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Plant Nutrition and Fertilizer Use*

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INTRODUCTION

ANIMAL life would not be conceived without plants and main in particular needs plants for both food and fibre. The inadequate supply of plant nutrients has long been recognised as a factor limiting maximum crop productivity.

ELEMENTS ESSENTIAL FOR PLANT GROWTH

Although more than sixty chemical elements have been reported to be present in plants only sixteen have been proved essential for plant growth. On the basis of the amounts generally present in plants these essential elements may be classified as follows :—

A. The macronutrient elements—C, H, O, N, P, S, K, Ca, Mg.

B. The micronutrient elements—Fe, Mn, Cu, B, Zn, Mo, Cl.

In addition to these are the beneficial elements Na, Si, V. Al, Co and Se which may be indispensable to some plants in certain situations.

The soil and the air are the sources from which plants obtain these chemical elements essential for normal growth. The elements acquired from the air are carbon, which accounts for approximately 42 per cent. of the dry weight of a plant, and oxygen which accounts for approximately 44 per cent. of the dry weight of a plant. Nitrogen from the atmosphere is also utilized by some plants like the legumes. Hydrogen which accounts for approximately 7 per cent. of the dry weight is acquired from water which is usually absorbed from the soil by plant roots. The balance dry weight of a plant is due to the other nutrient elements acquired from the soil by the roots.

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Crops remove substantial amounts of nutrients from soils and depending on the nature of the plant the amounts lost from the soil within a few seasons could be considerable. Nitrogen, phosphorus and potassium are the nutrient elements removed by crops in appreciable amounts (Table 1) . The object of manuring or fertilization is therefore to ensure adequate supplies of these nutrients—the fertilizer elements—for plant growth and maximum productivity. Although the list of essential elements is lengthy most of them are required only in very small amounts and are usually adequately present in the soil.

FARMYARD MANURES, COMPOST AND GREEN MANURES

Farmyard manures, compost and green manures have been used on cultivated soils since the beginnings of agriculture. Farmyard manure which is an important agricultural by-product exerts a desirable effect on the soil in addition to supplying nutrients for plant growth. The nutrient supply of farmyard manure is variable because its chemical composition is bound to change depending on the kind of animal, its age and condition, the food consumed, the litter used and handling and storage practices. Nevertheless compositions of some common farmyard manures are presented in Table 2, where it will be observed that the content of plant nutrients is considerably less than that of inorganic fertilizers. The outstanding characteristics of farmyard manure are its low, variable and unbalanced nutrient supply, its moisture content and its residual effects. In addition to farmyard manure, compost and green manures have been found beneficial to plant growth due to supply of organic matter, desirable biochemical effects and the conservation and availability of nutrients.

INORGANIC FERTILIZERS

Organic manures are not capable of meeting the demands of intensive agriculture by supplying adequate nutrients to crops unless large amounts are used. Mineral salts have therefore been employed to supplement the nutrients of of the soil. Nitrogen, phosphorus and potassium, which are referred to as the fertilizer elements, are the nutrients commonly supplied in commercial fertilizers. Calcium and magnesium are often supplied as lime (coral limestone, slaked lime or dolomite) and sulphur is a constituent of some fertilizers. Further, commercial fertilizers may often contain micronutrient elements as impurities.

The fertilizer elements nitrogen, phosphorus and potassium should be used in proportions to balance each other and to supplement their supply in the soil. These elements are supplied with " carriers " and three groups of fertiliser materials are known. This classification however is not as simple for some fertilizers like ammonium phosphate carry two nutrient elements. Some commonly used fertilizers together with other relevant information are listed in Tables 3, 4 and 5. It will be noted that the contents of phosphorous and potassium in the fertilizers are expressed as per cent P_2O_5 and K_2O respectively. The phosphorus pentoxide is often referred to as phosphoric acid, phosphate and even phosphorus potassium oxide is called potash. It is more appropriate to express them in terms of per cent. P and K respectively.

The Asiatic world is threatened with food shortage in the near future and increasing agricultural production appears to be a positive approach to averting famine. The use of more fertilizers for the quick increase in agricultural production is a sound technical possibility ; a direct relationship between increasing fertilizer use and rice production in Ceylon is evident from Figure 1. It cannot however be denied that factors such as better varieties, efficient pest and disease control and other improvements in cultural practices would also have contributed to the increased rice production.

The Acidity and Basicity of Fertilizers

Fertilizers influence soil reaction, and therefore may be classified as (1) acidic or acid-forming, (2) neutral, and (3) basic or alkaline. For example, ammonium fertilizers cause the development of acidity in soils due to nitrification as shown below :—

$2NH_4^+ + 3O_2$ ——— $2NO_2^- + 2H_2O + 4H^+$ + Energy. On the other hand nitrogen sources like sodium nitrate and calcium nitrate cause basicity in a soil due to the basic cations, and may create problems on heavy textured and alkaline soils.

The " acid equivalent " or " basic equivalent " of a fertilizer is an indication of the degree to which it will influence soil pH. It is the quantity of $CaCo_3$ necessary to neutralise the increase in acidity due to 100 parts by weight of a physiologically acid fertilizer or the quantity of $CaCO_3$ corresponding to the acid neutralising effect of 100 parts by weight of a basic fertilizer respectively.

Salt Index

Fertilizers add salts to the soil and vary in their effect on increasing the salt concentration of the soil solution. The "salt index" is a measure of this phenomenon and is the ratio of the increase in osmotic pressure produced by the material in question to that produced by an equivalent weight of sodium nitrate which is given a relative value of 100. Thus higher-analysis fertilizers tend to leave less of a salt effect on soils than lower-analysis fertilizers. For example, 50 per cent. potassium chloride has a salt index of 2.19 per unit of K_2O as compared with the relatively lower value of 1.94 per unit of K_2O for the 60 per cent. grade (Table 5.)

NITROGEN

Nitrogen makes up approximately 1 to 5 per cent. of the dry weight of a plant. Factors that determine the concentration of nitrogen in a plant or plant part are age of the plant, the type of tissue and the time of the day when sampling is made. Nitrogen enters into the structure of proteins, chlorophyll, amino acids, amids nucleotides, phospholipids, enzymes, hormones, alkaloids and some vitamins. A deficiency of nitrogen is characterised by a chlorosis and general stunting of plants which ultimately affect yields. Although an adequate supply of nitrogen promotes vigorous vegetative growth an excess of this element will prolong the growing period, retard maturity, induce lodging in cereals, cause low fruit and seed production in plants and increase their susceptibility to disease and pest attack. Late applications of this element may affect quality in tobacco and induce continued vegetative growth at the expense of boll setting in cotton. Excess nitrogen may also aggravate deficiencies of other nutrients which may be of limited availability in the soil.

In the biosphere nitrogen tends to circulate between organisms and their environment as shown in Figure 2. The air which contains about 80 per cent nitrogen is the reservoir and is continuously supplied by the action of denitrifying bacteria. Nitrogen fixing bacteria in leguminuous plants, those living free in the soil and the blue-green algae bring the element from the environment to the organisms. Some nitrogen returns to the soil due to the action of lighting. In modern agriculture soil fertility is maintained by crop rotations involving legumes and by the application of nitrogenous fertilisers.

With the exception of leguminous plants and a few others most plants obtain nitrogen from the soil. It is absorbed either in the ammonium or nitrate form by plants. Most soils are inadequately supplied with these readily available forms of nitrogen due to appreciable removal by leaching and dentrification. Hence the frequent use of commercial nitrogenous fertilizers in crop production to compensate for this loss and to provide adequate amounts of the nutrient. The effect of a readily available nitrogenous fertilizer is apparent within a few days when the foliage acquires a deep green colour and growth is improved. This effect which may last throughout the growing season will invariably be reflected in highly remunerative yield increases. Crops like cabbage and other leafy vegetables display marked responses to nitrogenous fertilizers, while in the case of cereals like rice increase in straw yield is generally greater than that of grain.

Nitrogenous Fertilizers

The approximate composition and important characteristics of some inorganic nitrogenous fertilizers are presented in Table 3.

Ammonium sulphate is one of the most widely used nitrogenous fertilizers. It has he advantage that it could be stored for long under conditions of high humidity and temperature without ill-effects. The chances of loss by leaching and washing away are little due to the ionic nature of the compound. Ammonium sulphate is recommended for rice on well-drained heavy textured soils adequately supplied with iron and manganese. On ill-drained rice soils containing high amounts of organic matter and on the degraded and sandy soils this fertilizer may create problems due to the formation of hydrogen sulphide by reduction of the sulphate. Ammonium sulphate is an acid-forming material and may be best used on calcareous or alkaline soils. It has the advantage of supplying sulphur in addition to the nitrogen.

Urea or carbamide, which is an important industrial chemical in the manufacture of plastics is a water-soluble, nitrogenous fertilizer widely used at present. Due to its high nitrogen content it is frequently used in foliar sprays, especially for pineapples and citrus. Its disadvantages lie in its deliquescent character and its acid-forming property. When conditioned (prilled, granulated or coated) however, it could be handled and stored well. Small amounts of biuret that are sometimes present as an impurity may prove deleterious to crops like citrus, coffee, pineapple and maize. Urea is a non-ionic compound and therefore is not retained by the colloid-complex of soils. However, it is readily hydrolysed to ammonium carbonate which under favourable conditions may be oxidised to the nitrate. Thus the immediate effect of urea is to make the soil alkaline due to the formation of ammonium carbonate which on nitrification would cause acidification as shown below.

$$CO(NH_2)_2 + 2H_2O\ (NH_4)_2CO_3$$
$$2NH_4^+ + 3O_2\ 2 \rightarrow NO_2^- + 2H_2O + 4H^+ + \text{Energy}$$
$$2NO_2^- + O_2\ 2NO_3^- + \text{Energy.}$$

Sodium nitrate which is one of the oldest nitrogenous fertilisers is usually mined from salt deposits in Chile, although a synthetic fertilizer is also marketed. The Chilean product has the advantage of containing several micro-nutrient elements which are present as impurities. In addition to the nitrogen this fertilizer supplies sodium which may be beneficial to certain crops like cotton, sugar beets and red beets. The alkaline effect it has may be an advantage on acid soils.

Ammonium nitrate which contains half its nitrogen in the ammonium form and half in the nitrate form is a readily available source of the element due to its extreme solubility. Its disadvantages are its deliquescence and acid-forming nature. Due to its explosive nature adequate precaution must be observed in its storage.

Ammonium sulphate nitrate contains 6.5 per cent. nitrate nitrogen and 19.5 per cent. ammonium nitrogen in addition to 14.0 per cent. sulphur. It has been found suitable for rice on ill-drained fields of the wet zone of Ceylon.

PHOSPHORUS

The phosphorus content of plants is generally about one tenth that of nitrogen. This element plays a central role in plant metabolism especially in energy transformations. Therefore a lack of phosphorus in plants may adversely affect the absorption of other elements. Phosphorus is an essential constituent of many important compounds such as nucleotides, phytins, lecithins and several enzymes. It is required for seedling establishment, root development, hastening maturity, ensuring resistance to disease, and for improving crop quality especially in forages and vegetables. In cereals it is also necessary for maximum tillering and strengthening of straw.

Relative to nitrogen, phosphorus is rare in the biosphere. The phosphorus cycle (Figure 3) shows that unlike in the case of nitrogen the natural supply of this element is the rocks and other deposits in the sea bottom. In the absence of any geologic upheaval the amount of phosphorus returning to the cycle may be inadequate to compensate for the removal of the element by erosion and other means to marine sediments. It has been estimated that sixty thousand tons of phosphorus are removed to the sea annually, thus making the phosphorus cycle less perfect. It is therefore believed that phosphorus would eventually be limiting for life on earth if man fails to complete the cycle in the future.

In the soil this element occurs as phosphate in primary minerals (apatite), in complexes with the oxides of iron and aluminium, in organic matter and in the soil solution. The optimum conditions for phosphorus availability are (1) a high phosphorus supply in the soil, (2) soil moisture content near field capacity, (3) actively decomposing organic matter, (4) soil pH about neutral or just below 6.0-7.2, (5) a high silica: sesquioxide ratio, and (6) a medium textured soil.

In the soil water-soluble phosphates are rapidly "fixed" when they are converted into forms unavailable to plants. The specific nature of the less soluble forms depends upon the chemical and biological conditions in the soil. Hence soils differ considerably in their "phosphorus fixing" powers. Factors that promote phosphorus fixation in soils are (*a*) aeration and drainage, (*b*) low content of easily decomposable organic matter, (*c*) high content of clay minerals —(greater fixation in the montmorillonite than in the kaolinite clays), (*d*) high amounts of iron and aluminium oxides especially in acidic soils, and (*e*) calcium carbonate. General two or more of these conditions may combine to reduce the availability of applied or natural soil phosphorus. In soils having high contents of iron and aluminium, as for instance the lateries, insoluble phosphates of these elements are formed, while in soils rich in lime apatite-like minerals may be formed. The manner in which added phosphorus may be fixed at various values of soil pH are shown digramatically in Figure 4.

The fixation process can be delayed to a certain extent by the placement of phosphate fertilizers in bands or pockets, because intimate mixing of fertilizers with soil leads to increased reversion. The use of granular or pelletised fertilizer also lessens the chances of phosphorus fixation. In soils which are liable to fix water-soluble phosphates it is therefore an advantage to use less soluble phosphatic fertilizers like ground rock phosphates. Surface applications of phosphatic fertilizers after the crop is planted will be of little value except perhaps in the case of forage crops where it is believed that this element may be absorbed by the above ground portions as well as by surface roots. Broadcast applications may also be profitable in long-term fertilizer programmes designed to build up fertility in phosphorus poor soils.

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Plants absorb phosphorus as the PO_4^{---} or $H_2PO_4^-$ ion. In contrast to nitrogen and potassium the recovery of fertilizer phosphorus by plants is generally less than 25 per cent. indicating the relatively inefficient use of this element from fertilizers. Soil phosphorus is not readily replenished like nitrogen where considerable amounts may be added to the soil through the activities of micro-organisms (Figure 2). It has therefore to be supplied as farmyard manures, plant residues including green manures and inorganic fertilizers to meet the demands of intensive agriculture.

Phosphatic Fertilizers

Some phosphorus carriers, their composition and characteristics are listed in Table 4. Ground rock phosphate is used as a fertilizer although its content of water-soluble nutrient is nil, while that of the total and citrate-soluble nutrient may vary. The effectiveness of rock phosphates depends on the type of material, fineness of grinding and the soil and crop on which it is used. Rock phosphate may most profitably be used on acid soils deficient in phosphorus.

Superphosphate which is manufactured by the treatment of rock phosphate with concentrated H_2SO_4 contains between 16 and 20 per cent. P_2O_5, approximately 85 per cent. of which is water soluble. This fertilizer contains large amounts of calcium sulphate and other impurities in addition to the phosphorus. Although superphosphate by itself is acidic it has no effect on soil pH. It tends to reduce acidity on soils having low pH value and has the opposite effect on soils having pH value between 7.5 and 8.5.

Concentrated superphosphate which contains 42 to 50 per cent. available P_2O_5 is manufactured by acidulating rock phosphate with phosphoric acid. It may contain appreciable amounts of sulphur depending on the purity of the acid used although theoretically it should be completely free of this element. Because this fertilizer is 2 to 3 times more concentrated than ordinary superphosphate storage, handling, transportation and distribution costs per unit of nutrient are comparatively less.

Basic slag which is a by-product of the steel industry may contain from 6.0 to as much as 86.0 per cent. total P_2O_5. Slags differ very much in their contents of total P_2O_5 as well as the proportion of the P_2O_5 which is soluble in 2 per cent. citric acid. In addition to the phosphate content basic slags carry between 40 to 50 per cent. lime, but should not be regarded as a substitute for lime on strongly acid soils. This fertilizer is used most on grassland. other crops like beans and corn especially in areas of high rainfall, may be benefited from applications of basic slag at time of land preparation.

Bone meal contains between 20 to 28 per cent. total P_2O_5. It may be as good as superphosphate on acid soils, but on alkaline soils it would be less effective than superphosphate.

POTASSIUM

An adequate supply of potassium—the third fertilizer element—is essential for the general tone and vigour of plants and in increasing their resistance to disease. In the metabotism of plants this element is essential for photosynthetic activity, translocation of sugars and for the development of chlorophyll. It is important for stiffer straw formation and grain production in cereals and for tuber development in root crops. The content of potassium in plants generally ranges between 1.0 and 4.0 per cent. of the dry weight. Its deficiency leads to stunted plants with scorched leaf tips and margins and in advanced cases may lead to bronze coloured leaves.

Crop removal and leaching account for the losses of potassium from most soils, and potassium deficiency is most likely on light textured sandy soils, peats and calcareous soils. Even though adequate amounts may be present in soils, plants may not always receive their optimum requirements of this element due to its unavailability in most soils. " Fixation " of potassium accounts for its unavailability in some soils and the factors that affect this phenomenon are (1) the nature of the soil colloids, (2) the presence of lime, and (3) alternate wetting and drying. An abundance of other nutrients may also contribute to inadequate potassium absorption by some plants.

Potassium Fertilizers

The chief fertilizer materials carrying potassium are presented in Table 5. The choice of potassium fertilizers rests mainly on the relation of crop plants to sodium and chlorides. Thus the quality of tobacco is impaired by excessive amounts of chlorides and potatoes may also be sensitive to this anion. For these crops therefore potassium sulphate would be desirable while for those like cotton and sugar beet muriate of potash would be advantageous due to the beneficial effects derived from sodium which is contained as an inpurity. Kainite and sulphate of potash-magnesia contain appreciable quantities of water-soluble magnesium in addition to potassium.

Table 1.—Removal of Nutrients by Crops*

Crop	*Yield per acre*	*Nitrogen* N lbs./acre	*Phosphorus* P_2O_5 lbs./acre	*Potassium* K_2O lbs./acres
Rice ..	35 cwt. Grain 24 cwt. Straw	58	18	67
Potatoes	8 tons ..	127	35	173
Sweet Potatoes (Batata)	6 tons Tubers	62	18	98
Cassava (Manioc)	14 tons Tubers	54	45	232
Soya Beans	16 cwt. Grain	112	26	34
Groundnuts	14 cwt. Grain	80	22	54
Coconut Palm	50 Palms ..	66	28	123
Sugar-Cane	36 tons Cane	76	54	170
Cotton ..	350 lbs. Lint 800 lbs. Seed	75	30	78
Pineapples	16 tons ..	98	27	245
Tobacco	16 cwt. ..	116	36	214
Rubber ..	350 lbs. Latex	42	5	19
Bananas	40 cwt. Fruit	56	14	185
Citrus ..	600 boxes Fruit	94	20	129
Onions ..	12 tons all	71	36	107
Cacao ..	8 cwt. Pods	12	6	10
Coffee ..	8 cwt. ..	27	5	40
Tea ..	400 lbs. Manufactured Tea	31	4	13
Maize ..	2,700 lbs. ..	65	33	48

* Adapted from Jacob, A. and Uexkull, H von. Fertilizer Use, Verlagsgesellschaft fur Ackerbau mbH. Hanover, Germany 1958; and Fertilizers and Their Use, F. F. H. C Fertilizer Programme, F. A. O., Italy, 1 65.

Table 2.—Approximate Composition of Some Farmyard Manures *

Material	*Total Nitrogen* %N.	*Total Phosphorus* $\%P_2O_2$	*Total Potassium* $\%K_2O$	*Total Calcium* % CaO	*Total Magnesium* %MgO
Cattle Manure dried	2·0	1·5	2·0	4·0	1·0
Goat Manure dried	1·5	1·5	3·0	2·0	no data-
Poultry Manure dried	5·0	3·0	1·5	4·0	1·0

* From Ignatieff, V. and Page, H. J., Efficient Use of Fertilizer. F. A. O. 1958.

Table 3.—Approximate Composition and Characteristics of Some Nitrogenous Fertilizers

Material	*Analysis N per cent.*	*Acid Equivalent (A) or Basic Equivalent (B) per 100 lb. Fertilizer*	*Salt Index per Unit of Nitrogen*	*Characteristics of Importance*
Ammonium Sulphate	20.6	(A) 110	3.25	Lumps easily. Desirable for calcareous soils.
Ammonium Nitrate	35.0	(A) 60	2.99	Deliquescent but may be pelleted and coated to prevent lumping.
Ammonium Phosphate (Ammophos) 1	16.0		1.61	20% P_2O_5 Supplies two nutrients
2	20.0			35% P_2O_5
Ammonium Chloride	24.0	(A) 128	—	Claimed to inhibit nitrification.
Ammonium Sulphate Nitrate	26.0	(A) 85	3.12	Contains 25%N as the Nitrate. Has performed well on ill-drained rice fields.
Inhydrous Ammonia	80—83	(A) 148	0.57	May be kept under pressure, so requires special equipment.
Aqua Ammonia	20—25	(A) 36—45		Not much used because of cost.
Urea	46.0	(A) 80	1.62	May be pelleted and coated to keep in dry granular state.
Sodium Nitrate	16.5	(B) 29	6.06	Chilean nitrate of soda contains helpful impurities. Sodium seems helpful on acid soils.
Calcium Cyanamide	21.0	(B) 63	—	Very alkaline and adapted to acid soils. Slower than above forms. Used more as a defoliant.
Calcium Nitrate	15.5	(B) 21	—	Contains 50% of nitrogen as the nitrate.
Calcium Ammonium Nitrate	20.5			

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Table 4.—Approximate Composition and Characteristics of Some Phosphate Fertilizers

Material	*Analysis* $\% P_2O_5$	*Acid Equivalent (A) or Basic Equivalent (B) per 100 lb. Fertilizer*	*Characteristics of Importance*
Saphos (Rock) Phosphate	28·5	basic	Insoluble. Slowly available on acid soils in regions of adequate rainfall. Best for crops having long growth period.
Bone Meal	22·0	(B) 20	Proivdes 3% N in addition to slowly available phosphate.
Superphosphate (Ordinary)	18·0	0	More active than above forms.
Concentrated Superphosphate	42·0—50·0	0	Readily available. May be used for all purposes. Contains high amount of nutrient.
Basic Slag, Bessemer	17·5	basic	Most used for grasslands. Contains 40-50 per cent. lime—hence its neutralizing value.
Basic Slag, Open-Health	16·0—86·0	basic	
Basic Slag, Open-Heath Fluorspar	6·0—12·0	basic	
Mono-Ammonium Phosphate	48·0		Readily available, Contains 11·0% N in addition
Ammo-Phos B	20·0		Readily available. Contains 16·0% N in addition.

Table 5.—Approximate Composition and Characteristics of Some Potassium Fertilizers

Material	*Analysis K_2O per cent.*	*Acid Equi. A or Basic Equi. B per 100 lb. fertilize*	*Salt Endex per unit of K_2O*	*Characteristics of Importance*
Potassium Chloride ..	50 ..	0 ..	2.19	Low-grade muriate. contains about 15% NaCl
Potassium Chloride ..	6 ..	" ..	1.94	High grade muriate. Contains only about 3% NaCl
Potassium Sulphate ..	54 ..	0 ..	0.85	Contains practically no chloride. Important for crops like Tobacco
Kainite	10–20 ..	0 ..		Low grade salt. Contains about 50% NaCl Good for crops that respond to sodium.
Sulphate of Potash-Magnesia..	21–30 ..	0 ..	1.97	

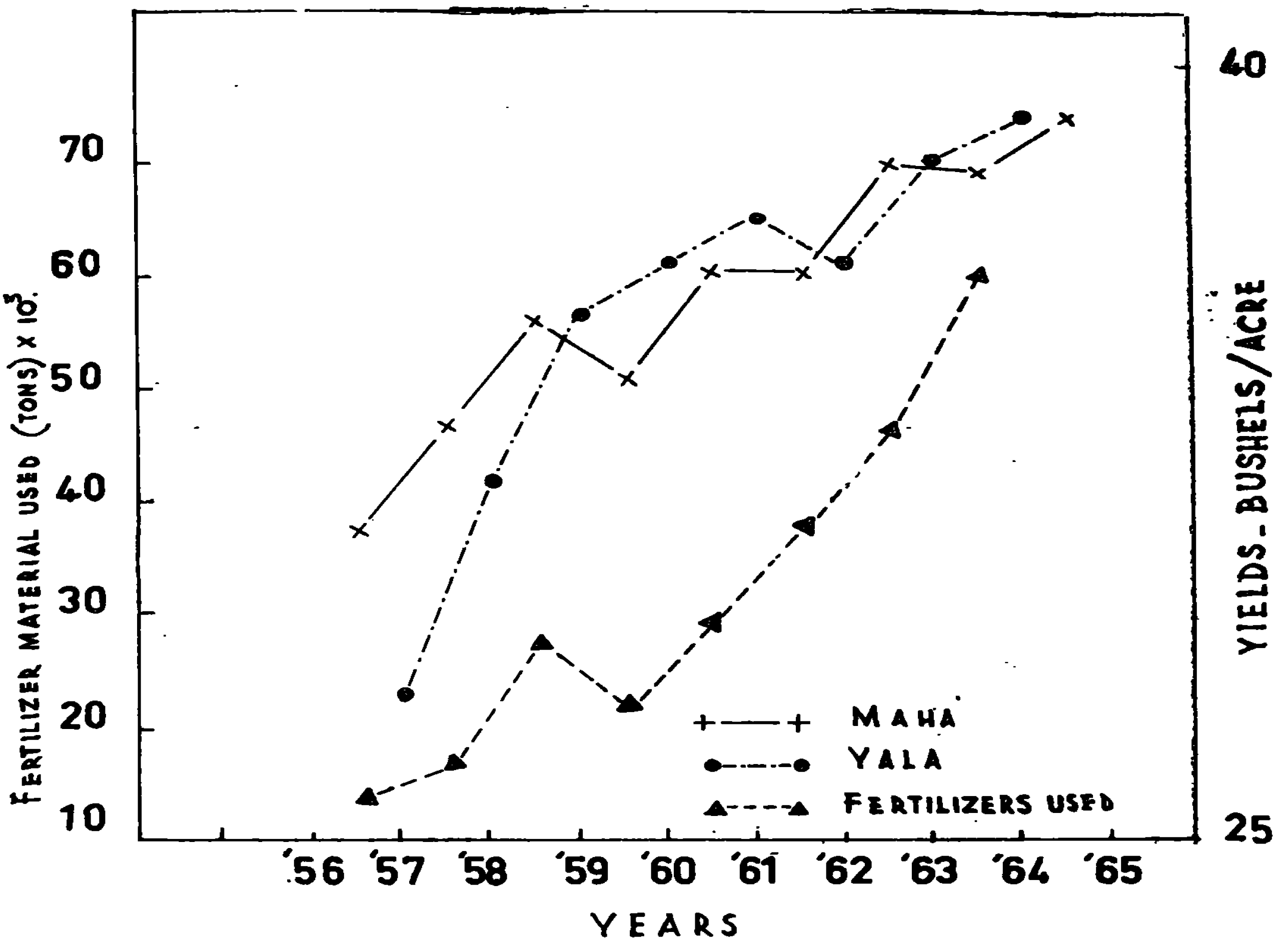
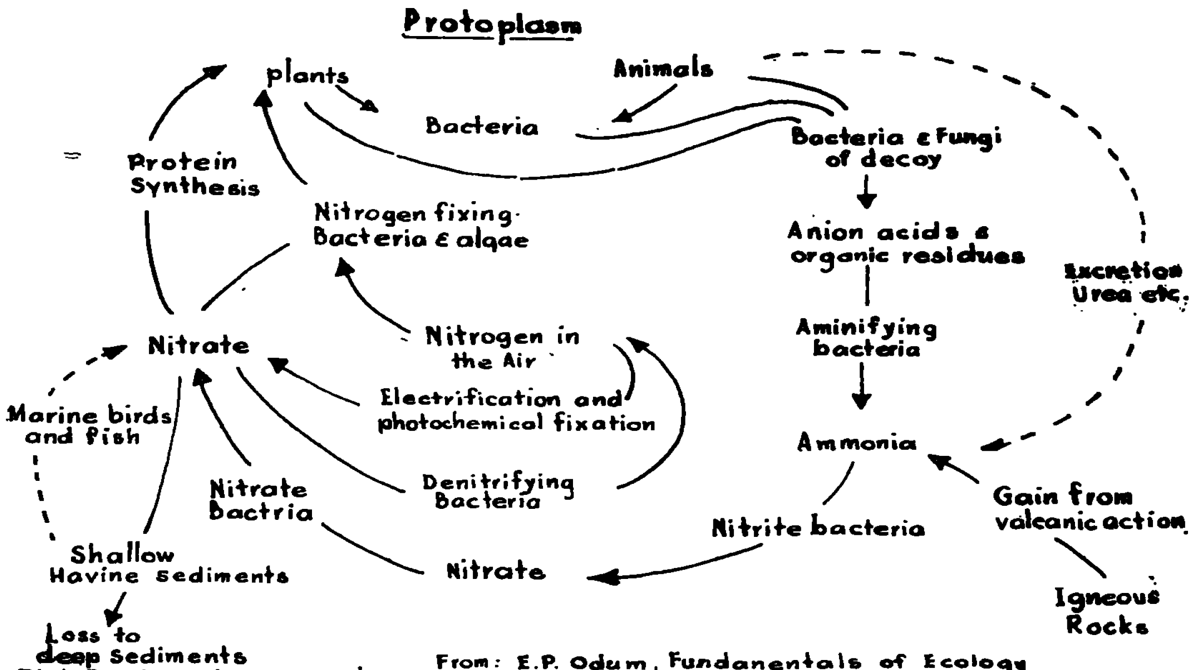
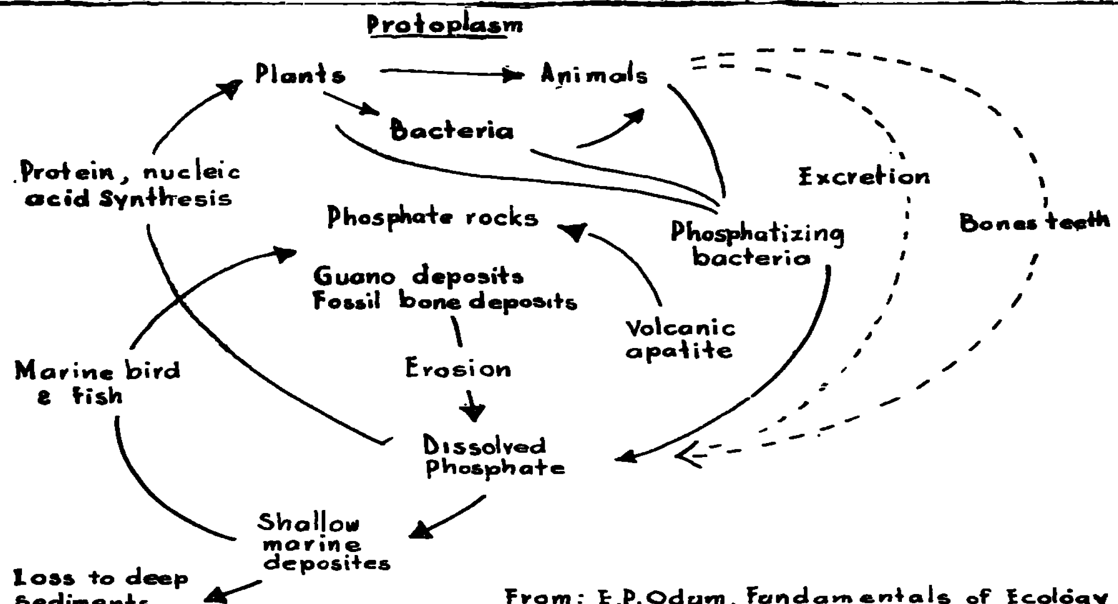


Fig. 1. Relationship between fertilizer material used and yields of rice in Ceylon, 1956 to 1964.



From: E.P. Odum, Fundanentals of Ecology

FIG. 2 The Nitrogen Cycle



From: E.P. Odum, Fundamentals of Ecology
Saunders Co., London 1954.

FIG. 3 The Phosphorus Cycle

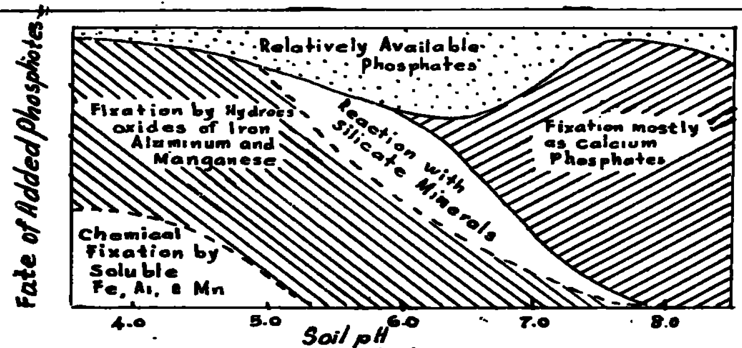


FIG. 4 Inorganic fixation of added phosphates at various Soil pH values
From: H.O. Buckman and N.C. Brady
The Nature and Properties of Soils
The Macmillan Co. New York 1961