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PEDOLOGICAL DIFFERENCES IN A CAMBISOL IN THE LOWER VOLTA FLOODPLAIN OF GHANA

By

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PEDOLOGICAL DIFFERENCES IN A CAMBISOL IN THE LOWER VOLTA FLOODPLAIN OF GHANA

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Legon

By

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DEDICATION

The Lord is good and His mercies endureth forever. "Behold I am the Lord God of all flesh, is there anything too hard for me" ? Whatsoever ye say in my ears that will I do. And when it is done as you desired you shall publish my good works and glorify my name.

Let everything that has breadth praise the Lord. Amen. This thesis is dedicated to the Glory of the Lord God Almighty who made it possible and for the good of mankind.

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DECLARATION

I hereby declare that this thesis "Pedological differences in a Cambisol in the Lower Volta floodplain of Ghana" has been written by me and that it is the record of my own research work.It has neither in whole nor in part been presented for another degree elsewhere. Works of other researchers have been duly cited by reference to the authors and all assistance received also acknowledged.

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ABSTRACT

This study evaluated pedological differences in three soil profiles of Amo series following cessation of seasonal flooding due to construction of the Volta Dam. Three Pedons were used in this study. Pedon 1 is a modal profile; Pedon 2 is sited about 500m downslope from an oyster shell deposit site while Pedon 3 is on the oyster shell site . Soil properties determined include particle size distribution, hydraulic conductivity, pH, organic carbon, available and total phosphorus, exchangeable bases and acidity and dithionite extractable iron (free iron). The texture of the diagnostic horizons of pedon 1 is clayey which is typical of the Amo series. This changes to sandy clay loam in Pedons 2 and 3. Pedon 2 is underlain by sand at 110 cm depth. The increase in sand content of Pedon 2 with depth is likely due to the high contents of sand-sized oyster shells.The coarse texture has influenced the greater hydraulic conductivity in the two latter Pedons. The pH of Pedon 1 is strongly acid while that of Pedon 3 is near neutral to slightly alkaline as a result of neutralization by the Ca and Mg-rich oyster shells. The CEC of Pedon 3 is higher than that of Pedons 1 and 2; the CEC of the diagnostic horizons of Pedon 3 is greater than 25 cmol(+)/kg with very low exchangeable acidity because of the influence of oyster shells. Organic carbon content in Pedon 3 is also higher because of greater biomass build up from intense biological activity. Total phosphorus concentration ranges from 122-244 mg/kg in Pedon 1, 53-173 mg/kg in Pedon 2 and 380-1444 mg/kg in Pedon 3 with corresponding available P contents of 3-9 mg/kg, 3-8 mg/kg and 6-84 mg/kg. It is apparent that phosphorus in Pedons 1 and 2 is Fe-bound because of the relatively higher concentration of free iron in these two profiles. The high P concentration in Pedon 3 is consistent with the high P content of the shells and suggest that the nutrient element is Ca-bound. Pedons 1 and 2 could be classified as Vertic

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Cambisol (Vertic Dytsropept) whereas Pedon 3 could be classified as Calcaric Cambisol (Vertic Ustropept). The oyster shells have modified the properties of Pedon 3 and provide a greater potential for sustainable low-input soil productivity which confirms field observations of better crop performance on this soil.

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CHAPTER ONE

1. INTRODUCTION

The Lower Volta floodplain of Ghana used to be seasonally flooded from September to November prior to the construction of the Akosombo Dam in 1966. After the construction, in 1966, however, the soils were subjected to all-year drier conditions because of water volume control upstream. The most dominant soil of the floodplain, Amo series, which occupies about 246 sq km has been used for agricultural production. Pre-damming data show the soil's reaction as moderately acid i.e pH = 5.0–6.0 (Brammer, 1955,1967; FAO, 1963). Other studies (McDonald and Partners, 1987; Amatekpor, 1989, 1993) revealed post-dam soil reaction to be strongly to very strongly acid (pH 4.5-5.0).

Soils can change when there is change in their environment, which also influences the surface chemistry (Schofield, 1949; Nikiforoff, 1953; Cline, 1961). As long as the dam remains in place this problem of increased acidity of the soils will persist because the self-liming mechanisms in the soil have been halted and a hitherto reversible reaction now operates in one direction only. The pre-dam Amo series used to be very good for arable agriculture due to its high inherent fertility. Traditionally it used to be, and still is cultivated broadly to cassava, sweet potatoes, maize, groundnuts, soybeans, vegetables, and under wetter conditions rice, bananas and plantains. Crop production has thrived predominantly on shifting cultivation for fertility regeneration but at increasingly narrower fallow periods due to increased population pressures. Yields are now low but could be increased significantly through soil amendment practices.

The problem of restricted access to good agricultural lands makes it imperative to transform cultivation to permanent form of land use. The World Bank's recent declaration that growth of agricultural production in sub-Saharan Africa should pace up at a minimum 4% annually to arrest

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decline in economic performance, can only be realised through increasing availability of nutrients (Graaf and Brena, 1993) and intensified agriculture. Acid soils, however, do pose problems that constrain the development of successful sustainable agriculture as they are rendered deficient in important nutrient elements especially some macro elements such as available and total phosphorus. This problem can be overcome through application of lime and fertilizer.

The use of lime in the tropics, especially by rural small holder farmers, is limited by the relatively high cost of the material. The problem has been worsened by withdrawal of subsidies on agricultural inputs imported into developing countries.

The use of locally available liming material is being advocated as economically cost-effective and therefore a more attractive alternative to the more expensive imported materials (Hailu et al., 1993). Therefore, there is the need for much work to be done to investigate the suitability of non-conventional but locally available materials for soil acidity amendment purposes in the least developed countries around the world.

The use of locally available liming materials that are readily accessible to farmers will be a pragmatic measure in the quest to promote and sustain crop productivity on this soil. Knowledge of the presence of oyster shell deposits which occur as inclusions in the Lower Volta floodplain is not new in Ghana. Although shells in general are known to contain calcium in amounts sufficient to neutralize soil acidity and offset the detrimental effects of acidity on soil properties and crop productivity, no work had been done in that area of research to investigate the impact of shell materials on soil properties in Ghana. The objectives of this study therefore are:

(i) to evaluate the impact of oyster shells on soil properties,

(ii) to infer from the results if oyster shells could be used to lime the acid Amo series in Ghana.

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CHAPTER TWO

2. LITERATURE REVIEW

2.1 Shifting cultivation: limitations and the need for intensified land use

Africa's agricultural sector is faced with restricted access to good agricultural land and an increasing population growth rate. There is the need to intensify land use but increased agricultural output can only be achieved if nutrients removed from the fields are continuously replaced. Farming practices are based on shifting cultivation and therefore land productivity remains so low that agriculture cannot provide the means of livelihood for all the. People. Thus men tend to seek jobs outside agriculture leaving farming to the weak aged.

Palte (1992) observes that shifting cultivation should be transformed gradually to a permanent form of land use to help lessen the already too heavy pressure on the low financial reserves of farmers. Kessler (1994), using the concept of the “human carrying capacity” expatiates on the need for a more sustainably-managed land resource. He defined the human carrying capacity as the maximum level of exploitation of a renewable resource, imposing limits on a specific type of land use that can be sustained without irreversible land degradation within a given area, and this is based on the sustainable supply of natural resources and on resilience thresholds of the ecosystem. According to Kessler (1994), a comparison of human carrying capacity levels with current exploitation rates of natural resources provides a useful framework to consider the ecological aspects of sustainable land use.

The global supply of agricultural land will be inadequate to accommodate the prospective increase in global demand (Crosson, 1992). The likelihood of expanding the supply of agricultural land sufficiently to accommodate, at an acceptable cost, an increase of 100% in

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global demand for agricultural output and of 270% in demand in developing countries over the next 40 years is small to negligible.

Recent World Bank calculations declared that growth of agricultural production in the Sahel regions should be 4% a year to counteract the growing population and the declining economic performance. However, it is questioned whether there is a potential for this growth and how it should be realized. Briefly put, there exists a situation of over-exploitation of the natural resources due to an overpopulation in relation to the production potential and existing economic situation. As agriculture is still the most important motor of development, priority should be given to its intensification, which means that the availability of nutrients to the soil should be increased (Graaf and Brena, 1993).

Shifting cultivation causes reduction in the amounts of available phosphorus, exchangeable Ca and Mg, CEC, and carbon and total nitrogen.soils. The decline in soil fertility with cultivation is due mainly to a reduction in organic matter resulting from clearance of the rainforest vegetation (Wood, 1979). Self-standing agriculture must aim at establishing high and lasting soil productivity and thereby conserving or re-establishing a well balanced ecological environment. The endeavour to make tropical agriculture self-sustaining has to face the constraints of the scarcity of land, insufficient external inputs and a low soil fertility. The most readily available measures to reach self sustaining agriculture with low external input on tropical smallholder-farms include agroforestry, multicropping, intensive gardening, and vegetable growing, the measures of which must be adapted or improved according to the specific site (Adelhelm, 1985).

Nana-Sinkam (1992) argues that Africa's food and agriculture situation is paradoxical since food insecurity and abundant natural resources capable of securing food availability seem

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to co-exist. It is emphasized that government policies should focus on domestic food production, as, generally, it has stronger linkages with the rest of the economy than other sectors such as employment, technology, consumption, and taxes. As the need for intensive farming systems becomes much more of a reality so too is the need for soil and water conservation programmes. Oosten and Cahill (1986) have observed that soil conservation should be seen as part of the regular field operations of the farmer and as a public effort to support intensification of land use.

Soil and water conservation programmes will have to contribute to greater self-reliance in production (Bali, 1985). The programmes will have to be implemented in an integrated manner on watershed basis supported by requisite data on soil and land characteristics. Consequently, studies are needed that can provide adequate information that can be used to quantify nutrient removal and fertilizer required to maintain sustainable soil productivity (CTA Netherlands, 1994). Moreover, there is the need to understand the soil as a resource base which reinforces the urgency to pay special attention to the understanding and assessment of the potential roles of indigenous measures to maintain soil productivity (Hailu and Runge-Metzger, 1993).

Soil properties crucial to the production of some specific crops need to be identified and the soils rated based on the relevant soil properties so identified (Gbadegesin, 1987). Given the very diverse nature of the natural resource base in tropical countries, every country should have to indicate the limits and possibilities to its resources to avoid failures and disappointment. African soils need careful management to remove the limiting factors of soil productivity which include correction of soil acidity by liming, as majority of the soils have nutrient limitation due to their inherently acid nature. Correction of acidity is to be followed by addition of fertilizers, which type and quantity must be determined by local experiments and experience. These two factors will increase organic matter content of the soils, through better plant growth, which has

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beneficial effects on nutrients (Mare, 1984).

2.2 Pedologic environment of soils

Some of the major soil-related constraints to agricultural development on the continent beside soil acidity include moisture stress and nutrient deficiency. However, lack of knowledge of soils and their distribution are also major constraints to agricultural development on the continent (Eswaran, 1987). It is not possible to provide unique solutions for land use from pedological studies alone, but experience shows that such studies can be used as basis for solving many land-use problems. We must understand our soils and landscapes before they can be properly managed. The best and shortest route to understanding this is to conduct good research in areas where problems occur.

Acid soils are common in regions of moderate to high rainfall or areas where soils have been strongly leached, either in the past or under present climates. Soil acidification has many implications for plant production, soil conservation and animal health. Whether induced or accelerated by the activities of man, several processes are believed to be responsible for soil acidification. These include increase in the production of acidic organic matter that accompanies improvement of agricultural soils, the use of acidifying fertilizers (e.g ammonium sulphates) and indirectly by loss of the basic cations that can balance acidity when nitrate anions are leached following nitrogen fixation by legumes. The toxicities that affect plants (aluminum, manganese, hydrogen) are frequently accompanied by simple or complex fertility problems including physical ones, which must be corrected if the management practices designed to overcome them are to have their full impact.

Approaches to ameliorate soil acidity include breeding of acid-tolerant plant species and organisms such as Rhizobia, but they will not reverse the detrimental soil processes and will

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narrow the range of crop options. Where lands have barely been used and are still fertile the problem of soil acidity often make farmers abandon their farms. Liming and other approaches that will improve the status of basic cations in soil offer the best solution for maintaining productivity in the long term.

Liming affects soils as a plant growth medium and touches every aspect of plants' growth and life causing plant behaviour to alter because of the many soil characteristics that are simultaneously changed when soils are subjected to changes in acidity. When acid soils are limed the, neutralization effect causes rapid negative charge increases as pH is raised. Liming increases the extent to which the exchange complex is saturated by Ca through hydrolysis, polymerization and precipitation of Al, an increase in CEC, a decrease in the proportion of exchange capacity saturated by Mg and K and a decrease in acidic ions relative to Ca. Increase in pH also decreases the solubility and thus availability of micronutrients such as Zn and Cu.

Any assessment of soil fertility and transfer of management results must deal with problems of soil variability and scale. Data available on soil characteristics for the acid soils of the tropics are limited and transfer of information involves extrapolation from field and or laboratory assessment. For information transfer, it is assumed that if a soil at one site is fully characterised and classified, a soil similarly classified elsewhere will have similar properties and behaviour. This premise however, depends on a high degree of covariance among soil properties and assumes that a satisfactory soil classification is available. It is necessary to consider soils on on-site basis to give local solutions that work.

Chemical properties important to tropical acid soils (P sorption, aluminum toxicity and low base status measurement of soil acidity, and cation retention) all show the lack of and the need for more appropriate soil characterization. It is necessary to enable functional relationships

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relevant to soil fertility to be established and then it will be appropriate and profitable to devise models that can predict plant behaviour (Isbell, 1987) or it will continue being difficult to counteract nutrient deficiencies in tropical soils.

Monitoring the status of soils will need some description of their capacity to store and transmit water, nutrient, and gases for plants and microorganisms. Soil features which relate to their inherent ability to support plant growth include nutrient status and physical features such as water retention characteristics. The physical properties of soils which determine their ability to sustain plant growth are those which determine the extent of root proliferation, and air-and-water movement and those that control the amount of water stored and available to crops.

Relationships exist between $CaCO_3$ content, soil texture and age of parent rock (Kern, 1985). Studies on the effect of liming and gypsum application on aggregate stability and water infiltration showed that aggregate stability and infiltration increase with level of liming rate. Highly significant positive correlations were found between aggregate stability and pH, exchangeable Ca and Ca+Mg and infiltration. Application of gypsum resulted in slight increase in aggregate stability and infiltration rate equivalent to liming to pH 6.0 (Roth et al., 1986).

2.3 Soil acidity

The Soil Survey Staff (1997) defines acid soil as having a pH of less than 5.0 in 0.01M $CaCl_2$ (2:1) throughout the control section. Soil science definition for pH: the negative logarithm of the hydrogen ion activity, recognizes that there are other hydrogen ions in the soil system such as in organic matter and in the mineral structure but that only the active H^+ in the soil solution is being measured (Buol et al., 1980).

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The positively charged acidic ion species which encounter the negative charge on soil clays and organic matter are hydrogen and aluminum present in acid soils referred to collectively as "exchange acidity". Exchange acidity is caused almost completely by aluminum ions (Coleman and Thomas, 1967). Aluminum is adsorbed by clays as the exchangeable monomeric trivalent ion and as hydroxy-Al polymers of indefinite size and degree of hydroxylation. The hydroxy- Al and hydroxy-Fe^{3+} coatings on layer silicates are proton donors responsible for much of the pH-dependent charge of soils and also adsorbed anions. Such polymers counter exchange sites of clay in non-exchangeable form, occupy interlayer spaces of 2:1 clays and inhibit free expansion or collapse.

2.3.1 Soil pH

Soil pH is about the most telling chemical characteristics of soils. Extensive use has been made of it's measurements in soil and water acidification studies in ecosystems which are subjected to acidic inputs from many different sources. Soil pH has been used to assess the extent of soil acidification (Tamm and Haubacken, 1986; Sjöstrom and Qvarfort, 1992), to estimate the susceptibility of a soil to further acidification (van Breemen et al., 1993) and to evaluate the availability or toxicity of elements for plant growth (Sumner et al., 1991). It influences soil chemical and biological processes such as the retention and release of ions at the solid: liquid interface (Barrow, 1987), the rate of mineral dissolution (Cronan 1985), the aqueous speciation of metals (Lindsay 1979), the decomposition of organic debris (Krug and Isaacson, 1984) and the activity of micro-organisms (Wong-Chong and Loehr, 1978).

Of the various electrolytes used to determine pH of soil, water (pHw) and 0.01M $CaCl_2$ (pH_{ca}) are the most widely used but generally low pH values are reported for $CaCl_2$ because of

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the displacement (and subsequent hydrolysis) of exchangeable Al and Fe by Ca^{2+}. From the pH of mineral soils inferences are made on the nature and cause of the hydrogen ion activity (Buol et al., 1980)

$\mathrm{pH} < 3.5$: If associated with significant pH drop after wetting-drying cycles indicates presence of acid sulphates. A sample from coastal marsh represents "cat clays" or acid sulphate soils with very serious agricultural problems. A sample from mine spoil or pits indicates presence of sulfides which have been oxidized .

$\mathrm{pH} < 4.5$: Means significant amount of exchangeable hydrogen in addition to exchangeable aluminum.

pH 4.5 to 5.8 : In mineral soils indicates sufficient exchangeable aluminum is present to significantly affect plant growth and the percentage base saturation is low (Kamprath, 1967).

pH 5.8 to 6.5 : Indicates acidity is present, ordinarily hydrogen in amounts sufficient to affect acid-sensitive crops, and the soil is 70-90% base saturated depending on the type of clay minerals present.

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pH 6.5 to 8.0 : Shows that the soil is essentially base saturated; no exchangeable Al is present and that free calcium carbonate may be present only if protected inside soil aggregates with restricted diffusion rates.

2.3.2 Effect of soil acidity on soil fertility

Soil acidification causes crop yield reduction which is rapid on sandy soils with low absorption capacity. If exchangeable Al occupies more than 60% of the CEC, toxic levels of Al in soil solution results (Nye et al., 1961; Evans, 1968). At a critical pH value of about 5 Aluminum becomes mobile and in the ionic state it is toxic to roots because it hinders cell division. Gyori et al. (1985) showed that reductions in maize yields were closely correlated with Al saturation. Fertility of acidified soils is restricted both by lack of nutrients and enrichment of aluminum and manganese in soil in concentrations toxic to plants. Acidification increases the proportions of hydrogen ions in soil solution and on colloid surfaces at the expense of basic cations. At the same time the propensity of soil minerals to weather increases leading to the release of both basic and acidic cations which have a buffering effect and prevent a rapid reduction in pH but the basic cations are generally easily leached from the soil profile whereas acidic cations such as Al^{3+} accumulate. A soil reacts to acidification by successive buffer systems as pH declines. These reactions include hydrolysis of calcium carbonates and silicates, cation exchange and release of Al^{3+} (Bonneau et al., 1987). They found that below pH 5.5, soil acidification resulted in large increases in amounts of aluminum in soil and simultaneously exchangeable cations were displaced from exchange sites and Ca, Mg, K, and Na in soil solution increased markedly. With increasing soil acidification, increasing amounts of cations were leached; the magnitude of leaching loss was in the same order as the magnitude of the cation

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concentration in the soil: $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$. The CEC of the leached soil decreased with increasing soil acidification. Also,the levels of NO_3^- were reduced during leaching in acidified soil and led to inhibition of nitrification (Haynes and Swift, 1986). Whelan and Alexander (1986) noted that extreme soil acidity inhibits multiplication of *Rhizobium trifolii* and nodulation of subterranian clover due to aluminum toxicity.

2.3.3 Effect of soil acidity on crop productivity

Soil acidity and aluminum toxicity are detrimental to most field crops. Xu et al. (1986) observed that tung oil trees grew well in moderately acid soils but grew poorly in soils with a pH < 4.5. Strong to very strong soil acidity (pH 4.8-5.4) reduced *Vigna radiata* yield by 23-63% and that of soybeans by 22-36% (Samonte, 1985).

Experiments on local cassava cultivars on a Tropudult with Al (KCl-extractable) content of 4.0 to 5.7 cmol (+)/kg showed that the cation caused the sink capacity in most cultivars to shift from roots to tops. Roots turned weak competitors for assimilates while photosynthetic production merely aimed at developing and sustaining canopy growth, thus resulting in low harvest index values. The reduced sink size of roots was due to the impairing effects of Al on root growth (Manrique, 1987). High Al levels reduced plant height and root yield of most cultivars of cassava stem cuttings planted in a clayey, kaolinitic, isohyperthermic Typic Tropudult of pH 3.7 - 3.8 (Manrique, 1986). The ion also reduced plant height and root yields of cassava cultivars although some genotypes showed good potential to produce acceptable root yields at Al concentration below 5 cmol(+)/kg. Cultivars showed distinctive leaf area indices (LAI) and leaf area distribution patterns that appeared aluminum-toxicity related (Manrique, 1985). Two ways Al affected LAI, leaf area distribution and hence root yields of the crop

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included impairment of its ability to develop and sustain leaf area and the disturbance of its capacity to distribute and accumulate assimilates by roots. Soil Al reduced tillering of wheat and was the yield limiting factor (Unruh, 1989). A soil of pH 4.8 reduced soybean yield from 3.4 t/ha at pH 5.6 to 2.7 t/ha. Also, soybean yield was 2.8 t/ha at pH 5.9 but fell to 0.8 t/ha at pH 4.0 (Rhoades and Manning, 1989).

The nodulation of subterranean clover roots growing in a very acid soil was influenced by soil pH. Restricted nodulation occurred in regions with very low soil pH and appeared to be due to low numbers of *Rhizobium trifolii* or poor colonization of the more acidic horizons of the profile (Richardson et al., 1988).

2.3.4. Causes of soil acidity

The most important causes of soil acidity are inorganic adsorbents, organic matter, soluble salts, crop removal of cations, leaching, and the drying of soils.

2.3.4.1 Inorganic adsorbents

Inorganic substances that influence soil acidity are layer silicates, oxide minerals and combinations of layer silicates and oxide minerals such as montmorillonite or vermiculite with hydroxy-Al or Fe interlayers, or ferric oxide-coated kaolinite.

2.3.4.1.1 Layer silicates and oxide minerals

Aluminum and or iron hydrous oxides that are positively charged and develop on the surfaces of layer silicates are bound electrostatically to the aluminosilicate layers. Soil intergrade materials generally give 1.4-axis spacing whose partial collapse upon saturation and heating

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indicate presence of gibbsite-like interlayers occurring in islands rather than in continuous sheets (Rich, 1960). The cation-exchange capacities of intergrade minerals are smaller than expected for uncoated layer silicates but the removal of interlayer material increases CEC and leads to the expansion-contraction properties of the parent layer silicate (montmorillonite or dioctahedral vermiculite).

Ferric and aluminum oxides and hydrous oxides, present in all soils, occur as discrete crystals, coatings on layer silicates and as mixed gels, which may incorporate silica, phosphate, and organic colloids. Iron oxide coatings on kaolinites appear to be amorphous until more than a limiting amount of the sesquioxide is present which then causes hematite crystals to form.

Allophane-like materials with appropriate silica: alumina ratios, low crystallinity, and high CEC occur in many soils but allophane as the only oxide mineral buffers soil and contributes to the chemistry of acidity in the relevant pH range. Amorphous alumino-silicates contribute significantly to the CEC and buffer characteristics in volcanic ash soils (Birrell, 1958, 1961) and the high pH-dependence of their CEC leads to buffer characteristics different from that for layer silicates.

2.3.4.1.2 Cation-exchange capacity of inorganic soil constituents

The most important layer silicate minerals in soils include illite (muscovite), muscovite-derived vermiculite, hydrobiotite, montmorillonite, kaolinite, and halloysite. Lattice charge in cmol(+)/100g of soil is reported as 250 for illite and muscovite-derived vermiculite, 200 for hydrobiotite, 80- 120 for montmorillonite, and 2-10 for both kaolinite and Halloysite.

The percentage lattice charge countered by exchangeable cations is 15 for muscovite (illite), 60 for muscovite-derived vermiculite and 40 for hydrobiotite. Montmorillonite,

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kaolinite, and halloysite all have 100 each. Kaolinite and Halloysite have definite but small lattice charge and appear to have permanent charge CEC of 5 cmol(+)/kg (Robertson et al., 1954; Coleman and Craig, 1961). The lattice charge of 2:1 minerals is attributed to isomorphous substitution. Schofield(1949) uses "permanent charge CEC" to refer to the component of CEC due to lattice charge from isomorphous substitution. The CEC of clay is relatively constant between pH 2.5 and 5 but increases between 5 and 7. The CEC of montmorillonite is invariant below pH 6 but increases as pH is raised from 6 to 9 (Schofield, 1949). The permanent charge component is attributed to isomorphous substitution whereas the variant or high pH is attributed to the ionization of hydrogen ions from S_1OH groups.

The major source of pH-dependent charge of soil is the layer silicate- sesquioxide complex (Coleman and Thomas, 1914; Schwertmann and Jackson, 1964; and Volk and Jackson, 1964). The pH-dependent component of CEC is characteristic of clays from many acid soils, and of clay minerals such as kaolinite or montmorillonite that have been artificially coated or interlayered with Al or Fe hydrous oxide (Thomas and Swoboda, 1963; Coleman et al., 1964).

The hydrous oxide coatings appear positively charged (Hsu and Rich, 1960; Jackson, 1963a, b; Hsu and Bates, 1964), with the magnitude of the positive charge varying inversely with pH. The cation-exchange behaviour of layer silicate-sesquioxide complexes results because the negative charge of the layer silicate does not change with pH whilst the opposite charge on the clay-sesquioxide complex varies with pH. This causes net charge to vary from positive at low pH to negative at high pH. The net charge is zero when the positive charge of the sexquioxide equals the lattice charge of the layer silicate, and reaches a net negative charge which equals lattice charge of the layer silicate at pH near 8. This phenomenon causes effective CEC to vary with pH and prevents the identification of CEC at pH 6 with lattice charge. This variation results

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because the number of hydroxide groups on the sesquioxides is increased as pH goes up and the positive charge of the polycation is reduced liberating negative sites on which other cations can be retained.

Besides OH^-, other tightly held anions have the same effect of increasing CEC. Ions, which are bound more tightly by Fe and Al than by the clay, such as F^- or $H_2PO^-_4$, lead to apparent increases in CEC. Sulphate, chloride, or nitrate salts interact with clay mineral-sesquioxide complexes, with the sorption of the anion on the hydrous-oxide component and the cation on the layer silicate (Thomas and Swoboda, 1963; Chang and Thomas, 1963).

2.3.4.1.3 Distribution of clay minerals

The distribution of clay minerals in soils partly determines the cation-exchange properties of soils. The proportions of clay minerals in soils vary considerably even within limited regions (Jackson,1964). Many acid-soil areas have more completely chloritized or sesquioxide-coated minerals in the surface soil and the more vermiculite-like minerals with larger permanent charge CEC in subsoils.

2.3.4.2 Organic matter as a cause of soil acidity

Partially decomposed plant remains in soils release extremely complicated products much of which are organic matter functional groups which include carboxylase, phenols, enols and other alcoholic hydroxyls (Gillain, 1940; Broadbent and Bradford, 1952; Mortensen and Himes, 1964; Schnitzer and Gupta, 1964, 1965;). Because carboxyl groups are fairly strongly acidic they ionize appreciably when soil pH is below 7. Some polyphenols and substituted phenols do contribute acid ions (Lewis and Broadbent, 1961). Acidification coincides with accumulation of

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organic matter in all soils and with decreasing CEC in most sandy soils but increasing CEC in loamy soils (Ronse et al., 1988).

The density of carboxyl groups and the CEC capable of developing under acid conditions vary from one soil or horizon to another. Values for humic and fulvic acids vary from 200 cmol(+)/kg to 900 cmol(+)/kg. Carboxyl-group concentrations for whole organic matter range between 100 and 200 cmol(+)/kg. Fifty five percent of CEC of soil organic matter is contributed by carboxyls whilst phenolic and enolic groups and imide contribute 35% and 10%, respectively (Broadbent and Bradford, 1952). Schnitzer and Skinner (1963) attributed 55% of the CEC of organic matter from a podzol to carboxyl groups and the remainder to phenolic and enolic groups.

2.3.4.3 Soluble salts as a cause of soil acidity

Soluble acids formed from biological activities produce significant fluctuations in soil pH and cause leaching of Ca and Mg ions from soil thereby creating soil acidity.

Accumulations of high concentrations of $HN0_3$ and H_2SO_4 following heavy additions of ammonium fertilizers to slightly buffered soils which create pH below 4 lead to rapid loss of exchangeable Ca and Mg. Monocalcium phosphate added to soil as fertilizer causes intense but temporary acidity. Its hydrolysis in water yields dicalcium phosphate and phosphoric acid which dissolves in soil water, diffuses away from site of fertilizer application and causes a zone to be formed around the fertilizer particle where pH may fall to about 1.5.

The production of very high concentrations of H_2SO_4 and consequent low pH when soils containing FeS are drained and exposed to oxidizing conditions causes rapid loss of exchangeable Ca and Mg (Moorman, 1963; Kohnke, 1950). The presence of organic acids

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dissolved from litter or produced from plant residue contributes significantly to the development of acid soils (Mortensen, 1963; Mortensen and Himes, 1964).

The exposure of high-sulphide sediments to oxidation through drainage, in marine floodplains, results in low pH (about pH 2) and the formation of "cat clays" sufficiently high in organic matter to be classified as peat or muck. These contain much mineral material dissolved in H_2SO_4 to yield large amounts of soluble Al, Mn, and Fe. Free H_2SO_4 as much as 300 cmol(+)/kg of soil have been produced in such processes.

2.3.4.4 Drying of soils as a cause of soil acidification

Drying causes changes in soil surface chemical properties and increases organic matter solubility and metal extractability. The effects of such changes on pH are extremely variable with pH of limed soils generally decreasing from 6.7 to 6.2 (Bartlet and James, 1980). Bartlet and James (1980) and Davey and Conyers (1988) showed that air-drying causes soil acidification and hypothesized that changes in soil surface acidity after drying are related to the increased solubility of organic materials after breakdown and exposition of fresh organic surfaces. They are also related to changes in the structure of inorganic solids that could increase the availability of metals such as Al and Mn and their subsequent hydrolysis.

2.3.4.5 Continuous cropping as a cause of soil acidification

Intensive crop production causes increased loss of Ca and Mg from soil and greater soil acidity. Such losses are affected by type and dose of fertilizer applied, liming, soil properties, crop rotation and irrigation. Continuous cultivation of maize and sweet potato gradually exhausted soil Ca, Mg, available P and organic matter and increased soil acidity as noted by

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Siebert, (1987). The biological uptake of cations, nitrification, deprotonation of CO_2 and organic acids, and oxidation of some minerals produce the greatest part of the internal proton load of soils (Bonneau et al., 1987).

2.3.4.6 Leaching as a cause of soil acidification

Data from 104 sites showed that between 1949 and 1985 soil pH (H_20) values declined by 0.5 units in acid soils (pH 4.0-5.0) and by 1.5 units in less acid soils. The decrease, which occurred throughout the soil profile was accompanied by considerable losses of exchangeable Na, K, Mg, Ca as well as Zn and Mn (Falkengren-Grerup et al. 1987). Below pH 5.5 soil acidification marched the displacement of exchangeable cations from exchange sites and exchangeable bases in soil solution increased markedly. The magnitude of leaching loss was in the same order as the magnitude of the cation concentration in the soil: $Ca^{2+} > Mg^{2+} > K^+ > Na^+$ (Haynes and Swift, 1986).

2.3.5 Cation exchange capacity of acid soils

The CEC, which is the amount of cations adsorbed from salt solutions buffered at pH 7 or 8.2 (Jackson, 1958), has the rational of neutrality if determined at pH 7 .If determined at pH 8.2, its relevance is in calcareous conditions (Bradfield, 1942). A pH of 8 or higher corresponds with complete neutralization of sorbed Fe^{3+} or Al ions (Coleman and Thomas, 1964). Therefore, CEC determined using salt solutions buffered at pH 8.2 (Mehlich, 1948) gives reasonable estimate of the lattice charge of layer silicates and of contributions from organic matter or allophane which may be present.

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The CEC of soils may be determined by leaching with unbuffered solution of a salt such as KCl or $CaCl_2$ at the pH of the soil or the pH of a soil-salt solution mixture and has been referred to as "effective CEC" (Coleman et al., 1959b,c; Pratt and Bair, 1962; Bhumbla and Mclean, 1965). The CEC measured at pH 8.2 is larger than that at pH 7 (Coleman et al., 1959b; Mehlich, 1942, 1943; Pratt and Bair, 1962), and that measured with unbuffered salt solution depends on soil pH. It is larger in limed than in unlimed sample of the same soil (Bhumbla and Mclean, 1965).

For layer silicates CEC results mainly from lattice charge (Schofield, 1949) and CEC at pH 7 and CEC at pH 8.2 are almost the same. With intergrade minerals or Fe^{3+} oxide-coated kaolinite (Sumner, 1963) neutral salt CEC is smaller than CEC at pH 8.2 for samples which are initially acid (Coleman et al., 1964). Additional CEC develops as soil pH is raised by adding base so that acid soils behave as though they have two components of acidity.

2.3.6 Products of neutralization

As neutralization reaction proceeds hydrogen ions first get displaced from the soil followed by monomeric aluminum. Generally, few monomeric aluminum ions exist in soils with pH of 5.5 or more. A complete liming reaction produces exchangeable Ca and Mg, $Al(OH)_3$ and $Fe(OH)_3$ and soil pH in such idealized case is about 8.3. Complete base saturation is however not achieved as soils are limed to pH rarely higher than 6.5. When acid soil reacts with $CaCO_3$ to reduce the pH to 6.5, much of the Ca and or Mg from the carbonate becomes exchangeable and soil acidity is neutralized. Large amounts of titratable acidity and unreacted carbonate, however, remain. Compounds that make up titratable acidity in partly neutralized soil are the hydroxy compounds of Al and Fe^{3+} and the non-ionized groups on organic matter and clay.

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2.3.7 Exchange properties in a neutralized soil

When soil acidity is neutralized with $CaCO_3$ (limestone) monomeric exchangeable Al is first precipitated. Hydroxy Al or Fe is further hydrolyzed and the exchange sites become occupied by Ca and Mg. The reactions produce profound effects on the exchangeability of K and Na. Calcium-saturated sandy soils retained twice as much K against water leaching as did the same soils when Al-saturated (Thomas and Coleman, 1959). Also, with two K-fertilized mineral soils, the amount of K in the soil solution was half as high when limed as when acid.

Liming acid soils to pH 5.5 where all monomeric Al is precipitated causes much of the exchange sites to become covered by unexchangeable ions thus simultaneously reducing the effective CEC by equal amounts of irreplaceable polycations. Hence liming reduces the number of available sites (and the ECEC) up to pH 5.5 and gradually increases the cation exchange at higher pH

2.3.8. Soil acidity management: the liming option

Soil acidity management should use a multifaceted approach, taking into account crops, soils, weather, and farmers' preferences. The recommendation process should be structured to ensure that major considerations are not overlooked. The relevant data required are Al^{3+} plus H^+ extracted by KCl, after determining critical aluminum saturation values for crops. Soil and weather data are combined to develop water-balance criteria (Yost et al., 1986).

For such soils whose constraints include general nutrient deficiency and excess of active Al, subsistence cropping without inputs of fertilizer and lime seems unlikely to succeed in the long run. Therefore any soil management strategy must concentrate efforts on:

i. decreasing the detrimental effects of soil acidity,

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ii. building the fertility status, especially that of phosphorus,

iii managing the soil surface properly to avoid compaction and erosion, and

iv improving root growth conditions below the plough layer (Goedert, 1987).

The IBSRAM (1987) progress report recommended principal research topics to include pedology-fertility relationships, management of soil acidity, phosphorus fertilization, soil dynamics in diferent cropping systems and organic-input use. The soil management options include low-input cropping systems, agroforestry, intensive crop production systems and pastures (Sanchez and Jot-Smyth, 1987). Amelioration of soil acidity and addition of organic matter along with balanced chemical fertilization is essential for sustaining higher yields under different cropping systems especially where the production system is to be intensive.

2.3.8.1 Soil acidity amendment by liming

Soil pH is the most rapid indicator of potential detrimental effects of soil acidity. Soil pH levels for neutralization of detrimental acidity and maximizing crop yields on most soils have been shown to be directly related to the removal of exchangeable Al^{3+} and to a less extent, exchangeable Mn^{2+}. The pH level for neutralization of detrimental acidity and maximizing crop yields is believed to be 6.5.

2.3.8.1.1 Liming practices and effects on soils and crops

Various indigeneous liming materials have been used and found to generally increase the pH and Ca levels, decrease Al^{3+} saturation to desired levels and improve crop productivity (Singh, 1989). There is emphasis on the use of locally available materials to solve local

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problems. It is possible to counteract soil acidification by cultivation techniques. Crops which utilize large amounts of water are grown to reduce the leaching of basic cations. The carbon dioxide content of soil air is reduced by allowing harvest residues to decay on the soil surface. Fluidized bed combustion residue, a by-product of fossil fuel-fired boilers was as effective a liming amendment as the agricultural limestones. "Elberta" peach seedlings was more effective in neutralizing soil acidity and increasing extractable soil Ca than calcitic limestone (Edwards et al., 1985). Two different marine limes and one agricultural lime all had similar effects on soil pH, and on the dry matter production and nutrient (Ca, Mg, Zn) content of maize after 60 days in the amended soils (Miranda, 1985).

The efficiency of liming depends on the properties of the liming materials used. Dolomite meal is widely used to improve acid demopodzolic soils and is a good source of plant available magnesium. Ground power station ash (<0.25mm particle size) is more effective than granulated material. Some slags from the metallurgical industries improve yields (Shil' nikov, 1987). Liming trials on acid soils (Ultic Haplustox) reveal different responses by different crops. Groundnuts were more responsive than maize at one area, soybean responded to liming at another, and liming improved wheat yields at another site (Singh, 1987).

Liming an acid cocoa producing soil corrected soil acidity, increased Ca and Mg concentrations, and lowered Al concentrations in all plots after 6 years (Nakayama, 1986). Increasing soil pH from 5.1 to 5.9 by applying 2.5t of lime/ha significantly increased tuber yields of potatoes and decreased weed populations i.e *Spergula arvensis* (Sahota, 1984). Liming an acid Oxisol with 15% slope and pH 4.7 in the top soil (0-15cm) at rates up to 4t/ha increased maize yield, reduced soil and water losses, caused prolific root development and led to loose soil structure (Bonsu, 1991). Liming had the effect of reducing soil acidity, stimulating growth and

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development of tung oil trees, and increasing fruit yield by 55.5 to 147% when applied in combination with N and P at an optimum application rate of 1.5kg/tree (Xu et al., 1986).

Application of $CaCO_3$ to an alluvial soil at the rate of 10mg $10g^{-1}$ soil under waterlogged condition caused a marked increase in pH and a decrease in exchangeable Al. Water logging alone increased the pH, available N and K contents and decreased exchangeable Al content (Halder and Mandal, 1987). Individually, both lime and NPK fertilizer had good yield-increasing effects on wheat. When combined, however, the yield increases were found to be the sum of yield increases of the individual treatments showing that acid soils are deficient in both lime and nutrients, and that neither can replace the other (Siman, 1987).

Liming reduced the concentration of exchangeable Al from 30mg/kg to 1mg/kg, raised soil pH by 0.6 to 1.0 units and increased the grain yield of all crops and cultivars (Brooke et al., 1989). Yield increases of *Medicago sativa* obtained from surface applied and incoporated lime, Ca, Mo, and N application were due to low soil Al activity in the limed soil as these are necessary for optimum N fixation and root growth (Rechgigl and Rechcigl, 1987).

Liming decreased plant available Fe content from 34.1 mg/kg in unlimed soil to 14.1 mg/kg in limed soil, titratable acidity from 16.0 cmol(+)/kg to 1.6 cmol(+)/kg of soil and exchangeable acidity from 3.0 cmol(+)/kg to 1.0 cmol(+)/kg of soil, while soil pH in KCl increased from 4.03 to 6.42 (Bertic et al., 1988).

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CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of the study area and field procedures

Three soil profiles (Pedons 1-3) were used in the study. Pedon 1 is sited at Kpenu (Long. $00^{0}\ 08'\ 39.4''$E, Lat $06^{0}\ 06'\ 13.1''$N) Pedon 2 at Volivo (Long. $00^{0}\ 15'\ 36.2''$ E, Lat. $06^{0}\ 05'\ 26.8''$) and Pedon 3 at Tokpo. Pedon 1 is the modal Amo series, Pedon 2 is about 500 m downslope of an oyster shell deposit area while Pedon 3 is on an oyster shell deposit. The pedons were excavated and morphological characteristics described in the field. The soils were then sampled from genetic horizons for laboratory analysis. All the three Pedons were sited in the Coastal Savanna Zone of the country

3.2 Climate and vegetation

3.3.1 Climate

The study area experiences two rainfall maxima annually, a major wet season from March/April to July and a minor wet season from September to Mid-November. The period from November to March, which is the major dry season, is marked by the dry windy Harmattan, which causes streams to dry up and also brings the primary savanna vegetation under occasional bush fires. The annual and monthly total amounts of rainfall vary between the onset of the rains from year to year. While the total annual rainfall is about 1145mm, about 800mm may fall in the major wet season. The daily annual Temperatures are high and constant with a mean value of about 27°C. The highest mean monthly maxima of 34°C to 35°C is recorded in July, August/September. Generally, the relative humidity for the wet periods may be about 100% but falls to 60% or 54% in the dry season.

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3.2.2 Vegetation

The vegetation of the study area belongs to the Coastal Savanna and Thicket Zone of Ghana (Taylor, 1952). It is dominated by tall grasses, scattered trees and shrub species. The thicket is composed of thorny species including *Combretum ghasalenses*, *Ficus spp*, *Anona spp*, *Chromolaena odorata*, and *Kigelia africana*. Others are *Fagara xanthoxyloides*, *Azadirachta indica*, *Acacia siamea* and *Bauhimia thonmingi*. Other diverse species, which compose the undergrowth are *Andropogon spp*, *Cymbopogon gigantus*, *Vetiveria fulvibarbis*, *Setaria spp*, *Brachiaria spp* and *Imperata cylindrica*.

3.2.3 Geology, relief and drainage

The Amo series is developed over recent alluvium occupying the Volta floodplain and intermitent streams of the area. The alluvial materials were transported from the Volta river catchment areas, which include the black clay belts. The soil is moderately well-drained except in low lying sites where drainage may be poor.

3.2.4 Laboratory analytical methods

3.2.4.1 Particle size analysis

Particle size distribution was determined by the modified Bouyoucos hydrometer method as described by Day (1965). A 40g soil sample was weighed into a dispersion cup and 100 ml of calgon (sodium hexametaphosphate) solution prepared by dissolving 50g of calgon in a litre of water was added. The suspension was allowed to soak for about 10 min. and mixed for 5 min. with a motor mixer after which it was transferred into a sedimentation cylinder with the help of distilled water from a wash-bottle and the level of water brought to the 1 litre mark. The

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suspension was allowed to equilibrate and the initial temperature taken. A plunger was inserted close to the bottom of the cylinder and the suspension stirred vigorously by moving it up and down several times (about 10 times). Timing was started immediately with a stop, watch and the hydrometer reading taken at 5 min and then at 5 hours from the time of mixing of the suspension. The sand fraction was recovered by sieving the suspension through 50μm sieve and the dry weight recorded after it had been oven-dried for 3 days. The procedure was repeated for a blank which contained no soil and the textural class was determined using the USDA textural triangle.

3.2.4.2 Soil reaction

Soil pH was determined in both distilled water and in 0.01M $CaCl_2$. In water, it was measured at a soil: water ratio of 1:1 while in 0.01M $CaCl_2$ it was measured at a soil: solution ratio of 1:2 using a Pracitronic pH meter.

3.2.4.3 Organic carbon

Organic carbon was determined by the wet oxidation method of Walkley and Black (1934). Ten ml of 1M potassium dichromate ($K_2Cr_20_7$) solution and 20 ml. of concentrated sulphuric acid (H_2S0_4) were added to 0.5 g soil which had been passed through an 0.5 mm sieve. The flask was swirled to ensure full contact of the soil with the solution after which it was allowed to stand for 30 min. The unreduced $K_2Cr_20_7$ remaining in solution after the oxidation of the oxidizable organic material in the soil sample was titrated with 0.2N ammonium ferrous sulphate solution after adding 10 ml of orthophosphoric acid and 2 ml of barium diphenylamine sulphonate indicator.

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3.2.4.4 Total phosphorus

Total phosphorus was determined by digesting a 2 g soil sample sieved with 0.5 mm mesh with 25 ml. of 1.5:160% perchloric/nitric acid mixture for 40 min. The digest was filtered through a No. 42 Whatman filter paper into a 100 ml volumetric flask and made up to volume. Phosphorus in the filtrate was determined by the molybdate-ascorbic acid method of Watanabe and Olsen (1965) as follows:

Suitable aliquots of the filtrate were taken (in duplicate) into 50 ml volummetric flasks containing distilled water. The pH was adjusted using P-nitrophenol indicator and neutralized with few drops of 4M ammonium hydroxide (NH_40H) until the solution turned yellow. The solution was diluted to about 40 ml with distilled water after which 8 ml of reagent B was added and made to volume with more distilled H_2O Reagent B was prepared by dissolving 1.056g of Ascobic acid in Reagent A and made to 200ml. Reagent A was prepared by diluting 138ml of conc. H_2SO_4 with H_2O to 1L plus 12g Ammonium molybdate dissolved to 200ml with H_2O plus 0.2908g Antimony Potassium Tartrate dissolved to 100ml. The whole solution was then made up to 2 litres. The solution was mixed thoroughly by shaking and was allowed to stand for 15 min for the colour to stabilize. A blank was prepared with distilled water and 8 ml of reagent B. The method was calibrated using a 25 mg 1^{-1} standard P solution in the same way as above. The intensity of the blue colour was measured using the Phillips PU8620 spectrophotometer at a wavelength of 712 mμ and the P concentrations read on a standard curve prepared with aliquot of a KH_2PO_4 standard solutions containing 5,10,15,20,25,30,35, and 40 mgl^{-1} of P.

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3.2.4.5 Available phosphorus

Available phosphorus was determined by the method of Bray and Kurtz (1945). Five grammes of soil was weighed into a 100 ml centrifuge tube and 35 ml of Bray 1 solution (0.03M NH_4F in 0.025M HCl) was added. The suspension was shaken for 1 min on a reciprocating shaker and filtered. Phosphorus in the filtrate was measured as above described in section 3.2.4.4

3.2.4.6 Total nitrogen

One-half gram (0.5g) of soil was weighed into a 250ml Kjeldahl flask and a tablet of digestion accelerator (selenium catalyst) was added and followed by 5 ml conc. H_2S0_4. The mixture was digested until the digest became clear. The flask was then cooled and its contents transferred into a 100 ml. volumetric flask with distilled water and made to volume. An aliquot of 5 ml of the digest was taken into a Markham distillation apparatus, 5 ml of 40% Na0H was added and the mixture distilled. The distillate was collected in 5 ml of 2% boric acid to which 3 drops of mixed indicator containing methyl red and methylene blue were added and then titrated against 0.01M HCl (Bremner, 1965).

3.3.4.7 Exchangeable bases

Ten grammes of soil were weighed into a 200 ml extraction bottle and 100ml of 1M neutral ammonium acetate (NH_40Ac, pH 7.0) solution was added. The suspension was shook for 1 hour and centrifuged at 1500 rpm for 20 min. The supernatant solution was then filtered through No. 42 Whatman filter paper after which aliquots of the extracts were used for the determination of, calcium, magnesium, potassium, and sodium.

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Determination of calcium

To a 10 ml aliquot of the sample solution, 10 ml of 10 % KOH and 1 ml triethanolamine were added. Three drops of KCN solution and a few crystals of cal-red indicator were then added and the mixture was titrated with a 0.02M EDTA solution from red to blue end point. The result was used to calculate for the concentration of Ca.

Determination of magnesium

To a 10 ml aliquot of the sample solution 5 ml of NHCl–NHOH was added, followed by 1 ml of triethanolamine. Three drops of KCN solution and a few drops of Eriochrome Black T solution were then added after which the mixture was titrated with 0.02M EDTA solution from a red to blue end point. This procedure determined the amount of Ca and Mg in the solution. The concentration of Mg was then determined by substraction of the value obtained for calcium.

Determination of potassium

The flame photometer was standardized such that 5 mg/kg of K gave 100 full scale deflection and the concentration of potassium in the aliquot then determined. The result was used to calculate the concentration of K

Determination of sodium

The flame photometer was standardized so that 10mg/kg of Na gave 100 full scale deflection. Sodium concentration in the aliquot was then determined.

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3.2.4.8 Exchange Acidity

Twenty-five ml of 1M KCl were added to 10g of soil sample. The suspension was allowed to stand for 30 min. The suspension was then transferred to a Buchner funnel fitted with a No. 42 Whatman filter paper and mounted on a 250 ml vacuum flask. The soil was successively leached with 25 ml increaments to a total of 150ml. Four drops of phenolphthalein were added to the leachate and titrated with 0.1M NaOH to the first permanent pink end point. Correction for a blank of NaOH titre on 150 ml KCl solution was made and the KCl-extracted acidity calculated as:

$$\text{KCl acidity (cmol (+)/kg)} = \frac{\text{(ml NaOH sample - ml NaOH blank)}}{\text{weight of sample}} \times M_1 \times 100 \quad \text{..........(1)}$$

where, M_1 is molarity of Na0H.

$$\text{KCl exchangeable Al (cmol(+)/kg)} = \frac{\text{ml HCl} \times M_2 \times 100}{\text{weight of sample}} \quad \text{..............(2)}$$

where M_2 is molarity of HCl.

For the estimation of Al^{3+} and H^+, the titre for NaOH was recorded; 10ml 1M NaF was added to the NaOH and titrated with 0.1 M HCl until the pink colour disappeared. The solution was then allowed to stand for about 30 min and additional HCl added to a clear end point (Thomas, 1982). The effective cation exchange capacity (ECEC) was obtained by summation of the exchangeable bases and the exchangeable acidity (Coleman et al., 1959a).

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3.2.4.9 CEC by ammonium acetate (pH 7) method

Ten grams of air-dried soil sample sieved with 2mm mesh was weighed into a shaking bottle and 100 ml NH_4OAc (pH7) was added. The mixture was shook for 5min using a shaking machine. The bottles with contents were centrifuged for 20min and the solution discarded. Twenty millilitres of ethyl alcohol was added, and the sample was shaken for 5 min and then centrifuged for 20 min. The solution was discarded and the procedure repeated with ethyl alcohol. The samples were washed with distilled water and the procedure repeated twice to clear all traces of ethyl alcohol. The samples were shaken with 20ml of 1M KCl for 5min and centrifuged for 20min after which it was filtered for the determination. of CEC Five millilitres aliquot of the extract was pipetted into a Kjeldahl flask, 5 ml of 40% NaoH and some distilled water were added and the solution distilled. The distillate was collected in 2% Boric acid (H_3BO_3) to which three drops of methylene blue indicator was added and then titrated with 0.1 M HCl from green to reddish endpoint. The titre value was then used for the calculation of the CEC of the soil.

3.2.4.10 Dithionite–Citrate-Bicarbonate extractable iron

The method of Mehra and Jackson (1960) was used to determine the dithionite-citrate extractable iron. A 0.5g soil sample (<100 mesh) was weighed into a 15ml test tube marked at the 5ml mark and citrate-bicarbonate, and a scoop of 0.2g sodium diothionite ($Na_2S_2O_4$) were added, mixed, and the tube placed in a water bath at 80°C. The mixture was stirred every 3 min throughout a 15 min extraction period. The tubes were removed from the bath, 1ml of saturated NaCl solution was added and the mixture stirred. The stirring rod was then washed off into the tube and the solutions centrifuged at 1500 rpm for 5min. The supernatants were poured off into

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100 ml volumetric flasks and the extraction procedure repeated on the same samples. The soil was washed twice with 5 ml. of citrate-bicarbonate buffer solution and 1ml of saturated NaCl. After centrifugation and mixing the wash solutions were added to the volumetric flasks and the extracts made to volume after thorough mixing

A 5 ml. of the extract was pipetted into a 50ml volumetric flask and after 5 ml of conc. HNO_3 and 1.0 ml. of 16M $Na_2S_2O_4$ had been added, the samples were heated at 120°C on a hot plate; the heat been gradually increased as the water evaporated till white fumes of sulphuric acid rose to the necks of the flasks. The flasks were then cooled to 50°C and 30ml of distilled water added. The sample was then heated at 80°C for one hour, cooled and made to volume.

For the determination of Fe, 5 ml. aliquot of the digested solution was pipetted into 50ml. volumetric flask and after 3ml. of 10% $NH_2OH.HCl$ were added and allowed to stand for 5 minutes. Four milliliters of 0.1% 0-phenanthroline and 5 ml. of 20% sodium citrate were then added and the solution was made to volume, mixed well, and allowed to stand for a minimum of one hour after which the concentration of μg Fe was determined on a spectrophotometer at 510 mμ. The reading was done after the spectrophotometer had been calibrated with Fe standard solutions.

The percent free Fe was determined using the relation:

$$\%Fe = \frac{\mu g \text{ in final solution}}{500 \times 1000} \times \frac{50}{5} \times \frac{50}{10} \times \frac{100}{1} = \frac{mg}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

3.2.4.11 Bulk density

The core method (Blake and Hartge, 1986) was used to determine bulk density. Undisturbed core samples were weighed, dried in oven at 105°C for 2 days and reweighed. The

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bulk density of the soil was determined by finding the ratio of the dry weight of the soil to its volume.

3.2.4.12 Saturated hydraulic conductivity (K_s)

The saturated hydraulic conductivity (K_s) of the various genetic horizons was determined by the Constant Head Method of Klute and Dirksen (1986). Samples of soils were taken with metal cores 10 cm long and 5cm in diameter allowing about 4 cm of space above the soil surface in the core. The soil was presaturated overnight by wetting from the bottom. A constant head of water was maintained on the soil using the Marriote arrangement. The volume of water flowing through the soil per unit time was recorded and the saturated hydraulic conductivity (K_s)value calculated by the Darcy's relationship given by :

$$qw = \frac{Q}{At} = -Ks\,H/L \quad \text{...(4)}$$

$$K_s = \frac{QL}{At(H_2-H_1)} \quad \text{...(5)}$$

Where A= cross sectional area (m^2) of the sample,

L = length (m) of the sample,

Q = volume(m^3)of water flowing through sample in unit time, t (s) , and

H = (H_1-H_2)= hydraulic head difference imposed across the soil sample (m).

3.2.4.13 Soil aggregate stability determination

Aggregate stability of the soil was determined by using the mean weight diametre method (Van Bavel,1950). Soil clods of approximately equal weight were selected to give a total weight of 100g and then placed on a set of sieves of varying mesh sizes (9mm, 7mm, 4.75mm, 2mm, 1mm, and 0mm). The sieves with the soil samples were placed on a mechanical shaker and after setting the amplitude and time the machine was started. The weights of soil samples collected on the various sieves were recorded and their respective proportions determined. These were then used to compute the aggregate stability as:

$$\text{Aggregate Stability} = \sum X_1 W_1 \quad \ldots\ldots(6)$$

where X_1 is the mean diameter of each size fraction. W_1 is the proportion of total sample weight occurring in the corresponding size fraction.

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CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1 General profile description

Pedon 1: Pedon 1 is deep (> 200cm) and the texture ranges from clay loam in the surface 0-12cm depth to clay in the subsoil. The soil colour varies from dark brown in the surface through bright brown to yellowish brown in the underlying horizons. The structure is mainly moderate medium angular and subangular blocky. Several fine tubular pores permeate the profile and root distribution is normal. The pH is strongly acid (pH 5.0) to very strongly acid (pH 4.8) throughout the profile.

Pedon 2: Pedon 2 is a deep (>200cm) profile with clay loam in the 0-21cm depth, sandy clay loam in the 21-110 cm depth which is underlain by sand at the 160-200 cm depth. The colour varies from dark brown at the soil surface through dull orange and grayish yellowish brown to yellowish red in the C horizon. The soil has weak fine granular to moderate medium subangular blocky structure and with slightly sticky consistency. Manganese oxide concretions and stains are common at the 85-60cm of the profile. The pH increases from 5.4 at the surface through 5.7 and 5.9 to 6.7 in the underlying horizon.

Pedon 3: Pedon 3 is a deep (> 200cm) sandy clay loam intimately mixed up with oyster shells throughout the entire There are pieces of broken pottery at the 32-95cm depth of the profile. Soil Colour varies from brownish black at the surface through dark brown to dull yellowish brown in the C horizon layer. The structure is weak fine to medium angular and subangular blocky with slightly sticky consistency. Abundant medium roots permeate the entire profile. The soil reaction is generally neutral with pH which varies from 6.9 in the surface to 7.6 in the C horizon.

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4.2 Taxonomic Classification

Amo series had a pre-dam history of seasonal flooding from September to November in most years. Although distinct mottles still exist in the subsoil, it no longer has aquic soil moisture regime. Pedogenic processes have altered the alluvial parent material to give the soil a moderately developed structure, stronger chroma and higher subsoil clay content, which could be diagnosed as a "Cambic horizon". According to the Soil Survey Staff (1997) all the three Pedons 3 of the Amo series, by reason of their well developed Cambic horizons, are Inceptisols at the Order level. Pedons 1, 2, and 3 are all located in the Lower Volta basin, which has an iso-hyperthermic soil temperature regime, hence all three soils can be classified as Tropepts at the Suborder level. Analytical data on Pedons 1 and 2 show that they do not have a "base saturation" (by NH_4OAc) of 50 percent or more in horizons between 25 cm from the mineral soil surface". Therefore these two Pedons may come under the Dystropepts at the Great Group level. The detailed profile descriptions indicate the presence of few vertical cracks and few slickensides in subsoils of the two Pedons which can place them in the ***Vertic Dystropepts*** Subgroup. Data on Pedon 3 show a base saturation (by NH_4OAc) of 50 percent or more in all horizons between 25 cm from the mineral soil surface which means that this pedon is an Ustropept at the great group level. The soil has few vertical cracks and also can be described as ***Vertic Ustropept*** at the Subgroup level. The soils could not be classified down to the family level because no mineralogical analysis was done.

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4.3 Chemical properties

4.3.1 Soil reaction

Vertical distribution of pH values in both 0.01M $CaCl_2$ and H_20 showed increases from the top to the bottom horizons for all the three soil profiles (Fig. 1). The pH of the soils vary in decreasing order as: Pedon 3 > Pedon 2> Pedon 1. The soil reaction of Pedon 3 is neutral throughout the profile (pH 6.9 - 7.6). The pH from 0-53 cm depth of Pedon 2 is strongly acid (pH 5.2 - 5.4) but changes to slightly acid below 53cm. The pH of Pedon 1 profile is strongly acid throughout the entire pedon (pH 4.8 – 5.5). The near-neutral pH of Pedon 3 is due to the acid neutralising effect of the oyster shells .

4.3.2 Exchangeable cations

At all comparable depths, exchangeable calcium content was highest in Pedon 3 (Fig. 2). The Ca concentration in Pedon 2 is slightly greater than in Pedon 1 at 0-52 cm. Below this depth, the concentration in Pedon 1 slightly exceeds that of Pedon 2. Generally, exchangeable calcium saturation of the effective CEC (ECEC) is very high for Pedon 3 (78.36 97.05%) followed by Pedon 2 (64.05 - 69.20%); Pedon 1 has the least saturation (42.72 - 45.55%). Calcium saturation of the ECEC increases progressively in Pedon 3 from the Ap to the Bw4 horizon at the profile bottom, but Pedons 2 and 3 showed random and less consistent trend throughout the profile. Calculated correlation coefficient between exchangeable calcium and pH for the soil was positive but not significant in Pedon 3 ($r = 0.363$; $\alpha\sim 0.05$) and Pedon 1 ($r = 0.665$; $\alpha\sim 0.05$). The relationship between the two properties in Pedon 2, however, was inverse and highly significant ($r = -0.918$; $\alpha\sim 0.01$).

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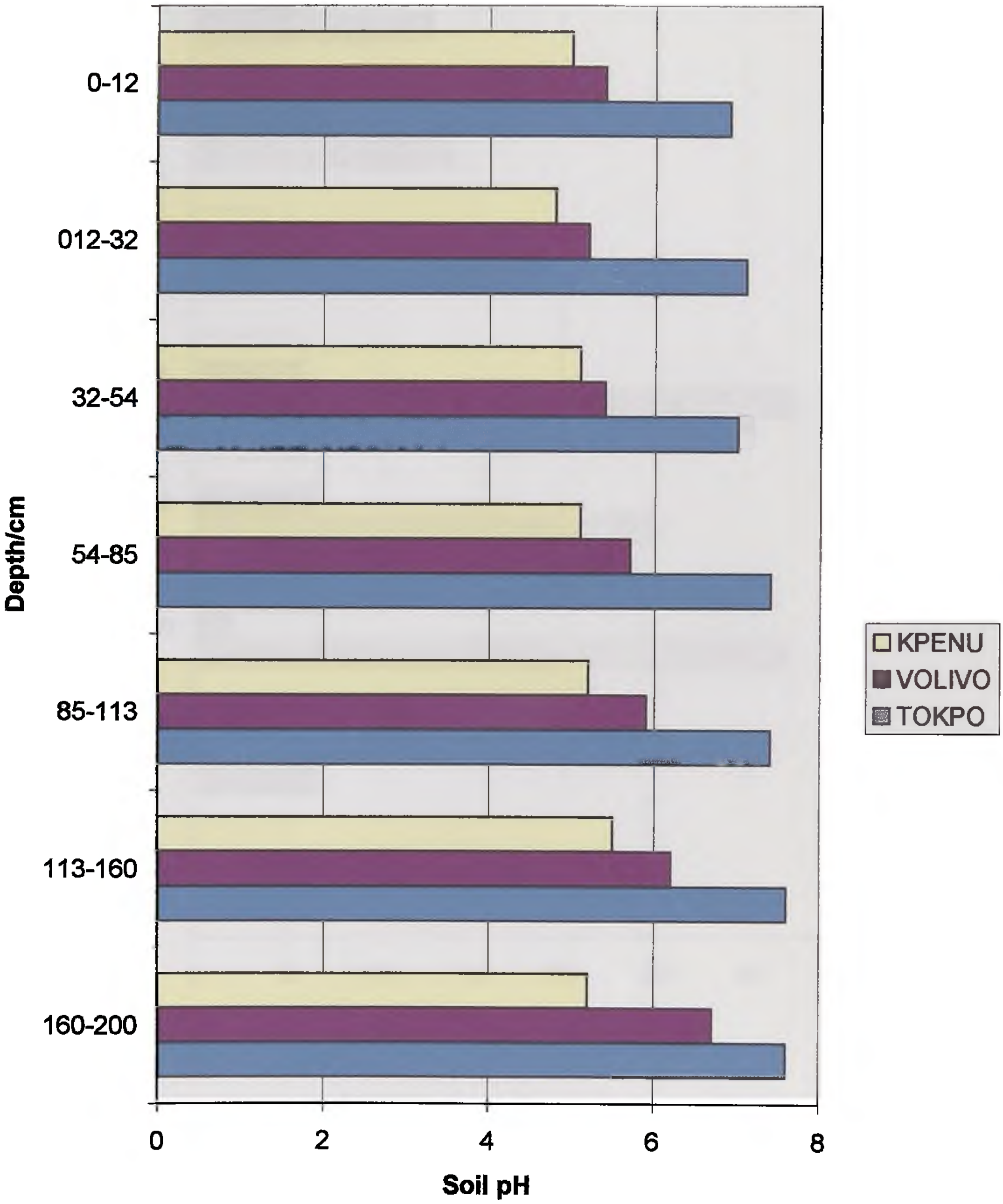

Fig.1 pH (1:1 soil:water) of genetic horizons of the various pedons.

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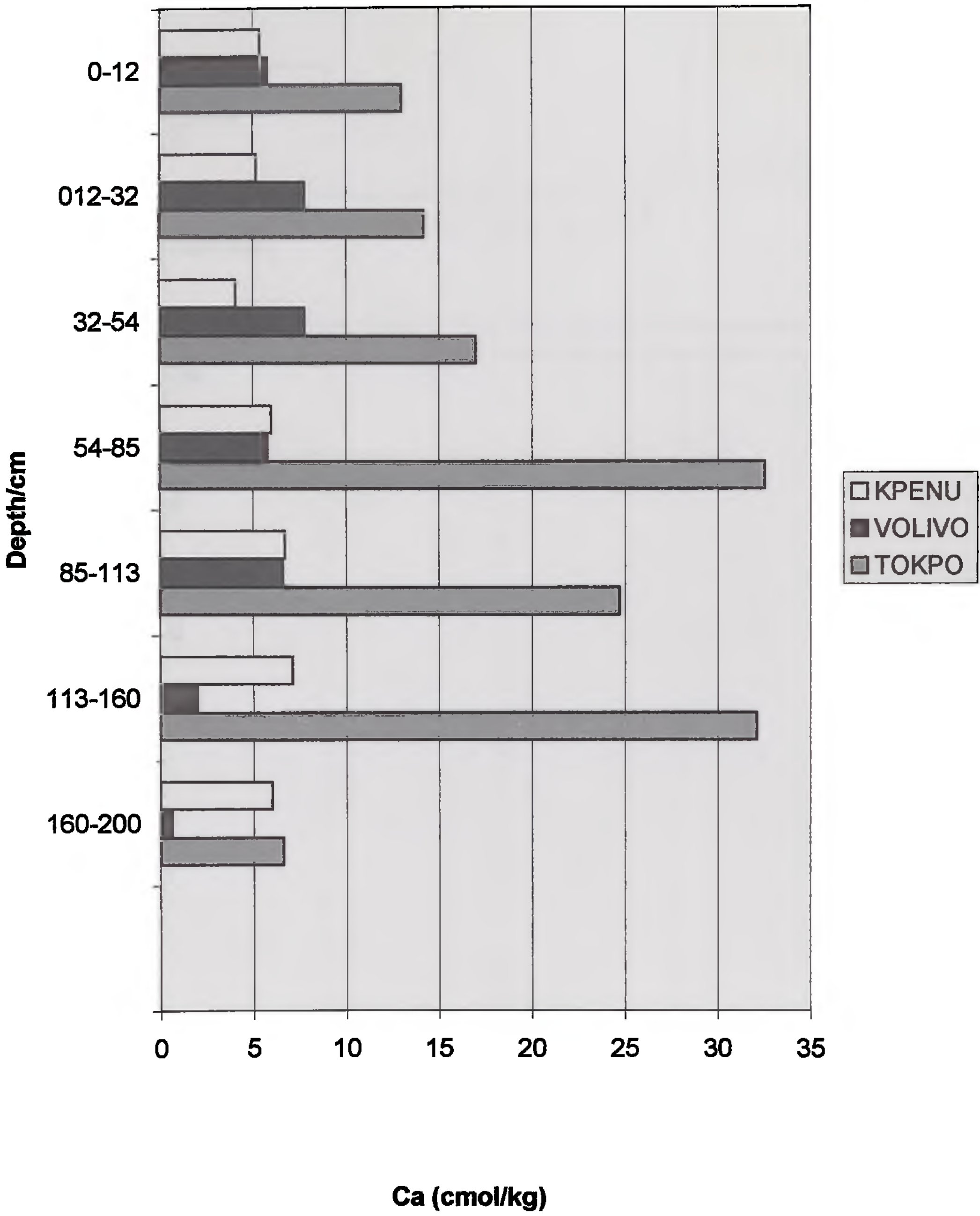

Fig.2 Calcium concentration in the horizons of the three pedons.

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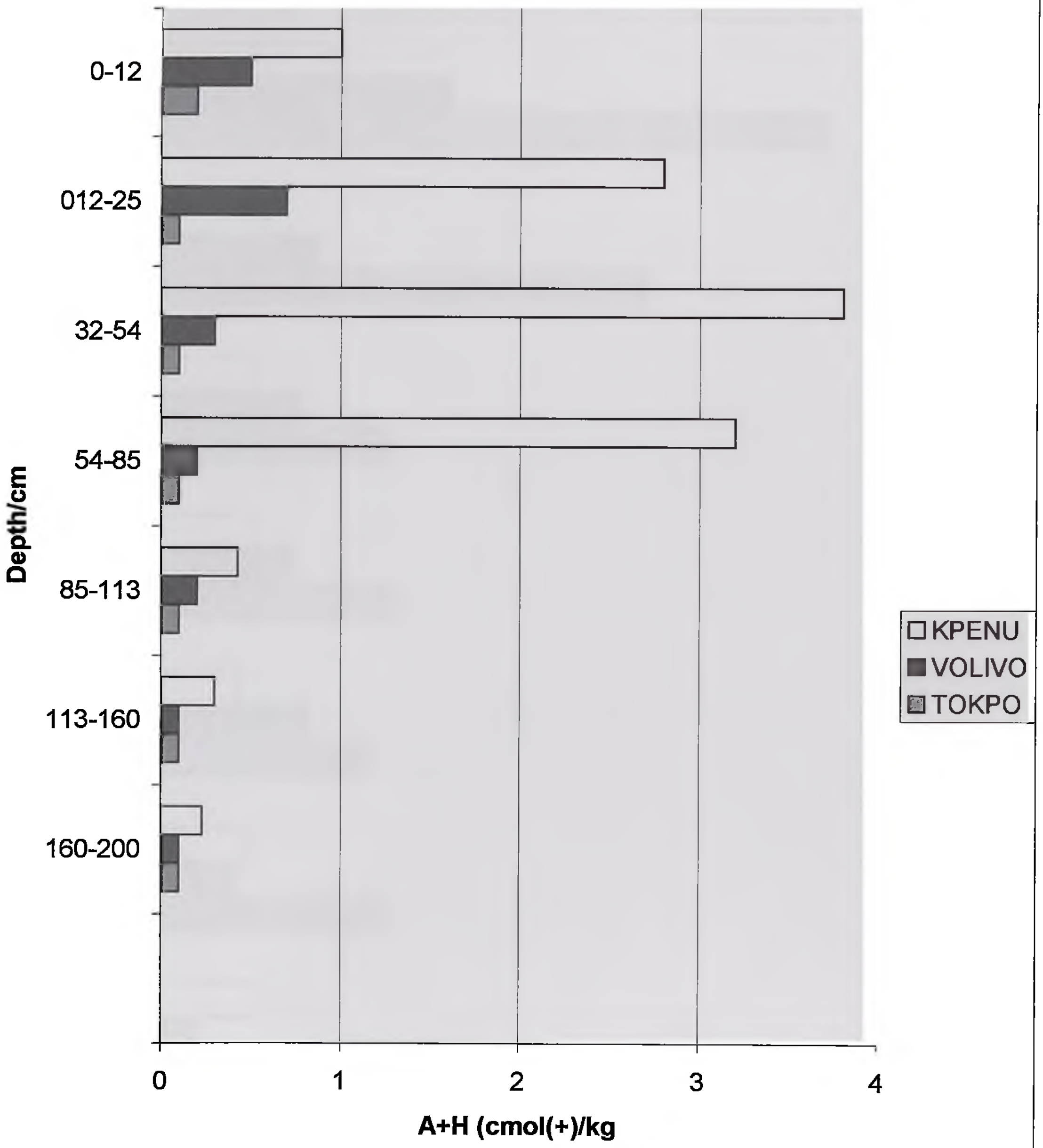

Fig.3 Exchange acidity in horizons of the pedons.

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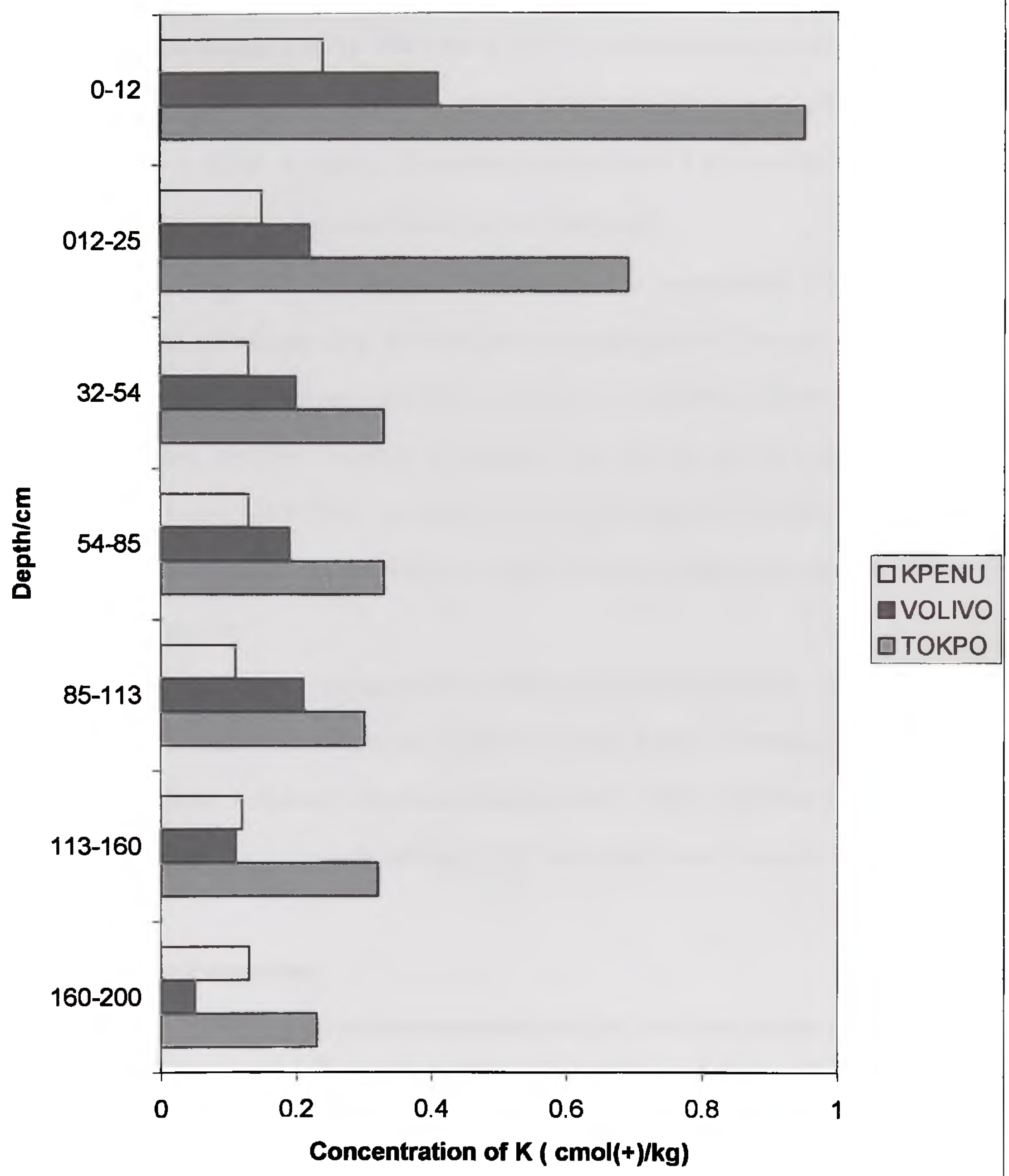

Fig.4 Exchangeable K concentration in the soils.

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Exchangeable acidity was highest in Pedon 1 and least in Pedon 3 within all comparable horizons of the three pedons (Fig. 3). The trend in $Al^{3+}+H^{+}$ concentration in the three soils is in the order Pedon 3< Pedon 2< Pedon 1. The cations significantly but inversely correlated with pH in Pedon 2 ($r = -0.820$; $\alpha \sim 0.05$). The relationships in Pedon 3 ($r = -0.596$; $\alpha \sim 0.05$) and Pedon 1 ($r = -0.554$; $\alpha \sim 0.05$) were also inverse but not significant.

Within similar genetic horizons of all the three pedons, exchangeable K followed the order Pedon 3> Pedon 2> Pedon 1(Fig. 4) for the first five upper horizons. The horizons are Au1, Au2, AB, Bw1, and Bw2 for Pedon 1, and Au1, Au2, Bw1 Bw2 and Bw3 for Pedon 2. Those of Pedon 3 are Ap, Au1, Au2, Bw1 and Bw2. The order for the sixth and seventh was Pedon 3 (K) > Pedon 1 (K) > Pedon 2 (K). This is consistent with the observation by Thomas and Coleman (1959) that Ca-saturated sandy soils retain about twice as much K against water leaching when the soils are Al-saturated.

In all horizons Pedon 1 had highest levels of exchangeable magnesium. Exchangeable magnesium levels in the 0-25cm depth were higher for Pedon 3 than for Pedon 2, but the 21-53cm horizon of Pedon 2 showed higher values except in the C horizon where its value was less than that of Pedon 3. This is due to the fact that the 2C horizon of Pedon 2 is sandy

4.3.3 Percent base saturation

Percentage base saturation positively correlated with pH in all three pedons (Fig 5). The relationship was significant for Pedon 1 ($r = 0.775$; $\alpha \sim 0.05$). Pedon 2 ($r = 0.2445$; $\alpha < 0.05$) and Pedon 3 ($r = 0.395$; $\alpha \sim 0.05$) correlation coefficients were, however, not significant. There was also a significant inverse correlation between base saturation and exchangeable aluminum in Pedon 1 ($r = -0.841$; $\alpha \sim 0.05$). Although the correlation was high it was not significant in Pedon

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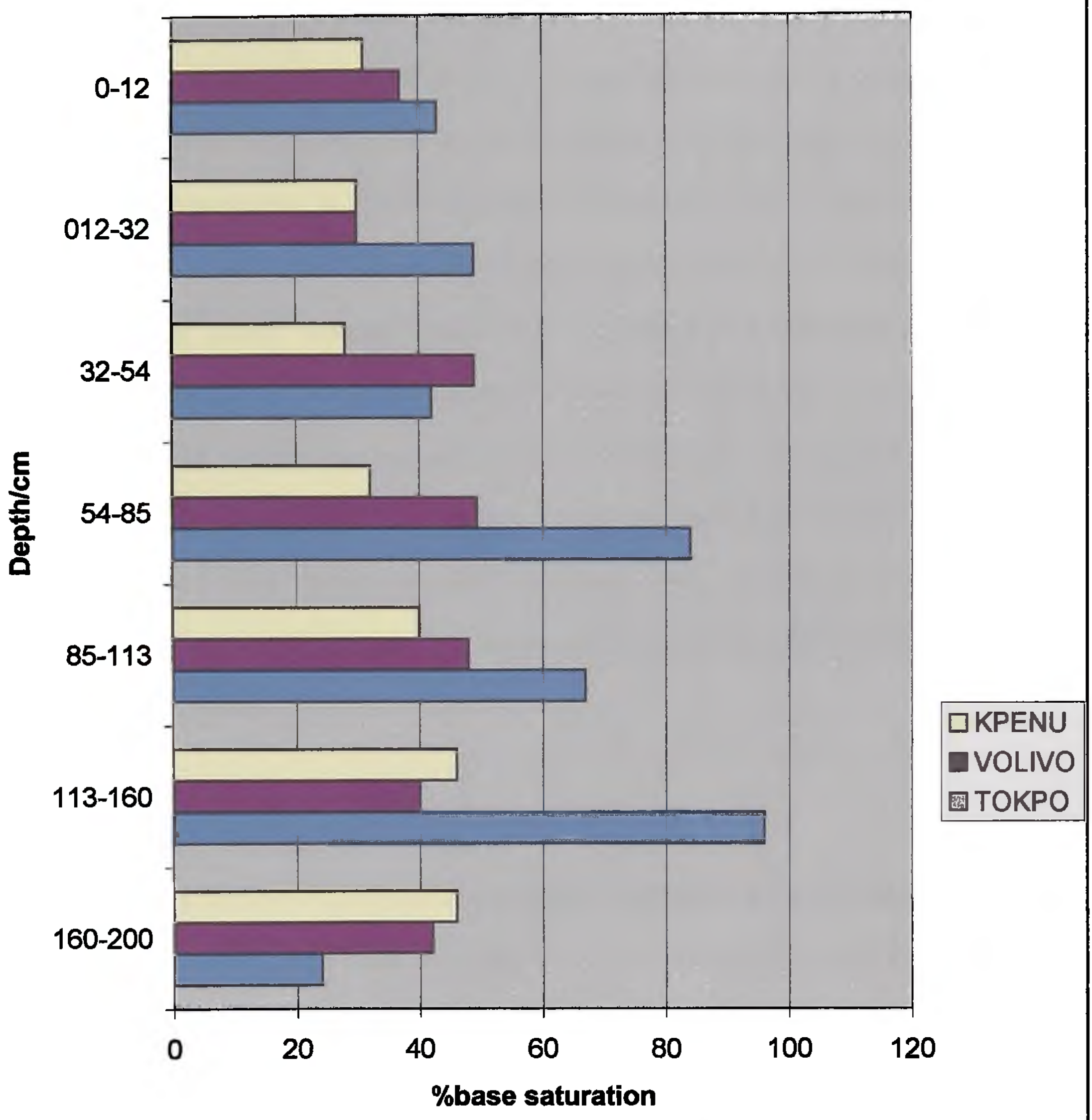

Fig.5 Percent base saturation in horizons of the pedons.

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2 ($r = -0.698$; $\alpha \sim 0.05$). Pedon 3 value was quite low ($r = -0.256$; $\alpha \sim 0.05$). The percent base saturation in Pedon 1 decreased from 31 in Au1 to 30 and 28 in Au2 and AB genetic horizons respectively. The value then increased to 32, 40, 46, and 46 in the Bw1, Bw2, Bw3, and Bw4 genetic horizons respectively. In Pedon 2 the trend was a decrease from 37 Au1 to 30 in Au2. The value stabilized at 45 in the Bw1 and Bw2 horizons then decreased to 48, 40, and 42 in the Bw3, Cg and 2Cg genetic horizons respectively. The percent base saturation in Pedon 3 increased from 43 in the Ap to 49 in the Au1 then decreased to 42 in the Au2 horizon. The value then increased 84 in the Bw1 horizon, decreased to 67 and 24 in the Bw4 horizons while remaining at 96 in the Bw3 genetic horizon. It could be seen that although there were fluctuations in percent base saturation values within each pedon, the values were generally highest in Pedon 3 and least in Pedon 1. The average trend therefore was Pedon 3 %B S > Pedon 2 % B S > Pedon 1 % B S.

4.4 Calcium content of oyster shells

The calcium content of the oyster shell material was 36.8% and the calcium carbonate equivalence was 91.87%. These values are quite close to the values for pure $CaCO_3$ which are 40% Ca and a calcium carbonate equivalence of 100%. Skinner et al., (1959) established that these values indicate the material should be chemically effective as an agricultural liming material.

4.5 Organic carbon

In Pedon 3 organic carbon content decreases with depth from 2.79% to 0.9% in the bottom layer. Pedon 2 has a lower carbon content in its surface horizon. Similarly, Pedon 1

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showed a low organic carbon in its surface horizon, but a rather large accumulation in the 12-25 cm horizon with a sharp decrease below this depth. The lowest carbon contents were found in the 80-113 cm and 113-150 cm depths. The average organic carbon content in decreasing order was Pedon 3 (1.54%) > Pedon 1 (1.22%) > Pedon 2 (1.07%). The higher organic carbon content in Pedon 3 than in Pedons 1 and 2 is due to the greater biomass build-up as a result of higher fertility of this soil and the intense biological activity.

4.6 Total nitrogen

The variation of total nitrogen content with depth among the soils closely matched the distribution of soil organic carbon. Thus, Pedon 3 (%N) > Pedon 1 (%N) > Pedon 2 (%N). Pregistzer(1981) found that 81% of the variability in total nitrogen was explained by a simple linear relationship between total nitrogen and organic matter.

4.7 CEC (NH_4 OAc)

Generally, cation exchange capacity in the Pedon 2 is the lowest. Pedon 3's Au2, Bw1, and Bw4' genetic horizons'CEC values of 46 cmol/kg, 40 cmol/kg and 34 cmol/kg respectively were higher than the corresponding Pedon 1 values of 30 cmol/kg, 39 cmol/kg and 28 cmol/kg respectively (Fig 6). Most values were similar for both soils whilst Pedon 1's value for the 12-25cm depth was higher than that of Pedon 3 (34 cmol/kg). This contrasted the expected trend of Pedon 3 CEC > Pedon 2 CEC > Pedon 1 CEC. The observed trend was probably due to clay content which was generally highest in Pedon 1 and lowest in Pedon 3. Thomas (1961) noted that raising pH above 5.5 increased the CEC. Schofield (1949) found that CEC of some clay soils was constant between pH 2.5 and 5 but increased between pH 5 and 7. Although the clay

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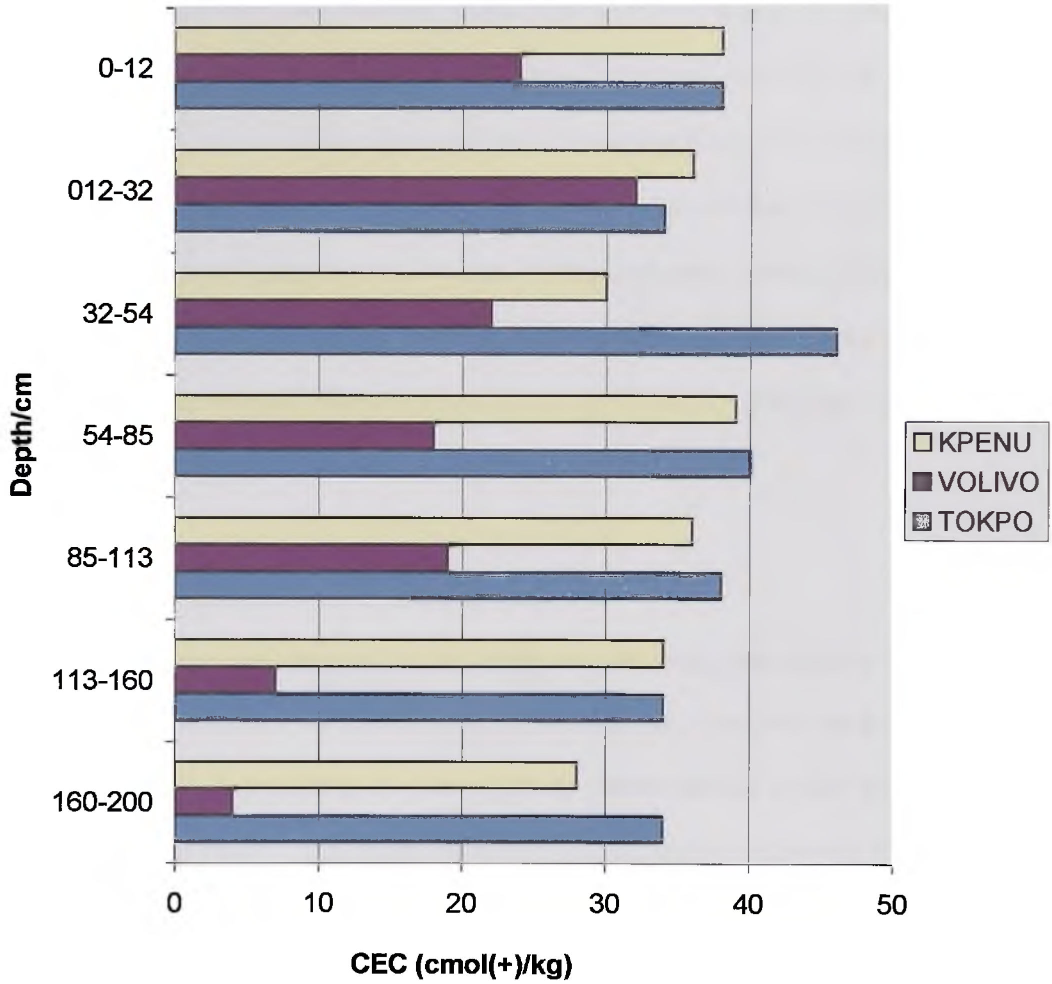

Fig.6 Cation exchange capacity (NH4OAc pH 7) of soils in genetic horizons of the various pedons.

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content in Pedon 1 seemed to have compensated for the expected low CEC value, the true effect of a neutralized acidity was observed for the profiles. Although in all the soils the clay content was higher in Pedon 2 horizons, the CEC values were relatively greater in Pedon 3 than in similar horizons of Pedon 2. Generally, the CEC was closely and inversely related to pH in Pedon 2 ($r = -0.953$; $\alpha \sim 0.01$) but the correlation was not significant in either Pedon 3 ($r = 0.570$; $\alpha \sim 0.05$) or Pedon 1 soil ($r = -0.284$; $\alpha \sim 0.05$). In all the soils the CEC did not seem to depend on organic matter content as was revealed by the correlation values for Pedon 3 ($r = -0.102$), Pedon 2 ($r = 0.152$) and for Pedon 1 ($r = 0.18$) . The dependence of CEC on exchangeable calcium was most pronounced in Pedon 2 ($r = 0.922$ $\alpha \sim 0.01$) but insignificant in Pedon 3 ($r = 0.112$ $\alpha \sim 0.05$) and Pedon 1 ($r = 0.231$ $\alpha \sim 0.05$).

4.8 Phosphorus content of oyster shell material

The total phosphorus content of oyster shells was 689.6mg/g equivalent to 0.0689% of oyster shell sample. Generally, the total phosphorus concentration of the soils was in the order of Pedon 3 > Pedon 1 > Pedon 2 (Fig 7). The relatively greater amount of total phosphorus in Pedon 3 than those of Pedon 1 and Pedon 2 indicated that although pH influenced the increased availability of phosphorus, some significant amounts of phosphorus were supplied by the shells as evidenced by the relatively high 0.0689% phosphorus in the shell material. The available phosphorus content was very high throughout the profile of Pedon 3 except at the Bw1 and Bw3 genetic horizons having 6.78mg/kg and 8.72mg/kg, respectively (Fig. 8). The peak P concentration in the Ap horizon (84mg/kg) decreased to 6.78mg/kg in the 54-72cm horizon. The pattern from the Bw2 genetic horizon to the bottom horizon was not so consistent. Although

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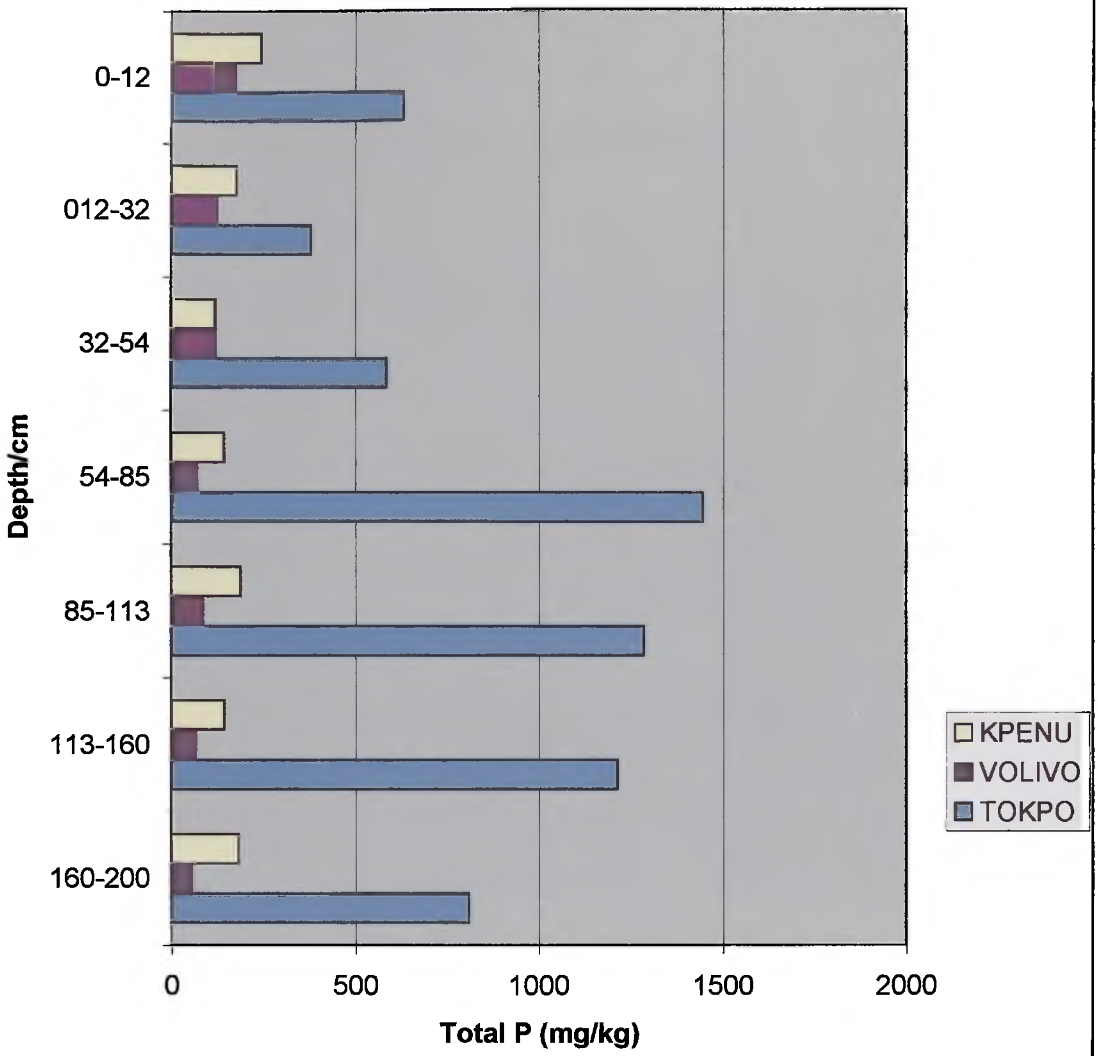

Fig.7 Total P concentration in the horizons of the various pedons.

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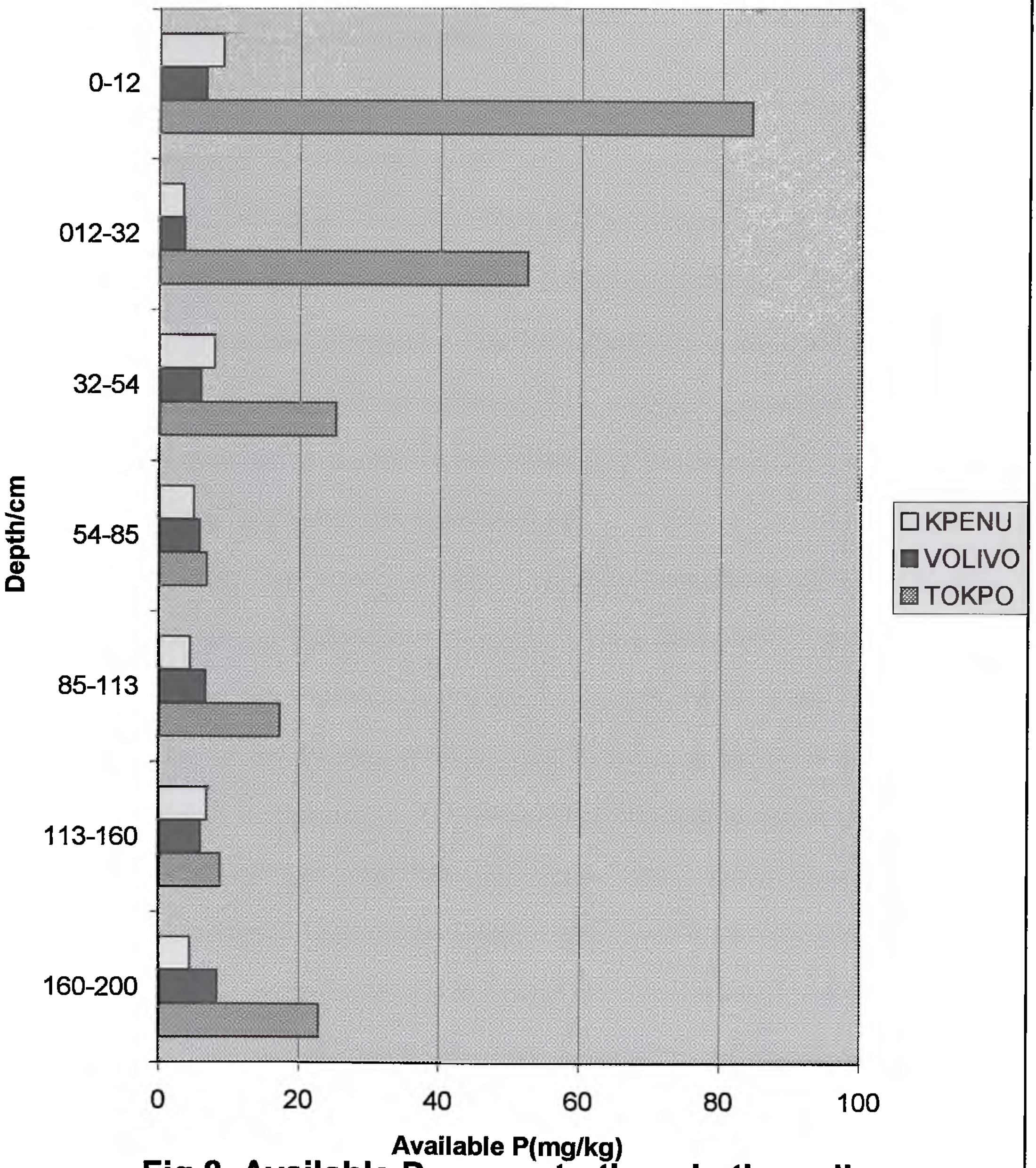

Fig.8 Available P concentrations in the soils.

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available P content in the surface horizon of Pedon 1 (9.05mg/kg) exceeded that of Pedon 2 the P concentration generally exceeded those of Pedon 1.

The rate of increase of available phosphorus is influenced by the presence of $CaC0_3$ and is in close correlation with the pH (Fuleky, 1978). The decreasing trend of available phosphorus content from Pedon 2 to Pedon 1 is in agreement with the view of Birch (1951) that soil phosphorus availability is depressed at high acidity. The higher pH of Pedon 3 due to the liming effect of oyster shells may have increased the available phosphorus content. Mandal and Dey (1979) noted that liming significantly increased water soluble or immediately available phosphorus of non-phosphatic soils. Sharma and Varshney (1979) observed that the amount of available phosphorus in soil profiles were influence by pH.

The soils studied are known to have about equal proportions of kaolinite and montmorillonite including a high charge mica-montmorillonite (Oteng, 1976). The amount of phosphorus adsorbed by clay minerals is greater at pH 3 and 4 than at pH 6 and 7 (Black1942; Perkins, 1945). Most of the retaining power of soil for phosphate lies in its clay fraction. Adsorption of phosphate is greatest in the finest fraction and decreases as particle size increases (Hibbard, 1935). Beather (1937) and Neller and Comar (1947) also found a fairly close relationship between phosphate adsorption and clay content. However, the higher clay content in Pedon 1 and the greater available phosphorus contents in Pedons 2 and 3 coupled with the influence of pH on P content in the latter Pedons, show that availability of phosphorus in the soil is more closely associated with pH than with clay content.

4.9 DCB - extractable iron

Free iron oxide content of the various horizons of the soils increased in the order Pedon 3

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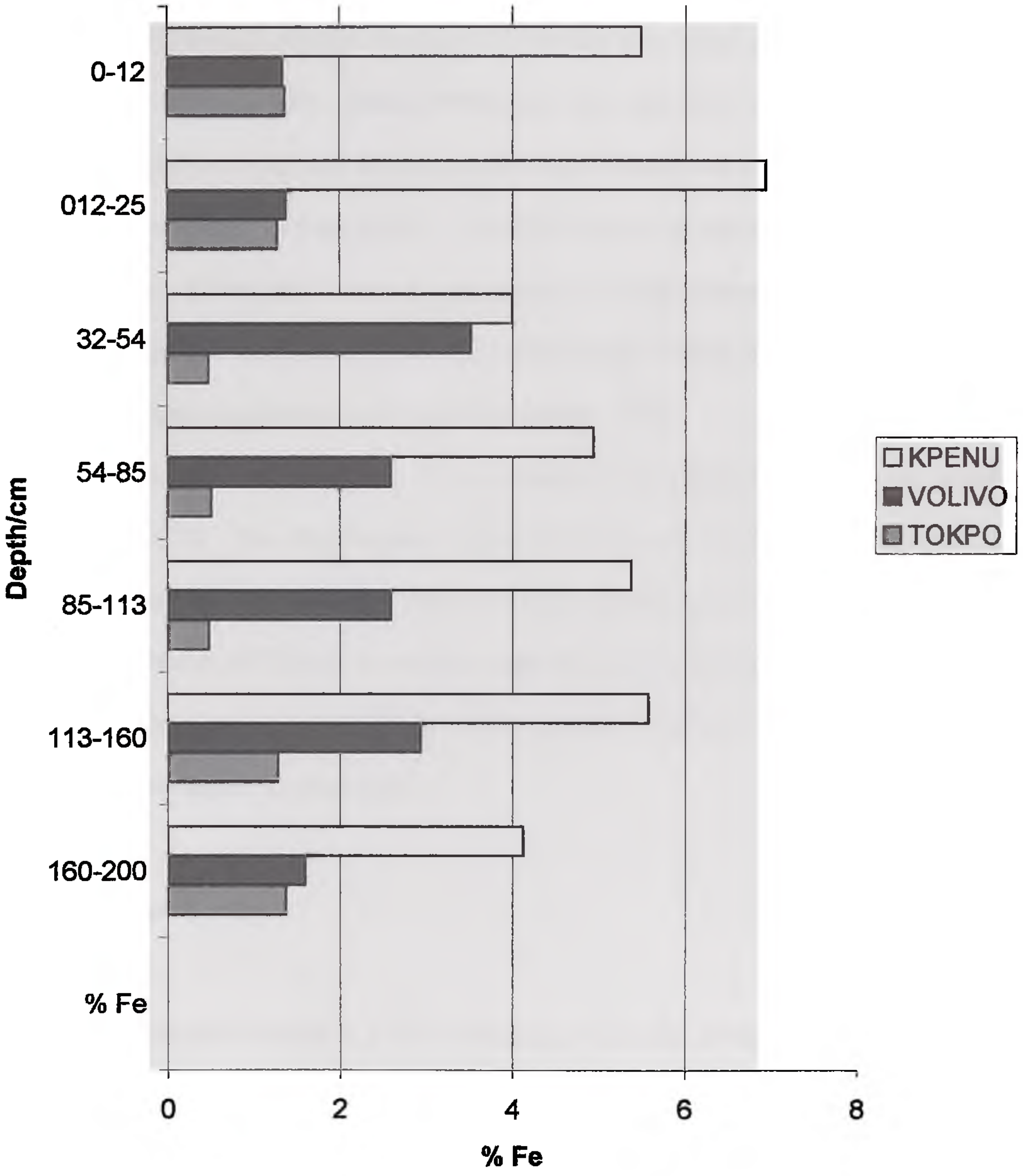

Fig.9 Percent Fe concentrations in the soils.

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<Pedon 2 < Pedon 1 (Fig 9). Profile averages rank in the order Pedon 1 (5.21%) > Pedon 2 (2.28%) > Pedon 3 (0.95%). Free iron content seemed to depend on percentage clay of the various horizons. Free iron content therefore followed the same order as clay: Pedon 1 %Fe > Pedon 2 %Fe > Pedon 3 %Fe. Heck (1934), and Pugh and Du Toit (1936) noted that Fe hydroxides and hydrous oxides can adsorb phosphates and established that an exchange reaction exists between the phosphate ions H_2PO_4 and HPO_4^{2-}as well as the hydroxyl ions present in these compounds. Above pH 7 there is complexing of insoluble phosphate and below pH 5 insoluble Fe compounds fix phosphate ion while between pH 6 and 7 phosphate fixation is at a minimum thus maximising phosphorus availability (Brady, 1974).

All the profiles showed mostly 7.5 or yellower hues which is indicative of goethite (Bigham et al., 1978). The alluvial parent materials of the soils contained haematite but the oxide dissolved under under the wetter pre-dam conditions and caused the Fe to precipitate as goethite (Schwertmann, 1977) with the amounts depending on the amount of clay. Daugherty et al.(1982) noted that Kaolinite clays adsorb 10-14% of Fe_2O_3 before the surfaces are saturated and aggregated into larger size particles.,

4.10 Physical properties

4.10.1 Texture

The soil texture of Pedon 1 is clay throughout the profile except for the Au1 horizon, which is clay loam. Pedon 2 has a texture that varies from clay loam in the Au1 and Bw1 horizons to sandy loam in the Bw1 and Bw3 horizons. It is sand from the Cg to the 2Cg horizons of the profile. Pedon 3 soil texture is generally sandy clay loam but sandy loam in the Ap and clay in the Bw2 horizons of the profile.

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4.10.2 Aggregate stability

Aggregate stability of the three soils studied was found to follow the order Pedon 1 > Pedon 2 > Pedon 3 (Fig 10). This contrasted with the expected order of Pedon 3 > Pedon 2 > Pedon 1.Although the Cg and 2Cg horizons of Pedon 2 were sand, and could not be included for comparison, the trend for the remaining horizons followed the order stated above. Differences in aggregate stability are related to presence or absence of binding agents known to possess stabilizing properties. The amount and kind of clay influence aggregate stability. Kaolinite - dominated granules are more stable than those in which montmorillonite is prominent. Differences in stability of the aggregates in the soils are due to the different amounts of free iron oxides and amounts of clay which follow the same decreasing trend of Pedon 1 > Pedon 2 > Pedon 3.

4.10.3 Hydraulic conductivity

The Au1 ,Au2 and AB genetic horizons of Pedon 1, Au1, Au2 and Bw1 of Pedon 2 and Ap Au1 and Au2 of Pedon 3 ,all within 0-12cm, 12-32cm, and 32-54cm depth, show hydraulic conductivity values in a decreasing trend as Pedon 1 > Pedon 3 > Pedon 2 (Fig 11). The order for the 54-80cm and 80-113cm horizons was Pedon 3 > Pedon 2 > Pedon 1 whilst the trend for the 113-150cm and 150-200cm horizons was Pedon 2 > Pedon 3 > Pedon 1. The observed trend in the three soils could be explained by the fact that hydraulic conductivity is positively related to sand content and negatively related to clay content and micro-aggregation.

The expected order of increasing hydraulic conductivities in the pedons is Pedon 3 > Pedon 2 > Pedon 1. The relatively greater hydraulic conductivities of Pedon 1 within the 0-50cm depth can be attributed to highly stable aggregates resulting from the high clay and free iron

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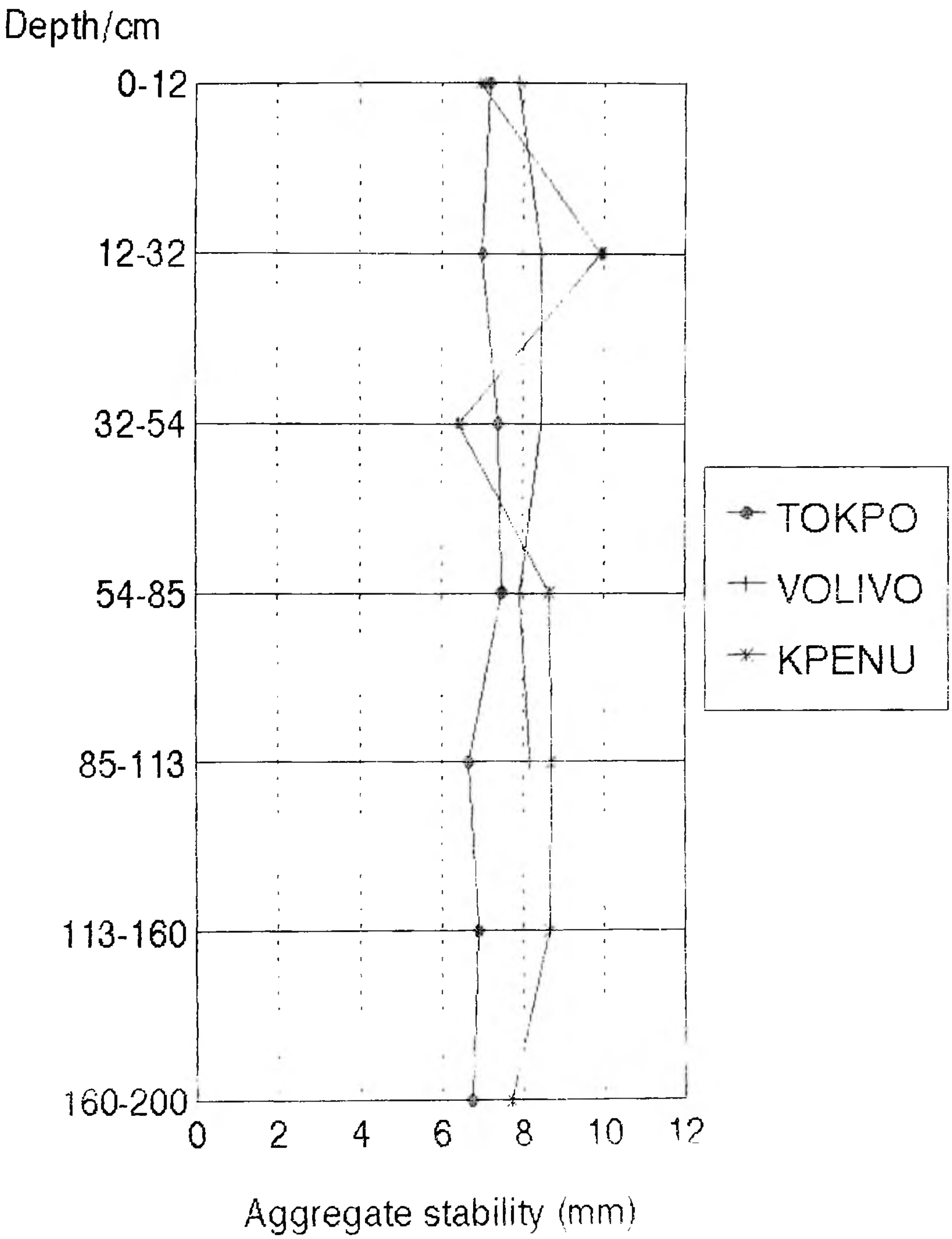

Fig.10 Aggregate stability of the soils

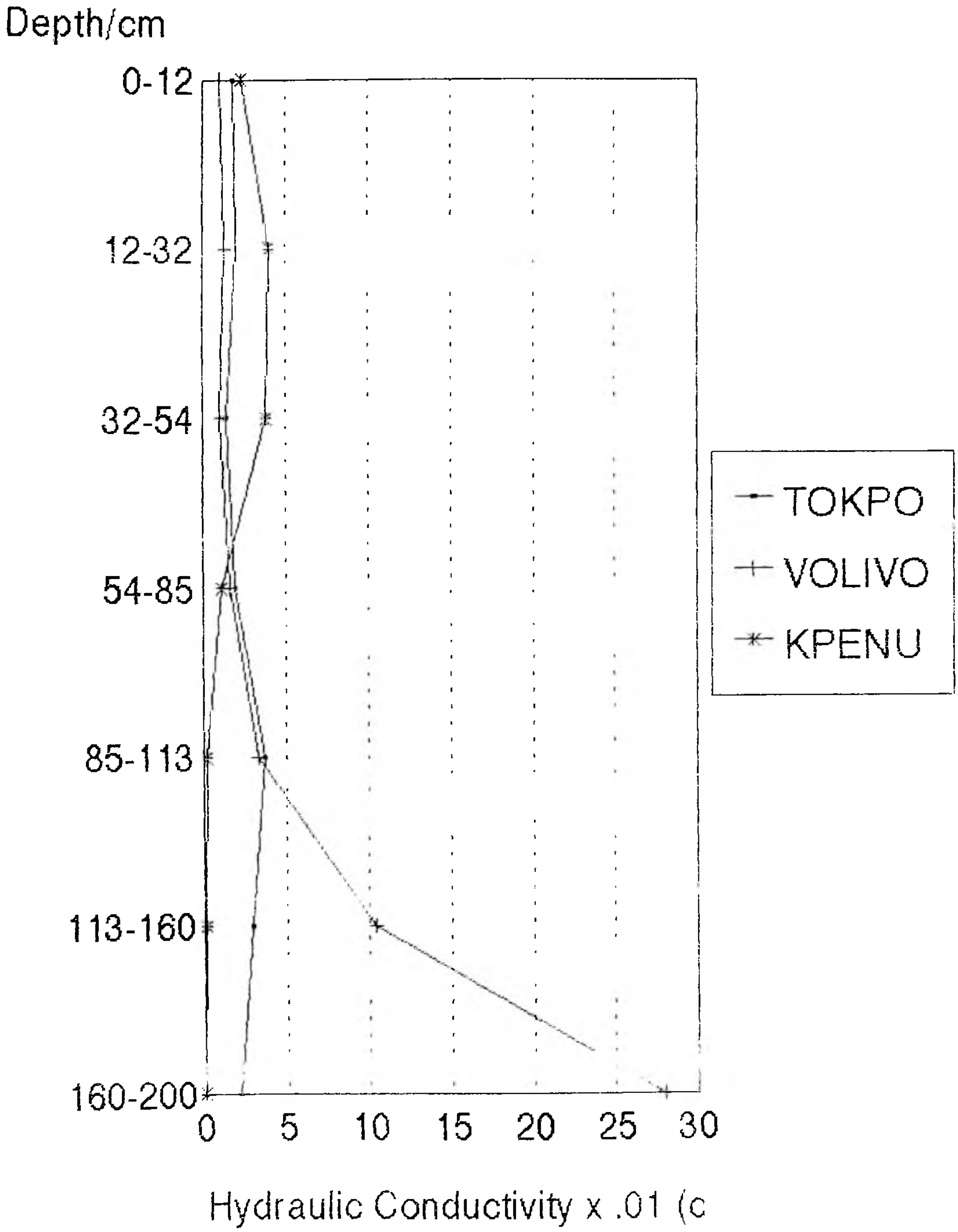

Fig.11 Hydraulic conductivity of the soils

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oxide contents. The hydraulic conductivity in Pedon 1 was lower than in Pedon 3 and Pedon 2 from the 54-85cm depth because of its increased clay content (61.9%) compared to 29.2% for Pedon 3 and 18.4% for Pedon 2. On the other hand aggregate stability and percent free iron oxide were higher in Pedon 2 (7.92mm and 2.59%, respectively) than in Pedon 3 (7.48mm and 0.51%, respectively) although the saturated hydraulic conductivity was higher in Pedon 3 (0.0192 cm/sec) than in Pedon 2 (0.016cm/sec). This portion of the profiles underscores the significant improvement in hydraulic conductivity due to the liming effect of the oyster shells. This agrees with the observation by Roth et al. (1986) that application of gypsum resulted in slight increase in aggregate stability and infiltration rate equivalent to liming to pH 6.0. The saturated hydraulic conductivity increased in Pedon 2 because of the relatively high sand content. Pedon 1 shows a relatively lower saturated hydraulic conductivity between the 52-200cm depth due to its consistently high clay content and consequently high microporosity.

4.11 Liming effects on soil properties

Ruffi (1821, 1852) promoted liming practice and reported that marl applications improved crop yields. The efficiency of liming depends on the properties of the liming material used. Any agricultural liming material should have Ca- and Mg-compounds capable of neutralizing soil acidity. Availability of Ca and Mg to plants depends on the concentration of exchangeable Ca and Mg in soil and water to transport these ions to plant roots by massflow (Al-Abbas and Barber, 1964). For a given soil with constant anion concentration in soil solution, availability of these nutrients increases as more Ca and Mg move from the liming material onto exchange sites and into solution, with consequent increase in available calcium and magnesium and a decrease in amounts of Al that reach plant roots. The percent exchangeable Ca saturation

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of the exchange complex (ECEC) (Table 1) was highest in Pedon 3, medium in Pedon 2 and least in Pedon 1. In Pedon 2 Ca saturation of the ECEC increased consistently from 78.36% in the Au1 horizon to 97.62% in the Cg horizon then dropped to 78.76% in the 2Cg horizon. The patterns for both Pedons 2 and 1 were not consistent.

Conversely, exchange acidity saturation of the exchange complex (Table 2) was highest in Pedon 1 where it shot up from 7.9% in the Au1 to 30.94% in the AB and 20.42% in the Bw1 genetic genetic horizons, respectively. The Bw2, Bw3, and Bw4 genetic horizons recorded 2.92%, 1.90%, and 1.75%, respectively. Exchangeable aluminum saturation of the Pedon 2 exchange complex was highest in the Au2 followed by the 2Cg horizon. The B1, B2, B3, and Cg genetic horizons recorded 2.64% average. Pedon 3 recorded its highest value of 1.2% saturation in the Ap horizon. The Ap and Au1 horizon had average saturation of 0.55% while the Bw1, Bw2, and Bw3 horizons recorded 0.32%. Thus percent exchangeable calcium saturation of the exchange complex ranked in decreasing order as: Pedon 3 > Pedon 2 > Pedon 1 whereas percent exchange acidity saturation ranked conversely in decreasing order as: Pedon 1 > Pedon 2 > Pedon 3. The strong acidity (pH 4.8-5.2) of the soil, as evidenced in Pedon 1, had been neutralized in Pedon 2 (pH 5.4-5.9) and Pedon 3 (pH 6.9-7.6) with Pedon 3 exhibiting maximum liming effects of the oyster shell material.

Percent Mg saturation of the ECEC (Table 3) is in decreasing order Pedon 1 > Pedon 2 > Pedon 3. Mg saturation in Pedon 3 is 14.46% in the Au1 horizon but this decreased consistently to its lowest in the Bw3 horizon with profile maximum (16.7%) in the Bw4 horizon. The trends for Pedons 2 and 1 were not consistent.

The saturation of the ECEC (Table 4) by Ca+Mg was in the decreasing order: Pedon 3(%Ca+Mg) > Pedon 2(%Ca+Mg) > Pedon 1(%Ca+Mg) for all corresponding genetic horizons.

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Values increased consistently from the Au1 to the 2Cg genetic horizon for Pedon 2 and from the Ap to the Bw4 genetic horizon for Pedon 3

Ca:Mg ratios computed for the soils (Table 5) showed a consistent order of Pedon 3(Ca:Mg) > Pedon 2(Ca:Mg) > Pedon 1(Ca:Mg) for all horizons compared. The trend for Pedon 3 was a systematic increase from profile surface to bottom whereas those in Pedons 2 and 1 were not so orderly.

The Ca:K ratios of Pedon 3 increased from 13.68:1 in the Ap horizon to a profile maximum of 100.31:1 in the Bw3 horizon underlain by 28.69:1 ratio. The ratio for Pedon 2 increased from 14.14:1 in the Au1 horizon to a 39:1 maximum in the Au2 horizon. The ratio for Pedon 1 rose inconsistently from minimum of 22.5:1 in the profile surface to its maximum of 60.9:1 in the 85-113cm horizon (Table 6).

The cation saturation ratios (Bear et al., 1945; Toth 1948) for making recommendations for additions of lime and fertilizer K, are based on the concept of the ideal soil defined as one having the exchange complex saturated with 65%Ca, 105%Mg, 5%K and 20%H. It is expected that these percent saturations lead to a soil Ca:Mg ratio of 6.5:1, Ca:K of 13:1 and Mg:K of 2:1. Although composition of the exchangeable cation site varied considerably among the soils and within each soil examined, the Pedon 3 Ca:Mg, Ca:K, and Mg.:K ratios were consistently closest to the idealized soil on horizon by horizon basis. The exchangeability of K was highest in Pedon 3 followed by Pedon 2 in the 0-12cm zone (Table 7) although Pedon 2 values slightly exceeded Pedon 3 counterparts between the 32-200cm zone of the profiles.

For a given combination of climate, organisms, parent materials, relief and time, the state of the soil system is fixed so that only one soil exists under these prescribed conditions (Jenny, 1941). Although slight differences in soil properties were observed showing that the soils were

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not completely identical, yet the major differences in exchangeable aluminum saturation, exchangeable calcium saturation, available phosphorus contents, pH and exchangeable potassium concentrations, have been observed to be due to the presence of oyster shells in Pedon 3, its influence on Pedon 2 close to it, and complete absence in Pedon 1.

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Table of values

Table 1 .Percent calcium saturation of ECEC

Depth/cm	Pedon 1 (Kpenu)		Pedon 2 (Volivo)		Pedon 3 (Tokpo)	
	Ca(cmol/kg)	%Saturation	Ca(cmol/kg)	%Saturation	Ca(cmol/kg)	%Saturation
0-12	5.4	42.72	5.8	64.05	13.0	78.36
12-32	5.2	38.06	7.8	75.14	14.2	84.42
32-54	4.1	33.38	7.8	70.33	17.0	87.76
54-85	6.0	38.28	5.8	64.80	32.5	96.49
85-113	6.7	45.45	6.6	71.27	24.7	97.05
113-160	7.1	44.59	2.0	69.20	32.1	97.62
160-200	6.0	45.55	0.6	33.80	6.60	78.76

Table 2 Percent exchange acidity saturation of ECEC

Depth/cm	Pedon 1 (Kpenu)		Pedon 2 (Volivo)		Pedon 3 (Tokpo)	
	Al+H (cmol/kg)	%Saturation	Al+H (cmol/kg)	%Saturation	Al+H (cmol/kg)	%Saturation
0-12	0.55	7.90	0.4	4.42	0.2	1.2
12-32	2.05	20.50	0.6	5.78	0.1	0.59
32-54	3.60	30.94	0.3	2.71	0.1	0.51
54-85	2.60	20.42	0.2	2.23	0.1	0.29
85-113	0.30	2.92	0.2	2.16	0.1	0.39
113-160	0.20	1.90	0.1	3.46	0.1	0.30
160-200	0.20	1.75	0.1	5.65	0.1	1.19

Table 3 .Percent magnesium saturation of ECEC

Depth/cm	Pedon 1 (Kpenu)		Pedon 2 (Volivo)		Pedon 3 (Tokpo)	
	Mg (cmol/kg)	%Saturation	Mg (cmol/kg)	%Saturation	Mg (cmol/kg)	%Saturation
0-12	5.9	46.67	2.3	25.41	2.4	14.46
12-32	5.4	39.53	1.6	15.41	1.8	10.70
32-54	4.1	33.38	2.7	24.34	1.9	9.80
54-85	6.1	38.92	2.7	30.16	0.7	2.07
85-113	7.2	48.84	2.2	23.75	0.3	1.17
113-160	8.0	50.25	0.6	20.76	0.3	0.91
160-200	6.4	48.59	1.0	56.49	1.4	16.7

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Table 4 Percent Ca + Mg saturation of ECEC

Depth/cm	Pedon 1(Kpenu)	Pedon 2 (Volivo)	Pedon 3 (Tokpo)
	% Ca + Mg	% Ca + Mg	% Ca + Mg
0-12	89.39	89.50	92.82
12-32	77.59	90.55	95.12
32-54	66.77	94.67	97.57
54-85	77.21	94.97	98.57
85-113	94.30	95.03	98.23
113-160	94.84	89.96	98.54
160-200	94.15	90.39	95.46

Table 5 .Calcium : Magnesium ratios

Depth/cm	Calcium:Magnesium Ratios		
	Pedon 1(Kpenu)	Pedon 2(Volivo)	Pedon 3(Tokpo)
0-12	0.91	2.52	5.4
12-32	0.96	4.87	7.8
32-54	1.00	2.80	8.9
54-85	0.98	2.15	46.4
85-113	0.93	3.00	82.3
113-160	0.88	3.30	10.7
160-200	0.93	0.06	40.7

Table 6 .Calcium : Potassium Ratios

Depth/cm	Calcium:Potassium Ratios		
	Pedon 1(Kpenu)	Pedon 2(Volivo)	Pedon 3(Tokpo)
0-12	22.50	14.14	13.68
12-32	34.66	35.45	20.57
32-54	31.53	39.00	51.51
54-85	46.15	30.52	98.48
85-113	60.90	31.42	82.33
113-160	59.16	18.18	100.31
160-200	46.15	12.00	28.69

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Table 7..Exchangeability of K as a percent saturation of ECEC

Depth/cm	K saturation of ECEC		
	Pedon 1(Kpenu)	Pedon 2(Volivo)	Pedon 3(Tokpo)
0-12	1.89	4.53	5.73
12-32	1.09	2.18	4.10
32-54	1.05	1.8	1.70
54-85	0.83	2.12	0.98
85-113	0.74	2.26	1.18
113-160	0.75	3.80	0.97
160-200	0.98	2.82	2.27

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CHAPTER FIVE

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

In this study three pedons of the Amo series in the Lower Volta floodplain of Ghana were studied to find the effect of oyster shell deposits on the soil properties. The study revealed that oyster shell deposits have chemically and physically transformed the modal Amo series from ***Vertic Dystropept*** in Pedons 1 and 2 to ***Vertic Ustropept*** in Pedon 3 according to the Soil Survey Staff (1997) of the USDA.

Significant differences exist in the pHs of the pedons. Whereas the pHs of Pedons 1and 2 are strongly acid (pH 5.2-5.4), that of Pedon 3 is near-neutral due to the acid neutralizing effect of the oyster shell material. The exchangeable Ca saturation of the effective cation exchange capacity was highest for Pedon 3 (78.36-97.05%), followed by Pedon 2 (64.05-69.20%) with Pedon 1 having the least value of 42.72-45.55%. Conversely the trend for $Al^{+}+H^{+}$ concentration in the soils was in the order Pedon 3 $Al^{3+}+H^{+}$>Pedon 2 $Al^{3+}+H^{+}$> Pedon 1 $Al^{3+}+H^{+}$. Within similar genetic horizons of the pedons exchangeable K concentration was in the order Pedon 3 K^{+}> Pedon 2 K^{+} > Pedon 1 K^{+}, showing that the concentration of K highest in the Ca-saturated pedon than in all the others. Percent base saturation values were highest in Pedon 3 and least in Pedon 1 giving a trend that followed the order Pedon 3 %BS > Pedon 2 %BS > Pedon 1 %BS.

The Ca content of the oyster shell material is 36.8 % and the calcium carbonate equivalence is 91.8% These figures are quite close to the corresponding pure $CaCO_3$ values of 40.0% Ca and a calcium carbonate equivalence of 100% and therefore indicate that the oyster shell material has the chemical capacity to effectively neutralize soil acidity as any good

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agricultural acid soil liming material should.

The average organic carbon content was highest in Pedon 3 and like the trend for total nitrogen was in the order Pedon 3 %OM > Pedon 1 %OM>Pedon 2 %OM. The observed trend of CEC in the soils was in the order Pedon 3 CEC>Pedon 1 CEC >Pedon 2 CEC. This contrasted the expected trend of Pedon 3 CEC >Pedon 2 CEC >Pedon 1 CEC, all things being equal. Even though the CEC values of Pedon 1's Au1 and Pedon 3's Ap were the same, as well as the value in genetic horizon Bw3 which was the same for both Pedons 1 and 3, the CEC values in the diagnostic horizons were on the average higher in Pedon 3 than in Pedon 1. The distinctly higher CEC value in Pedon 1 than in Pedon 2 could be explained by the fact that clay content in Pedon 1 is higher than in Pedon 2 whose sand content increases down the profile. The higher clay content more than compensated for the otherwise lower CEC values in this profile.

The oyster shell material supplied the soil with available phosphorus amounting to 689.6mg/g or 0.0689% of the oyster shell sample. The total phosphorus concentration in the soils was in order Pedon 3 total P >Pedon 1 total P >Pedon 2 total P. Although the high availability of phosphorus in Pedon 3 was partly due to the influence of the neutral soil pH on releasing the nutrient element from associated complexes, quite a high amount of it evidently came from the oyster shell material.

The soil texture of Pedon 1 is clay throughout the profile except in the Au1 horizon where it clay loam. That of Pedon 2 varies from clay loam in the Au2 and Bw2 genetic horizons to sandy loam in the Bw1 and Bw3. In the Cg horizon the texture is sandy. Pedon has texture that is generally sandy clay loam but sandy loam in the Ap and clay in the Bw2 genetic horizons. The trend in stability of the soil aggregates ranked in the same order as free Fe oxides and clay contents. Thus Pedon 1 Aggregate stability >Pedon 2 Aggregate stability >Pedon 3 Aggregate

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stability. There was a significant improvement in hydraulic conductivity in Pedon 3 due to the liming effect of the oyster shell material on soil properties.

5.2 Conclusions

The exchangeable calcium saturation of the exchange complex was highest in Pedon 3 and least in Pedon 1. The calcium-rich oyster shells neutralised the soil's strong acidity, increased the CEC and added plant available phosphorus. Organic carbon content, aggregate stability and hydraulic conductivity were all highest in Pedon 3 due to the effect of oyster shells. Results of the study show that the influence of oyster shells on Amo series provides a great potential for sustainable low input soil productivity as they have dual property as liming material and as fertilizer.

5.3 Recommendations

It is recommended that as part of future efforts in this area of research, research programmes should include field trials with oyster shell lime to determine crop responses to lime applications . Also, experiments must be done to establish the relationships between rates of lime application and crop yields.

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REFERENCES

Adelhelm, R. and Kotschi, J. 1985. Abteilung koordinierung, planung, beratung, Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ), Eschborn, Germany F.R. *In* Entwicklung-und-Landlicher-Raum (Germany F.R) CAPut!'(4) p.17-20.

Al-Abbas, A.H. and Barber S.A. 1964. Effect of root growth and mass-flow on the availability of soil calcium and magnesium to soybeans in a greenhouse experiment. Soil Sci. 97:103-107.

Amatekpor, J.K. 1989. The effect of seasonal flooding on the clay mineralogy of a soil series in the Volta Lake draw down area, Ghana. John Wiley and Sons. Land Degradation and Rehabilitation I No. 2:89-100.

Bali, Y.P. 1985. Soil surveys and soil conservation for agricultural development. Dept. of Agric. and Coop, New Delhi, India. J. of Indian Soc. Soil Sci. (India).

Barrow, N.J. 1987. Reactions with variable-charge soils. Martinus Nijhoff Publishers, Dordrecht, The Netherlands.

Bartlett, R. and James, B. 1980. Studying dried, stored soil samples-Some pitfalls. Soil Sci. Soc. Am. J. 44:721-724.

Bear, F.E. and Toth, S.J. 1948. Influence of calcium on availability of other soil cations. Soil Sci. 65:69-74.

Bear, F.E., Prince, A.L. and Malcolm, J.L. 1945. Potassium needs of New Jersey soils. N.J. Agric. Exp. Stn. Bull. 21.

University of Ghana http://ugspace.ug.edu.gh

Beater, B.E. 1937. The measurement of phosphate fixation in soils. Soil Sci. 44:277-290.

Bertic, B, Vukadinovic, V, Kovacevic, V and Juric,I. 1988. Influence of liming on soil acidity and iron availability. Fac. Agric. Univ. Osijek, Osijek, 54000, Yugoslavia. J. Plant-Nutrition. 1988. 11:6-11

Bhumbla, D.R. and McLean E.O. 1965. Aluminium in soils: VI. Changes in pH-dependent acidity, cation-exchange capacity, and extractable aluminium with additions of lime to acid surface soils. Proc. Soil Sci. Soc. Amer. 29:370-374.

Bigham, J.M., Golden, D.C., Bowen L.H., Buol S.W., and Weed S.B. 1978. Iron oxide mineralogy of well-drained Ultisols and Oxisols: 1. Characterization of iron oxides in soil clays by Mossbauer Spectroscopy, X-ray diffractometry, and selected chemical techniques. Soil Sci. Soc. Am.. J. 42:816-825.

Birch, H.F., 1951. Relationship between base saturation and crop response to phosphate in acid soils. Nature 168:388-389.

Birrell, K.S. 1958. Reactions of amorphous soil colloids with ions in solution. New Zeal. Soc. Soil Sci. Proc. 3:11-13

Birrell, K.S. 1961. The adsorption of cations from solution by allophane in relation to their effective size. J. Soil Sci. 12:305-316.

Black, C.A. 1942. The penetration of phosphate into the kaolinite crystal. Soil Sci. Soc. Am. Proc 6:157-161.

University of Ghana http://ugspace.ug.edu.gh

Blake, G.R. and Hartge K.H. 1986. Bulk density P.363-375.*In* Klute, A.(Ed.). 1986. Methods of soil analysis. Part 1 (2nd edition) Physical and Mineralogical Methods.Agronomy Monograph no. 9. ASA –SSSA, Madison, Wisconsin.

Bonneau, M., Dambrine, E., Nys, C. and Ranger, J. 1987. Soil acidification. INRA, Cent. Recherches For, Champenoux 54280 Seichamps, France.

Bonsu, M. 1991. Effect of liming on maize production and erosion on an acid soil in SW Ghana. S.R.I., C.S.I.R., Kumasi, Ghana.

Brady, N.C. 1974. The Nature and properties of soils. 8th ed. Macmillan Pub. Co., Inc. New York, London.

Bradfield ,R. 1942. Calcium in the soil : I. Physico-chemical relations. Soil Sci. Soc. Am. Proc. 6 : 8-15.

Brammer , H. 1955. Detailed soil survey of the Kpong Pilot Irrigation Area. Gold Coast Dept. of Soil and Landuse Survey. Memoir No.1. S.R.I., Kumasi.

Brammer, H. 1967. Soils of the Accra Plains. Memoir No.3 S.R.I. Kumasi.

Bray, R.H. and Kurtz L.T. 1945. Determination of organic and available forms of phosphorus in soils. Soil Sci. 59:39-45.

Bremner, J.M. 1965. Total Nitrogen. P.1149-1178 *In* Methods of soil analysis. Part 2. Chemical and Microbiological properties.(Eds) C.A. Black. Agronomy monograph 9. ASA-SSSA, Madison, Wisconsin.

University of Ghana http://ugspace.ug.edu.gh

Broadbent, F.E., and Bradford G.R. 1952. Cation-exchange groupings in the soil organic fraction. Soil Sci. 74:447-457.

Brooke, H.D., Coventry, D.R., Reeves, T.G and Jarvis, D.K. 1989. Limimg and deep ripping responses for a range of field crops. Dep. Agric. and Rural Affairs. Rutherglen Res. Inst., Rutherglen, Vic. 3685, Australia.

Buol, S.W., Hole, F. D. and McCracken, R.J. 1980. Soil Genesis and Classification(2nd Edition). The Iowa State University Press, Ames.

Chang, M.L. and Thomas G.W. 1963. A suggested mechanism for sulphate adsorption by soils. Soil Sci. Soc. Am. Pro. 27:281-283.

Cline, M.G. 1961. The changing model of soil. Soil Sci. Soc. Am. Proc. 25 :442-445.

Coleman, N.T. and Craig, D. 1961. The spontaneous alteration of hydrogen clay. Soil Sci. 91:14-18.

Coleman, N.T., and Thomas, G.W. 1964. Buffer curves of acid clays as affected by the presence of ferric iron and aluminum. Soil Sci. Soc. Am. Proc. 28: 187-190.

Coleman, N.T. and Thomas, G.W. 1967. The basic chemistry of soil acidity. P 1-41 *In* R.W. Pearson and F. Adams (eds), Soil acidity and liming, Agron. Monograph Am. Soc. Agron., Madison, Wisconsin.

Coleman, N.T. Thomas G.W., IeRoux, F.H., and Bredell, G. 1964.Salt exchangeable and titratable acidity in bentonite-sesquioxide mixtures. Soil Sci. Soc. Amer. Proc. 28:35-37.

University of Ghana http://ugspace.ug.edu.gh

Coleman, N.T., Weed, S.B., McCracken, R.J. 1959a. Cation exchange capacity and exchange cations in Piedmont soils of North Carolina. Soil Sci. Soc. Am. Proc 23:146-149.

Coleman, N.T., Weed, S.B., McCracken, R.J. 1959b. Cation exchange capacity and exchangeable cations in Piedmont soils of North Carolina. Soil Sci. Soc. Am. Proc. 23:146-149.

Coleman, N.T., Kamprath, E.J. and Weed, S.B. 1959c. Liming, Advance Agron. 10:475-522.

Cronan, C.S. 1985. Chemical weathering and solution chemistry in acid forest soils: Differential influence of soil type, biotic processes, and H^+ deposition. *In* the chemistry of weathering. J.I. Drever (ed.). D. Reidel Pub. Co., Dordrecht, The Netherlands.

Crosson, P. 1992. The global supply of agricultural land. P. 155-170. *In* Public and Private roles in agric. dev. Proc. World Bank Washington D.C.,U.S.A

CTA(Netherlands).1994. Sustaining soil productivity in intensive African agriculture. Spore No.49, p.1-4.

Daugherty, L.A. and Arnold, R.W. 1982. Mineralogy and iron characterization of plinthitic soils on alluvial landforms in Venezuela. Soil Sci. Soc. Am. J. 46:1244-1252.

Davey, B.G and Conyers, M.K. 1988. Determining the pH of acid soils. Soil Sci. 146:141-150.

Day, P.R. 1965. Particle fractionation and particle size analysis. P.545-567. *In* Methods of soil analysis, part 1. Black C.A. (ed) Agronomy No.9 Am. Soc. Agron., Madison ,Wisconsin.

University of Ghana http://ugspace.ug.edu.gh

Edwards, J.H., Horton, B.D., White, A.W, Jr. and Bennett, O.L. 1985. Effects of fluidized bed combustion residue on pecan seedlings growth and nutrient content. Comm. Soil Plant Anal. 16:6,639-652.

Eswaran, H. 1987. Soil related constraints to agricultural development in Africa. F.A.O. World Soil Res. Reports. No. 62,15-21. Soil Man. supp. serv., Washington. D.C, USA.

Evans, C.E. 1968. Ion exchange relationships of aluminum and calcium in soils as influenced by organic matter. Ph.D thesis, N.C. State Univ. (order 68-14,651) Univ. Microfilms, Ann Arbor, Mich.

Falkengren-Grerup, U., Linnermark, N. and Tyler, G. 1987. Changes in acidity and cation pools of South Swedish soils between 1949 and 1985. Chemosphere 16: 10-12, 2239-2248.

F.A.O., 1963.Report on Survey of the Lower Volta River floodplain. Vol.II, Soil Survey and Land Classification. F.A.O., Rome.

Fuleky, G. 1978. Available phosphorus content of soil affected by P fertilization and its change in time. Comm. Soil Plant Anal. 9(9) : 851-863.

Gbadegesin, A. 1987. Soil rating for crop production in the savanna belt of South-Western Nigeria. Agric.-Systems (UK). Vol.23 (1) p 27-42. Dept. of Geography, Univ. of Ibadan, Nigeria.

Gillam, W.S. 1940. A study on the chemical nature of humic acid. Soil Sci. 49:433-453.

Goedert, W.J. 1987. Management of acid tropical soils in the Savanas of South America. Magt. of acid tropical soils for sustainable agriculture. IBSRAM Proc. No. 2. 1987. 109-127.

University of Ghana http://ugspace.ug.edu.gh

Cent. Pesquisa Agropecuaria dos Cerrados (CPAC), EMBRAPA, Planaltina-DF, Brazil.

Graaf, S. Van-der; Breman,H. 1993. Agricultural production : ecological limits and possibilities. Contribution to the Sahel ecology, economy and demography study. Rapports-PSS-Production-Soudano-Sahelienne (Netherlands). no. 3, 39p., CABO-DLO, Wageningen, Netherlands.

Gyori, D., Kisfalusi, F. and Palkovics, M. 1985. The influence of acidity on soil fertility. Agrokemia-es-Talajtan.34,73-76. Keszthely Agric. Univ., Keszthely, Hungary.

Hailu, Z. and Runge-Metzger, A. 1993. Sustainability of landuse systems: The potential of indigenous measures for the maintenance of soil productivity in sub-saharan Africa agriculture. A review of methodologies and research results. Tropical-Agroecology. Weikersheim, Margraf, Germany.

Halder, B.R. and Mandal, L.N. 1987. Effect of calcium carbonate on extractable aluminum content and availability of some nutrient cations in an acid soil of Assam under waterlogged condition. J. Indian Soc. Soil Sci. 35:1,35-40.

Haynes, R.J. and Swift, R.S. 1986. Effects of soil acidification and subsequent leaching on levels of extractable nutrients in a soil. Plant-Soil. 95:3,327-336. Agric Res. Div., Ministry of Agric and Fisheries. P.O. Box 24, Lincoln, Canterbury, New Zealand.

Heck, A.F. 1934. Phosphate fixation and penetration in soils. Soil Sci. 37:343-355.

Hibbard, P.I. 1935. Factors influencing phosphate fixation in soils. Soil Sci. 39:337-358.

University of Ghana http://ugspace.ug.edu.gh

Hsu, P.H. and Rich, C.I. 1960. Aluminum fixation in a synthetic cation exchanger. Soil Science Soc. Am. Proc.24:21-25.

Hsu, P.H., and Bates, T.F. 1964. Fixation of hydroxy-aluminum polymers by vermiculite. Soil.Science.Soc.Am. Proc. 28:763-769.

IBSRAM. 1987. AFRICALAND-Land development and management of acid soils in Africa II. Proc. no.7: 57-65.

Isbell, R.F. 1987. Pedological research in relation to soil fertility. Proc. IBSRAM inaugural workshop, No.2: 131-146.

Jackson, M.L. 1958. Soil chemical analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 498p.

Jackson, M.L. 1963a. Aluminum bonding in soils : A unifying principle in soil science. Soil.Science.Soc.Am. Proc. 27:1-10.

Jackson, M.L. 1963b. Interlayering of expansible layer silicates in soils by chemical weathering,p. 29-46. Clays and clay minerals. Proc. 11th Conf. Macmillan Co. (Pergamon), New York.

Jackson, M.L. 1964. Chemical composition of soils.71-141 *In* F.E. Bear (ed.) Chemistry of the soil. 2nd ed. Reinhold Publ. Corp., New York.

Jenny, H. 1941. Factors of soil formation, McGraw-Hill Book Co., Inc., New York..

Kamprath, E.T. 1967.Soil acidity and response to liming. Tech. Bull.4,Intern. Soil Testing Series,Soil Sci. Dept.,N.C.State Univ.,Raleigh.

University of Ghana http://ugspace.ug.edu.gh

Kern, H. 1985. Acidity and calcium carbonate contents in soils of the agricultural areas of Poland. Pamietnik-Pulawski. No.85, 189-196. Zaklad Gleboznastwa i Ochrony Gruntow, I.U.N.G., Poland.

Kessler, J.J. 1994. Usefulness of the human carrying capacity concept in assessing ecological sustainability of landuse in semi-arid regions. Agric.-Ecosystems-and-Envt. Dept. of Forestry, Agric. Univ., Wageningen, Netherlands.

Klute, A. and Dirksen, C. 1986. Hydraulic conductivity and diffusivity :laboratory methods.P 687-734 *In Methods of soil analysis, physical and mineralogical* ..Agronomy Monograph no. 9

Kohnke, H. 1950. The reclamation of coal mine spoils. Advance Agron. 2:317-349.

Krug, E.C. and P.J. Isaacson, 1984. Comparison of water and dilute acid treatment on organic and inorganic chemistry of leachate from organic-rich horizons of an acid forest soil. Soil Sci. 137:370-378.

Lewis,T.E. and Broadbent, F.E 1961. Soil organic matter-metal complexes : 4. Nature and properties of exchange sites. Soil Sci. 91:393-399.

Lindsay, W.L. 1979. Chemical equilibria in soils. John Wiley and Sons, New York.

MacDonald and Partners. 1987. Supplementary Soil Survey for Kpong Irrigation Project.

Mandal, S.K. and Dey, S.K. 1979. Effect of liming on phosphate transformation and availability in acid tea soils.Tocklai Exptl. Station,Tea Research Association, Tocklai, India.

University of Ghana http://ugspace.ug.edu.gh

Manrique, L.A. 1985. Effect of extreme soil acidity conditions on plant growth and yield of cassava.In Comms.-in- Soil-Science-and-Plant-Analysis.16:9,959-970.

Manrique, L.A. 1986. Effect of extreme soil acidity conditions on plant growth and yield of cassava. Tropical-Root-and-Tuber-Crops-Newsletter. 16-17, 27-36.

Manrique, L.A. 1987. Leaf area development and growth performance of cassava germplasm on a strongly acid Ultisol of Panama. In J.-of-Plant-Nutrition.10:6,677-698.

Mare, P.H.Ie. 1984. Limitations imposed by nutrient supply in tropical African soils. *In* Advancing agricultural production in Africa.Procs. of CAB's first Scientific conf.,p357-361.

Mehlich, A. 1942. Base saturation and pH in relation to soil type. Soil Sci. Soc. Am. Proc. (1941) 6:150-156.

Mehlich, A. 1943. The significance of percent base saturation and pH in relation to soil differences. Soil Sci. Soc. Am. Proc.. 7:167-174.

Mehlich, A. 1948. Determination of cation and anion exchange properties of soils. Soil Sci. 65:429-445.

Mehra, O.P.and Jackson, M.L. 1960. Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. . Clays Clay minerals. 317-327.

Miranda, L.N-de. 1985. Use of marine lime to correct soil acidity. Revista Brasileira de Ciencia do Suelo. 9:3, 245-248.

Moorman, F.R. 1963. Acid sulfate soils (cat clays) of the tropics. Soil Sci. 95: 271-275.

University of Ghana http://ugspace.ug.edu.gh

Mortensen, J.L. 1963. Complexing of metals by soil organic matter. Soil Sci. Soc. Am. Proc. 27:179-186.

Mortensen, J.L. and Himes, F.L. 1964. Soil organic matter. p 206-241. *In* F.E. Bear (ed.) Chemistry of the Soil. 2nd ed. Reinhold Publ. Corp., New York. .

Nakayama, L.H.I. 1986. Effect of lime on the pH and calcium, magnesium and aluminum contents of acid soils in cocoa plantation. Revista-Theobroma 16:4 243-247.

Nana-Sinkam, S.C. 1992. Food security or food self-sufficiency: Why should Africa increase its food production? F.A.O. Report No.2, FAO, Rome. 28pp.

Neller, J.R. and Comar, C.J. 1947. Factors affecting fixation of phosphorus in soils as determined with radioactive phosphorus. Soil Sci. 64:379-384.

Nikiforoff, C.C. 1953. Pedogenic criteria of climatic change pp. 189-200. In H. Shapley (ed.) Climatic change: Evidence, causes, and effects. Havard Univ. Press, Cambridge, Massachussets..

Nye, P. H., Craig, D., Coleman, N.T and Ragland, J.L. 1961. Ion-exchange equilibria involving aluminum. Soil Sc. Soc. Am. Proc. 25:14-17.

Oosten, A.M. van. and Cahill, E.J. 1986. Towards integrated soil conservation. Land- Use-Policy (U.K.).

Oteng, J.W. 1976. Fixation and some adsorption-desorption characteristics of ammnium and potassium in four Ghanian soils. Ph.D Thesis Fac. Grad. Studies, The Univ. of Guelph

University of Ghana http://ugspace.ug.edu.gh

Palte, H. D. 1992. Farming Unlimited?: quest for appropriate soil conservation in Ibo land. Centre for Inter. Coop. and Appropriate Tech. (CICAT), Delft Univ. of Technology., Delft, The Netherlands.

Perkins, A.T. 1945. Phosphate fixation by soil minerals. V. Time of reaction. Soil Sci. Soc. Am. Proc. 10:102-106.

Pratt, P.F. and Bair, F.L. 1962. Cation-exchange properties of some acid soils of California. Hilgardia 33: 689-706.

Pregitzer, K.S. 1981. Relationship among physiography, soils, and vegetation of the McCormic Experimental Forest,Upper Michigan. Ph.D Thesis. Univ. of Michigan.,Michigan, Ohio.

Pugh, A.J. and Du Toit, M. S. 1936. The composition and ionic exchange of ferric silicates and phosphates Soil Sci. 41:417-430.

Rechgigl, J.E. and Rechcigl, J.E. 1987. Alfafa growth on acid soils as influenced by Al, Ca, pH, and Mo. Virginia Polytech. Inst. and State Univ., Blacksburg, V.A 24061, U.S.A.

Rhoads, F.M., and A., Manning. 1989. Soybean, corn, and wheat yields with variable soil pH on plinthic Acrisols. Fertilizer Research. CAPut!':3, 137-142.

Rich, C.I. 1960. Aluminum in interlayers of vermiculite. Soil Sci. Soc. Am. Proc. 24:26-32.

Richardson, A.E., Henderson, A.P., James, G.S. and Simpson, R.J. 1988. Consequences of soil acidity and the effect of lime on the nodulation of Trifolium subterraneum L. growing

University of Ghana http://ugspace.ug.edu.gh

in acid soil. Plant and Soil Sci. section, Sch. of Agric. and For., Univ. Melbourne, Parkville 3052, Australia.

Robertson, R.H.S., Brindley, G.W and Mackenzie, R.C. 1954. Mineralogy of kaolin clays from Pugu, Tanganyika. Amer. Mineral. 39:118-138.

Ronse, A, Temmerman, L-de, Guns , M ,and Borgen, R-de. 1988. Evolution of acidity , organic matter content , and CEC in uncultivated soils of North Belgium during the past 25 years. Ministerie van Landbouw, Inst. Scheikudig Onderzoek, Museumlaan 5, B1980 Tervuren, Belgium.

Roth, C.H., Pavan, M.A., Chaves, J.C.D., Meyer, B. and Frede, H.G. 1986. Effect of lime and gypsum applications upon aggregate stability and water infiltration of a typic Haplorthox cultivated with coffee. Revista-Brasileira-de-Ciencia-do-Suelo. 10: 163-166.

Ruffin, E. 1821. On the composition of soils, and their improvement by calcareous manures. Amer. Farmer 3:313-320.

Ruffin, E. 1852. Essays on calcareous manures. P.71-84. J.W. Randolph, Richmond, Va.

Sahota,T. S. 1984 Effect of liming on soil acidity , weed infestation and yield of potato. Cent. Potato Res. Sta., Shillong 793 009, Meghlaya, India.

Samonte, H. P. 1985. Liming of acid soils grown to mungbean and soybean. College Agric., Univ Philippines Philippine Agriculturist. 68: 1, 29-43.

University of Ghana http://ugspace.ug.edu.gh

Sanchez, P.A. and Jot-Smyth, T. 1987. The IBSRAM acid tropical soils network: a progress report.In Africaland. Land Development. and managementt. of Acid Soils in Africa II. Proc. No.7.,CAPut!'-40., IBSRAM, Bankok , Thailand.

Schnitzer, M. and Gupta, U.C. 1964. Chemical characteristics of the organic matter extracted from the O and B2 horizons of a Gray Wooded soil. Soil Sci. Soc. Am. Proc. 28: 374-377.

Schnitzer, M. and Gupta, U.C. 1965. Determination of acidity in soil organic matter.Soil Sci. Soc. Am. Proc. 29:274-277.

Schofield, R.K. 1949. Effect of pH on electric charges carried by clay particles. J. Soil Sci. 1: 1-8.

Schwertmann, U. 1977. Transformation of hematite to goethite in soils. Nature (London) 232:624-625.

Schwertmann, U. and Jackson, M.L. 1964. Influence of hydroxy-aluminum ions on pH titration curves of hydronium-aluminum clays. Soil Sci. Soc. Am. Proc. 28:179-182.

Sharma, B.D. and S.P. Varshney. 1979. Available phosphorus in salt-affected soils. J. Indian Soc. Soil Sci. 27: 383-386.

Shil,nikov, I.A. 1987. Liming of acid soils as a factor of optimizing soil characteristics as well as the magnesium and calcium contents in the upper soil layer. All-Union Res. Inst. Fertilizer and Soil Sci., Moscow, USSR.

Siebert, S.F. 1987. Land use intensification in tropical uplands effects on vegetation, soil fertility and erosion. Forest Ecol..Management.. 21:1-2,37-56.

University of Ghana http://ugspace.ug.edu.gh

Siman, G. 1987. Acid-base balance. In Kungl Skogs och Landbruksakademiens Tidskrift. No. CAPut!', Supplement, 93-103. SLU, Uppsala, Sweden.

Singh, B.R. 1987. Amendments for soil acidity amelioration. In Africaland. Land Developmentt. and Management. of Acid Soils in Africa II. IBSRAM Proceedings No. 7., 241-259.

Singh, B.R. 1989. Evaluation of liming materials as ameliorants of acid soils in high rainfall areas of Zambia. Norwegian J. Agric. Sciences. 3:1,13-21.

Sjöstrom, J., and Qvarfort, U. 1992. Long- term changes in soil chemistry in central Sweden. Soil Sci. 154:450-457.

Skinner, S. I. M.,Halstead, R. L. and Brydon, J. E. 1959. Quantitative manometric determination of calcite and dolomite in soils and limestones. Can. J. Soil Sci. 39: 197-204.

Soil Survey Staff. 1997. Keys to Soil Taxonomy, 7th ed., Soil Conservation Service, USDA, Blacksburg,VA .

Sumner, M.E. 1963. Effect of iron oxides on positive and negative charges of clays and soils. Clay Mineral Bull. 5:218-226.

Sumner, M.E., Fey. M.V. and Noble, A.D. 1991. Nutrient status and toxicity problems in acid soils. P.149-183. *In* Soil Acidity. B. Ulrich and M.E. Sumner (eds). Springer-Verlag, New York.

Tamm, C.O. and Haubacken, L. 1986. Changes in soil pH over a 50-year period under different forest canopies in SW Sweden. Water Air Soil Pollution. 31:337-341.

University of Ghana http://ugspace.ug.edu.gh

Taylor,C.T. 1952. The vegetation zones of the Gold Coast. Bulletin No. 4 Govt. Printer, Forestry Dept, Accra.

Thomas, G .W. 1982. Exchangeable cations. *In* Methods of Soil Analysis. Part 2. A.L. (ed), second edition. Agronomy No. 9, Madison , Wisconsin , U.S.A. pp. 159-164.

Thomas, G.W. and Coleman, N.T. 1959. A chromatographic approach to the leaching of fertilizer salts in soils. Soil Sci. Soc. Am. Proc. 23: 113-116.

Thomas, G.W.,and Swoboda,A.R. 1963. Cation exchange in kaolinite-iron oxide systems. 321-326. *In* W.F. Bradley [ed.] Clays and Clay minerals, Proc. 11th Conf. Macmillan Co., New York.

Unruh,L.G 1989.Influence of surface soil acidity in South Central Kansas on common hard winter wheat and grain sorghum cultivars. Kansas State Univ., Kansas city , Kansas.

van Bavel, C.H.M. 1950. Mean weight diameter of soil aggregates as a statistical index of aggregation.Soil Sci. Soc.Am. Proc. 14: 20-23.

van Breemen, N., Mulder, J and Driscoll, C.T. 1983. Acidification and alkanization of soils. Plant Soil 75: 283-308.

Volk, V.V., and Jackson, M.L. 1964.Inorganic pH dependent cation exchange charge of soils. P.281-285.*In* W.F.Bradley [ed.] Clays and Clay Minerals, Proc. 12th Conf. Pergamon Press Ltd., New York.

University of Ghana http://ugspace.ug.edu.gh

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.

Watanabe, F.S. and Olsen, S.R. 1965. Test of an ascorbic method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc Am. Proc 29:677-678.

Whelan,A.M. and M. Alexander.1986. Effects of low pH and high Al, Mn and Fe levels on the survival of *Rhizobium trifolii* and the nodulation of subterranean clover. Plant Soil. 92: 363-371.

Wood A.W. 1979. The effects of shifting cultivation on soil properties : an example from the Karimui and Bomai Plateaux, Simbu Province, Papua New Guinea. Papua New Guinea Agric J. 30:.1-9.

Wong-Chong, G, and R.C. Loehr. 1978. Kinetics of microbial nitrite nitrogen oxidation. Water Res. 12: 605-609.

Xu, W.B., Yue, J.L., Wen, J.L., Hu, H., Yang, F.R. and Wu, Z.G. 1986. Experiment on soil amelioration with lime in stands of Aleurites fordii. Forest-Sci.Tech. 10:23-25.

Yost, R., Itoga, S., Li, C.L. and Kilham, P. 1986. Soil acidity management with expect systems. P.225-236. *In* Soil Management. under Humid Conditions in Asia and the Pacific. IBSRAM Proc. No.5., IBSRAM ,Bangkok, Thailand.

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APPENDICES

APPENDIX 1A LABORATORY ANALYTICAL DATA ON PEDON 1 (KPENU PROFILE)

Depth (cm)	Particle Size Distribution by Weight (2mm) %			Textural Class	pH		Organic Carbon %	Organic Matter %
	Sand 2.0-.05	Silt 0.05-0.002	Clay <0.002		1:1 H_2O	1:2 0.01M$CaCl_2$		
0-12	30.3	32.1	37.5	Clay loam	5.0	4.2	1.57	2.71
12-25	24.6	32.7	42.7	Clay	4.8	3.9	1.96	3.37
25-52	23.16	25.6	51.2	Clay	5.1	3.8	1.08	1.86
52-80	12.2	25.6	61.9	Clay	5.1	3.9	1.32	2.28
80-113	10.5	39.5	50.0	Clay	5.2	4.7	0.61	1.06
113-150	14.9	33.5	51.5	Clay	5.5	5.2	0.66	1.14
150-200	19.6	31.1	49.3	Clay	5.2	5.0	1.32	2.28

APPENDIX 1B LABORATORY ANALYTICAL DATA ON PEDON 1 (KPENU PROFILE

Depth (cm)	Available P(mg/kg)	Total P (mg/kg)	N %	C:N	%Fe	Bulk Density (g/cm)	Aggregate Stability (mm)	Hydraulic conductivity (cm/sec)	Extractable Bases cmol(+)/kg			
									Ca	Mg	K	Na
0-12	9.05	243.5	0.15	10.5	5.49	1.1	6.94	2.25×10^{-2}	5.4	5.9	0.24	0.10
12-25	3.40	177.0	0.16	12.3	6.93	1.3	9.92	3.98×10^{-2}	5.2	5.4	0.15	0.11
25-52	7.85	120.0	0.11	9.8	4.00	1.4	6.44	3.77×10^{-2}	4.1	4.1	0.13	0.15
52-80	4.94	144.0	0.12	11.0	4.94	1.3	8.66	1.03×10^{-2}	6.0	6.1	0.13	0.24
80-113	4.44	188.0	0.09	6.8	5.38	1.5	8.71	1.52×10^{-3}	6.7	7.2	0.11	0.30
113-150	6.85	143.0	0.07	9.4	5.58	1.5	8.65	4.86×10^{-4}	7.1	8.0	0.12	0.40
150-200	4.41	183.0	0.04	33.0	4.13	1.6	7.74	2.7×10^{-3}	6.0	6.4	0.13	0.41

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APPENDIX 1C LABORATORY ANALYTICAL DATA ON PEDON 1 (KPENU PROFILE

Depth (cm)	Sum of Bases (cmol(+)/kg)	Exchange Acidity (cmol(+)/kg)		CEC (cmol(+)/kg) By Sum of Cations	P.B.S Sum of Cations	CEC By NH_4OAc pH 7	P.B.S NH_4OAc pH 7
		Al	Al + H				
0-12	11.64	0.55	1.00	12.64	92	38	31
12-25	10.86	2.05	2.80	13.66	79	36	30
25-52	8.48	3.60	3.80	12.28	69	30	28
52-80	12.47	2.60	3.20	15.67	79	39	32
80-113	14.31	0.30	0.43	14.74	97	36	40
113-150	15.62	0.20	0.30	15.92	98	34	46
150-200	12.94	0.20	0.23	13.17	98	28	46

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APPENDIX 2A LABORATORY ANALYTICAL DATA ON PEDON2 (VOLIVO PROFILE)

Depth (cm)	Particle Size Distribution by Weight (2mm) %			Textural Class	pH		Organic Carbon %	Organic Matter %
	Sand 2.0-.05	Silt 0.05-0.002	Clay <0.002		1:1 H_2O	1:2 0.01McaCl$_2$		
0-6	40.2	33.8	25.9	Clay loam	5.4	4.5	0.74	1.28
6-21	27.9	36.0	36.0	Clay loam	5.2	4.1	1.30	2.23
21-53	47.7	19.0	33.3	Sandy clay loam	5.4	4.6	1.36	2.34
53-85	70.5	11.0	18.4	Sandy loam	5.7	5.4	0.21	0.36
85-110	76.3	0.0	23.7	Sandy clay loam	5.9	5.5	1.97	3.39
110-160	94.0	3.0	3.0	Sand	6.2	5.5	0.72	1.24
160-200	100.0	0.0	0.0	Sand	6.7	5.9	1.22	2.11

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APPENDIX 2B LABORATORY ANALYTICAL DATA ON PEDON 2 (VOLIVO PROFILE)

Depth (cm)	Available P(mg/kg)	Total P (mg/kg)	N %	C:N	%Fe	Bulk Density (g/cm)	Aggregate Stability (mm)	Hydraulic conductivity (cm/sec)	Extractable Bases cmol(+)/kg			
									Ca	Mg	K	Na
0-6	6.62	173.0	0.11	6.7	1.34	1.4	7.90	1.0 x 10^{-2}	5.8	2.3	0.41	0.04
6-21	3.54	124.0	0.11	11.8	1.38	1.5	8.45	1.3 x 10^{-2}	7.8	1.6	0.22	0.06
21-53	5.87	121.0	0.08	17.0	3.52	1.6	8.46	1.0 x 10^{-2}	7.8	2.7	0.20	0.09
53-85	5.70	70.0	0.07	3.0	2.59	1.7	7.92	1.6 x 10^{-2}	5.8	2.7	0.19	0.06
85-110	6.65	85.0	0.06	32.8	2.59	1.6	8.16	3.3 x 10^{-2}	6.6	2.2	0.21	0.05
110-160	5.94	66.0	0.06	12.0	2.94	1.4	Sand	1.04 x 10^{-1}	2.0	0.6	0.11	0.08
160-200	8.28	53.5	0.05	24.4	1.59	1.3	Sand	2.8 x 10^{-1}	0.6	1.0	0.05	0.02

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APPENDIX 2C LABORATORY ANALYTICAL DATA ON PEDON 2 (VOLIVO PROFILE

Depth (cm)	Sum of Bases (cmol(+)/kg)	Exchange Acidity (cmol(+)/kg)		CEC (cmol(+)/kg) By Sum of Cations	P.B.S Sum of Cations	CEC By NH_4OAc pH 7	P.B.S NH_4OAc pH 7
		Al	Al + H				
0-6	8.55	0.4	0.5	9.05	94	24	37
6-21	9.68	0.6	0.7	10.38	93	32	30
21-53	10.79	0.3	0.3	11.09	97	22	49
53-85	8.75	0.2	0.2	8.95	98	18	49
85-110	9.06	0.2	0.2	9.26	98	19	48
110-160	2.79	0.1	0.1	2.89	96	7	40
160-200	1.67	0.1	0.1	1.77	94	4	42

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APPENDIX 3A LABORATORY ANALYTICAL DATA ON PEDON 3 (TOKPO PROFILE)

Depth (cm)	Particle Size Distribution by Weight (2mm) %			Textural Class	pH		Organic Carbon %	Organic Matter %
	Sand 2.0-.05	Silt 0.05-0.002	Clay <0.002		1:1 H_2O	1:2 0.01M$CaCl_2$		
0-12	65.5	18.3	16.2	Sandy loam	6.9	6.6	2.79	4.82
12-32	61.8	17.0	21.2	Sandy clay loam	7.1	6.8	1.95	3.36
32-54	47.6	19.6	32.7	Sandy clay loam	7.0	6.5	1.20	2.07
54-72	53.7	17.1	29.2	Sandy clay loam	7.4	7.0	1.02	1.76
72-95	27.2	26.5	46.3	Clay	7.4	7.1	1.63	2.80
95-140	62.5	12.5	25.0	Sandy clay loam	7.6	7.2	1.27	2.19
140-180	69.8	11.3	18.9	Sandy clay loam	7.6	7.0	0.90	1.55

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APPENDIX 3B LABORATORY ANALYTICAL DATA ON PEDON 3 (TOKPO PROFILE)

Depth (cm)	Available P(mg/kg)	Total P (mg/kg)	N %	C:N	%Fe	Bulk Density (g/cm)	Aggregate Stability (mm)	Hydraulic conductivity (cm/sec)	Extractable Bases cmol(+)/kg			
									Ca	Mg	K	Na
0-12	84.30	632.0	0.21	13.3	0.81	1.1	7.19	1.76×10^{-2}	13.0	2.4	0.95	0.04
12-32	52.38	380.0	0.18	10.8	0.47	1.3	7.01	1.96×10^{-2}	14.2	1.8	0.69	0.03
32-54	25.11	584.0	0.13	9.2	0.62	1.5	7.41	1.36×10^{-2}	17.0	1.9	0.33	0.04
54-72	6.78	1444.0	0.12	8.5	0.51	-	7.48	1.92×10^{-2}	32.5	0.7	0.33	0.05
72-95	17.22	1284.0	0.05	32.6	0.48	-	6.68	3.68×10^{-2}	24.7	0.3	0.30	0.05
95-140	8.72	1212.0	0.11	11.5	1.28	-	6.90	2.87×10^{-2}	32.1	0.3	0.32	0.06
140-180	22.80	808.0	0.11	8.2	1.37	-	6.73	2.08×10^{-2}	6.6	1.4	0.23	0.05

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APPENDIX 3C LABORATORY ANALYTICAL DATA ON PEDON 3 (TOKPO PROFILE)

Depth (cm)	Sum of Bases (cmol(+)/kg)	Exchange Acidity (cmol(+)/kg)		CEC (cmol(+)/kg) By Sum of Cations	P.B.S Sum of Cations	CEC By NH_4OAc pH 7	P.B.S NH_4OAc pH 7
		Al	Al + H				
0-12	16.39	0.2	0.2	16.59	99	38	43
12-32	16.72	0.1	0.1	16.82	99	34	49
32-54	19.27	0.1	0.1	19.37	99	46	42
54-72	33.58	0.1	0.1	33.68	100	40	84
72-95	25.35	0.1	0.1	25.45	100	38	67
95-140	32.78	0.1	0.1	32.88	100	34	96
140-180	8.28	0.1	0.1	8.38	99	34	24

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APPENDIX 4. Detailed Profile Descriptions

Appendix 4.1 Pedon 1

Profile Number		1
Soil Series		Amo (Pedon 1)
Higher Category Classification		USDA: Vertic Dystropept
		FAO: Vertic Cambisol
Date of examination		20th October ,1997.
Location		Near Kpenu Village about 500m off the Akuse-Asutsuare road (Long. 00^{0} $08^{\prime}$ $39.4^{\prime\prime}$E, Lat 06^{0} $06^{\prime}$ $13.1^{\prime\prime}$N)
Physiographic position		Gentle convex slope.
Slope	:	0-1%.
Vegetation and Land use	:	Tall grass
Parent material		Volta alluvium
Drainage	:	Moderately well drained
Moisture condition in soil	:	Profile dry throughout
Depth of groundwater	:	Not encountered
Presence of surface stones and rock Outcrops:		None
Evidence of Erosion	:	None
Human influence	:	About 5- year fallow farmland
Author	:	W. H . K. Dorgbetor

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Horizon	**Depth (cm)**	**Description**
Au1	0 – 12	Dark brown (7.5 YR 3/4) moist, light yellowish brown (10 YR 6/4) dry; sandy clay loam; weak fine granular; slightly sticky, slightly plastic wet, firm moist; abundant fine and few medium roots; clear smooth boundary; pH 5.0.
Au2	12 - 25	Dark brown (10 YR 3/4) moist, light yellowish brown (10 YR 6/4) dry; sandy clay loam; moderate medium subangular blocky; slightly sticky, slightly plastic wet, firm moist; few vertical cracks; frequent fine and few medium roots; clear smooth boundary; pH 4.8.
AB	25 - 52	Light yellowish brown (10 YR 6/4) moist, dark yellowish brown (10 YR 4/6) dry; clay; few fine faint yellowish (10 YR 7/6) mottles; moderate medium subangular blocky; slightly sticky, slightly plastic wet, firm moist; frequent fine roots; clear smooth boundary; pH 5.1.

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Bw1	52 - 80	Light yellowish brown (10 YR 6/4) moist, bright yellowish brown (10 YR 4/6) dry; clay; few fine faint yellowish (10 YR 7/6)mottles; moderate medium subangular blocky; slightly sticky, slightly plastic wet, firm moist; frequent fine roots; clear smooth boundary; pH 5.1.
Bw2	80 - 113	Yellowish brown (10 YR 5/6) moist, yellowish orange (10 YR 7/4) dry; clay; common medium distinct black (10 YR 2/1) mottles; moderate medium angular and subangular blocky; sticky, plastic wet, firm moist; very few very fine roots; clear wavy boundary; pH 5.2.
Bw3	113 - 150	Yellowish brown (10 YR 5/6) moist, yellowish orange (10 YR 7/4) dry; clay; moderate medium angular and subangular blocky; sticky, plastic wet, firm moist; very few very fine roots; clear smooth boundary; pH 5.5.

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Bw4	150 - 200	Yellowish brown (10 YR 5/6) moist, bright yellowish brown (10 YR 6/6) dry; clay; moderate medium angular and subangular blocky; sticky; plastic wet, firm moist; clear smooth boundary; pH 5.2.

Appendix 4.2 **Pedon 2**

Profile Number : 2

Soil Series : Amo (Pedon 2)

Higher Category Classification : USDA: Vertic Dystropept
: FAO : Vertic Cambisol

Date of examination : 2nd November 1997

Location : Near Volivo Village 500m downslope, west of oyster shell deposit area (Long. 00^{0} 15$^{/}$ 36.2$^{//}$ E, Lat. 0.6^{0} 05$^{/}$ 26.8$^{//}$)

Physiographic position : Gentle convex slope

Slope : 0-1%

Vegetation and Land use : Tall grass

Parent material :Volta alluvium

Drainage : Moderately well drained

Moisture condition in soil : Upper part of profile dry

Depth of groundwater : Encountered at the 195cm depth

Presence of surface stones and rock outcrops : None

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Evidence of erosion : Nil

Human influence : About 5-year fallow farmland

Author : W. H. K. Dorgbetor

Horizon	**Depth (cm)**	**Description**
Au1	0 - 6	Dark Brown (10 YR 3/3) moist, dull yellow orange (10 YR 6/3) dry; clay loam; weak fine granular; slightly sticky, slightly plastic wet, firm moist; few vertical cracks; abundant fine and medium roots; clear smooth boundary; pH 5.4.
Au2	6 - 21	Brown (10 YR 4/4) moist, light yellowish brown orange (10 YR 6/4) dry; clay; moderate medium subangular; blocky; slightly sticky, slightly plastic wet, firm moist; frequent fine and few medium roots; clear smooth boundary; pH 5.2.
Bw1	21 - 53	Brown (7.5 YR 4/6) moist, bright brown (7.5 YR 5/6) dry; clay; few fine faint dull yellow orange (10 YR 6/3) mottles; moderate medium subangular blocky; slightly sticky, slightly

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		plastic wet, firm moist; few fine roots; clear smooth boundary; pH 5.4.
Bw2	53 - 85	Dull orange (7.5 YR 7/2) moist, dull yellow orange (10 YR 7/2) dry; sandy clay loam; common medium prominent black (5 YR 1.7/1) and bright reddish brown5/8)mottles; moderate medium subangular blocky; sticky, and plastic wet, firm moist; very few very fine roots; clear smooth boundary; pH 5.7.
Bw3	85 110	Grayish yellowish Brown (10 YR 6/2) moist, light gray (7.5 YR 8/2) dry; sandy clay loam; common medium distinct brown (7.5 YR 5/8) and brownish black mottles; moderate medium subangular blocky; sticky, slightly plastic wet, firm moist; few very fine roots; frequent soft MnO_2 concretions and stains; clear wavy boundary; pH 5.9.
Cg	110 - 160	Dark greenish brown (10 YR 4/2) moist, light brownish grey (10 YR 7/6) sand; black (10 YR 5/1) and grey (10 YR 2/1) mottles; moderate

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		medium subangular blocky; sticky and plastic wet, firm moist; clear wavy boundary; pH 6.2.
2Cg	160 - 200	Yellowish red (5 YR 5/8) moist, reddish yellow (5YR 6/8) dry; sand; many large prominent white (7.5 YR 8/1) pinkish white (7.5 YR 8/2) mottles; single grained; non sticky, loose moist; pH 6.7.

Appendix 4.3 Pedon 3

Profile Number	:3
Soil Series	;Amo (Pedon 3)
Higher Category Classification	:USDA: Vertic Ustropept
	:FAO : Calcaric Cambisol
Date of examination	:14th November, 1997.
Location	:Near Tokpo village on oyster shell deposit area.
Physiographic position	:Gentle convex slope
Slope	: 0 - 1%
Vegetation and Land use	:Tall grass
Parent material	:Volta alluvium
Drainage	:Moderately well drained
Moisture condition in soil	Profile dry throughout
Depth of groundwater	Not encountered
Presence of surface stones and rock-	

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Outcrops	None
Evidence of erosion	Nil
Human influence	Recently cultivated to maize and cassava
Author	W.H.K. Dorgbetor

Horizon	**Depth (cm)**	**Description**
Ap	0 - 12	Brownish black (10 YR 2/3) moist, dull yellow brown (10 YR 5/3) dry; sandy clay loam; weak fine granular; slightly sticky, slightly plastic wet, firm moist; abundant fine and medium roots; clear smooth boundary; pH 6.9.
Au1	12 - 32	Brownish black (10 YR 2/2) moist, grayish yellowish brown (10 YR 4/2) dry; sandy clay loam; weak fine granular; slightly sticky, slightly plastic wet, firm moist; abundant fine and medium roots; clear smooth boundary; pH 7.1.
Au2	32 - 54	Brownish black (10 YR 3/2) moist, dull yellowish brown (10 YR 4/3) dry; sandy clay loam; moderate medium subangular blocky; slightly sticky, slightly plastic wet, firm moist;

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		pieces of pottery, several pieces of oyster shells, clear smooth boundary; pH 7.0.
Bw1	54 - 72	Dark Brown (10 YR 3/3) moist, dull yellowish brown (10 YR 5/3) dry clay; moderate medium subangular blocky; sticky and plastic wet, firm moist; abundant shells mixed with broken pieces of pottery; frequent medium roots; clear smooth boundary; pH 7.4.
Bw2	72 - 95	Dark brown (10 YR 3/4) moist, light yellow orange (10YR 8/4) dry ; clay ; moderate medium angular and subangular blocky; sticky, and plastic wet, firm moist; several pieces of oyster shells, frequent pieces of pottery; frequent medium roots; clear smooth boundary;pH 7.4.
Bw3	95 - 140	Dark brown (10 YR 3/3) moist, dull yellowish brown (10 YR 5/3) dry; sandy clay loam; moderate medium angular and subangular blocky; slightly sticky; slightly plastic wet, firm moist; several oyster shells and few snail shells

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		with very little soil; frequent medium roots; clear smooth boundary; pH 7.6.
Bw4	140 - 180	Dull yellow brown (10 YR 4/3) moist, dull yellow orange (10 YR 7/4) dry sandy clay loam; moderate medium angular and subangular blocky; sticky and plastic wet, firm moist; abundant oyster shells and few broken pieces of pottery;few fine roots; clear smooth boundary; pH 7.6.