THE PHYSICAL COMPONENTS OF SOIL RENEWAL UNDER BUSH FALLOW IN A TROPICAL ENVIRONMENT

L'évolution des composants physiques au cours du renouvellement des sols sous jachère buissonneuse dans un milieu tropical.

J.O. ADEJUWON & O. EKANADE *

RESUME

L'évolution de certaines propriétés physiques du sol (texture, humidité et structure) a été étudiée en relation avec la durée de la jachère dans une région du SW Nigéria. Des modifications appréciables ont été enregistrées en ce qui concerne les fractions granulométriques, l'humidité, la densité apparente et la porosité totale. Elles sont attribuées principalement à la désagrégation continue des particules du sol sous l'effet de l'altération et de l'activité des macro - organismes. La teneur en matières organiques, la composition chimique et la capacité d'échange ont été prises en considération dans le déroulement de ce processus. Une bonne connaissance de ces phénomènes est particulièrement utile pour la planification des cultures en milieu tropical.

ABSTRACT

This paper considers the role of physical properties of texture, moisture and structure in the renewal of soil under fallows of between one and 20 years in a part of the tropical region of South-Western Nigeria. Appreciable changes are recorded in the values of sand, silt, clay, soil moisture content, bulk density and total porosity during the period. These changes are attributed mainly to the continuous breakdown of soil particles into finer aggregates as a result of pronounced weathering processes and also to the activities of soil macro-organisms. The soil physical components of soil renewal are then related to the organic matter, chemical and

* Department of Geography Obafemi Awolowo University - Ile-Ife - Nigeria

nutrient components of soil renewal under bush fallows as the latter advance in age. Lastly, the implication of a better understanding of the physical components of soil renewal and the management of soil physical properties in a peasant agricultural system in the tropics is discussed.

INTRODUCTION

It is well known that cultivation reduces the fertility status of the soil and that the rate of reduction is proportional to the frequency of cropping. It is in recognition of this that the traditional systems of farming in the tropics usually include a period during which a bush regrowth occupies a previously cultivated plot and helps to rebuild soil fertility.

One well-known component of soil regeneration under fallow vegetation is the build-up of organic matter. As the vegetal biomass increases, litter generation is enhanced and the surface layer of the soil becomes a veritable repository for decaying organic matter thereby improving the nutrient status of the soil (P.H. NYE & D.J. GREENLAND, 1960 ; E.O. JAIYEBO & A.N. MOORE, 1964 ; A.S.R. JUO & R. LAL, 1977 ; A.O. AWETO, 1985).

Thus an increase in the amount of organic matter is usually associated with increases in the amounts of organic and nutrient elements such as nitrogen, phosphorus, calcium, magnesium, potassium, sodium, cation exchange capacity and base saturation.

It appears, therefore, that soil renewal under fallow vegetation could be ascribed to the processes of biogeochemical cycling of elements in the context of the ecosystem. This involves mainly the uptake of elements through roots and their return to the soil through mineralisation of litter. Much less emphasised in literature, however, are the changes in physical properties of soil during cultivation which are reversed during the periods of fallow (A.O. AWETO, 1978). The changes in soil physical properties need to be given greater consideration than they had been previously accorded. First, it would be difficult to explain changes in the physical properties of soil terms of bio-geo-chemical cycling. This means that there might be other components of soil renewal under fallow vegetation that are purely physical. These need to be identified, assessed and compared with the purely chemical processes.

Secondly, changes in soil physical properties affect nutrient holding capacity of the soil and may, in fact, be more fundamental to the overall change in fertility than nutrient cycling.

Therefore, the main objective of this paper is to examine the changes that occur to the soil physical properties under fallows of varying ages and assess their contribution to the renewal of soil in a tropical rain forest environment relative to soil chemical and nutrient properties as the fallow vegetation advances in age. It is believed that such an assessment will lead to a better understanding of the processes of soil renewal under fallow vegetation, and contribute significantly to the achievement of more effective methods of soil management in the tropics.

THE STUDY AREA

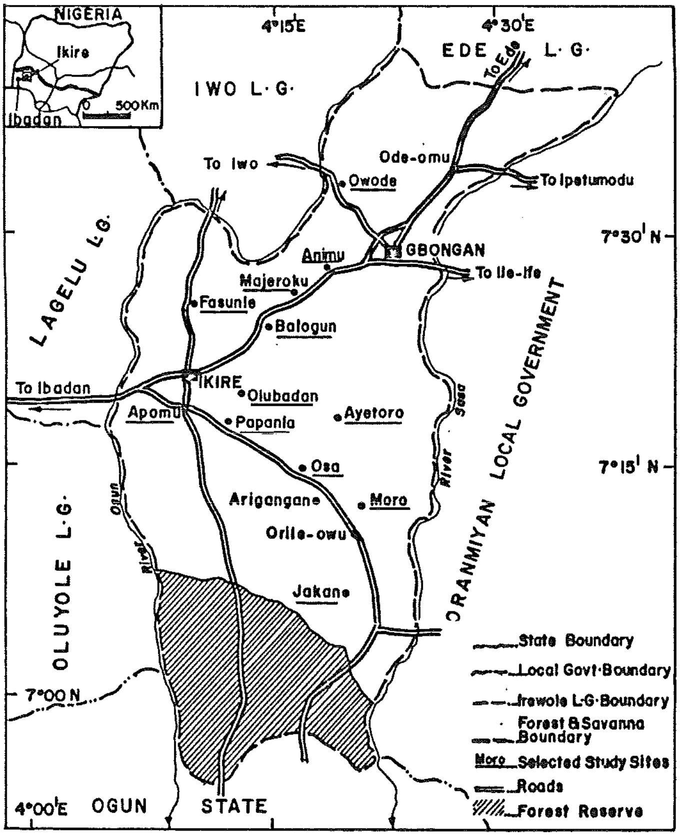

Fig. 1 : Map of irewole local government area (Inset study area within Nigeria).

This study was carried out in Irewole Local Government Area of Oyo State, Nigeria. It lies between Latitude 7°03' and 7°40' north; and Longitude 4°07' and 4°32' east with a land area of about 1550 km^2 (fig.1). The area is characterized by tropical rainforest climate of Köppen and ferruginous tropical soils according to the *Soil Map of Africa.* The rain forest has been removed substantially over most of the area and replaced by tree crops, espacially cocoa, food crop plots and fallow regrowths

METHODS OF STUDY

The topographical maps (1 : 50,000) and airphotos (1 : 40,000) were used to demarcate the study area and locate study sites. The processes of choosing the study followed a randon selection of ten villages from a total number of 82 (fig. 1). In each of the villages, five different plots of ages one, five, ten, 15 and 20 years under fallow vegetation were selected with the information as to the age of each fallow obtained from the owner-farmers whose permission was also obtained to enter and collect soil samples from such plots. The sample plots were selected on flat summit areas with slope angle not exceeding 2° to ensure that the soils belong to the same soil series (A.J.SMYTH & R.F. MONTGOMERY, 1962).

Each sample plot was 30 m by 30 m which was again divised into 5 m by 5 m quadrats. These quadrats were then assigned numbers from where five were randomly selected. It was from these five smaller quadrats that soil samples were collected to a depth of 15 cm of the soil profile using the bucket auger. This depth is considered adequate since it has been recognised that the most significant changes in the soil characteristics that take place during the course of fallow are confined to the soils (P.H. NYE & D.J. GREENLAND, 1960 ; P.A. SANCHEZ, 1976). In essence, there were 50 plots from where 250 soil samples were collected. The soil samples were collected into well-labelled polythene bags and taken to the laboratory for analysis.

The soil samples were air-dried and sieved through 2 mm diameter mesh after which standard laboratory techniques were used to determine the following soil parameters : particle size distribution; moisture content, bulk density, total porosity, pH, nitrate-nitrogen, available phosphorus; exchangeable calcium, magnesium, potassium and sodium, cation exchange capacity (C.E.C.) and base saturation.

Soil particle size distribution was determined by the hydrometer method. Soil moisture content (%) was determined by oven drying at 105° C after maintaining the soil moisture at field capacity. Bulk density (g/cm^3) and total porosity (%) were determined by the core method. Soil pH was determined potentiometrically in 0.01M calcium chloride solution using a soil to calcium chloride solution ratio of 1:2 while organic matter (%) was determined by the Walkley-Black method. Nitrate-nitrogen (p.p.m.) was determined by using 2,4 phenoldisulfonic acid on the prepared soil sample solution and available phosphorus (p.p.m.) was by Bray N° 1 method. Soil samples were leached with 1N Neutral ammonium acetate to obtain extracts used for the determination of exchangeable cations (me/100g soil). Thereafter, exchangeable calcium, potassium and sodium were determined by flame analyser and exchangeable magnesium by atomic absorption spectrophotometry. C.E.C. (me/100g soil) was determined as the sum of exchangeable bases and exchange acidity while base saturation (%) was calculated as the sum of the exchangeable bases divised by the C.E.C. and multiplied by 100.

RESULTS AND DISCUSSION

Status of Soil Physical Properties over time

Table I shows the soil physical properties under fallow of different ages. Sand particles decreases over time being 82.3 % in the first year fallow but 63.3 % in the 29 year fallow. Silt content and clay fractions increases over time. While silt increases from 9.4 % to 14 %, clay increases from 8.3 % to 22.7 % over time. The table further shows

	One-year	5-year	10-year	15-year	20-year
Sand (%)	82.3	78.2	74.7	70.5	63.3
Silt (%)	9.4	9.5	10.5	10.2	14.0
Clay (%)	8.3	12.3	14.8	19.3	22.7
Moisture content (%)	6.5	9.2	9.9	11.4	14.8
Bulk density (g/cm^3)	1.51	1.47	1.40	1.22	1.10
Total porosity (%)	59.0	61.0	62.0	69.0	72.0

Table I : Mean values of soil physical properties under fallow of different ages.

that moisture content and total porosity increase while bulk density decreases. In the one-year-old fallow moisture content is 6.5 % but 14.8 % in the 20-year-old fallow, while total porosity under the fallows of the ages are 59 % and 72 % respectively. The bulk density in the first year is 1.51 g/cm^3 and in the twentieth year it is 1.10 g/cm^3.

The results depicted by this table clearly indicate that soil renewal has been affected through changes in both the mechanical and structural properties of soil. These changes include, in the main, the decrease in sand particles and bulk density and the increase in the values of silt, clay fractions, moisture content and total porosity.

It is well known that the clay fractions help in the retention of both nutrients and water. Thus, up to a point, an increase in clay and silt fractions will tend to correspond to an improvement in soil fertility. The question at this stage really pertains to how the mechanical composition of soil changes in the way demonstrated in this study moreso that it is generally believed that soil texture is the most permanent and is hardly affected even by cultivation practices (e.g. A. FANIRAN & O. AREOLA, 1978). There are two main possibilities. Firstly, there is the possibility of a breakdown of particles to clay size fractions as a result of continued weathering processes. It is also probably true that the sand fraction is not entirely made up of quartz but also of minerals that are still susceptible to decomposition over time. The latter process could be enhanced by a number of factors among which are the supply of organic acid through root decay and other organic matter components and the promotion of hydrolysis and hydration processes by the greater retention of moisture by soil under fallow vegetation.

Secondly, and perhaps more importantly, the changes in the particle size in favour of an increase in clay may be attribued to the activities of macro-organisms especially earthworms.

For example, P.H. NYE (1955) has shown that *Hippopera nigeriae* (Sjost), the dominant earthworm species in the study area, is capable of bringing on to the surface 5,100 g/m^2/annum of soil material through warm-casting to more than 30 cm deep. From the mechanical analysis of worm-casts P.H. NYE (1955) showed that they contained no particle greater than 0.5 mm in diameter and only a low proportion with diameters between 0.2 and0.5 mm. He further showed that while a large proportion had diameters between 0.2 and 0.02 mm, it is closely followed by that proportion with less than 0.002 mm as diameter. In fact, studies have shown that in the study area clay fractions in the subsoil are higher than those of the topsoil (e.g. P.H. NYE, 1955 ; A.J. SMYTH & R.F. MONTGOMERY, 1962). It is therefore reasonable to assume that earthworms bring up clay fractions from the subsoil to the topsoil thereby increasing the proportion of clay fractions in the topsoil causing a reduction in sand particles. The importance of colloidal composition of clay in the soil complex has been emphasised (e.g. H. KOHNKE, 1968; T.R. PATON, 1978) and it is a crucial element in the fertility status of soil.

Soil moisture content is one of the most useful ways of expressing hydrological processes in the soil. Hence, its improvement with increase in the length of the fallow period, as indicated in this study, constitutes a crucial component in soil renewal under fallow.

It is known that water plays a major part in almost all the physical, chemical and biological processes in the soil. It is involved in most forms of mechanical weathering, it is fundamental to all aspects of chemical weathering, redistributes material throughout the soil profile, carries away both soil particles and solutes, and transports nutrients to plants (D.J. BRIGGS, 1977). Therefore, the improvement of soil moisture content under fallow could be attributed to the protective nature of fallow vegetation which disallows undue loss of soil moisture through land exposure.

The decrease in soil bulk density under fallow vegetation over time indicates a reduction in the compaction of soil. During cropping, soil bulk density tends to increase owing to the impact of rain drops which break down soil aggregates. The finer soil aggregates are then washed down to seal soil pores thus making the soil more compact. The decrease of soil bulk density with increasing age of fallow could be due to the combined effect of plant roots which open up the soil or to the activities of macro-organisms which burrow into soils. With such a change in bulk density, it is expected that soil fertility renewal under fallow, over time, will be enhanced.

Soil porosity is inversely related to the density of soil particle packing, and it is important in the status of soil fertility for several reasons. Soil porosity acts as the main passage for air and water movement through the soil, and thus control aeration and drainage. It also provides space in which soil organisms can live, and to which plant roots can extend. To these ends, soil porosity influences the chemical conditions of the soil. As this study shows, total porosity increases over time under fallow vegetation. This improvement in total porosity invariably constitutes an important component in soil renewal under fallow. The conditions that bring about improvement to total porosity under fallow of varying ages are as discussed for bulk density.

It is thus clear from the foregoing discussion that the role of soil physical properties as a component of soil renewal under fallow vegetation is a significant one. Significant in the sense that through them (especially clay fractions, moisture content, bulk density and total porosity) other soil renewal components are enhanced. Before considering how soil physical properties enhance the renewal capabilities of chemical properties of soil as fallow vegetation advances in age there is the need to focus on the form and magnitude of relationship between age of fallow and individual soil properties.

Changes in soil with age of fallow

The fallow regrowths considered in this study range from one to 20 years. The changes in soil properties over this period of time is depicted by the Pearson's product-moment correlation coefficients in Table II. This table shows that, in general, most of the soil properties are significantly correlated with age of fallow except nitrate-nitrogen. While sand content and bulk density are inversely related with age of fallow other are positively related. The inverse relationships between sand content and bulk density on the one hand, and age of fallow on the other, appear to imply that as the ages of fallow increase, these soil physical properties decrease. If the latter were true in respect of sand content, then corresponding increases should be expected in silt and clay over time. In terms of texture, therefore, it could be claimed that as the percentages of silt and clay increase, the soil texture becomes finer. It is further pertinent to observe that clay has greater correlation coefficient with age of fallow than silt meaning that clay gains more as sand content reduces over time. Soil moisture content has high correlation coefficient (0.66) with age

Soil Properties	Correlation Coefficients
Sand	-0.61
Silt	0.41
Clay	0.63
Moisture content	0.66
Bulk density	-0.74
Total porosity	0.68
Soil pH	0.46
Organic matter	0.68
Nitrate-nitrogen	0.28
Available phosphorus	0.44
Calcium	0.68
Magnesium	0.57
Potassium	0.61
Sodium	0.33
C.E.C.	0.66
Base saturation	0.40

Correlation coefficients that exceed /0.35/ are significant at 1 % confidence level

Table II : Correlation coefficients between age of fallow and soil properties.

of fallow denoting that an increase in age of fallow is responded to be an increase in soil moisture content. The reduction in bulk density over time makes the soil less compact which invariably results in high positive correlation (0.68) of total porosity with age of fallow.

Among the chemical properties, organic matter, calcium, C.E.C., potassium and magnesium have very high positive correlations with age of fallow. Others, such as pH, available phosphorus, base saturation and sodium are also significantly correlated with age of fallow. All these show that as fallow advances in age soil chemical properties also improve. The significance of organic matter as an important component of soil renewal under fallow has been stressed (e.g. O.AREOLA *et al.*, 1982 ; A.O. AWETO, 1985) but the results of the correlations between age and all the soil properties clearly indicate that other components of soil renewal under fallow vegetation are identifiable. These include the clay textural component, the hydrological (moisture content) component, the bulk density and total porosity (structural) component and the exchange capacity (calcium, potassium, magnesium, C.E.C.) component. In short, these various components can easily be subsumed under physical and chemical components of soil renewal under fallow. While the latter has been woven round organic matter and has been extensively discussed with particular reference to southwestern Nigeria (O. AREOLA *et al.*, 1982; A.O. AWETO, 1985), the former has not been given proper attention.

Relationships between components of soil renewal

Table III shows the intercorrelations among all the soil properties under fallow over time. This table could aid our understanding of the importance of soil physical properties as a major component of soil renewal under fallow vegetation. This is because the table will make it possible to assess the relative importance of soil physical properties in the restoration of soil fertility in comparison with the chemical component of soil renewal under fallow vegetation.

Both sand content and bulk density have mostly high negative correlations with other soil properties except between themselves (0.55). These, in a way, show that the reduction of sand content and bulk density result in higher quantities of other soil parameters. While clay, moisture content and total porosity are mostly highly correlated with other soil properties positively, silt is also positively but weakly correlated with most of the other soil properties. Exceptions in the latter case include its relationship with sand, clay, pH, organic matter and nitrate-nitrogen. Among the chemical properties, the correlation matrix indicates that only exchangeable sodium and available phosphorus are weakly related with most of the other soil properties.

O. AREOLA *et al.*. (1982) have evaluted the influence of each soil parameter in the restoration of soil fertility under fallow vegetation by considering the magnitude of values of correlation coefficients. Therefore, based on the higher values of correlation coefficients between organic matter and other soil properties than what exist among others they concluded that soil organic matter has a dominant influence. If the same measure is used in this study, it is crystally clear that soil physical properties will also constitute a distinct component of

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
X 1	1.00	-0.82	-0.75	-0.71	0.55	-0.50	-0.57	-0.68	-0.43	-0.21	-0.56	-0.55	-0.38	-0.04	-0.49	-0.40
X 2		1.00	0.38	0.32	-0.24	-0.17	0.44	0.56	0.35	0.21	0.16	0.23	0.15	0.09	0.18	0.17
X 3			1.00	0.64	-0.63	0.52	0.48	0.59	0.49	0.30	0.63	0.61	0.56	0.09	0.85	0.48
X 4				1.00	-0.60	0.54	0.21	0.41	0.51	0.19	0.68	0.70	0.60	0.59	0.73	0.55
X 5					1.00	-062	-0.51	-0.69	-0.60	-0.45	-0.64	-0.70	-0.48	-0.34	-0.60	-0.36
X 6						1.00	0.63	0.64	0.45	0.59	0.71	0.68	0.61	0.16	0.75	0.57
X 7							1.00	0.68	0.36	0.38	0.62	0.70	0.57	0.18	0.71	0.35
X 8								1.00	0.59	0.25	0.64	0.59	0.57	0.22	0.79	0.53
X 9									1.00	0.11	0.30	0.35	0.26	0.20	0.33	0.25
X10										1.00	0.37	0.40	0.47	0.08	0.43	0.15
X11											1.00	0.81	0.57	0.31	0.81	0.68
X12												1.00	0.58	0.29	0.86	0.60
X13													1.00	0.20	0.59	0.55
X14														1.00	0.31	0.14
X15															1.00	0.43
X16																1.00

Correlation coefficients that exceed |0.35| are significant at 1 % significance level

X1	Sand	X5	Bulk density	X 9	Nitrate-nitrogen	X13	Potassium
X2	Silt	X6	Total porosity	X10	Available phosphorus	X14	Sodium
X3	Clay	X7	pH	X11	Calcium	X15	Cation exchange capacity
X4	Moisture content	X8	Organic matter	X12	Magnesium	X16	Base saturation

Table III : Intercorrelations among soil properties under fallow.

soil fertility restoration under fallow. With the exception of silt, other physical properties of soil are relatively highly correlated with other soil properties which are comparable with those of organic matter.

In this study, textural properties, especially sand and clay, are strongly related to soil structure, drainage and chemical properties. D.J. BRIGGS (1977) has indicated that soil texture has several important indirect effects on plant growth, through its control of factors such as structure, drainage and aeration. He further points out that clay acts as a major store of plant nutrients, and therefore, many aspects of soil fertility are ultimately influenced by texture. In fact, T.R. PATON (1978) has indicated the susceptibility of silt materials to erosion while H. KOHNKE (1968) and P.A. SANCHEZ (1976), among others, have discussed the importance of the colloidal composition of clay in the soil complex. This means that clay is made up of particles that are so small that distinctive reactions of the surface are appreciable. Once this happens to the soil, favourable condition then exists for other soil elements to regenerate as the structure and soil moisture holding capacity will improve. In that case, it can rightly be assumed that as fallow progresses in age increase in clay fractions enhances the fertility status of the soil.

The reduction in bulk density and the consequent positive increase in total porosity, both of which are highly related with other physical and chemical properties, suggest a fair degree of particle aggregation and structural stability which denote improvement and enhancement of soil fertility. It has also been realised that a critical factor in the restoration of soil fertility under fallow is the ability of the soil to give way in the face of the limited pressure exerted by the tips of the growing roots which invariably depends on the consistance and bulk density of the soil. However, as the latter decreases and total porosity increases over time many fine rootlets can gain entry and thereby create conducive atmosphere for the cycling of nutrients in the soil.

Soil moisture content also shows very strong relationships with most physical and chemical properties (Table III). These strong relationships between moisture content and other soil properties, indicate that the distribution of materials throughout the soil profile and the transportation of nutrients to plants are enhanced under fallow as the latter advances in age. In this form, therefore, the physical, chemical and biological processes in the soil will improve over time under fallow.

CONCLUSION

While not disputing the fact that the improvement in soil properties consequent upon the progressive age of fallow could be due to biogeochemical cycling processes, the capability of the soil to retain and circulate nutrients is a primary function of the preponderance of the status of the physical properties of soil. This is especially so with regards to clay fractions, the structural and the hydrological properties of soil. Thus, it can be responsably argued that the fundamental soil change that occurs in soil renewal under fallow of varying ages is the change in these soil physical properties. Therefore, the significant relationships between the soil physical properties on the one hand and most of the soil chemical properties on the other could be seen as one in which changes in the physical properties of soil are the cause while the other changes are the effect. In that case, while nutrient cycling can be recognised as one of the major means of soil renewal under fallow whatever changes occurring in the physical properties of soil must be regarded as a fundamental process of soil renewal upon which other changes take place under fallow over time.

The results of this study show that the advancement of fallows over time brings about the renewal of soil fertility under them. This means that the opening up of the tropical rain forest to field crops cultivation results in soil fertility deterioration before such plots are left to fallow. Since such opening of the tropical environment is the major cause of the removal of the finer particles of the soil with its attendant problems of soil compaction, non-porosity and low moisture content, the proper management of soil physical properties during cultivation then becomes very important. In other words, attempts should be made during period of cultivation to minimise the degradation of the physical properties of soil. In the context of the peasant farmers in south-western Nigeria, the surest way to bring this about is by mulching their food crop plots. This will largely minimise surface wash which is the chief cause of degradation of physical properties of soil in a tropical environment. Besides, mulching may supply some chemical elements to the soil while decomposing.

BIBLIOGRAPHIE

AREOLA, O., AWETO, A.O. & GBADEGESIN, A.S., 1982. Organic matter and soil fertility restoration in forest and savanna fallows in southwestern Nigeria. *Geo-Journal,* 6, 182-192.

AWETO, A.O., 1978. Secondary succession and soil regeneration in a part of the forest of South-Western Nigeria. Unpublished Ph.D. Thesis, University of Ibadan, Ibadan.

AWETO, A.O., 1985. Organic matter and nutrient contents of soils under four types of bush fallow vegetation in S.W. Nigeria. *Geo-Journal,* 10, 409-415.

BRIGGS, D.J., 1977. *Soils.* London.

FANIRAN, A. & AREOLA, O., 1978. *Essentials of soil Study,* Ibadan.

JAIYEBO, E.O. & MOORE, A.W., 1964. Soil fertility and nutrient storage in different sub-vegetation systems in a tropical rain forest environment. *Tropical Agriculture* (Trinidad), 41, 129-143.

JUO, A.S.R. & LAL, R., 1977. The effect of fallow and continuous cultivation on the chemical and physical properties of an alfisol in the tropics. *Plant and Soil,* 47, 567-584.

KOHNKE, H., 1968. *Soil Physics.* New Delhi.

NYE, P.H., 1955. Some soil-forming processes in the humid tropics IV. The action of the soil fauna. *Journal of Soil Science,* 6, 73-83.

NYE, p.H. & GREENLAND, D.J., 1960. *The Soil under Shifting Cultivation.* Harpenden.

PATON, T.R., 1978. *The formation of Soil Material.* London.

SANCHEZ, P.A., 1976. *Properties and Management of Soils in the tropics.* New-York.

SMYTH, A.J. & MONTGOMERY, R.F., 1962. *Soil and Landuse in Central Western Nigeria.* Ibadan.