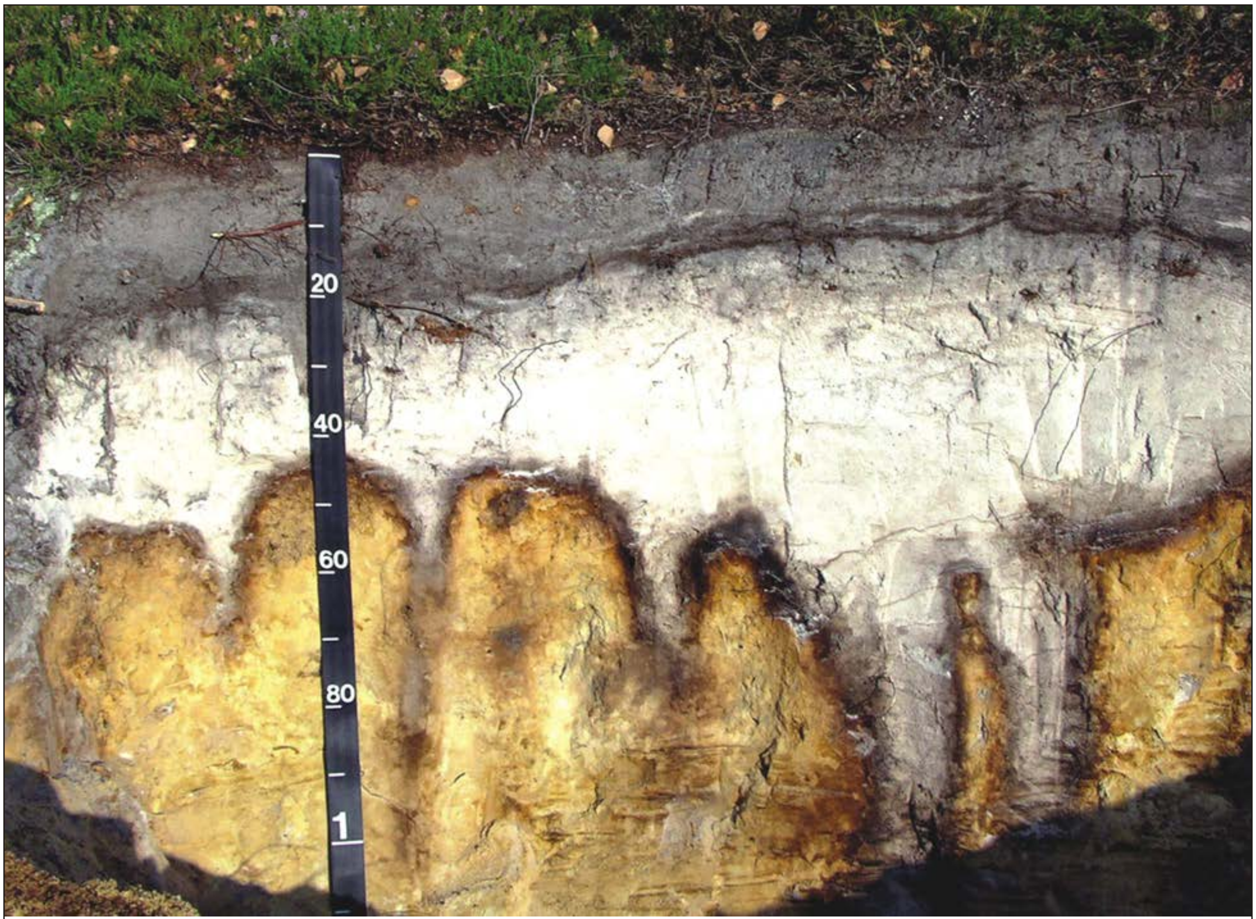

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Nutrient Management for Maize Production in Soils of the Savannah Zone of South-Western Nigeria

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Abstract: Farmers would adopt fertilizer recommendations that are based on soil fertility information in order to realize the potentials for high maize yields offer by features of the savannah zone. Surface (0-15 cm) samples of soil formed on basement complex rocks in the derived and guinea savannah zone of south-western Nigeria were analysed and nutrient status evaluated in relation to established critical levels. Sample of four commonest soil series used to evaluate response to addition of single nutrient: 100 mg N, 25 mg P, 20 mg Mg, 5 mg Fe, 5 mg Zn and 2.5 mg Cu L^{-1} using dry weight of maize grown for weeks in greenhouse pot studies. Maize grain yield responses to treatments that consisted of N, P, K, NP, NK, PK, NPK, NPKMg, NPKMgFeCuZn and unfertilized control were studied in four sites. The second field study in eight sites involved comparison of maize grain yield obtained from two treatments: + and - respective nutrients. The results indicated that soils are slightly acid to neutral sands and loams with very low to high organic matter and total N, low to medium exchangeable cations, low available P, Cu and Zn while Mn and Fe are high. The order of maize response was N, Mg followed by K, Zn and P in the greenhouse, single application of N fertilizer gave high response while responses to P and K were low where soils exceeded respective established critical nutrient levels. Yield response were enhanced with fertilizer combinations that contained N, P and Mg. The primary needs are N, P and Mg fertilizer soon after opening up the land for cultivation from short fallows. After year of continuous cropping, K is needed while addition of Cu and Zn would produce higher yields on plots that received NPK fertilizers. The higher correlations with nutrient show that management recommendation must emphasize the need to raise and maintain soil organic matter levels, to ensure nutrient availability and increase response to fertilizers.

Key words: Savannah, soil properties, macronutrients, micronutrients, critical levels, deficiency, response

INTRODUCTION

Savannah vegetation, consisting largely of perennial mesophytic grasses, at least 80 cm in height, covers almost 80% of the land area in Nigeria. The savannah zone in south-western Nigeria, is located between latitude 7°-9° 30'N and consists of vegetation variants referred to as derived savannah (forest-savannah mosaic, southern and northern guinea savannah. The extent and floristic composition are being continuously altered by slash- and burn bush-fallow cultivation, grazing and annual (dry season) burning. The climate is fairly uniform tropical humid and hot with a marked dry season which lasts from October/November to March/April and so fall within the sub humid agro-ecological zone Annual rainfall ranges between 1120 to 1350 mm with a bimodal

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distribution that allows for two maize crops between March-July and August-November, The area consists of tropical ferruginous soils, with sandy surface layer, low organic matter content loe exchangeable bases. The soils have been classified as Luvisols, Arenosols, Cambisols, Lithosols and Fluvisols which correspond to Alfisols, Entisols and inceptisols with ustic moisture regimes and isohyperthermic (FDALR, 1990). The clay fraction consists of kaolinite quartz, mica, sesquioxides and montmorillonite chlorite or vermiculite-chlorite intergrades Murdoch *et al*. (1976). The preponderance of non-swelling, 1:1 lattice low-activity clays (Juo, 1980), with low specific surface reflects in equally low water holding capacity of the soils. Thus, rapid infiltration and saturation of the surface layer cause nutrient leaching losses, run-off and soil erosion. Besides, water loss by evaporation from the sandy topsoils creates droughty conditions between rainy periods (Jones and Wild, 1975).

Hand-hoe traditional subsistence farming is the dominant form of agriculture. The grass-dominated vegetation is easily cleared, especially b bush burning. Food crops are grown in various intercropping and interplanting systems on land tilled with hoes, to make mounds, heaps or ridges. Low density and small to medium size of woody tree species make the savannah suitable for mechanized farming projects, as land development would involve low capital investment. The climatic features, notably of bimodal rainfall distribution, sunshine and temperature and the undulating topography.

Efficient fertilizer use, based on recommendations from soil testing that recognizes inherent variability in soil properties is the tool for realizing these potentials. The recommendations would differ from the blanket rates made over large geographical areas which farmers are being encouraged to adopt. Moreover, recent studies have shown the inappropriateness of these blanket recommendations, being wasteful and causing yield reductions when used continuously (FMANR, 1990). The status of nutrients, to identify areas of deficiencies is vital to making soil fertility management recommendations. This study presents data on the nutrient fertility status of soil in the derived and guinea savannah zones of South-Western Nigeria, formed on basement complex rocks, the nature of responses to applied nutrients and the implications for efficient fertilizer management practices.

MATERIALS AND METHODS

Soil and Analytical Methods

Five hundred and forty surface (0-15 cm) soil samples were collected from the area covered by derived and guinea savannah vegetation in South-Western Nigeria. The soils are derived from igneous and metamorphic rocks of the pre-Cambrian basement complex. The samples were air-dried, sieved (<2 mm) and analyzed for pH (in distilled water); particle size distribution; organic matter and total N; exchangeable bases and total acidity, Effective Cation Exchange Capacity (ECEC) and % base saturation; available P, Fe, Cu, Zn and Mn using the recommended procedures described in IITA (1979).

Greenhouse Studies

Four of the commonest soil series were used for the studies. Four hundred milliliter of soil samples were measured into half-litre plastic cups; 100 mg N, 25 mg P, 20 mg Mg, 5 mg Fe, 2.5 mg Cu and 5 mg Zn^{-1} was added singly in solution form and the soils watered to near field capacity. Maize was sown and thinned to five seedlings per cup after emergence. The plants were watered daily, being careful to avoid water logging, The top growth of four weeks old plants was harvested by cutting at soil surface level, oven-dried, at 80°C for 72 h and weighed.

Field Studies

Simple unreplicated plots, in which each treatment row, 20 m long, was separated from the other by unfertilized treatment rows, were used in two field experiments. Maize was sown on ploughed and harrowed land at a spacing of 75×25 cm and later thinned to one seedling $hill^{-1}$ to attain a population of 53,330 plants ha^{-1} in four sites. The treatments consisted of N, P, K, NP, NK, PK, NPK, N P K Mg, NPKMgFeCuZn and unfertilized control. The nutrients were applied at 120 kg N, 50 kg P_2O_5, 60 kg K_2O, 20 kg MgO, 2.5 kg Cu, 3 kg Fe and 5 kg Zn ha^{-1} using urea (46% N), single superphosphate (SSP, 18% P_2O_5), muriate of potash (KCI or MOP, 60% K_2O) and the sulphates of Mg, Fe, Cu and Zn. Urea was split-applied; two-thirds mixed with the respective nutrient carriers in each treatment, banded in 5 cm grooves, 8 cm away from the seed row at planting (basal) and covered with soil and the remaining top dressed at about tasselling. Eight sites were used for the second experiment involving two treatments: + and − a particular nutrient, for yield to be compared with that in which a complete combination of all the nutrients was applied. The number of plants, number of cobs and weight of dehusked cobs were recorded at harvest. The cobs were shelled and weight of grains taken. Grain moisture was determined and yield adjusted to 15% moisture content.

RESULTS AND DISCUSSION

Soil Characteristics and Nutrient Status

The means and ranges of soil properties are shown in Table 1. In evaluating the fertility status, the data were compared with critical soil nutrient levels established for maize in South-Western Nigeria (Table 2) Few of the soils have acidity problem, (pH <5.0) while 75% are in the low acidity range (pH 6.0-6.9). The soils are, therefore, slightly acid to neutral and so, ideal for most arable crops. The coarse texture (loams to sands) is typical of the surface horizon of soils derived from crystalline basement complex rocks (Jones and Wild, 1975; Murdoch *et al.*, 1976).

The low means organic matter 1.8%, compares with 1.3-1.8% reported as average for soils of the savannah zone in South-Western Nigeria (FMANR, 1990). Over 80% of the soils contain <3% organic matter, a level above which maize would not respond to N and P application. Mean total N, is low (0.11%) compared with the established 0.15% critical level for maize such that 70% of the soils are deficient. Maize is a high N-demanding crop in which N deficiency readily shows up when soils contain less than 1% organic matter Sobulo and Osiname (1985). Thus, high maize yield would not be supported, due to severe deficiency expected in >35% of the soils which contain very low (<1.0%) organic matter. Annual dry season burning and slash - and - burn land clearing practices cause complete oxidation of litter and humified organic materials, with loss of N as oxides into the atmosphere (Jones and Wild, 1975; FMANR, 1990).

Mean available P at (11.4 mg kg^{-1} soil) exceeds the critical value of 8.5 mg kg^{-1} soil suggested for the soils in the derived savannah and places the soils in the medium P fertility class base on the soil test criteria and fertility map developed for Nigeria (FMANR, 1990). Nevertheless only 12% of the soils would probably not show response to P application. There is presently no criterion for the interpretion of effective CEC but the low values, which average 6.3 cmol kg^{-1} soil, reflect the high degree of weathering and leaching associated with soil forming processes (Kang *et al.*, 1991). The dominant cation is Ca, though the value of less than 4.0 cmol kg^{-1} was found in >60% of the soils. The suggested 1.5-2.0 cmol kg^{-1} soil as critical level means that ca supply should not limit crop production. With 0.16 and 0.28 cmol kg^{-1} as critical exchangeable K and Mg, respectively, >20% of the soils would probably respond to K application while only 10% of the soils are deficient in Mg. The 94% mean base saturation stresses the fact that need for liming is not crucial to high crop yield in the soils. The established critical levels for micronutrients imply that Mn and Fe deficiencies may not occur while only 30 and 40% of the soils are within the sufficiency range for available Zn and Cu, respectively.

Responses to Nutrient Applications

The respective single nutrients gave higher dry matter yields of maize than the control treatment in the greenhouse, with N and Mg as the best followed by K, Zn and P (Fig. 1). Response to N could

Table 1: Means and ranges of nutrient status in surface soils of the savannah in South Western Nigeria

Soil properties	Mean	Range
pH (H_2O)	6.40	4.5-8.2
Organic matter (%)	1.80	0.1-7.9
Total N (%)	0.11	0.02-0.70
Exchangeable acidity	0.30	0.00-0.80
Effective CEC* (cmol kg^{-1})	6.30	1.00-73.00
Exchangeable Bases (cmol kg^{-1})		
Ca	4.52	0.30-70.00
Mg	1.19	0.10-4.30
K	0.33	0.06-1.00
Base saturation (%)	95.20	78.3-100.0
Available P (mg kg^{-1})	11.40	0.0-130.0
Fe (mg kg^{-1})	37.50	0.8-342.0
Cu (mg kg^{-1})	1.80	0.3-7.8
Mn (mg kg^{-1})	45.30	3.0-208.1
Zn (mg kg^{-1})	2.70	0.9-7.8
Sand (%)	81.40	46.0-94.0
Silt (%)	12.10	4.0-39.0
Clay (%)	6.50	1.0-39.0
Textural class	LS	L-S

*: Effective CEC = Sum of exchangeable cations and exchangeable acidity. L = Loam, LS = Loamy sand, S = Sand

Table 2: Criteria for soil test interpretation and soil fertility classes in South Western Nigeria

		Fertility class		
Soil properties	Criteria level	Low	Medium	High
Acidity (pH)	-	6.0-6.9	5.0-5.9	<5.0
Organic matter (%)	2.00	0-2.0	2.0-3.0	>3.0
Total N (%)	0.15	0-0.15	0.15-0.20	>0.20
Available P (mg kg^{-1})	8.50	0-8.5	8.5-12.5	>12.5
Exchangeable K (cmol kg^{-1})	0.16	0-0.16	0.16-0.31	>0.31
Mg (cmol kg^{-1})	0.28	-	-	-
Ca (cmol kg^{-1})	1.50	0-1.5	1.6-4.0	>4.0
Available S (mg kg^{-1})	5.00	0-5.0	5.0-7.0	>7.0
Zn (mg kg^{-1})	1.00	0-1.0	1.0-1.5	>1.5
Cu (mg kg^{-1})	0.50	0-0.5	0.5-0.7	>0.7
B (mg kg^{-1})	0.50	0-0.5	0.5-0.6	>0.6
Fe (mg kg^{-1})	3.50	-	-	-
Mn (mg kg^{-1})	3.00	-	-	-

Source: Agboola and Ayodele (1985), FMANR (1990)

be attributed to low organic matter and total N levels in the soil unlike addition of K and Mg which despite the high content, increased dry matter yields. The order of increase in yield with micronutrients is: Zn> Fe> Cu. Maize grain yields from single and combined nutrients, expressed as percentage (%) of NPK treatment are shown in Fig. 2. The low percentage yield of the control treatment shows that there was significant response to fertilizer. Response to N was greater than control, P and K treatments. Single P and K application compared to the control at Ikare and Ogbomoso which had 0.20, 0.17 cmol kg^{-1} soil exchangeable K and 31, 18 mg kg^{-1} soil available P, respectively. These values were higher than critical levels established for maize in the soil of the savannah zone (Agboola and Ayodele, 1985; Sobulo and Osiname, 1985; FMANR, 1990). When the fertilizer combination contained N, yield responses further increased, indicating its primary need, followed by P while K was next only at Ogbomoso. Thus, the recommendation of a fertilizer mixture that contains N, P and K is in order for maize. The inclusion of Mg and micronutrients should further increase grain yields.

The percentage yield using the minus-one nutrient technique is shown in Table 3. Its interpretation, as follows: <50, 51-75, 76-88, 89-95 and >95% for very high, high, moderate, low and no response, respectively, confirms the primary need of N, followed by P. The response to P was low, even as P would not be recommended for Ikare and Osogbo sites. Response to K was high at Osun and

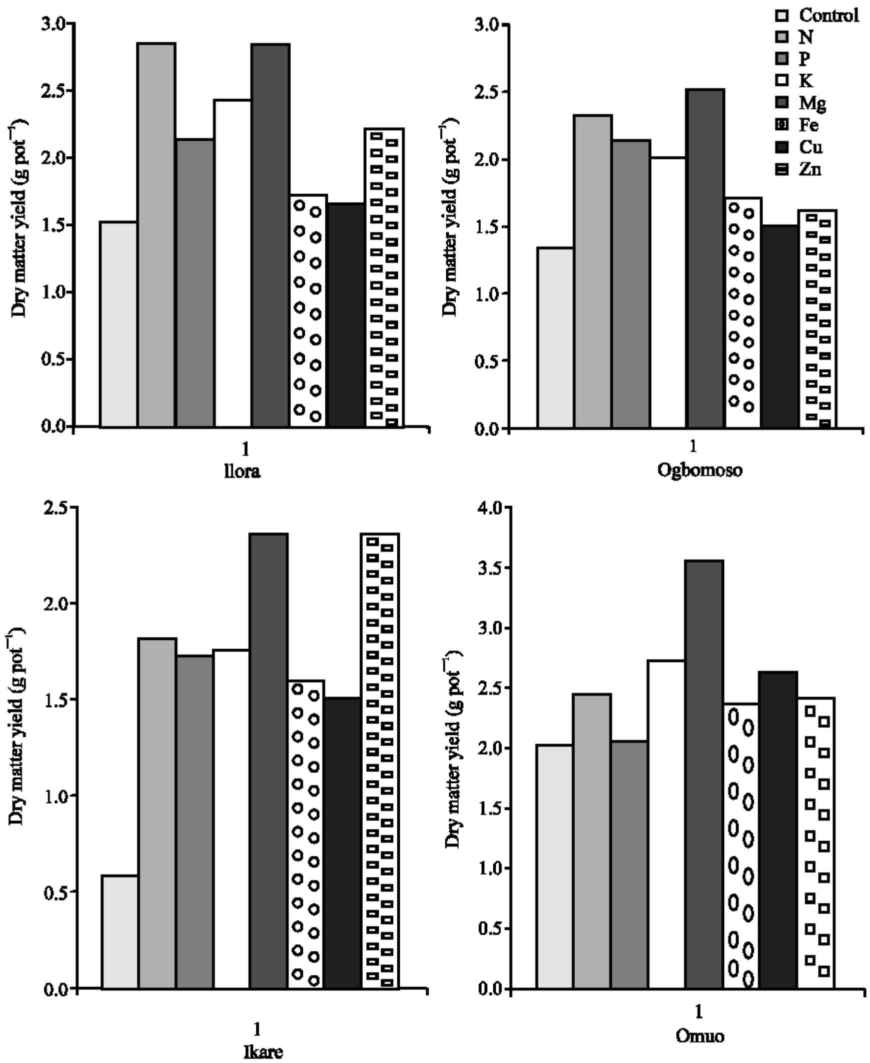

Fig. 1: Dry matter yield of maize in derived savannah soils as influenced by nutrient additions

moderate at Ikole and Ogbomoso. Response to Mg was high at Ikare and Iwo, but low at Osun and Ogbomoso. The response despite high exchangeable Mg in the sites suggests that the index of availability is probably inadequate and needs re-evaluation (Agboola *et al*., 1976). Response to Mg depends on the ratios with Ca and K, being low at Ca/Mg ≤ 5:1 but assured at K/Mg ratio greater than 1:10. The Ca/Mg and K/Mg ratios varied between 1-2 and 4-12, respectively in these soils and so indicate the possibility of responses to Mg. A critical K/Mg ratio of 2.0 was suggested by Lombin and Fayemi (1977) and that even at high levels in the soil, Mg uptake can be suppressed by high exchangeable K status. Ilora, Omuo and Osun, with history of continuous cultivation and use of blanket NPK compound fertilizer required Zn while Osun and Iwo needed application of Cu.

Implications for Nutrient Management and Sustainable Maize Production

Appropriate solutions to identified soil physical and chemical constraints, in any farm, must be components of the improved management recommendations for sustainable arable crop production.

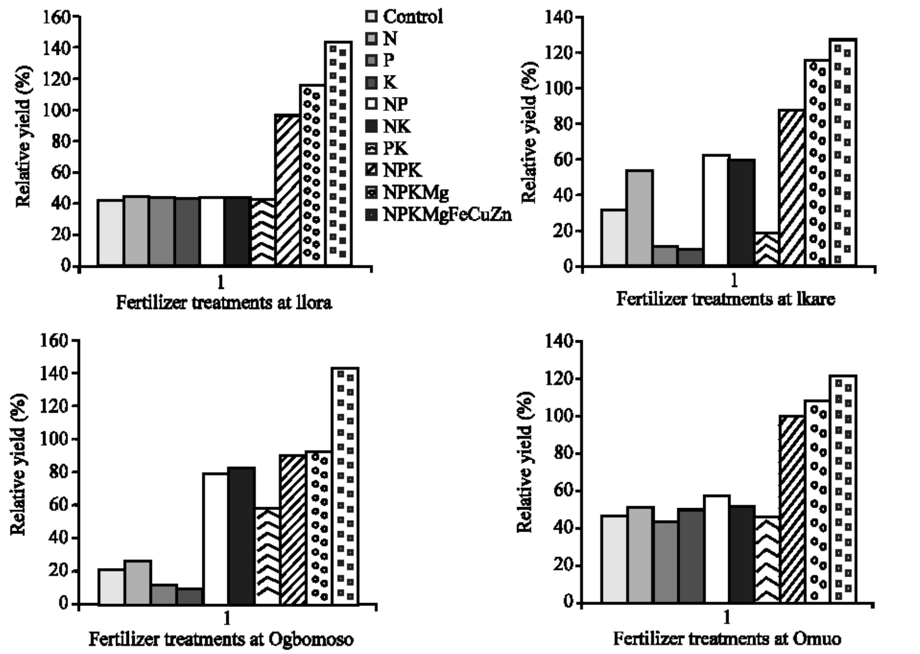

Fig. 2: Effect of single and combine fertilizers on yield of maize expressed relative to yield of NPK treatment

Table 3: Percentage yield increase of maize in minus-one nutrient treatments

Locations	-N	-P	-K	-Mg	-Zn	-Fe	-Cu	Control
Ikare	65	124	100	65	100	97	113	33
Ikole	68	87	81	119	115	97	115	69
Ilora	57	83	97	130	94	100	148	41
Iwo	20	74	176	75	88	108	79	11
Ogbomoso	47	87	81	90	131	105	107	32
Omuo	43	83	109	107	48	102	102	38
Osogbo	57	104	92	109	100	104	107	75
Osun	45	69	72	92	86	110	78	76
Average	50	89	101	98	95	103	106	47

Table 4: Correlation coefficients of the relationship between clay and organic matter with soil nutrients

	Correlation coefficient (R)	
Soil properties	Clay	Organic matter
Total N	0.59**	0.99**
Available P	0.19	0.52**
Exchangeable Ca	0.36**	0.64**
K	0.30**	0.60**
Mg	0.59**	0.83**
ECEC	0.41**	0.70**
Mn	0.40**	0.29**
Fe	0.60**	0.55**
Cu	0.67**	0.77**
Zn	0.57**	0.79**

**: Correlation coefficients ≥0.30 and 0.25 are significant at $p<0.05$ and 0.01, respectively

Thus, the nature of variability in soil properties, notably nutrient fertility status and crop responses to levels of management are issues for consideration in assessing these soils formed on basement complex rocks in the savannah zone of South-Western Nigeria for sustainable maize production.

The coarse texture of the topsoil, due to low clay content and dominance of lACs make the soils to lose physical quality and become compacted under continuous mechanized tillage practices (Lal *et al*., 1986). The undesirable consequences: rapid internal drainage and heat transfer, rise in soil and air temperatures, soil loss through runoff and erosion, nutrient leaching losses, etc become more intense under compaction. The low clay contributes minimally to nutrient availability compared to soil organic matter, whose roles as the main source of nutrient supply and provision of cation exchange sites are explained by the higher correlation coefficients (Table 4).

Fallows use natural processes to restore soil fertility, through organic matter build-up and nutrient cycling between vegetation and the surface layer of soil, such that during the cultivation phase, crop performance depends on nutrient reserves and the rate of organic matter mineralization. This is quite relevant to N and P availability whose major forms in soils are as the organic fraction (Osiname, 1979). Thus, with average 0.11% total N in these soils and assuming the 4% mineralization rate estimated for cultivated soils in the savannah Jones and Wild (1975) much less than 120 kg N ha^{-1} recommended for high maize yields is released, necessitating supplemental N from appropriate sources. Available P released at this mineralization rate can be substantial; to reduce P fertilizer requirements. Since P fixation is low, deficiency can be readily corrected. As a result, maize responses have been to low P rates in several locations of the derived savannah (Osiname, 1979; Ayodele, 1987). The organic matter built up during fallows is reduced by mechanized land clearing and tillage, intensive cultivation, continuous N application at high rates and shortening of fallow lengths FMANR (1990). Thus, sustainable maize production must emphasize some form of fallow given the low level of integrated crop-livestock production in the zone, which should have ensured addition of animal manures to the farms. The potentials of in-situ and live mulches, no tillage (zero or reduced) and alley cropping systems, in which plant residues or hedgerow pruning are returned as manures for nutrient recycling and soil cover (Kang *et al*., 1990) need to be exploited.

Exchangeable K is high due to the nature of parent rocks-basement complex rocks rich in K bearing minerals and large quantities of ashes, deposited on the soil surface during slash and burn cultivation practices, as sources of soluble K. However, since K uptake increases with N and P fertilization and soluble K is lost through leaching, surface run-off and erosion, the addition of K is necessary, especially under continuous cropping.

The inclusion of Mg and micronutrients would correct deficiencies that show up under intensive cultivation and continuous use of NPK fertilizers, to increase maize yields. For Cu and Zn, the levels are low but P build up is possible to induce Zn deficiency. Available Fe is high while the conditions for deficiency low pH in sandy soils and slightly acid to neutral soils with high Cu, Zn and P (Kang *et al*., 1977), are not typical of the zone. Where burning accompanies then cultivation practices, increase in soil pH from deposited ashes would reduce Fe availability to cause deficiency in upland rice (Vose, 1982). Conventional NPK fertilizer procured for agricultural use is inadequate for sustainable maize production. Once the land, opened from fallow, is cultivated for more than two to four years and in soils with less than 3% organic matter, the need to include Mg and micronutrients in the fertilizer schedule becomes essential for high maize yields in the savannah zone of South-Western Nigeria.

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