ASPECTS OF TROPICAL SOIL DEVELOPMENT IN KWALE DISTRICT, KENYA.

JOHN MAKIN.

National Agricultural Laboratory, Kenya.

INTRODUCTION:

The object of this paper is to highlight some interesting soil features evident in the country between the Shimba Hills and the Kenya Coast. Dale (1939), in his descriptions of Coastal vegetation, mentioned several possible edaphic relationships, and a superficial outline of Coastal Ecology has been presented by Moomaw (1960). Otherwise, Kwale has been neglected so far as soil investigations are concerned. Yet there, possibly more than anywhere else in Kenya, one finds an unusually close relationship between soil type and topography on the one hand, and country rock on the other. On slopes however, this classical picture is profoundly distorted by both Colluviation (the transport, sorting and redeposition of soil parent materials downslope), and also the influence of percolating soil water moving laterally across the profile.

This paper does not contain comprehensive descriptions of the soils discussed, nor are analytical data provided. These details are included in "The Soils in the Country around Shimba Hills Settlement, Kikoneni and Jombo Mountain" (Makin; 1968)

Acknowledgements:

I would like to express my gratitude to Victor D'Costa, who assisted in the field work; and to those other members of the Soil Survey who endured several months in Camp. Soil

......../2

analyses were performed by the National Agricultural Laboratory: particular tribute is due to Mr. G. Hinga and Mr. R. Leyder.

The Coastal Environment:

The Coastal (Eastern) side of Kwale District lies within the warm, humid and equable belt of 'Coastal Influence', having a mean annual temperature of around 80°F. and an average daily temperature range of about 14°F. The rainfall varies between 1700 and 1000 m.m. with a maximum on the Coast between Gazi and Msambweni. Inland, there is a dramatic decline in rainfall which is only partially reversed by the orographic influence of the Shimba Hills. It is, however, the length and severity of the dry season that is of the utmost agronomic significance. Between April and July, just over half the total rainfall is received. Indeed, significant rainfall cannot be relied upon in any month other than April and May, and even these rains fail on occasion. Mean relative humidity exceeds 80% except through January to March. The potential evaporation (Penman - Eo) varies with cloud cover but seems to be in the range 1900 to 2200 m.m. In any case, evapotranspiration significantly exceeds precipitation except during the long rains.

Little of the contemporary vegetation cover can be described as 'natural' in the strict sense. The chief community may be defined as 'Open high grass - bushland', with patches of remnant forest largely maintained by leaf condensation in ultra-humid microclimates. Old mango trees scattered over the countryside testify to the extent to which it was once occupied.

The geology of the area has been comprehensively described

......../3

by Caswell (1953).

Coral Soils:

The plain lying immediately behind the littoral comprises variable deposits of Pleistocene and more recent corals, marine sands, dunes, mixed lagoon deposits and local alluvium. In certain situations, a dark reddish brown and somewhat calcareous loam or clay loam terra rossa has developed *in situ* from the coral. The exchange complex is dominated by calcium with a surface pH of between 6 and 7.5. There is normally an abrupt transition between soil and underlying coral blocks. These soils are normally contaminated by wind-blown fine sands which are thoroughly integrated with the terra rossa. Hence soil textures are often coarser than expected. The presence of this sand also has the effect of lowering the pH. These aeolian sands affect much of the Coast Plain and will not be considered further.

Magarini "Sands".

These so-called sands form a belt of low hills and plain country inland from the Coast, though it is evident that their extent has been exaggerated by Caswell. The deposit is generally poorly stratified, ill-sorted and unconsolidated, varying in texture from silty clay to coarse quartz gravels, and having a wide range of properties depending upon the texture of the parent material and the topographic situation. Serious consequences have therefore resulted from the injudicious application of the essentially stratigraphic term "Magarini" to the large number of soil types that develop upon this diverse formation.

Within the triangle between Mafisini, Mrima and Ramisi, there are extensive slightly undulating erosion deposits of coarse whitish and extremely infertile deep quartzitic sands; these normally contain less than 10% clay. On higher-lying sites where the ground water is at a considerable depth, the associated vegetation (characteristically including the palm - Hyphaene parvula) is largely xerophytic, the surface organic content is normally less than 0.5% and much of the clay fraction is composed of kaolin. Where however there is seasonally high ground water and the profile is distinctly mottled, there may be up to 15% of poorly crystallized montmorillonite in the clay fraction and a surface accumulation of 2% organic material. In these lower-lying sites, the natural vegetation is often dominated by the bracken fern (Pteridium aquilinum)

Superficial Sandy Deposits:

Rather extensive deep drifts of superficial sandy loams cover areas of South Shimba, Mkundi and parts of the Lower Ramisi Valley. Though unrecorded on the geological map, these deposits are of considerable importance since they mask the underlying sandstones. Similar patches of sandy loam, capping certain hill tops in the area of the Shimba Hills Settlement Scheme, appear to be relic deposits. These are regarded as remnants of a previous cycle of erosion, derived primarily from the Mazeras sandstone after the Pliocene.

The well drained soils normally comprise pale brown and very friable sandy loam, which becomes gradually coarser with depth. There is little or no evidence for profile development, though the permeability is such that the soil must be subject to marked leaching. The pH ranges between 5 and 6 throughout the profile. Though the topsoil clay is dominated by kaolin, the proportion of illite increases markedly with depth.

South of Shimba Hills, these deep sandy loams tend to be seasonally poorly drained, with distinct mottling near the surface and gleied subsoils, even on upper slopes. This is surely remarkable in a soil that contains less than 25% clay throughout the profile, though it may be explained by reference to the chemical composition. Horizons below about 75 cms., though acid in terms of pH, suffer an accumulation of both sodium and magnesium; e.g. a subsoil just North of the Ramisi River had a pH of 5.5 and exchangeable sodium percentage of 26! Presumably the subsoil sodium induces clay dispersion and consequent low permeability. This has the effect of causing acid seepage to flow across the slope through the sub-surface horizon. Consequently this intermediate layer is leached and acidified (mean pH = 5.3; permanent charge acidity = 1.3 m.e. %). The movement of this seepage permits the accumulation, in the dry season, of significant levels of electrolyte within the surface horizon.

This sandy loam neatly demonstrates the influence of soil solutions upon clay mineral formation. Topsoils are dominated by kaolin and illite; the acid sub-surface by kaolin alone; and the alkaline subsoil by kaolin and montmorillonite.

- TABLE I -

Bedrock and Topography:

Throughout Kwale District, there is a strong correlation between topography and the texture of the bedrock, whilst the drainage patterns admirably illustrate the lithological variations of the Duruma Sandstones (Table 1). Thus the more upstanding

......../6

conical hill features in the Shimba Hills, with characteristically broken landscape and steeply incised valleys, are underlain by massive coarse sandstones, whilst the coarsest Shimba Grits form a resistant capping to the highest summits. In contrast, the relatively gentle topography of the Bambakofini basin is developed on finer textured sandstones; and the country to the South of Shimba is underlain by fine sandstones that give rise to long ridges and allow the formation of broad U-shaped valleys along their strike.

Sandstone Soils:

Though soil development has progressed in a broadly similar direction upon both the coarse (Mazeras) sandstone and the very much finer (Maji-ya-Chumvi) beds, mentioned above, the differences between the resulting soils are considerable.

The fundamental distinction stems from differences in the texture of the parent material. Fine sandstone topsoils average 24% clay (11% more then coarse sandstone soils); subsoils average 40% clay (12% more); and moreover the silt content is higher and the sand fraction appreciably finer.

All the sandstone soils suffer a downward translocation of silica, bases and finer clay minerals; but the coarser sands are of course the more permeable and hence experience a greater degree of leaching. This intensive leaching serves to remove the weathering products more rapidly, so promoting more complete decomposition of the felspars; and hence higher quartz: felspar ratios and, also, a deeper solum. Whilst the coarse sandstone subsoils may demonstrate textural homogeneity to depths below

....../7

2 metres, the fine sandstone soils show increasing proportions of clay throughout the solum, until a layer of gravels and decomposing rock is reached at a mean depth of around 100 to 120 cms.

It also follows that soils with a lower colloid content will have a less effective adsorption capacity. The combined effect of high permeability with low adsorption results in soils low in both organic matter and fertility. Thus, compared with the coarse types, the fine sandstone soils have about four times the level of available calcium. There is also a marked contrast in the clay mineralogy. Whilst the coarse sandstone soils are predominantly kaolinitic with between 25 and 40% of illite; the finer soils have almost equal amounts of kaolin and illite in the topsoil, though the proportion of illite decreases with depth. It is to be remarked that the fine topsoils may contain up to 10% montmorillonite, despite the excellency of the drainage.

Soil Acidity:

Another difference between the sandstone soils lies in the relatively high level of permanent charge acidity found in coarse sandstone soils in contrast with its virtual absence elsewhere. There is however one striking similarity. This is the steady decrease in pH with depth, which invariably occurs beneath grassland, light bush or cultivation. Whilst the topsoil pH is between 5.5 and 6.5, subsoils are around pH 5, with even lower values associated with subsoil gravels (Maji-ya-Chumvi). Possibly the first to draw attention to this phenomenon were Gracie and Le Poer Trench in 1931. Doyne (1935) indicates that increase in acidity with depth is a common feature in Nigerian soils. It has also been noted (by the author) in well drained soils in the Samia area of the Lake Victoria basin.

There is presumably a concentration in the topsoil of bases drawn up by roots from considerable depths. The increasing subsoil acidity is apparently associated with permeable and acidic parent materials that are affected by periodic leaching and uniformly high temperatures.

Forest Soils:

Although the percentage of carbon under Shimba forest is very similar to that under grass, the forest litter is so light in colour that the soil surface may be red or even whitish; whilst grasslands are covered by a very dark brown organic accumulation. The forest litter is subject to rapid decomposition, in the course of which much free acid is liberated (mean topsoil pH under forest is 4.5). Consequently the infertile profiles are severely leached of bases. There is therefore a tendancy for pH levels to increase with depth in contrast to the situation elsewhere. Russell (1961), amongst others, has emphasised the vital role played by tropical forest in maintaining a nutrient cycle. This certainly does not seem to apply in the Shimba Hills. Furthermore Lehrer (1966) has shown that remaining forest phosphates and potassium are in no way depleted through cultivation. He attributes the decline in yields on previously virgin land at Shimba as being due to the initial boost given to the crop by nutrients supplied during land preparation; e.g. accumulation of tree ash. Thus the early harvests reflect a nutrient level higher than an analysis of the forest soil would indicate as being probable. Dale proposed that the loss of soil nutrients following forest destruction limits its potential for regeneration. Since we now know that this proposition was based upon a false premise, some other factor must be involved.

Seedlings of Chlorophora excelsa fail to become established when planted out in open plots. Some natural regeneration is, however, evident along the margins of the existing forest on the same soil. These observations surely support the contention that it is the level of soil moisture that determines the success of forest establishment. Owing to the relatively low rainfall, it is only in the humid microclimate provided by existing forest that seedlings can thrive.

Colluviation and Slope Acidification:

Over the years, the steep Shimba topography has experienced constant colluviation. Consequently only soils on almost level surfaces are developed in situ. All other soil profiles are a result of differential transportation. Whilst coarse fractions tend to be left behind on the upper convex slopes, the finer grades are transported downslope to be deposited as loams and clays on the lower concave slopes. Above these finer materials, ground water tends to be forced towards the surface. This lateral movement, across the profile, of highly acid drainage causes leaching and acidification in the hillslope soils, thus contradicting Russell's thesis that slopesoils are enriched with bases brought in from higher ground. Similar slope acidification has been noted (by the author) in widely diverse situations in Kenya, and has been described (Makin; in the Press) on a catena

....../10

in Western Kenya. Indeed, slope alkalinization seems to be confined to drainage basins surrounded by young and base-rich parent materials, as in the Lambwe Valley of South Nyanza.

Acid and Alkaline Clays:

The poorly drained valley clays of the Coast Range (Kwale to Marenje) are mostly of colluvial origin. Their properties are governed by their mode of deposition and the quality of associated drainage waters. Mottled and gleied acid clays are therefore associated with valleys carrying acid drainage. It is of interest that where subsoil pH values are below 5.5, the mottles are red (2.5 YR); at pH levels above 5.5, mottling is a distinctive brownish yellow (10 YR 6/4 to 6/6). With subsoil pH levels over 7.5, free calcium also tends to be deposited in the form of concretions set in an olive glei. In certain valleys, these poorly drained clays form a sequence, with acid clays towards the valley heads and a gradual accumulation of the more mobile ions - sodium and magnesium - in the lower parts of the valley. It is notable that the acid clays are almost completely dominated by illite and totally lack montmorillonite; whereas the alkaline clays have equal proportions of kaolin and montmorillonite, with little or no illite except in the more acid surface horizon.

Shale Soils.

An exposure of Jurassic shales occurs between Kwale and the main Coast road. This gives rise to greyish blocky clays with calcareous subsoil (pH normally exceeds 8). The accompanying savanna is dominated by Cymbopogon and Hyparrhenia, with Dalbergia melanoxylon, Acacia mellifera etc. Having regard to the rainfall, this is a relatively xerophytic association. The presence of this edaphic type may be explained by the poor infiltration and slow permeability of the clay together with its relatively high level of unavailable moisture.

Soils of the Intrusive Cones:

On the lower flanks of the complex intrusives in the vicinity of Jombo -(Mrima Hill, Kiruku, Nguluku and Jombo itself)- there is an extremely deep and well drained, dark red friable clay, which is texturally and structurally homogeneous. The clay fraction (between 50 and 70% of the soil) is remarkable in that it contains virtually 100% kaolin: a slight trace of illite was also detected. This kaolin is poorly crystallized. The soil is moderately acid throughout the profile (pH 5 to 6), a high proportion of the exchange capacity being taken up by variable charge acidity.

It must be presumed that this material derives from the metamorphic rocks that make up much of these cones. The red clays on Mrima show relatively high levels of manganese, which may indicate a contribution from weathering manganiferous laterites that are found higher up the hill. The true origin of these soils remains obscure.

Ecology of the Ramisi Hot Springs:

The springs along the Lower Ramisi Valley are characterised by a high level of salinity (Electrical Conductivity = 8,500 m.mhos/cm.), including concentrations of sodium, bicarbonate and chloride. The soils surrounding the springs are influenced by intense levels of salt and /or alkali : up to 80 m.e.% of sodium was recorded.

........./12.

Several ecological micro-zones may be defined as one approaches the springs. On sandy clays affected by alkalinity farthest from the springs (non-saline soil; pH levels between 8 and 10), there is a patchy and rather stunted herbaceous cover of Buchneria hispida, Fimbristylis dichotoma, F. obtusifolia, F. triflora, Hibiscus cannabinus, Jatropha spicata, Lobelia anceps, Pluchea sordida and Pycreus hildebrandtii. Where however these conditions are combined with a topsoil concentration of salt, the surface is usually completely bereft of vegetation : the surface few centimetres comprising a porous, reddish yellow, coarse sandy wash encrusted with salt. Around the edges of these salt pans, between the pan and the herbaceous border, a degree of hydrolysis has taken place, such that the organic matter has dispersed to form a characteristic black alkali surface crust.

Close to the hot springs themselves, the continuing accumulation of 'peat', under anaerobic and intensely saline conditions, has led to the formation of 'raised bogs'. These may be sparsely covered by stunted grasses and sedges - Cyperus difformis, C. laevigatus and Sporobolus sp. (near marginatus); an unidentified species of Blepharis acting as a pioneer invader. Where the Blepharis has become established, there is a deep reddish brown surface peat which, despite the high content of sodium, has a pH of only 7.5. The spongy, greenish, lichen-covered bogs of the neighbouring cold springs are rather more saline and alkaline; but are also well endowed with calcium. Indeed, the soils and peats close to the cold springs have appreciably higher Ca : Na ratios than those in the vicinity of the hot springs. On areas subject to frequent incursions of cold saline and alkaline spring waters, one finds solitary tussocks of Cyperus laevigatus and

Fimbristylis obtusifolia; sites flooded by hot waters are invariably barren.

Sections below the peats revealed a grey alkaline sandy clay loam which merges into a non-saline, bluish-green calcareous gleied sandy clay; with common, though extremely fine, concretions of calcium carbonate, and a pH of around 9.5.

REFERENCES

CASWELL P.V. 1953 "Geology of the Mombasa-Kwale Area." Geol. Survey Kenya Rep. 24.

DALE I.R. 1939 "The woody vegetation of the Coast Province of Kenya" Imp.For.Inst. Paper 18.

DOYNE H.C. 1935 "Studies in Tropical Soils. Increase in acidity with depth." J.Agric. Sci.25 P.192.

GRAGE D.S. and LE POER TRENCH A.D. 1931 "Soil Conditions affecting coffee in Kenya." Bull.Dep.Agric. Kenya, 7.

LEHRER P.L. 1966 "The effects of parent materials and cultivation on the nutrient levels of three Kenya Soils." E. afr. agric. For.J.32P.31.

MAKIN J. 1968 "The Soils in the country around Shimba Hills Settlement, Kikoneni and Jombo Mountain." Soil Survey Kenya Report.

MAKIN J. (in Press) "The use of Identification Keys in distinguishing Individual Soil Categories."E.afr.agric. For. J.

MAKIN J. (in Press) "A Soil Catena and Associated Laterite Levels in Western Kenya." E.afr.agric.For J.

MOOMAW J.C. 1960 "Plant Ecology of the Coast Region." Govt. Printer, Nairobi.

RUSSELL E.W. "Soil Conditions and Plant Growth." 9th Ed. Longmans. London.

T A B L E I

% GRADE SIZES OF THE DURUMA SERIES

	PARTICLE DIAMETERS IN M.M.				
	2 - 1	1 - 0.5	0.5 - 0.25	0.25 - 0.10	< 0.10
MAZERAS	48	29	22	1	
LOWER MAZERAS	15	46	32	7	
MARIAKANI		2	40	49	9
MAJI-YA-CHUMVI			1	25	74