers upon land in which reasonable proportions of less marked crust and hardpan occur does, at least, permit an improved production of maize, sorghum, millet, sunflower, safflower, groundnut and, occasionally, even established pasturage. ~~Locally~~ The establishment of hardy exotic and, sometimes, even native trees may be accomplished with some measure of success, where the crust or hardpan are broken locally. This has been done in the tropics of West and Equatorial Africa as well as in the subtropics of Southern Africa.

Unquestionably the extent of the problem and the challenge of its solution varies with the bioclimate and other features: it is as dangerous to accept its occurrence in the cleared lands of the Humid to Humid/Subhumid bioclimates as of little danger as it is to cry "wolf" about its terrors! Careful attention to local detail alone is likely to suggest how best to counteract the induration of the materials and the erosion of the softer soil associated therewith. (Vide D'Hoore: 1954, 1964 for various details regarding the group of materials in Africa.)

FACTORS AFFECTING THE ECONOMIC USE OF FERTILIZERS

From this summary of responses to fertilizers under the relatively simple conditions of crop production by indigenous farmers in the tropics and subtropics of Trans-Saharan Africa, there is much to support the view that suitably guided, planned and locally directed usage of carefully selected chemical nutrients should go a long way toward providing more food and other domestic materials for man and his animals. A few general factors are noteworthy in this connection:-

1) The Suitability of the Bioclimatic Unit

As rain-fed cultivation depends upon a satisfactory volume and distribution of rain and upon the minimum of ecologically dry periods during the season of growth, it is evident that the bioclimatic units suitable for the use of fertilizer are limited to the Humid to Humid/Subhumid Forests, the Derived Savanna, the Subhumid Wooded Savanna and, in some parts, to the Subarid Wooded Savanna. In the more severe faciations the rainfall in the Subarid Wooded Savanna climate is somewhat too unreliable for the planning of production with the aid of fertilizers. Wholly or widely ruled out is rain-fed production of any extent in the Subarid/Arid Wooded Savanna transition, the Arid Wooded Savanna and, in most years, the Subdesert. Locally tribesmen attempt to win "snatch" crops in even the worst of seasons ... but to use fertilizer would be worse than useless - it could even be harmful through "scorching" germinating seed and young seedlings.

Under irrigation crop production in the Subarid/Arid, the Arid and the Subdesert Wooded Savanna could, of course, benefit from the sound use of chemical nutrients. Successful use of fertilizer in the Desert has been proved on various irrigation projects of vast extent - such as the Gezira, in the Sudan.

(2) Accessibility

Areas where extensive use of fertilizer is planned should be reasonably accessible, to reduce transportation and other costs on the chemicals and the outward transporting of materials harvested. A simple and obvious point

- this has too often been overlooked by administrative minds!

(3) A Promise for the Development of Sound Husbandry

Until the standard of soil preparation and the details of soil and crop husbandry attain an appropriate level, the use of fertilizer should not be encouraged, because this will inevitably lead to wastage of money and, to what is even more serious, the disillusionment of the cultivator: it is difficult to retrieve confidence once lost by simple farmers.

(4) The Purchasing Power of the Cultivators must be at a Suitable Level

Fertilizers cost money and so do the simplest of hand and animal drawn and other equipment necessary to the adequate preparation of soil and a reasonable standard of soil and crop husbandry. Outright subsidies and *ex gratia* aid are surely not to be set wholly aside at the inception of campaigns aimed at educating tribesmen and others in better farming methods - but, in general, the fact should be faced that nothing is appreciated adequately unless it is paid for by sweat and toil, in kind or by cash.

Too much generosity, of the weak emotional kind, has already been shown in parts of the subcontinent: it is time more realism was introduced. Communities should therefore be encouraged to contribute toward the cost of fertilizers and associated requirements - repayment of preliminary loans being made from the income from the earlier harvests, should these prove capable of this.

(5) Priority for Areas of Known Promise Likely to Benefit Early

As search through any African state would readily reveal, certain localities have produced relatively well, because of local ability and energy and despite various problems. Such areas should be selected for priority trials, in an endeavour to demonstrate that, given the interest, energy and intelligence on the part of the people, the sound application of fertilizers, along with other desirable details of husbandry, could raise yields economically.

(6) General Caution

The foregoing all appear to be very simple matters - but their neglect or maladministration could spell local disaster and thus disappointment. Nothing succeeds like success - but equally, failure has an awkward habit of impeding progress for years after a particular agricultural disaster.

It is imperative that the "popularizing" of the use of fertilizers be approached with the greatest caution: It is sounder to let the results themselves serve as an agency for propaganda! Raw haste in spreading the gospel of the use of fertilizer could arouse the demons of disillusionment and lack of co-operation. Festina lente should guide policy and practice!

SUMMING UP (no underlining)

The following points can now be made:-

1) Prime nutrients - N,P,K - in the forest and wooded savanna soils of Trans-Saharan Africa, whilst adequate for the requirements of indigenous vegetation, for the production of browse and grazing for game and live-stock and for the simple annual and perennial subsistence crops, are frequently not sufficient in amount and in availability for a much enhanced production compatible with the food, clothing and other economic needs of man in this rapidly changing world.

2) Research, field experimentation and demonstration all prove that subsistence and cash crops respond to a sound application of the principal essential nutrients, N,P,K and, in specific instances, to certain trace elements. Organic matter, although a splendid material when present in adequate amount and kind, is widely lacking in most bioclimates. Responses by crops to the prime chemical nutrients, produce an increased amount of organic matter, which if wisely used, improves the physico-chemical-biological characteristics of the soils, particularly in the humid to subhumid bioclimatic regions.

3) The use of fertilizers on a grand scale raises questions which require answering as rapidly and as fully as possible. Among these are the following:-

a) The kind of fertilizer for a specific purpose in a particular ecosystem,

b) the correct amount of fertilizer for a particular requirement,

c) the interactions of the prime elements in mixed fertilizers and whether the application of a particular element or combination of elements is likely to induce an imbalance of nutrients in the soil,

d) the amount of acidification likely to be produced by, say, ammonium salts, under particular bioclimatic and cropping conditions, and how this could be counteracted effectively and economically,

e) the timing of the application of given fertilizers, according to ecological and related factors,

f) the toxicity associated with some fertilizers,

g) the fixation of P in the soils in certain ecosystems,

h) the rapid leaching of N and P from the soils in certain ecosystems,

i) the mechanics and the economics of the distribution of petty amounts of fertilizer to small cultivators in the hinterland of rugged, isolated terrain,

j) the training and, later, the educating of junior extension staff in the elements of the use of fertilizers, so as to enable them to guide tribesmen to apply these correctly, and to support the application by suitable soil and crop husbandry and protection, before and also subsequent to the application.

4) The ecological influences of fertilizers:-

a) Upon the Soil

i) The beneficial effects in producing greater yield are well established, even in primitive subsistence cultivation.

ii) Some potentially harmful influences - such as inducing of extreme acidity, nutrient imbalance and the fixation of P in certain ecosystems, are known and attention should be given to avoiding these wherever possible.

b) Upon the Indigenous Vegetation

i) Instances of an ecological reversion - such as the replacement of a later successional stage by an earlier one are known, but these are not linked, necessary with economic retrogression but rather with economic improvement.

ii) Loss in resistance to drought, to cold and to ravages of insects, is known to occur.

iii) Although it is said by the "muck and mystery" enthusiasts that fertilizers disturb the intimate ecology and biochemical interplay of bacteria, other soil organisms and organic matter, little or nothing to substantiate this has been established by research.

c) Upon Man

i) Greater availability of subsistence and cash crops per unit area are widely demonstrable, not only on the rain-fed soils of the humid to subhumid bioclimatic regions but also under supplementary and full irrigation in the subarid, arid, subarid and desert regions. Man's economy is thus aided, the degree varying with the local circumstances.

ii) Man's health is in no way impaired: indeed, the nutrient enrichment of some staple crops through the provision of additional materials might even be a boost to man's metabolism!

RECOMMENDATIONS

I concentrate, purposely, upon a few matters of particular significance, because satisfactory handling of these could set in motion so much else that could be useful:-

(1) Research should be conducted more intensively into those effects of the use of fertilizer which might prove detrimental to the soils and to the crops within the developing countries.

(2) Specific study should be made of the effect of fertilizers upon the ecology of soil and of community within the ecosystem.

(3) Should the results of these researches warrant any special action, this should include the guidance of extension staff in accordance with a suitably prepared list of points of importance.

(4) The extensive programme of fertilizer trials being conducted by FAO should be supported, wherever desirable, by those in the position to co-operate and otherwise assist. This field service should, however, be checked against a more intensive and more widely distributed programme of scientific research into problems which are either known to exist or which are suspected as likely to show themselves in due course.

(5) At the risk of appearing to be over insistent, I stress the imperative necessity for educating all concerned with research, extension, field trials and guidance of the cultivators and farmers to understand that fertilizers will produce their best results only if their application be in accord with a sound understanding of each major ecosystem involved.

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