EFFICIENT USE OF NITROGEN AND PHOSPHORUS
FERTILIZERS ON TROPICAL SOILS

by

CYRIL BAKO YAKUBU

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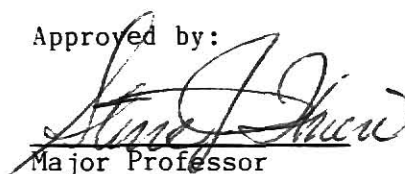
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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EFFICIENT USE OF NITROGEN AND PHOSPHORUS

FERTILIZERS ON TROPICAL SOILS

INTRODUCTION:

Soil is a complex physical, chemical and biological system that supports vegetation. The role of nitrogen and phosphorus in this complex has been the subject of exhaustive research. N, P, and K play a major role in plant nutrition and are appropriately termed "major nutrient elements." Because of the transitory nature of N in soil, its tendency for loss from the soil, and its potential for becoming a pollutant of air and water, fertilizer N should receive more care in its overall management than any other primary or secondary plant nutrient. Nitrogen can also have more deleterious impact than other major fertilizer nutrients on the chemical properties of many soils due to its tendency to accelerate the soil acidification processes.

Acidity induced by the fertilizer N must be neutralized sooner or later if soil conditions and productivity are to be maintained. The acidifying effect of fertilizer N varies among carriers. Some N compounds, such as KNO_3, tend to increase soil pH, while others such as $(NH_4)_2SO_4$, decrease soil pH quite markedly.

With continuous and intensive crop production, the soil is depleted of large quantities of the elements, but can be replenished by judicious fertilization and addition of crop residues. When large quantities of plant nutrients are regularly applied, the unused nutrients, over a period of years, will amount to a considerable investment to the grower. In addition, losses due to fixation, volatilization and leaching present a serious problem. Of these, the leaching or loss of nutrients in

drainage water is of particular importance in tropical soils and areas with coarse textured soils which permit ready penetration of water. In such cases water moves through the soil profile carrying various solutes with it. The type, magnitude, and cause of these losses, if known to the farmer, will greatly help him to modify cultural practices and select the best methods of fertilizer applications to suit his needs.

Phosphorus is known to be associated with several vital plant growth functions such as: utilization of sugar and starch, energy transfer in photosynthesis, nucleus formation and cell division, seed germination, cell organization and the transfer of heredity, fruiting, flowering and, in fact, in every phase of a plant's vital processes. The reaction of P with an organic substance within the plant to form energy-rich compounds is one of the most important reactions of P in plant metabolism (Seatz and Stanberry 1963).

Evaluation of leaching losses are generally carried out on a field scale by analyzing the soil and plants after a known amount of fertilizer application. A lysimeter investigation method involves the determination of percolation and nutrient losses from the soil under controlled conditions. As pointed out by Kohnke and Dreilbelbis (1940), the correct use of a lysimeter can answer questions concerning pedology, soil fertility and hydrology. Lysimeter investigations for different soils and crop conditions have been carried out to ascertain the fate and loss of plant nutrient elements, especially the nitrogen and phosphorus in soil.

Much research has been done to find the best method of placement to achieve the beneficial effects of added nitrogen on phosphorus efficiency. The best results were obtained in the field when both

nitrogen and phosphorus fertilizers were knifed and placed together (Miller and Ohlrogge 1958; Grunes et al., 1959). The efficiency with which fertilizer is utilized by a crop is a major factor in determining the economic returns from fertilization. The degree of physical contact between the soil and fertilizer particles, and the location of fertilizer particles with respect to the root system in the soil profile are important aspects controlling the efficiency of fertilizers.

Thus, the need for agronomic evaluation prompts the establishment of studies with these objectives:

1. To evaluate the effect of N and P rates in conjunction with various band spacings on the growth and grain yield of crops in tropical soils.

2. To evaluate the effect of various spacings of pre-plant bands of N and P fertilizers on the growth and grain yield of crops in tropical soils.

LEACHING OF NITROGEN

Manure and fertilizer applications make soils productive and continuous crop production practicable. In most soils, the natural supply of nitrogen is relatively small. A large percentage of the applied element is probably utilized by the current crop and the rest of it is either utilized by soil organisms or lost from the soil. These losses include the volatilization as ammonia and percolation losses as nitrate, since soils have virtually no adsorptive capacity for nitrates (Wadleigh and Richards, 1953). The nitrogen loss in the percolate makes the soil less fertile and depletes the supply of bases to a considerable extent. Reviewing the fate of nitrogen in leaching losses, Raney (1960) noted a close correlation between nitrogen and bases in leachates (r = 0.9941, r = 0.902, r = 0.898) under different conditions. Leaching losses of plant nutrients is shown on Table 1.

Wetselaar (1962), Burns and Dean (1964), and Johnston et al., (1965) noted the downward movement and loss of nitrogen in the drainage effluent. Harmsen and Van Schreven (1955) have presented information to point out the heavy leaching of mineral nitrogen from different soils. Lysimeter experiments were carried out in Alabama, California, Connecticut, Cornell, Florida, Illinois, Ohio, Tennessee and other locations to evaluate the leaching losses of nitrogen under different conditions.

In Alabama, Jones (1942) observed a 33 to 65% leaching loss of added nitrogen from a sandy loam soil. The losses were greatly influenced by the kind of legume and time of mixing it into the soil.

Table 1   Leaching losses of plant nutrients from Lakeland sand (S.C.) with relatively high fertility levels for 7-year period 1938-1945.

Water (cm)	N in crop equiv. kg./ha	Equivalent kilograms per hectare in leachate				
		K	Ca	Mg	K+Ca+Mg	N
317.5	21.6	3.2	29.1	13.6	45.9	33.2
345.4	19.2	4.1	34.6	15.9	54.6	39.8
391.2	13.7	6.5	45.9	20.5	72.9	60.9
381.0	13.0	6.3	48.0	20.8	75.1	62.4
396.2	13.8	5.9	44.7	20.3	71.0	55.5
320.0	21.1	3.1	33.7	15.8	52.6	41.9
375.9	15.3	6.1	46.0	20.3	72.4	61.5
340.4	17.4	4.8	40.5	18.3	63.6	52.7
325.1	20.1	3.7	31.0	14.1	48.8	34.9
294.6	22.0	3.2	30.2	13.7	47.1	33.0
330.2	19.3	3.9	30.5	14.0	48.4	34.6
309.9	13.1	3.5	29.5	14.5	47.2	33.8
320.0	22.0	3.7	29.3	13.9	47.4	32.8
327.7	22.3	3.8	34.1	15.3	53.2	40.4
342.9	21.5	3.1	23.5	10.7	37.3	22.9
345.4	20.3	3.3	24.3	11.1	38.7	23.0
292.1	16.4	3.0	30.0	13.7	46.7	33.4
327.7	15.1	4.4	40.5	18.6	63.5	52.7
256.5	13.0	2.4	32.5	15.2	50.1	37.9
297.2	12.7	3.9	35.5	16.1	56.1	43.8
259.1	12.4	2.4	30.1	14.0	46.5	33.7
330.2	14.5	2.3	22.1	9.2	33.6	16.8
330.2	23.9	3.2	24.3	11.6	39.6	24.6
467.4	7.2	7.8	47.8	22.1	77.7	63.6

Source: Chapman et al., 1949

Lysimeter studies at Riverside, California (Broadbent and Chapman 1947, and Chapman et at., 1949) revealed substantial losses of nitrogen from sandy soils cropped to a legume and fertilized. In other lysimeters, these losses were converted to gains when cover crops, in addition to regular cash crops were used. Extensive lysimeter investigations were carried out at Cornell (Lyon and Bizzell 1918, 1936; Bizzell (1943, 1944) and percolation losses of nitrogen ranging from 40 to 313 pounds per acre per year were reported from uncropped soils. Cropping reduced the losses from a trace to 15 pounds per acre.

Factors that influence N loss:

The amount of nitrogen lost is influenced by many factors, for example soil type, vegetation and climate. Physical conditions such as waterlogging and compaction of the soil may affect aeration and establish more or less anaerobic conditions. Such conditions hamper microbial activity and stimulate NH_4^+ or NH_3 formation and accumulation, causing NO_3^- losses by denitrification. Sudden changes of the soil, for example wetting and drying or freezing and thawing, may kill microorganisms and be followed by sudden and temporary flushes of energy stimulating mineralization-immobilization turnover (MIT).

There are numerous reports that the addition of organic materials such as plant residues or manure greatly increase denitrification activity. The effects of these additions are dependent on the quality of the organic matter added. Reports of minimum temperatures for the occurrence of denitrification in soils range from 2.7 to 10 C and 75 C for a maximum temperature.

In a relatively neutral pH range of soils (pH 6-8), there is little effect of pH on denitrification rates. However, in naturally acid

soils, denitrification activity is inhibited.

Martin and Chapman (1951) reported that NH_3 losses increased with increasing soil moisture contents up to field capacity only at high temperatures. Small NH_3 losses at low moisture contents has been attributed to a lack of water necessary to dissolve added urea, and NH_3 losses at high moisture content were due to long period of time required to bring soils to an air dry state where NH_3 losses are minimal.

Wagner and Smith (1958) suggested a new field of soil investigation concerning reactions of soil nitrogen. The study supported the hypothesis that nitrogen fertilizer treatments may undergo losses by volatilization of gaseous nitrogen compounds. The measured losses ranged up to 85 percent of the applied N. Indications of some mechanisms of nitrogen losses were obtained from measurements of gaseous nitrogen products evolved from nitrogen treated soil. It was established that losses involved volatilization of nitrogen gases other than elemental nitrogen. A small amount of nitrogen may be lost by volatilization as ammonia. Also, small losses may occur in the form of nitric oxide or nitrogen dioxide. Nitrous oxide, on the other hand, may account for a large part of the nitrogen loss under other certain conditions which lead to denitrification. The further reduction of nitrous oxide under other conditions would give rise to elemental nitrogen as the major gas evolved.

Martin and Chapman (1951) clearly demonstrated that when the pH of a soil exceeds approximately 7.0 and ammonium is present in the soil, some of the ammonium will be lost by volatilization as ammonia. Increasing the amount of ammonium nitrogen applied to an alkaline soil increased the total quantity of nitrogen lost but did not appreciably

affect the percentage lost. The moisture content of the soil had little effect except that evaporation of water was necessary for appreciable volatilization of ammonia from the soil. Losses increased with an increase in temperature. More ammonia volatilized from soils high in sodium and potassium than from soils high in calcium and magnesium, probably because of the higher pH of soils containing the former. A summary of the ammonia loss data is recorded in Tables 2, 3 and 4.

Role of N on leaching losses:

Raney (1966) observed that nitrogen added at the rate of 200 pounds of N per acre per year on a Merrimac sandy loam gave a very close relation between nitrogen and base losses in drainage waters. Nitrogen leaching losses from applications of salts exceeded those from organic forms of nitrogen. This finding indicates that crop residues which are made a part of the soil organic matter help to immobilize nitrogen. This soil management does not prevent losses of nitrogen and bases, however.

Data from Tennessee (Ellett et al. 1952) and Virginia (Ellett et al. 1937) further substantiate the implication that nitrogen dominates removal of bases from soils by the leaching process. Stauffer (1942) evaluated the losses of nutrients and water from lysimeter that had been filled with different soil types. For all soil types, there was a close association between nitrogen in leachates and the equivalents of bases removed. The more productive soil lost more plant nutrients in the leaching process. However, the results of the analyses showed wide variation in the amounts of plant nutrients removed from the different soils by leaching. For example, during the period covered by the phase of the study, Muscatine lost 311.4 pounds of calcium per acre, or

TABLE 2

Volatilization loss of ammonia from several surface-fertilized soils*

Nitrogen Source+	Nitrogen Added	ADDED NITROGEN LOST BY VOLATILIZATION			
		Yolo sandy loam (pH 7.7)	Hanford sandy loam (pH 7.5)	Placentia sandy loam (pH 7.1)	Ramona Sandy loam (pH 6.7)
	g	%	%	%	%
None	0	—	—	—	—
(NH₄)₂SO₄	170	19	26	2	5
(NH₄)₂SO₄	283	14	19	2	4
NH₄OH	175	45	36	34	51
NH₄OH	292	40	34	45	41
Urea	300	14	16	18	36
NH₄NO₃	298	7	7	1	1
NaNO₃	300	0	0	0	0
Dried Blood	300	3	3	1	18
Orange leaves	186	5	6	0	7

*Soils adjusted to 75 per cent of moisture capacity and aerated continuously until dry. Process repeated four times. About 70 days elapsed between beginning and end of tests.

+Salts and urea added in solution to 600 g dry soil. Dried blood mixed with soil before placing in bottles. Orange leaves spread on surface of soil.

Source: Martin et al., 1951.

TABLE 3

Effect of amount of ammonia nitrogen added on its volatilization from Meloland clay loam (pH 8.0)*

NITROGEN SOURCE	NITROGEN ADDED+	NH_3 NITROGEN LOST				TOTAL	ADDED NITROGEN LOST
		1st drying	2nd drying	3rd drying	4th drying		
	mg	mg	mg	mg	mg	mg	%
None	0	0.4	0	0	0	<1	---
$(NH_4)_2SO_4$	28	5.1	0.3	0.2	0	6	20
	57	9.7	2.0	0.5	0	12	21
	113	19.3	3.1	0.7	0	23	21
	226	37.8	6.6	0.6	0.3	45	20
	340	55.7	14.7	3.8	0.7	75	22
	453	66.5	17.5	7.0	2.8	94	21
	567	85.8	22.5	8.7	3.7	121	21
NH_4OH	29	11.1	0	0	0	11	38
	58	19.2	0	0	0	19	33
	117	43.8	0.7	0	0	45	38
	234	58.1	4.6	0.4	0	64	27
	350	84.4	8.0	4.3	2.9	100	28
	467	144.5	17.1	9.0	5.6	176	38
	583	224.7	21.2	11.2	7.9	265	45

* Soil adjusted to 75 per cent of moisture capacity and aerated continuously until dry.. Process repeated for approximately 70 days.

+ Added to 600-g portions of soil.

Source: Martin et al., 1951.

11

TABLE 4

Effect of temperature and moisture on volatilization of ammonia nitrogen from Meloland clay loam (pH 8.0)*

NITROGEN SOURCE+	NITROGEN ADDED, MG	25% OF MOISTURE CAPACITY			75% OF MOISTURE CAPACITY			100% OF MOISTURE CAPACITY		
		Room temperature	100°F	150°F‡	Room temperature	100°F	150°F	Room temperature	100°F	150°F
		Nitrogen lost from check soils, mg								
None	0	1	2	6	1	2	31	2	1	23
		Added nitrogen lost, per cent								
$(NH_4)_2SO_4$	170	27	55	53	23	45	100	18	32	100
$(NH_4)_2SO_4$	283	26	50	61	27	47	93	22	47	99
NH_4OH	175	28	57	77	27	44	100	50	38	100
NH_4OH	292	36	59	71	28	48	90	48	50	97
Urea	300	12	48	30	14	24	95	12	29	85
NH_4NO_3	298	11	21	32	11	17	50	8	12	50
Dried blood	300	2	26	19	3	23	---	3	31	83
Orange leaves	186	2	11	---	---	23	---	7	28	51

* Soil adjusted to proper moisture content and aerated continuously until dry. Process repeated for approximately 65 to 70 days.

+ Salts and urea added in solution to 600-mg portions of soil. Dried blood mixed with soil. Orange leaves placed on surface of soil.

‡Aerated 40 days only. Ammonia lost almost constant for last six dryings.

Source: Martin et al., 1951.

approximately 27 times as much as Cisne which lost only 11.5 pounds. These differences were probably because Cisne contained a smaller amount of calcium than Muscatine, and the amount of water draining through Cisne was also smaller.

The variation in drainage losses of different constituents seemed to depend largely on the amount of drainage which in turn depended to a considerable extent upon the amount of precipitation. Distribution and intensity of the precipitation also influenced the amount of drainage.

Total amount of water passing through the soil is not important. Rather, it is leaching that occurs after a buildup of nitrate in soils. Other anions such as sulfur or chlorine are not important factors in humid region soils because of their small amounts present in soil solution as compared to nitrates.

Because of the open texture and ready penetration of water into many soils, soluble plant food components are exposed to and lost by direct leaching. This is especially true of nitrogen and accounts largely for the constant attention required to maintain in such soils an adequate balance of this nutrient for plants.

Effect of N form on leaching:

Nels and Barnette (1939) investigated the leachability of different forms of nitrogen - nitrate, nitrite and urea at various intervals following the application of nitrogenous materials to Norfolk sand. The top soil and the subsoil used were calculated in proportion to the depths of the profile and the depth of the pots which had a range of 0 to 25 cm. Five to seven liters of water was used to effect a percolate of 3 to 4 liters. The results showed that all nitrogen applied as nitrate was leached, one third of the ammonium nitrogen applied as

ammonium sulfate or ammonium nitrate was leached and the leaching of ammonium ion from ammonium phosphate was very low. The same result showed that urea leached as urea to the extent of 35% and 16% after 1 and 4-day incubation periods respectively. Ammonium nitrogen was retained very efficiently by the soil until nitrification began. The percentage of the nitrogen applied which was leached from the different soils is given in Table 5. The pH values of the soils before and after leaching and the pH values of the leachates are given in Table 6.

Nitrogen applied as sodium nitrate was almost completely recovered in the drainage, after 4 days incubation period, from Norfolk sand (96.7%), Baldon fine sand (96.3%) and from Fellowship fine sandy loam (97.6%). It was observed that very little ammonium and urea were leached until nitrates were formed. This is observed in Table 7.

Jacobson et al., (1948) reported that when nitrogen in the form of commercial fertilizers was added to soils, it was not uncommon for half or more of it to be lost in the drainage water or in other ways. In a series of lysimeter experiments at Windsor, Connecticut, (Morgan 1936), (Morgan et al. 1939) conducted lysimeter experiments for a 5-year period and found that about 95 percent of the nitrogen leaching from the soil occurred during the first 6 months after the application of fertilizers. For the exchangeable nutrient cation, the average total exchangeable bases (Ca, Mg, K, Na) in the soil at the end of the experiments was highest where potassium had been a constituent of the fertilizer materials added and considerably less where magnesium, calcium, and sodium had been applied.

The replaceable calcium was less at the end of the experiment, followed by magnesium. Calcium, magnesium, sodium and manganese were

Table 5 -- The percentage of nitrogen leached at different intervals from Norfolk sand following the application of various nitrogen fertilizers.

	Leached as nitrate				Leached as ammonium				Leached as urea				Total nitrogen leached			
	1 day	4 days	10 days	21 days	1 day	4 days	10 days	21 days	1 day	4 days	10 days	21 days	1 day	4 days	10 days	21 days
Sodium nitrate	105.1	99.0	101.7	96.7	0.4	1.0	1.3	1.3	--	--	--	--	105.5	100.0	103.0	98.0
Calcium nitrate	94.1	91.4	100.4	91.3	3.0	3.8	4.9	4.8	--	--	--	--	97.1	95.2	105.3	96.1
Ammonium nitrate	53.2	52.0	58.0	55.0	17.3	15.4	18.1	18.6	--	--	--	--	70.5	67.4	76.1	73.6
Ammonium phosphate	0.3	2.7	1.2	2.3	10.6	14.0	8.3	2.6	--	--	--	--	10.9	16.7	9.5	4.9
Ammonium carbonate	--	--	3.4	8.8	3.1	--	0.6	6.0	--	--	--	--	3.1	--	4.0	14.8
Ammonium sulfate	--	0.9	2.0	2.0	32.0	41.9	33.1	39.7	--	--	--	--	32.0	42.8	35.1	41.7
Urea	--	--	2.0	8.1	0.1	0.4	1.8	10.6	35.0	16.0	--	--	35.1	16.4	3.8	18.7
Fish meal	--	--	3.3	2.4	0.2	1.7	2.6	9.7	--	--	--	--	0.2	1.7	5.9	12.1
Castor pomace	--	--	2.0	2.2	0.1	0.1	0.9	5.1	--	--	--	--	0.1	0.1	2.9	7.3
Tankage	0.3	--	0.7	1.5	0.1	0.7	0.7	1.8	--	--	--	--	0.4	0.7	1.4	3.3

*Nitrite nitrogen not included in total nitrogen leached.

Source: Benson and Barnette, 1939.

Table 6

The pH values of soils and leachates from cultures receiving different sources of nitrogen.*

Nitrogenous material added	pH of soil		pH of leachate
	Before leaching	After leaching	
Norfolk Sand			
Sodium nitrate	5.69	6.31	5.05
Ammonium sulfate	5.46	6.16	4.87
Urea	6.52	6.98	5.16
Castor pomace	6.09	6.36	5.19
No treatment	5.63	5.84	5.16
Bladen Fine Sand			
Sodium nitrate	4.79	5.91	3.97
Ammonium sulfate	4.78	5.69	3.98
Urea	6.10	6.11	4.58
Castor pomace	5.80	5.74	4.48
No treatment	5.42	5.42	4.47
Fellowship Fine Sandy Loam			
Sodium nitrate	5.96	6.40	5.40
Ammonium sulfate	5.80	6.33	5.14
Urea	6.34	6.65	5.59
Castor pomace	6.16	6.44	5.62
No treatment	5.96	6.10	5.53
Norfolk Fine Sandy Loam			
Sodium nitrate	4.87	5.97	4.54
Ammonium sulfate	5.06	5.71	5.61
Urea	6.26	6.06	5.36
Castor pomace	5.72	5.83	5.22
No treatment	5.53	5.61	5.48

*Observations made after an incubation period of four days.

Source: Benson and Barnette, 1939.

Table 7 -- The percentage of nitrogen leached after four days of incubation from different soils when treated with various nitrogenous materials.

Treatment	Nitrate, %	Ammonium, %	Total %
	Norfolk Sand		
Sodium nitrate	96.7	1.2	97.9
Ammonium sulfate	----	40.3	40.3
Urea	1.5	1.1	2.6
Castor pomace	----	0.1	0.1
	Bladen Fine Sand		
Sodium nitrate	96.3	0.5	96.8
Ammonium sulfate	----	3.1	3.1
Urea	----	----	----
Castor pomace	----	----	----
	Fellowship Fine Sandy Loam		
Sodium nitrate	97.6	1.0	98.6
Ammonium sulfate	3.1	1.8	4.9
Urea	1.0	----	1.0
Castor pomace	----	----	----
	Norfolk Fine Sandy Loam		
Sodium nitrate	72.2	0.7	72.9
Ammonium sulfate	0.5	----	0.5
Urea	0.1	----	0.1
Caster pomace	0.4	----	0.4

Source: Benson and Barnette, 1939.

leached in the greatest amounts (90 percent of the total amount leached) during the first 6-month period following fertilizer application. The carbonate, sulfate, chloride, phosphate and silicate anions were removed in greater amounts during the second period.

<u>Summary:</u>

The majority of nitrogen is lost as nitrates since these ions are not held by the exchange complex to any great extent. Losses of nitrogen as nitrite and urea are almost negligible. Due to soil fixation, plant utilization, and volatilization, leaching losses of ammonia are minimal except from soils with reducing powers and under conditons favorable for denitrification. In a series of lysimeter experiments Morgan, (1936) found that about 95 percent of the nitrogen leaching from the soil occurred during the first 6 months after the application of fertilizers.

Further, the findings of Benson and Barnette indicate a direct positive relationship between the base exchange capacity of the soil and percolate losses of ammonium nitrogen. In soils with greater base exchange capacities, ammonium may be retained by fixation against leaching losses. The nitrogen loss in the percolate makes the soil less fertile and depletes the supply of bases to a considerable extent. Reviewing the fate of nitrogen in leaching losses, Raney, (1960) noted a close correlation between nitrogen and bases in leachates under different conditions. There was a close association between nitrogen in leachates and the equivalents of bases removed. The more productive soils lost more plant nutrients in the leaching process.

Well managed crops and proper fertilizer management programs to include adequate plant cover, and split applications of fertilizer when necessary, will go a long way in reducing leaching losses of nitrogen.

Effect of lime on soil:

Since most of the lime and fertilizer is of necessity applied to the surface of permanent pastures. Many investigators have examined lime placement and shown that lime compounds do move downward through the soil. Nelson (1929) applied 2,400 pounds of lime per acre to the surface of grassland. After six years a trend toward downward movement was indicated by a slight though consistent neutralization of the soil acidity to a depth of nine inches. Blair and Prince (1934) reported that limestone used at the rate of 2,000 to 4,000 pounds per acre over a period of 25 years changed the reaction of the subsoil (7 to 13 inches) to about the same degree that it changed the reaction of the surface soil.

Movement of P:

It has been generally concluded by most investigators that the downward movement of phosphorus in soil is very slow. Midley (1931) found that when superphosphate was applied as a surface dressing, most of the phosphate remained within the surface inch of soil after an interval of 6 months. Brown (1935) reported that biennial surface applications of superphosphate to pasture land penetrated not more than 2 or 3 inches and perhaps much less in 16 years. Metzger (1934) found that phosphorus from superphosphate accumulated largely in the surface 0 to 2 inches.

Van Alstine (1918) concluded that when phosphorus was used as fertilizer it remained almost where it was placed in the soil until removed in crops or removed by other agents such as erosion, wind, or water.

It has been noted that tha degree of phosphorus penetration is

affected *by a number of soil conditions* and by the use of other
fertilizer materials. Heck (1934) pointed out that the greatest
phosphate penetration occurred in soils of neutral to slightly acid
reaction which contain little active iron or aluminium.

Stephenson and Chapman (1931) concluded that phosphorus penetration
was dependent upon the soil texture, the amount of phosphorus applied,
and the manner of its application. Midley (1931) found that sodium
nitrate increased the movement of superphosphate while potassium and
ammonium sulfate slightly decreased it.

The soil types studied were Dekalb silty clay loam and Dekalb silt
loam located at Morgantown, Upshur clay loam at Aurora, and Monongahela
fine sandy loam at Wardensville. The Dekalb soils,which were derived
from non-calcareous shales and from sandstone were considered to be
among the least productive of the upland soils. Upshur soil was derived
from shales which were partly calcareous and somewhat more productive
than the Dekalb. Monongahela was a terrace soil derived from
non-calcareous material. The lime and fertilizers in all the trials
were applied to the surface of old established pasture sods. Soil
samples were taken with a soil tube and sliced in layers representing
the depths 0 to 0.5, 1.5 to 3, 3 to 5, and 5 to 7 inches. Available
phosphate analyses were made according to the method of Truog (1930).
The data showed that the amount of available phosphorus in the surface
1.5 inches on all treated plots was greater than that on the check
plots. This increase appeared to be due principally to the influence of
lime. Superphosphate and manure applications showed only a slight
additional increase. There was no apparent difference in available
phosphate on any of the plots below 1.5 inches. An examination of the

results showed that the available phosphorus in the surface 1.5 inches had been markedly increased but even after an interval of 7 to 8 years most of the phosphate remained in the layer. There had been some penetration to the 3 inch depth but almost none below that. Increased penetration of phosphorus resulted from an increase in the application of superphosphate and was further facilitated by a sandier soil texture.

Johnson et al., (1965) reported that under California conditions, with an intensive irrigated agriculture, nitrogen and phosphorus were the two elements that must be applied to crops in large quantities to assure that maximum yields were attained. Evidence obtained by Chapman and others (1949, 1962) indicated that nitrates were highly soluble and high leaching losses should be expected. Research and development work should cause improvement in utilization efficiency.

Brown, L. A. (1935) applied rockphosphate in the same manner as superphosphate and rockphosphate penetrated more than 7 inches. Eight years after the last application of rockphosphate and three years after the last superphosphate application, the rockphosphate treated pasture contained 188 pounds of phosphorus per acre. Soils receiving rockphosphate applications contained four times as much phosphorus as did superphosphate applications. Rockphosphate penetrated more rapidly than superphosphate in an acid soil, but the reverse was true in alkaline soils. Ammonium sulfate or sodium nitrate speeded the penetration of rockphosphate more than that of superphosphate, especially in an acid soil.

Cooke and Gasser (1955) in their 6 year field experiment indicated that iron and aluminium may not have combined with water-soluble phosphate to form compounds which were insoluble in dilute acids and

useless to crops, since the total amount of phosphate in the soil did not increase. Since there were large differences between amounts of phosphate applied, the greater part of the applied phosphate must have moved down the soil profile below the cultivated layer. McGregor (1953) showed that phosphorus moved down the soil profile in an uncultivated pasture in Scotland, such movement being most marked in poorly drained soils. Neller et al. (1951) indicated that 80 percent of the phosphate applied as superphosphate was leached out of the surface layer of very acid sandy soils in Florida during the course of the season. It was suggested that much of the fertilizer phosphate applied had moved down the soil profile below the cultivated layer.

Factors affecting P retention:

Larsen et al. (1958) conducted a study on the leaching of applied labelled phosphate in five organic soils and one mineral soil. After 15 inches of water were leached through the soil columns, phosphate retention appeared closely correlated to the sesquioxide content of the soils and the apparent degree of decomposition. When labelled phosphate was mixed into the surface 2 inches of a 14-inch column of a virgin organic soil, 60 and 80 percent appeared in the leachate from 15 and 30 inches of water, respectively. Lesser amounts of phosphorus appeared in the leachate from soils with greater sesquioxide contents and with longer drainage histories, while no fertilizer phosphate was leached from the mineral soil or from the organic soil which had been drained 15 or more years. The relationship of the sesquioxide and the fertilizer phosphate leached is shown on Table 8.

The results from these soils are in agreement with those reported for mineral soils by Metzger (1941), who found a significant correlation

Table 8   Relationship of the Sesquioxide content to the movement of fertilizer P (246.4 kilograms P per hectare) in soil which was leached with 38.1 cm of water after 3-day incubation period.

Soil	pH	Sesquioxide kg/ha	Percent P recovered	Max. Penetration P into Untreated Soil
Virgin Muck	5.0	1,904	60.98	through 30.5 cm
Deep plowed Muck	6.5	2,576	14.04	through 30.5 cm
Gumz muck	4.4	9,184	1.85	through 30.5 cm
Sod Muck Subsoil (25.4–35.6 cm)	6.1	10,304	0.33	through 30.5 cm
Sod Muck Surface (7.6–17.8 cm)	4.8	23,520	0.00	through 8.9 cm
Mineral Soil*	4.8	104,160	0.00	through 3.8 cm

*Leached with 27.9 cm of water.

Source: Larsen et al., 1958.

between total sesquioxides and the P fixed from solution with 42 soil samples. In the leachate from the virgin muck and the Gumz muck after the 3-day incubation period, the accumulative percentages of the fertilizer P that appeared were 80 percent and 57 percent, respectively. The virgin muck had a low retaining power for P with as much as 80 percent recovered in 30 inches of leachate which was somewhat comparable as reported by Neller (1947). From similar rates of P applied as a superphosphate, he found an average of 83 percent of the P in the leachate from 28.5 inches of rainfall on an 8-inch column of soil.

P mobility in soils:

Neller (1946) in his study reported that phosphates do not move down through the profiles of most soils to any appreciable extent. Losses of phosphate in Leon fine sand as large as those obtained in the lysimeters probably do not occur in the field for the reason that downward percolation of water is checked by the hardpan layer in the B_2 horizon. The lysimeter data indicated that phosphates applied on or in the surface horizon would be diffused throughout the soil mass above the impervious hardpan layer 18 to 24 inches below the surface. This process in itself would dilute the concentration of phosphorus to a considerable extent. The decrease in P concentration would be further increased by losses caused by run off of soil water and by fixation of some of the phosphorus by the soil. The data for added phosphate leached with and without lime is given in Tables 9 and 10.

Hingston (1960) sampled three representative soil types from virgin and pasture areas following application of superphosphate. Data on C:N:S:P ratios, increase in organic matter and increases in P and N per cwt. of applied superphosphate. Superphosphate in sand following winter

Table 9 -- Leaching by rainfall of the citrate-soluble phosphorus of superphosphate and calcined phosphate added to various soil types,

Soil type	Added phosphate leached		Soil Characteristics		
	Super-phosphate %	Calcined phosphate %	pH	Moisture equivalent, %	Organic matter, %
Norfolk fine sandy loam	6.30	1.84	4.75	7.33	2.14
Dunbar fine sandy loam	1.79	1.88	4.20	18.22	3.53
Coxville clay	1.59	1.86	4.20	32.06	8.27
Bladen fine sandy loam	1.79	1.32	4.25	22.67	4.74
Amite fine sandy loam	Trace	1.31	5.78	16.24	5.30
Plummer fine sandy	20.28	34.52	3.85	8.09	1.75
Leon fine sand	90.61	81.35	3.51	6.39	3.00

Source: Neller, 1947.

Table 10 -- Effect of lime upon the leaching of the phosphorus of various phosphates from Leon fine sand.

Amount of phosphate per lysimeter, grams	Type of phosphate	Phosphorus leached, %*		Reaction of phosphated soil, pH	
		Lime added	No lime	Lime added	No lime
3.976	Superphosphate	70.15	90.61	4.72	3.51
3.976	Calcined phosphate	62.35	81.35	4.97	4.03
5.592	Ground rock phosphate	10.47	46.88	4.82	3.76
11.183	Ground rock phosphate	10.14	48.27	4.93	3.86
22.365	Ground rock phosphate	6.19	27.28	4.85	3.91
5.592	Ground rock phosphate	1.26+	46.88	5.25+	3.76

*Based upon citrate-soluble phosphorus of superphosphate and calcined phosphate and upon total phosphorus for rock phosphate.

+Twice as much carbonate of lime was added to this lysimeter.

Source: Neller, 1947.

waterlogging leached out, probably due to the relative absence of clay and iron oxides. In Boyanub sandy loam and in Blythewood sand, despite saturation, no leaching was detected, probably because sesquioxides and clay absorbed the applied phosphorus.

The ability of soils to retain applied phosphorus is well known. When fertilizers are applied, the phosphorus is commonly retained in the surface layer of soils and firmly held against the leaching action of rain. The presence of a pasture cover has been found to particularly favor the retention of phosphorus. Donald and Williams (1954) found that all the phosphorus applied as superphosphate over periods of up to 26 years could be accounted for in the top 4 inches of the soil. As less than 20 percent of the phosphorus applied to a pasture or crop is normally used in the year of application, it is important that the remainder be retained within the root zone for use in successive years.

Ozanne et al. (1961) measured leaching of phosphorus in seven field trials carried out on soils in Australia which were mostly loamy sands. All soils contained about 4 percent organic matter. Losses from the top 4-inch layer of soil ranged from 17 to 81 percent of the applied phosphorus. A brief description of the soils used in the seven experiments is given in Table 11. Losses of applied phosphorus from the top soils of the seven experiments are summarized in Table 12. The surface 4-inches contained more applied phosphorus than did the lower layers. Williams (1959) concluded that the phosphate was probably fixed by a humate complex containing active iron and particularly aluminum. The buildup of phosphorus in soils does happen even on soils subject to leaching. But accumulation under these conditions may be slow and wasteful.

28

Table 11 -- Total and dilute acid-soluble phosphorus preceding and following lysimeter exposure of Leon fine sand to which different phosphates were added with and without lime.

Phosphate	Lime	Total phosphorus ppm		Dilute acid-soluble phosphorus, ppm		pH values		Phosphorus leached, %
		May 10	Sept. 4	May 10	Sept. 4	May 10	Sept. 4	
None	None	27.5	24.5	10.5	7.0	5.31	4.45	---
None	Added	40.0	30.0	12.5	8.6	4.63	5.00	---
Superphosphate	None	77.5	31.5	41.0	11.0	4.72	5.53	90.61
Superphosphate	Added	85.0	35.0	41.0	10.0	4.72	5.55	70.15
Calcined phosphate	None	79.3	40.0	40.0	10.5	4.03	4.55	81.33
Calcined phosphate	Added	71.5	34.0	41.2	13.5	4.97	5.65	62.35
Rock phosphate	None	231.8	125.0	16.0	14.0	3.86	4.78	48.27
Rock phosphate	Added	250.0	212.5	17.5	9.0	4.93	5.00	10.14

Source: Reller, 1947.

Table 12

DESCRIPTION OF SOILS

Expt. No.	Soil	Type	pH	Fractions (% of whole soil)			
				>2mm	Sand	Silt	Clay
483(b)	Boscabel gravel	Lateritic podzolic formed on a truncated lateritic B horizon	6.2	66	29	2.3	1.7
463	Kojonup gravelly loamy sand	Slightly podzolized soil with lateritic gravel	6.5	18	71	4.0	6.9
471	Balgarup loamy sand	Poorly developed podzolic	6.4	17	73	5.4	3.9
483(a)	Kojonup loamy sand (A)	Podzolic	6.2	6	85	3.3	5.4
1044	Kojonup loamy sand (B)	Podzolic	6.0	19	71	3.4	6.0
1020	Crawley sand	Deep yellow sand slightly podzolized	6.1	Trace	95	1.8	2.7
1034	Carrolup sand	Podzolized grey sand over massive laterite	4.9	1	91	4.0	1.0

Source: Ozanne et al., 1961.

Gupta and Cornfield (1963) defined the fixation of phosphate by soil as the conversion of added water-soluble phosphate to water-insoluble forms. Bassett (1917) considered that a basic compound such as hydroxyapatite was formed, while McGeorge (1942) concluded that initial fixation in calcareous soil was due to formation of tribasic calcium phosphate which was ultimately transformed into calcium carbonate-phosphate by a very slow process.

The results from experiments by Gupta and Cornfield (1963) showed that a large part of the soluble phosphate added to calcareous soil was fixed as non-apatitic calcium phosphate when the calcium carbonate content was high and the concentration of the added phosphate was low. When the concentration of the latter was increased, part of the phosphate was fixed in aluminum-bound form. With a low-calcium carbonate soil, however, more fixation occurred in the aluminum and the iron-bound forms and less in the non-apatitic form. The concentration of the added phosphate was an important factor in controlling phosphate fixation and its effect was related to the time of contact as shown on Tables 13 to 15.

It was suggested in early research (Perkin 1948) that the amount of phosphate fixed by kaolin, limonite and muscovite soil minerals showed that the addition of excessive phosphate to soils would result in the precipitation of phosphate and that the lower the moisture content of the soil, the greater the amount of phosphate precipitated. Between p^H values of 4.5 and 7.5, the solubility of the phosphate increases with the p^H reaction of the solution regardless of the solution concentration.

Table 13

LOSS OF PHOSPHORUS FROM TOPSOIL (0-10.2 cm) UNDER CLOVER PASTURE

Soil Type	Duration of Trial (years)	Total P Applied (kg/ha)	Fate of Applied P			99% Fiducial Limits + (%)
			Left in Soil (%)	Removed by Mowing etc. (%)	Lost (%)	
Boscabel gravel	4	105.3	71	12	17	9
Kojonup gravelly sand	7	105.3	56	22	22	18
Balgarup sand	7	276.6	60	6	34	12
Kojonup sand (A)	4	105.3	37	20	43	16
Kojonup sand (B)	1	47.0	21	12	67	13
Crawley sand*	18	435.7	22	2	76	5
Carrolup sand	3	68.3	11	8	81	9

*Received 30.2cm higher mean annual rainfall.

+Applies strictly to values for P "Left in Soil". Fiducial limits of values for P "Lost" are similar but strictly wider as they include the errors in measuring P "Removed by Mowing".

Source: Ozanne et al., 1961.

Table 14

Fixation of soluble phosphate by two calcareous soils

(values are given as p.p.m P_2O_5 (soil basis))

% CaCO$_3$ in soil	Amount of soluble phosphate added as KH$_2$PO$_4$	Easily replaceable form		Non-apatitic calcium phosphates		Al-bound phosphate		Fe-bound phosphate		Apatitic phosphate	
		Phosphate in the extract	Increase over the control	Phosphate in the extract	Increase over control	Phosphate in the extract	Increase over control	Phosphate in the extract	Increase over control	Phosphate in the extract	Increase over control
16.5*	0	17.5		217		165		75		600	
	100	38.8	21.3	250	33	167	2	75	nil	600	nil
	200	55.0	37.5	283	66	188	23	76	1	590	nil
0.15	0	12.5		17		170		150		83	
	100	27.5	15.0	33	16	210	40	170	20	80	nil
	200	38.8	26.3	58	41	211	41	200	50	83	nil

* Soil No. 18   Soil No. 2 (see Part II of this series: J/ Sci. Fd Agric., 1962, 13, 658).

Source: Gupta et al., 1963.

<u>Table 15</u>

Effect of concentration of added phosphate on fixation by a calcareous soil (2 7% $CaCO_3$)*

(values are given in mg of P_2O_5)

Phosphate added	Time of contact							
	24 h		48 h		72 h		144 h	
	P_2O_5 in the extract	% of added P_2O_5 fixed	P_2O_5 in the extract	% of added P_2O_5 fixed	P_2O_5 in the extract	% of added P_2O_5 fixed	P_2O_5 in the extract	% of added P_2O_5 fixed
0	0.038		0.048		0.050		0.050	
0.1	0.065	73.0	0.058	90.0	0.050	100.0	0.050	100.0
0.5	0.200	67.6	0.115	86.6	0.113	87.4	0.113	87.4
1.0	0.255	78.3	0.255	79.3	0.250	80.0	0.238	81.2

* Soil No. 8 Part II of this series

Source: Gupta et al., 1963.

Summary:

Phosphorus is the one element that is not generally found in appreciable quantities in the percolates collected from various lysimeters located at different institutions. Various factors contribute to the retention of soil phosphorus. Important among them are soil type, native phosphorus content, organic matter and sesquioxide content, base exchange capacity, calcium carbonate content, nature and amount of phosphorus applied and the method of application.

Most of the percolate losses of phosphorus have been recorded from coarse textured soils. A larger amount of available phosphorus is generally lost in the drainage from such soils during periods of heavy rainfall. The lysimeter data indicate that phosphates applied on or in the surface horizon are diffused throughout the soil mass above the impervious hardpan layer 18 to 24 inches below the surface. This process,however,depends on the soil type. Midley found that phosphate remained within the surface inch of soil after an interval of 6 months. Results from some studies show that superphosphate in pasture land penetrated not more than 2 or 3 inches and perhaps much less in 16 years. Rockphosphate penetrated more rapidly than superphosphate in an acid soil, but the reverse was true in alkaline soils.

Phosphate retention is closely correlated to the sesquioxide content of the soils and the apparent degree of decomposition. Lesser amounts of phosphorus appeared in the leachate from soils with greater sesquioxide contents, while no fertilizer phosphate was leached from the mineral soil.

Since there were large differences between amounts of phosphate applied as fertilizer and the amounts recovered by the crops, the

greater part of the applied phosphate must have moved down the soil profile below the cultivated layer. Under alkaline soils with an intensive irrigated agriculture, nitrogen and phosphorus are the two elements that must be applied to crops in large quantities to assure maximum yields.

<u>Effect of Nitrogen on P uptake:</u>

Percolate losses of nitrogen and phosphorus from soils, and the fixation of phosphorus by soils can be reduced by the additions of organic matter and placement of fertilizers N and P.

Robertson <u>et al</u>. (1954) in field experiments in Indiana in 1949 found that absorption of banded fertilizer P by corn (Zea mays) was greater when N was included in the band than when it was applied separately. In Nebraska N increased uptake of fertilizer P from bands by oats (Avena sativa) and wheat (Triticum aestivum) (Olson <u>et al</u>., 1956; Olson and Drier, 1956). In Saskatchewan, Canada, Rennie and Mitchell (1954) and Rennie and Sopher (1958) obtained a similar result for wheat. Grunes <u>et al</u>. (1958a) in field experiments in North and South Dakota found that N increased the relative absorption of banded fertilizer P by sugar beets (Beta vulgaris) and potatoes (Solanum tuberosum).

Greenhouse experiments have shown that N increased the fertilizer P absorption by barley (Hordeum vulgare) (Grunes <u>et al</u>. 1958b), corn (Miller and Ohlrogge, 1958), sugar beets (Werkhoven and Miller, 1960), and oats (Bouldin and Sample, 1958).

It is thus clear that the effect of N and P absorption is a general phenomenon in soil-plant relations, occurring with numerous crops under widely varying soil and climatic conditions.

Phosphorus is a mobile element within plant tissues and in growing plants is transferred from one plant part to another, particularly when phosphorus may be in short supply in the soil. Phosphorus is usually absorbed by plants as either the primary orthophosphate ion (H_2PO_4-) or as the secondary orthophosphate ion ($HPO_4=$). Tisdale and Nelson (1975) found that under acid soil conditions, H_2PO_4- is the dominant ion in

soil systems. They discovered that there are about ten times as many absorption sites on plant roots for H_2PO_4- as there are for $HPO_4=$. The relative amounts of these two ions, which will be absorbed by plants, are affected by the p^H of the medium surrounding the roots. Lower p^H values favour the absorption of the H_2PO_4- ion, whereas, higher p^H values favor the absorption of $HPO_4=$ (Tisdale and Nelson, 1975).

In greenhouse experiments conducted by Miller and Ohlrogge (1958) it was shown that nitrogen had a pronounced effect on the uptake of phosphorus from a fertilizer band. The effect was greatest when the nitrogen was mixed with the phosphorus band. This effect would indicate that nitrogen caused a relative increase in the phosphorus uptake capacity of the root system. The authors suggested that the N-P effect was due to either an increased availability of the banded phosphorus through chemical effects, or an increase in relative root sorption surfaces in the band volume due to root proliferation.

In field studies conducted in Kansas with wheat, Leikam (1980) found that placement of N and P fertilizer into the same soil zone about 6 to 8 inches deep was in many cases agronomically superior to broadcast application of N and P fertilizers. Blair et al. (1971) tested the hypothesis that reduction of p^H at the soil-root interface was the cause of increased P absorption when NH_4+ ions were absorbed. Application of $(NH_4)_2SO_4$ with monocalcium phosphate (MCP) was found to increase fertilizer P uptake when compared to MCP alone.

Much research has been done to determine the best method of placement to achieve the beneficial effects of nitrogen on phosphorus efficiency. Cabrera (1982) found the number of tillers/m^2 was significantly increased by the two highest rates of seed-banded

fertilizers, compared to the control, and by the second tiller count the number of tillers/m^2 at a later date, had doubled. The seed-banded N-P fertilizers enhanced wheat growth but failed to produce significant increases in grain yield where the crop was exposed to water stress and where the enhanced growth caused lodging. In the other 1982 study (Dickinson Co.) where soil moisture was not limiting and lodging did not occur, the application of seed-banded fertilizers significantly increased grain yields by increasing spike density.

INTERACTION OF N-P:

The increased absorption of phosphorus by plants when nitrogen is added to the soil has long been recognized as a significant phenomenon in soil-plant relations. In 1939, it was observed that N in a fertilizer band promoted phosphate uptake (Scarseth et al., 1942). Absorption of banded fertilizer P by corn (Zea mays) as reported by Robertson et al., (1954); Miller and Ohlrogge (1958) was greater when N was included in the band than when it was applied separately. This effect is shown on figure 1.

Leonce and Miller (1966) placed a fertilizer pellet 1.25 cm to the side and 5.0 cm above the tip of a corn root growing down the sloping front of a growth box. Inclusion of $(NH_4)_2SO_4$ with the P increased the absorption of P threefold. Placement of an $(NH_4)_2SO_4$ pellet 5.0 cm below the P pellet and 1.25 cm to the side of the tip of the same root did not influence the absorption of P. They concluded that the NH4+ ion must enter the root at the same point as the P to cause increased P absorption.

Thus it appears that the addition of N will increase the absorption of fertilizer P only when the N is in intimate association with the P.

The mechanisms responsible for the effect under consideration in the increased fertilizer P content of shoots may be due to either (a) increased fertilizer P absorption by the root or (b) an increase in the proportion of the absorbed P that is transferred to the shoot. The transfer to the shoot involves two major steps: (a) transfer across the endodermis and (b) transfer in the xylem vessels. An influence of N on either of these steps would result in an increased P content in shoots for a given quantity of P absorbed by the root. A schematic presentation
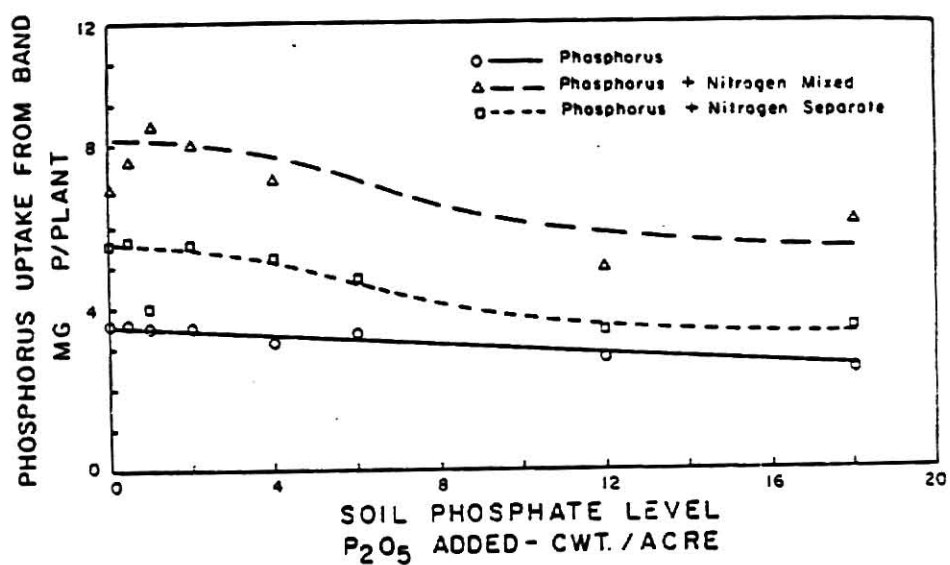
Fig. 1 Influence of soil phosphate level and N additions on the P absorption by corn from band-applied P fertilizer. Source: Miller and Ohlrogge, 1958.

is shown on figure 2. When N was included with P in a relatively small volume, a dense mass of roots grew in the volume of fertilized soil. When the entire soil was fertilized, there were no noticeable effects on root growth. They emphasized that the stimulation of root growth did not result in a larger ratio of roots to tops. The increase in root weight was due to increased branching of the roots growing in the fertilized soil rather than increased length of the roots.

Thien and McFee (1970) reported that phosphorus absorption and translocation were stimulated to different degrees suggesting two separate transport systems involved in P uptake and translocation. The observations suggested the existence of a N-requiring metabolite influencing the efficiency of P absorption and translocation mechanisms in corn.

When fertilizer P is added in a band, a concentrated P solution moves into the soil, and the P is precipitated in various reaction products. Any factor that affects this precipitation can be expected to influence the solubility of the fertilizer P in the soil and hence the amount absorbed by the plant.

Rennie and Mitchell (1954) attributed the increased availability of P in the presence of NH_4^+ salts to a lowering of pH in the fertilizer band volumes by the acid NH_4NO_3 or by nitrification of NH_4^+. Rennie and Soper (1958), however, found that K_2SO_4 had as great an acidifying effect as $(NH_4)_2SO_4$ but did not increase the fertilizer P absorption. They concluded that the increased fertilizer P absorption in the presence of $(NH_4)_2SO_4$ was due to an influence of NH_4^+ on the plants ability to take up P rather than to any alteration of the availability of the applied P.
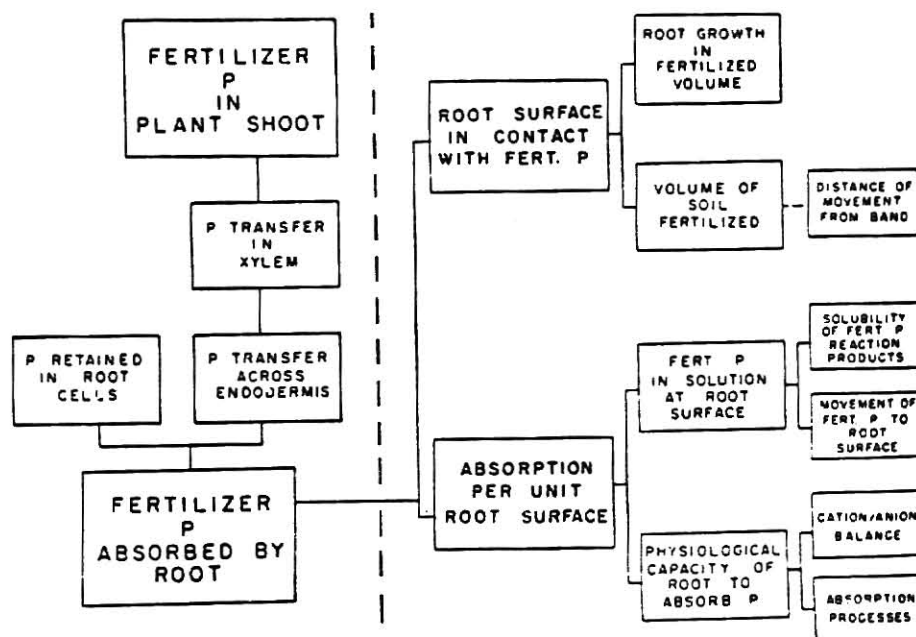
Fig. 2 Processes and factors involved in the effect of N on absorption of P.
Source: M. H. Miller, 1965.

Miller and Ohlrogge (1958) in a greenhouse experiment concluded that nitrogen, when placed with phosphorus in a localized band, increased the band phosphorus uptake at soil phosphorus levels ranging from zero to over 1800 pounds of added P_2O_5 per acre. However, nitrogen, when placed in a band 3 to 4 inches from the phosphorus band, increased the relative feeding power of the corn plant on the band phosphorus only at soil phosphate levels of less than 100 pounds of P_2O_5 per acre. Above this level there was no increase in relative feeding power. The nitrogen had the greatest effect on the uptake of phosphorus from the band, placement gave a 100% increase in weight of phosphorus per plant at all soil levels of phosphate. Placement of root mass development appears to be the most important mechanism responsible for these effects.

Miller and Ohlrogge (1958) conducted greenhouse experiments with corn in the seedling stage using divided root systems. They concluded that fertilizer nitrogen and phosphate mixed together in a portion of soil caused proliferation of corn roots in the fertilized volume only when a part of the root system was fertilized. Such root proliferation was a result of rapid growth of the smaller roots. The effect of nitrogen on the uptake of phosphorus is shown in figure 1. The absorption of ions by plant roots is a complex phenomenon which is not yet completely understood. Metabolic energy is required for the transportation of ions across one or more membranes that act as barriers to absorption. Numerous examples of competitive and synergistic effects of associated ions on the transport have been reported. Some of these are related to cation-anion balance effects, while others indicate an effect on absorption processes.

Electrical neutrality must be maintained across the membrane during

absorption. Therefore, either (1) the same number of anions and cations must be absorbed, (2) there must be an exchange of similarly charged ions in the root for those ions absorbed, or (3) there must be a shift of the organic acid balance within the cell to maintain neutrality.

Arnon (1939) found that barley plants growing in nutrient solutions with an NH_4^+ source of N had a higher content of P than those grown with a nitrate source. He believed that a rapidly absorbable cation such as the ammonium ion would favor the absorption of anions such as $H_2PO_4^-$ ions.

Blair et al. (1970) observed a significantly higher P content in tops and roots of corn grown in a nutrient culture with NH_4^+ rather than NO_3^- as the source of N. They believed this was the result of a stimulated anion uptake in response to cation N (NH_4^+) uptake.

Miller et at. (1970) reported that the increased absorption was related to the reduction in pH at the soil-root interface, and that this reduction must be due to a factor other than nitrification. The reduction in pH at the soil-root interface was mostly caused by the exchange of H+ ions from within the root for NH4+ or K+ ions in the soil. This mechanism caused the P to be precipitated on the root surface which increased P absorption in early growth stages, a major factor for the increased root proliferation that was frequently observed.

Bennett et al. (1962) explained that the causal factor for the increasing P uptake was that N application generally resulted in an increased N uptake as well as percent N, producing larger amounts of N compounds in the plant and some of these compounds, particularly nucleoproteins contain P. Other N compounds required P for their

formation, hence, additional P would be used and absorbed if available.

An increase in P available to the crop is known in many cases to reduce plant zinc-concentration and perhaps produce consequent characteristic zinc deficiency symptoms (Hahm et al. 1968; Sharma et al. 1968; Adriano 1970). The P depression of Zn uptake may often be great enough to reduce plant growth and dry matter production (Ward et al. 1963; Shukla and Hams, 1976; Takkar et al. 1976). Zinc deficiency symptoms in some crops have been reported to be induced by the high phosphorus content of plants, usually due to high available soil P levels (Ellis et al. 1964; Hedge and Relwani 1974; Chaundry et al. 1977). In addition to high rates of phosphorus, Ellis et al. (1964) observed a decrease in total zinc uptake by corn with decreased soil temperature, aggravating the P-Zn balance in the plant tissue.

SUMMARY:

Increased fertilizer P absorption on addition of N is a general phenomenon in the soil-plant system. This effect is most pronounced when the N is in the NH_4+ form and is applied in intimate association with the fertilizer P in a concentrated band.

Several mechanisms have been shown to be responsible, in part, for this effect. The principal ones are (a) increased root growth in the fertilized volume; (b) increased physiological capacity of the root to absorb P, probably due to an involvement of N-intermediates in the absorption process; and (c) alteration of the pH at the soil-root interface due to excess cation over anion absorption and a consequent release of H+ ions. The last mechanism is probably responsible for the increased absorption of P upon addition of NH_4+ at very early growth stages. The increased root growth, and increased physiological capacity

of the root to absorb P would be a factor after the first week or so of growth. Although it has not been conclusively shown, there is little evidence that NH_4^+ and NO_3^- differ in their effects on root growth or physiological capacity of the root to absorb P.

The increased absorption due to a reduction in pH of the soil-root interface would occur only with an $NH4^+$ source of N; NO_3^- would tend to increase the pH and hence reduce the absorption. This phenomenon, however, is not limited to NH_4^+; whenever cation absorption exceeds anion absorption a reduction in pH would occur. Conversely when anion absorption exceeds cation absorption an increase in pH would occur. The importance of these reactions at the soil-root interface is almost certainly not limited to P. They would have a very significant effect on absorption of several ions.

SUMMARY

The results of the studies show that nitrogen is a mobile soil nutrient when in nitrate form because it is not adsorbed appreciably by the soil and moves with soil water flow (Young and Aldag, 1982). Phosphorus P is an immobile soil nutrient because soil fixation reactions limit its movement (Sample et al. 1980). Since P fixation by Fe, Al, and Ca converts solution P to less soluble compounds, application of P fertilizers in restricted soil zones may show advantages over broadcasting. Band placement of water soluble P fertilizer can exceed the soils "fixation capacity" reducing the amount of P fixed. This should result in more soil solution P around the band, which in turn, may increase the uptake by roots nearby. Such increases in P uptake are likely in soils low in solution P levels. Increased P uptake by roots in the band should increase plant P content if a sufficient portion of the root system contacts the applied fertilizer (Barber, 1980).

Increased fertilizer P absorption on addition of N is a general phenomenon in the soil-plant system. Miller et al. (1970) reported that the increased absorption is related to the reduction in pH at the soil-root interface, and that this reduction is caused by the exchange of H^+ ions from within the root or NH_4^+ ions in the soil. This effect is most pronounced when the N is in the NH_4^+ form and is applied in intimate association with the P fertilizer.

Soils of the humid tropics have been found to have widespread P deficiency (Olsen and Engelstad, 1972). Fixation studies have indicated the high capacity of tropical soils to fix P, and this capacity to fix P has been related to the exchangeable Fe and Al, and the presence of

oxides of Al and Fe in these soils (Udo and Uzu, 1972).

Ojanuga and Awujoola (1981) in a study of the soils of the Jos Plateau reported that soils from different areas were distinct in their properties owing to the differences in the kinds of soils parent materials.

Leikam (1980); Leikam et al. (1983) demonstrated many times in short-term greenhouse studies the positive effect of placing N (especially NH_4+-N) with P on crop growth. They found that dual-knife N-P applications gave higher leaf P concentrations and grain yields than other N-P application methods in many of the field studies when ammoniacal N sources were used. In another experiment, Cabrera (1982) found the number of tillers/m2 was significantly increased by two highest rates of seed-banded fertilizers. The seed-banded N-P fertilizers enhanced wheat growth but failed to produce significant increases in grain yield where the crop was exposed to water stress and where the enhanced growth caused lodging. In the other 1982 study (Dickinson Co.) where soil moisture was not limiting and lodging did not occur, the application of seed-banded fertilizers significantly increased grain yields by increasing spike density.

Many researchers have noticed a difference between forms of nitrogen on giving beneficial phosphorus fertilizer efficiency (Blair et al., 1970; Engelstad and Allen, 1971; Olsen and Drier, 1956; Leikam, 1980). For this system to be effective in tropical soils, and for the efficient use of N and P fertilizers, several studies have to be carried out in the tropical soils including the N and P placement methods.

Proposed Program:

The large amount of fertilizers imported by some tropical countries, for example Nigeria, has not been used judiciously. Fertilizer importations are rarely based on the needs of the agricultural producers. Local farmers use the fertilizers at low rates per acre with low yields in return for subsistence. Farm production costs are often greater than farm returns. Inefficient use of fertilizers, especially N and P, attributes to the low farm returns.

Optimum nutrition can only be accomplished if the plant nutrients are adequately available in the course of the vegetative period. To advise the farmer accurately regarding fertility status of his soil before he plants the crop and to arrange his fertilization measures appropriately, soil testing laboratories require simple, precise, rapid, and cheap soil testing methods. A rapid soil extraction method must furnish reliable information on the plant available nutrients in the soil solution. It is known however that the level of nutrients in the soil solution alone does not determine the rate of supply according to the diffusion model of Nye (1969). Both Holford (1976) and Olsen and Watanabe (1970) emphasize the importance of the buffering capacity of the soil which is closely related to the soil chemical properties.

In a recent investigation, Obigbesan and Mengel (1981) have shown that the solubility of rockphosphate and superphosphate, as determined by the electro-ultra-filtration (EUF) technique depended much on soil properties, especially on soil pH. The range of phosphate extracted by EUF showed that maximum EUF recovered P values obtained from neutral soils were 40 to 60 ppm P (5 min fraction) and 150 to 190 ppm P (30 min. fraction) compared to acid soils that were in the range of 2-2.5 ppm P

for the 5 min. and 6 to 8 ppm P for the 30 min. fractions. The strongly buffered kaolinitic soil types had high exchangeable aluminium and were further distinguished by high P fixation while the neutral soils with low P buffering capacity had low P fixation. The results of this study further stressed the importance of phosphate buffering capacity (PBC) of soils in estimating the phosphate needs of soils as the buffering capacity affects the plant uptake from fertilizers applied.

Considering each soil on its own, regardless of type and quantity of fertilizer (rockphosphate or superphosphate) applied, the phosphate solubility in the particular soil is a major factor controlling phosphate uptake of plants. Thus, the poor solubility of rockphosphate in the neutral soils is reflected also by poor phosphate uptake by the plants and the good solubility of rockphosphate in the acid soils led to a big phosphate uptake. A striking result is that the acid soils showed much stronger phosphate adsorption than the neutral soils.

In soils of the humid tropics, P deficiency has been found to be widespread (Olsen and Engelstad, 1972) and in Nigeria responses to P applications have been encountered in all ecological zones. This low availability of P in the tropical soils is attributed to the nature of the chemical forms of soil P and the high content of oxides of Fe and Al which are associated with high P fixation.

Studies of P inorganic forms in Nigerian soils using the method proposed by Chang and Jackson (1957) have indicated that inorganic P exists in the decreasing order of occluded P, iron-bound P (Fe-P), aluminium-bound P (Al-P) and calcium-bound P (Ca-P) (Udo and Uzu, 1972; Uzu et al. 1975; Udo, 1976; Udo and Ogunwale, 1977). Fixation studies have indicated high capacity of these soils to fix P and this capacity

to fix P has been related to exchangeable Fe and Al, and the presence of oxides of Al and Fe in these soils (Udo and Uzu, 1972). The fate of P fertilizers added to acid Nigerian soils has not been widely studied.

Ojanuga and Awujoola (1981) investigated the characteristics and classification of the soils of the Jos Plateau,(Nigeria) and explained that the Jos Plateau consisted of plains at an average elevation of about 1,219 meters with groups of hills (younger granites) standing above the general level of the Plateau to about 1,786 meters (Pugh and King, 1952). The geology consisted of Precambian to Cambian undifferentiated basement complex (mainly gneisses) and "Older Granites" which have been eroded to expose the "Younger Granites" of Jurassic age mentioned above (Grove, 1952; Tomlinson 1965; Kogbe 1976).

Tertiary and Quarternary volcanic rocks (mainly basalts) occurred on the Plateau also. The basalts are mostly completely decomposed and denuded so that only a few remnants are preserved, forming flat-topped hills in the Western and Southern (south of Jos) parts of the Plateau.

Because of the altitudinal effect, the climate of the Plateau is moderate. The average temperature is 22 C and the mean annual rainfall is 1,410 millimeters with most of the rains (about 90 percent) falling between mid-April and October of each year. There is a distinct dry season of at least 5 months duration during which the upper horizons of soil dessicate markedly.

The vegetation of the Jos Plateau is the northern Guinea Savanna, an open woodland with tall grasses. From the climatic data, the soil moisture regime is inferred to be ustic. Also, the soil temperature regime is inferred to be isohyperthermic using the relation that in tropical Nigeria soil, temperature within 120 cm depth of soils are

generally warmer than air temperatures.

Soils in Granatic areas (Soils near Saminaka)

The soils in granatic area occur on gentle to strongly sloping plains studded with granite inselbergs. The soil parent materials are layered and consist of thin veneer of fine colluvium (less than one meter thick) separated from an underlying saprolitic parent materials by a thin stone lime. In upper slope positions, thin veneer of fine colluvium is missing and gravelly materials (of the stone lines) are exposed at the surface, forming a gravel layer in the soils.

Pedon 0385 (Appendix A) typifies the soils that are among common soils on the upper slopes. Generally horizons of well rounded nodules (ferrinodules) and subangular quarz grains merge into clay loam to sandy loam horizons having feldspar grains and decomposing rock remnants. Both feldspar grains and decomposing rock remnants tend to increase in amount with depth. On more gentle slopes, a varient of the soil profile may have superficial horizons of fine texture overlaying the gravelly horizons unless where erosion is apparent.

Soil in Basalt Areas (from Mangu toward Panyam)

Basalt landscapes consisting of residual granite hills capped with basalt remnants, jagged-topped granitic inselbergs, low ridges and lowlying flat plains occur. Red soils predominate on the low ridges which are littered with basalt boulders. Soil having black top-soil and greyed subsoils dominate the low-lying flat plains. A pedon (pedon 0590) typical of the soils in the alluvial slopes of the escarpment is described in Appendix A.

Below the escarpment occur the lowland plains adjoining the Jos

Plateau. Some of the soils on the lowland plains are formed in mixed colluvial materials derived from basalt and other rock types. Stone size to boulder size rounded vesicular basalt fragments litter the surfaces. Soil morphology and other soil characteristics vary depending on the nature of the parent materials. Pedon 0607, which is typical of the deep red soils occurring on the lowland plain is described in Appendix A. An analytical data of the soils of Jos Plateau (Appendix B) show that the soils have a low organic matter which decreases markedly from 40 cm depth of the soils to less than two tenths percent in the subsoil B and C horizons; and the cation exchange capacity is lower in amount in course-textured than in fine-textured soil horizons. CEC in the soils formed in parent materials derived from granitic rocks ranges between 2 and 11 me/100 g of soil or 14 and 140 me/100g of clay. In the soils formed by basaltic parent materials, CEC ranges from 9 to 22 me/100g of soil or 22 to 59 me/100g of clay.

A characteristic that is common to all the soils is the high silt content which indicates a high moisture holding capacity for the soils. Another common characteristic is the clay depletion in the uppermost A horizons.

In general organic matter is low. The amounts and distribution of exchangeable cations are influenced by the *kinds of soil parent materials*. The levels are higher in soils from the basalt areas than in soils from the granitic area. Also CEC is high in the soils from basalt areas and low in the soils from the granitic area.

Based on the *characteristics of selected tropical soils,* particularly the characteristics of the soils, several studies should be conducted. One such study would be the effect of lime and lime rates

according to the soil test recommendations. An experimental randomized block design with four replications and eight treatments would be used for a period of five to ten years. Approximately twice the rate of lime will be used to conclude the soil test recommendation rates. Crops like corn, sorghum, wheat and soybeans will be rotated in order to observe the effect with adequate nitrogen and phosphorus fertilizers.

Another experimental design would be used to test four nitrogen fertilizer rates and one high phosphorus rate. Similarly, four phosphorus fertilizer rates and one high nitrogen rate would be tested.

Different methods of N and P application such as broadcasting, banding, and knifing would also be compared. The results of the N and P experimental studies above would be used in choosing rates of N and P to be used in testing different methods of application. The methods compared, will to some extents, depend upon the equipment available in the particular locality where tests are made. The choice of using either superphosphate or rockphosphate, and the sources of N will depend on the resources available.

Results from the effect of liming, the rates of N and P, and the methods of application of N and P would determine the efficient use of N and P fertilizers.

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APPENDIX

APPENDIX A: SOIL PROFILE DESCRIPTION

Pedon 0385

Location:	On Jos–Zaria road: about 80km from Jos and 12km before Saminaka town from Jos.
Vegetation:	Cultivated to sorghum (S. vulgare)
Parent material:	Gravelly colluvium (stone layer) and underlying sapalite from granite or gneiss.
Drainage:	Well-drained
Topography:	Upper slope position

Horizon	Depth (cm)	Description
A1 0385	0–19	Gravelly sandy clay loam: weak medium crumb structure; friable; gravel about 45% by volume (73% by weight) consisting of well rounded nodules and quartz grains; clear, smooth, boundary.
11 B21t	19–40	Clay loam; moderate,medium subangular blocky structure; friable; many feldspar; few patchy cutans; diffuse smooth boundary.
11 B22t	49–57	Clay loam; moderate, medium subangular blocky structure; friable; many feldspar grains and few quartz grains; few patchy cutans clear, irregular boundary.
11 B23t	57–90	Clay loam; moderate, medium subangular blocky structure; firm; few decomposed rock remnants showing quartz-feldspar matrix; abundant feldspars and quartz grains; few patchy cutans; clear, irregular boundary.
11 B31	90–133	Sandy clay loam; weak; medium subangular blocky structure; friable; many decomposed rock remnants showing quartz -feldspar and quartz grains; clear, irregular boundary.
11 B32	133–150	Sandy clay loam; weak medium subangular blocky structure friable; abundant decomposed rock remnants interspersing with markedly argillized matrices; merging with similar material below.

Source: Ojanuga et al., 1981.

Pedon 0560

Location:	Between 60 and 62km posts on Jos – Bauchi road
Vegetation:	Guinea savanna (mainly Hyparrhenia spp and a few trees, Isobertina doka).
Drainage:	Well-drained

Horizon	Depth	
A1	0-10	Reddish brown; loam; moderate, medium sub-angular blocky to crumb structure; clear smooth boundary.
B21t	10-30	Reddish brown; clay loam; moderate medium subangular blocky structure; diffuse, smooth boundary.
B22t	30-50	Reddish brown stained black and gray (2.5Y or 5Y hues) by weathering basalt places; (very gravelly, clay loam to loam; many gravel to stone size, weathering rounded basalt fragments showing concentric weathered rings; few feldspars grains, becoming more abundant with depth; strong medium subangular blocky structure; diffuse, smooth boundary.
B31	50-70	Like B22t above except more feldspars and loam texture; diffuse smooth boundary.
B32	70-90	Like B31 above except more gravelly; diffuse, smooth boundary.
C1	90-110	Like B32 above except more gravelly and less clayey, clear, irregular boundary.
11 C2	110-130	Reddish brown; loam; quartz veins permeate the horizon; massive breaking to weak medium subangular blocky structure; diffuse, smooth boundary.
11 C3	130-150	Like 11 C2, sandy loam, massive structure; diffuse, smooth boundary.
11 C4	150-180	Like 11 C3, sandy loam, massive structure.

Source: Ojanuga et al., 1981.

Pedon 0590

Location: 8	About 10km southwest of Panyan village
Vegetation:	Savanna woodland (Hyperhennia ssp and Isoberlinia doka).
Parent material:	Mixed alluvium from basalt and granitic rocks.
Drainage:	Well-drained

Horizon	Depth(cm)	
A1	0-20	Dusky red (2.5YR 3/2); sandy loam; moderate medium crumb structure; friable, many roots; clear, smooth boundary.
B21t	20-40	Dark reddish brown (2.5YR 3/4); clay, moderate, medium subangular blocky structure; firm, many roots, diffuse smooth boundary.
B22t	40-65	Dark reddish brown (2.5YR 3/4), spotted white; coarse sandy clay; moderate medium subangular blocky structure; firm common gold yellow tiny mica flakes and black, soft basalt fragments, white spots due to churned white minerals; diffuse, smooth boundary.
	65-90	Dark reddish brown (2.5YR 3/4), spotted white coarse sandy clay; moderate medium subangular blocky structure; firm common golden yellow tiny mica flakes and black, basalt fragments; white spots due to churned white minerals; diffuse, smooth boundary.
B32	90-120	Same as B31; diffuse, smooth boundary.
C	120-150	Dark red (2.5YR 3/6) spotted white; coarse sandy clay loam; moderate, medium subangular blocky structure; firm; white spots due to feldspar and quartz grains; many gravel size black basalt fragments; merging with similar material below.

Source: Ojanuga et al., 1981.

Pedon 0607

Location:	About 4km from Pedon 0590
Vegetation:	Cultivated to vegetables
Parent materials:	Colluvium from basalt
Drainage:	Well-drained
Topography:	On a gently sloping plain; 2% slope

Horizon	Depth(cm)	
A1	0-20	Dusky red (10R 3/3); weak, medium crumb to subangular blocky structure, friable, occasional pieces of basalt; clear, smooth boundary
B21	20-40	Dusky red (10R 3/4); clay, weak medium subangular blocky structure; friable, diffuse smooth boundary.
B22	40-70	Dark red (10R 3/6); silty clay loam; weak medium subangular blocky structure; friable; diffuse smooth boundary.
B23	70-100	Dark red (10R 3/6); silty clay loam; weak medium subangular blocky structure; friable; diffuse smooth boundary.
B24	100-120	Dark red (10R 3/6); clay loam; weak, medium subangular blocky structure; friable; matrix stained black by weathered remains of basalt pieces; diffuse, smooth boundary.
B3	120-150	Similar to horizon B24 above; merging with similar material below.

Source: Ojanuga et al., 1981.

APPENDIX B: ANALYTICAL DATA

TABLE 1.   Particle size distribution in selected soils of the Jos Plateau.

Horizon	Depth	Lab. No.	Coarse frag	Sand			Total sand	Silt	Clay
				Coarse	Medium	Fine			
			>2mm	2000-500 μm	500-250 μm	250-50 μm	2000-50 μm	50-2 μm	<2 μm
	cm	%	%	% of <2mm soil separates					
Pedon 0385	(Ferric Luvisol, Haplustalf)								
Ap	0-10	0385	73	13	27	19	59	20	21
II B21t	19-40	0386	16	16	21	15	52	14	34
II B22t	40-57	0387	14	17	24	16	57	16	27
II B23t	57-90	0388	10	9	24	15	48	23	29
II B31	90-113	0389	13	17	26	14	57	19	24
II B32	113-150	0390	2	12	26	15	53	25	22
Pedon 0397	(Orthic Luvisol, Haplustalf)								
Ap	1-10	0397	7	16	30	24	74	19	7
B1t	10-36	0398	9	12	18	9	39	21	40
II B21t	36-58	0399	22	15	21	12	43	20	32
III B22t	58-79	0400	8	17	19	10	46	20	34
III B23	79-113	0401	8	18	19	11	48	23	29
III B24	113-143	0402	9	20	20	11	51	21	29
C1	143-178	0403	22	18	19	13	48	22	30
Pedon 0590	(Chromic Luvisol, Udic Rhodustalf)								
A1	0-20	0590	12				48	26	26
B21t	20-40	0591	9				36	16	48
B22t	40-65	0592	9				38	10	52
B31	65-90	0593	13				48	16	36
B32	90-120	0594	9				48	16	36
C	120-150	0595	13				42	26	32

Source: Ojanuga et al., 1981.

Table 1: (Continued)

Horizon	Depth	Lab. No.	Coarse frag. >2mm	Sand Coarse 2000-500 μm	Medium 500-250 μm	Fine 250-50 μm	Total sand 2000-50 μm	Silt 50-2 μm	Clay <2 μm
	cm	%	%		-% of <2mm soil separates -------				
Pedon 0405	(Urthic Acrisol, Haplustalf)								
A1	0-10	0405	3	14	30	24	68	24	8
B1t	10-37	0406	13	8	14	13	35	23	42
II B21t	37-60	0407	13	10	16	13	39	21	40
III B22t	60-86	0408	6	15	21	13	49	21	30
III B23t	86-119	0409	11	18	20	15	53	20	27
III B3	119-158	0410	24	19	19	12	50	22	28
III C	158-192	0411	15	21	22	11	54	20	26
Padon 0560									
A1	0-10		17	9	15	25	49	35	16
B21t	10-30		17	3	13	18	34	36	30
B22t	30-50		52	12	25	2	39	37	24
B31	50-70		46	9	24	6	49	35	16
B32	70-90		60	12	21	14	47	35	18
C1	90-110		41	12	29	14	48	31	16
II C2	110-130		6	13	33	-	46	32	16
II C3	130-150		1	15	30	10	55	27	22
II C4	150-180		1	10	28	16	54	28	18

Source: Ujanuga et al., 1981.

Table 1. (Continued)

Horizon	Depth	Lab. No.	Coarse frag. >2mm	Sand Coarse 2000-500 μm	Medium 500-250 μm	Fine 250-50 μm	Total sand 2000-50 μm	Silt 50-2 μm	Clay <2mm
	cm	%	%	% of 2mm soil separates					
Pedon 0607	(Chromic Cambisol Typic Eutropept)								
A1	0-20	0607	6				14	24	52
B21	20-40	0608	1				19	31	50
B22	40-70	0609	1				18	38	44
B23	70-100	0610	-				17	38	45
B24	100-120	0611	-				20	40	40
B3	120-150	0612	-				19	44	37

Source: Ujanuga et al., 1981.

APPENDIX B: ANALYTICAL DATA

TABLE 2   Chemical Characteristics of selected soils of the Jos Plateau

Horizon	Depth	OM	pH (H_2O)	Exch. cations (meg/100g of soil)				CEC	Base sat	C.E.C.
				Ca	Mg	K	Na			
	cm	%		------				-------	%	meg/100g clay
Pedon 0385	(Ferric Luvisol, Haplustalf)									
Ap	0-19	.98	6.2	1.9	1.3	.6	.06	7.5	51	24
II B21t	19-40	.36	6.3	2.10	1.5	.5	.07	7.8	53	20
II B22t	40-57	.24	6.3	2.3	1.8	.3	.07	8.7	51	30
II B23t	57-90	.17	6.2	2.4	1.8	.3	.08	8.3	55	27
II B31	90-113	.12	6.3	1.9	2.8	.3	.05	7.4	68	30
II B32	113-150	.14	6.3	2.0	2.2	.3	.08	6.9	66	29
Pedon 0397	(Orthic Luvisol, Haplustalf)									
A1	0-10	.60	5.7	0.8	1.1	.2	.05	2.4	90	14
B1t	10-36	.57	5.5	2.4	2.1	.4	.10	9.0	56	19
II B21t	36-58	.17	5.9	2.8	1.7	.5	.16	10.4	50	31
III B22t	58-79	.14	5.8	2.8	1.4	.5	.10	9.5	50	27
III B23	79-113	.10	5.8	2.6	1.2	.4	.07	8.8	49	29
III B3	113-143	.10	5.8	2.7	1.3	.3	.09	8.7	50	30
III C	143-178	.14	5.8	3.0	1.5	.3	.09	9.1	54	29

Source: Ojanuga et al., 1981.

TABLE 2: (Continued)

Horizon		Depth	OM	pH (H₂O)	Exch. cations				CEC	Base sat	C.E.C.
					Ca	Mg	K	Na			
		cm	%		----meg/100g of soil----					%	meg/100g clay
Pedon 0405		(Orthic Acrisol, Haplustalf)									
A1		0-10	.71	5.1	.6	.6	.2	.04	4.7	21	36
B1t		10-37	.57	5.4	3.0	1.8	.2	.06	10.7	47	22
11	B21t	37-60	.52	5.4	3.0	1.6	.3	.06	10.1	49	22
111	B22t	60-86	.24	5.9	2.6	1.2	.2	.06	9.0	45	28
111	B23t	86-119	.21	6.0	3.0	1.9	.2	.07	9.1	57	32
111	L3	119-158	.17	6.3	2.9	2.1	.2	.08	9.9	53	34
111	C	158-192	.10	6.2	3.3	1.8	.2	.08	10.7	50	40
Pedon 0607		(Chromic Cambisol, Typic Eutropept)									
A1		0-20	2.10	5.7	2.8	2.6	1.4	.2	12.4	56	24
B21		20-40	1.05	5.7	2.1	2.6	1.1	.3	13.3	47	27
B22		40-70	.48	5.7	1.5	3.4	.9	.2	14.9	40	34
B23		70-100	.36	5.8	3.1	8.8	.8	.2	20.9	62	46
B24		100-120	.45	6.0	3.5	10.1	1.0	.2	20.9	71	52
B3		120-150	.28	6.0	3.8	11.1	1.1	.3	21.8	75	59

Source: Ojanuga et al., 1981.

Table 2: (Continued)

Horizon	Depth	OM	pH (H₂O)	Ca	Mg	K	Na	CEC	Base sat.	C.E.C.
	CM	%		\-	\-\-\-\-meg/100g of soil			\-	%	meg 100g clay
Pedon 0560										
A1	0-10			9.0	3.3	.7	.1			
B21t	10-30			10.1	5.8	.5	.2			
B22t	30-50			20.1	9.5	.8	.3			
B31	50-70			31.7	11.7	.8	.5			
B32	70-90			28.5	11.5	.8	.5			
C1	90-110			22.0	11.1	.8	.4			
II C2	110-130			7.2	3.0	.4	.2			
II C3	130-150			6.3	2.2	.3	.2			
II C4	150-180			6.3	2.1	.3	.2			
Pedon 0590	(Chromic Luvisol, Udic Rhodustalf)									
A1	0-20	1.84	5.9	3.0	2.4	1.7	.13	9.5	76	37
B21t	20-40	.74	5.8	3.5	2.6	1.7	.16	12.0	66	25
B22t	40-65	.53	5.8	4.5	2.6	2.2	.16	11.5	82	22
B31	65-90	.28	5.9	4.0	2.6	1.5	.17	10.0	83	28
B32	90-120	.28	6.0	3.5	2.5	1.5	.20	10.3	92	29
C	120-150	.45	6.0	4.5	3.2	1.4	.21	11.2	83	35

Source: Ojanuga et al., 1981.

VITA

The author was born on July 22, 1946 at Gudi, Nigeria. He attended the College of Agriculture, Ahmadu Bello University and graduated in General Agriculture in 1975. He was then accepted to Kansas State University (U.S.A.) where he obtained a Bachelor of Science in Agronomy in 1980. After graduation he worked for Plateau Agricultural Development Corporation for two years. In 1983, he returned to Kansas State University to work on a Master of Science degree in Agronomy.

EFFICIENT USE OF NITROGEN AND PHOSPHORUS
FERTILIZERS ON TROPICAL SOILS

by

CYRIL BAKO YAKUBU

B.S., Kansas State University, 1980

AN ABSTRACT OF A MASTER'S REPORT

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ABSTRACT

Fertilizer use in developing countries is expected to increase
from 19.3 in 1974 to 92 million tons in the year 2000. This is an
estimate based on food requirements for adequate nutrition of the in-
creasing population for most developing countries. With continuous
and intensive crop production, the soil is depleted of large quantities
of elements, but can be replenished by efficient use of fertilizers.

Soil reaction or pH is an important factor controlling nutrient
availability. The range of pH corresponding to the highest nutrient
availability is not the same for all nutrients. Because of the trans-
itory nature of N in soil, its tendency for loss, and its ability to
accelerate soil acidification processes, fertilizer N should receive
more care in its overall management than any other primary or second-
ary plant nutrient.

Phosphorus is commonly retained in the surface layer of soils and
firmly held against the leaching action of rain. The organic matter
and sesquioxide content, the soil type and base exchange capacity,
the amount of phosphorus applied and the method of application are the
various factors that contribute to the retention of soil phosphorus.

Soils of the humid tropics have widespread P deficiency because
these soil s have high capacity to fix P. Generally tropical soils
have low organic matter content, low CEC, and high acidity.

Field studies conducted in 1958, 1980 and 1982, comparing N and
P placement methods on crops (corn and wheat) showed that the addition
of N increased the absorption of fertilizer P only when the N was in
intimate association with the P.

The provision of inputs like N and P, which allow the maximum
response to be obtained from a given dose of fertilizer is crucial in

expanding the profitable use of fertilizer. However, the great challenge
is to design appropriate systems to allow the maximum contribution to
be made by fertilizer so that this material can provide the increases
in agricultural output to the developing countries that it has already
provided to the developed nations. Effectiveness of N and P fertilizers
should be evaluated on the basis of how the farmers are likely to use
them as compared to how they should be used for maximum effectiveness.