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SOIL WATER MOVEMENT, RETENTION AND RELEASE PROPERTIES OF SELECTED SOILS OF KENYA

BY

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1982

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signed: .... Date: 12th/7/82

Sam Muwanguzi Sessanga

This thesis has been submitted for examination with my approval as University supervisor.

Signed: .... Date: 18/7/82

S. M. Kinyali

1982

DEDICATION

The thesis is dedicated to the family of Reverend and Mrs. N.E. Sessanga

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LIST OF ABBREVIATIONS

A = Amorphous

AWC = Available Water Capacity

AWS = Available Water Storage

BET = Brunauer-Emmett-Teller Values

CEC = Cation Exchange Capacity

CS = Coarse Sand

Csi = Coarse Silt

DAR = Decreasing Available Range

DMRT = Duncan's Multiple Range Test

EAMR = Easily Available Moisture Release

EAW = Easily Available Water

ESP = Exchangeable Sodium Percentage

FAW = Freely Available Water

FC = Field Capacity

FS = Fine Sand

Fsi = Fine Silt

HP-25 = Hewllet-Packard Programme

ISSS = International Soil Science Society

K = Kaolinite

K_{sat} = Saturated Hydraulic Conductivity

KSS = Kenya Soil Survey

M = Montmorillonite

MS = Medium Sand

Msi = Medium Silt

OD = Oven dry

OM = Organic Matter

PAW = Productive Available Water

PPP = Permanent Point Percentage

PWP = Permanent Wilting Point

r = Simple linear correlation coefficient

r^2 = Simple linear regression coefficient of determination

RAW = Readily Available Water

RAWC = Readily Available Water Capacity

RSθ = Moisture Release (Volume Fraction)

RSθ_{x--n} = Moisture Release (Specified bar range)

Rtθ = Moisture Retention (Volume Fraction)

SHAW = Strongly Held Available Water

SMSθ = Soil Moisture Storage (Volume Fraction)

SMSθ_{x--n} = Soil Moisture Storage (Specified bar ranges)

TAW = Total Available Water

TS = Total Sand

Tsi = Total Silt

TSS = Total Soluble Salts

USDA = United States Department of Agriculture

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ABSTRACT

The study evaluated the Soil Moisture Retention, Release and Saturated Hydraulic Conductivity, (Water Movement), in 6 Kenyan soils that included: 1 Andosol, 1 Luvisol/Acrisol, 1 Arenosol, 2 Nitosols and 1 Vertisol. Further investigations were carried out to establish the relationship between the three parameters and the selected soil characteristics.

Simple linear correlations showed that Saturated Hydraulic Conductivity was mainly a function of the Fine Silt and Medium Sand fractions of the soils studied and that the Total Sand and Coarse Silt Fractions became important down the profiles. However, Total Sand had a negative effect in the 30-36 cm depth. Ksat was mainly reduced by the Clay fraction, particularly the Montmorillonitic type.

Moisture Retention was mainly increased by the finer textural fractions of Clay, Medium Sand and Medium Silt. Organic Matter also was associated with high Moisture Retention.

The coarser textural fractions namely, Total Sand and Fine Sand, reinforced by the Bulk Density were associated with lower Moisture Retention at

specified suctions.

Soil Moisture Storage between Specified reference suctions was positively related to Total Silt, Medium Silt and Organic Matter Content. Low Soil Moisture Storage was related to high Bulk Density, Total and Fine Sand fractions. At very low suctions (0.1-1 bar), the Moisture Storage was positively correlated with Total and Fine Sand fractions whereas, at higher suctions, (0.3-1 and 1-15 bar ranges), the Total Silt and Medium Silt enhanced SMSθ.

The overall Moisture Release, ($RS\theta_{0-15}$), was positively influenced by the Fine Silt, Fine Sand and Total Silt in the 0-36 cm depth whereas the Total and Fine Sand were dominant in the 60-66 cm depth. The Clay fraction and Organic Matter had negative effects on the $RS\theta_{0-15}$ with such magnitudes that increased down the profiles.

The Moisture Release low suctions, (0-1 bar), was a function of Total Sand and Fine Sand where as at higher suctions, (1-15 bars), it was a function of the Total Silt, Medium Silt, Organic Matter and Fine Silt. Lower RSθ in the same range was associated with high Bulk Density and the Sand fractions.

High gradients of the moisture retention curves were attributable to high Sand fractions reinforced by Bulk Density while the lower gradients were related to higher Clay, Organic Matter and the Silt fractions.

Moisture release curves with high gradients were often associated with high Total Sand and Fine Sand at low suctions while at high suctions the Silt and Organic Matter content dominated. Bulk density and the Sand fractions led to lower gradients at high suctions.

The Clay Mineralogy variations did not feature very prominently in the study and most observations could be attributed to Texture, Organic Matter and Bulk Density, with strong indications of the structural influence.

Subdivision of the main textural fractions of Sand and Silt improved the soil moisture evaluations in this study.

In the overall soil moisture status evaluation, K_{sat} was considered a vital link between the SMSθ and RSθ as far as the potential moisture availability to both plants' and other varied soil life forms is concerned. Emanating from the study was the possibility of basing soils' potential productivity evaluations on their ability to release moisture.

CHAPTER 1

INTRODUCTION

Soil water is a necessary component of the soil environment in addition to other requirements namely, adequate nutrients supply, good aeration, optimum temperature, all of which jointly make the varied life forms in the soil possible.

The importance of soil water includes seed germination and development, growth of plants, plant nutrients uptake processes, translocation of these nutrients within the plant organs, various microbiological activities and temperature control within the plant systems by way of transpiration processes.

Plant activities such as photosynthesis, vegetative growth, flowering, seed and fibre production, may be related quite differently to the soil moisture status in the root zone. Hillel (1971) pointed out that transpiration may for a time be independent of the soil moisture variations in the root zone and more related to the prevailing atmospheric conditions. This condition could last until the supply rate of the soil moisture and the uptake rate of the plant jointly become markedly limiting due to the reduced moisture content and the corresponding decrease in the potential soil moisture availability.

To effectively support the varied and complex life forms within the soil environment, the soil water status should be at adequate level corresponding to the specific life forms.

The foregoing thus points to the importance of the evaluation of the soil moisture status prior to any limited or full scale experimentation leading to best soil utilization.

Soil water management practices aim at satisfactory rain or irrigation water acceptance by the soil, transmission through the soil matrix and finally sufficient soil water retention in the root zone for plant and other soil life forms' usage.

Equally important is the soil water movement (hydraulic conductivity). within the soil environment mainly demonstrated by the drainage properties of the soil in question.

Sufficient soil water movement is necessary to rid the soil environment of excess soil water that would otherwise adversely affect soil aeration, soil temperature, seed germination and microbiological activity; all leading to overall unsatisfactory nutrients' utilization by the varied soil life forms and thus low land productivity.

Adequate soil water movement also ensures maximum soil moisture potential storage provided the inherent soil physical properties such as texture, physiochemical properties such as organic matter, or modifications of these favour such soil moisture retention. A more uniform moisture regime in specified horizon would then be feasible and satisfactory plant or other soil life forms' activity would be expected once such a reliable moisture store does exist.

The use of irrigation water in combination with commercial fertilizers is on the increase in many developped and less developped nations and this clearly implies that, to some degree of satisfaction, solutions to many plant nutrients' deficiencies are being found to suit a specific problem as the situation demands.

As pointed out by Doyarenko (1975), Kohnke (1968) and Hillel (1971), the foregoing has for long worked on the assumption that all was well with the soils' physical properties used in such applications. It is therefore not surprising that the soil physics studies and more specifically, the soil water status evaluation in many soils has not,as yet, received adequate attention compared to that given to other soil science disciplines related to fertility, chemistry and microbiology.

Indeed some of the soil physical properties are taken for granted though it is probable that a closer evaluation of these properties could be valuable in many experiments that involve usage of soil as a growth medium. Such evaluation would significantly contribute to overall land productivity.

Soil fertility evaluates the soil nutrients' status as well as its ability to release these nutrients in adequate quantities as required by the plants' and other soil life forms' activities. It is therefore imperative, as stressed by Doyarenko (1975), that the multidisciplinary approach to soil science research problems is key to full nutrients' utilization and thus satisfactory overall soil productivity.

The correlation of plant responses with moisture status in soils often requires intergrating each of the two parameters over both space and time for practical conclusions to be drawn from the findings.

Successful cultivation has been related to soil conditions sufficiently suitable for germination and support of vegetation. This view was stressed by Siderius and Muchena (1977) in connection with soil moisture and soil productivity in Kenyan soils.

It is the view of the author that foregoing arguments and inadequate information regarding the soil moisture status in Kenyan soils were the basic reasons that prompted the study. It aimed primarily, at attempting to answer some of the moisture uncertainities in the soils studied thus forming a good basis for further research work on these soils and in the various soils science disciplines. Also encouragement to usage of volume fraction approach other than gravimetric methods as expression of soil moisture values, was made in this study. This view was stressed by Taylor (1972) as the expression of soil moisture that gave a closer evaluation of the volume of moisture potentially at the plants' roots exposure for extraction.

The study was not crop-specific but a preliminary soil moisture status evaluation of the soils studied leaving the findings to be adaptable to a wide range of soil related studies such as water applications in pot or green house experiments as well as irrigation water application in field situations using the relevant volume fraction equations.

The investigation to establish the relationship between the soil water status and the determined soil physical and chemical properties was intended to emphasize the physical aspects of the soil moisture status. Even when the soil properties are physio-chemical emphasis was on how these influenced the soil moisture physical aspects.

OBJECTIVES

1. The assessment and evaluation of the soil moisture retention and release properties over the 0.0 to 15.0 bar range; as well as the saturated hydraulic conductivity of the six soils at 0-6, 30-36 and 60-66 cm depths.

2. Establishment of simple correlation and regression relationships between the three soil moisture states and the selected soil characteristics; namely the Texture, Clay Mineralogy, Bulk Density and Organic Matter content.

CHAPTER 2

LITERATURE REVIEW

2.1 WATER FLOW THEORY

To describe the phenomenon of water flow through a porous medium, Darcy's law relating the flux of water V, to the driving force $\Delta\Phi$, is used.

$$V = -(k\rho/n)\,\Delta\Phi \quad \text{------------------------} \quad (1)$$

where V = volumetric flux of water in $cm^3\ cm^{-2}\ sec^{-1}$ i.e. volume of water flowing through a unit cross-section of soil per unit time.

K = Permeability of the soil or porous medium.

ρ = Density of fluid in gm/cm^3

n = Viscosity of the fluid

$\Delta\Phi$ = Driving force per unit mass of water.

Darcy's law can be generalized for saturated porous media into a three-dimentional mascroscopic differential equation in the form,

$$q = K\,\nabla H \quad \text{--------------------------------} (2)$$

where q = volumetric flux of water in $cm^3\ cm^2\ sec^{-1}$

K = Permeability of the soil or porous medium

∇H = Hydraulic gradient

The equation (2) indicates that the flow of the liquid through the porous medium is in the direction of, and at the rate proportional to the driving force acting on the liquid, (the hydraulic gradient) and to the hydraulic conductivity of the medium, (Hillel, 1971).

Stated verbally, Darcy's law is thus, the velocity of a liquid through a porous medium is proportional to the force causing the flow and to hydraulic conductivity of the medium (Kohnke 1968).

The hydraulic gradient is dimensionless when expressed as cm^3 of water per cm^3 of soil sample or space rate of change of hydraulic head (H) in the direction of flow, (Kinyali 1973).

The constant, K, varies markedly with water content in the medium,(Hillel, 1971). The constant K, is designated as hydraulic conductivity when used to describe the flow characteristics of a saturated medium and as capillary conductivity when used in the unsaturated flow, Richard , (1952 (a)).

Darcy's law is applicable under conditions such as when the inertial forces are neglible in comparison to viscosity forces as is the case in silts and finer materials, (Hillel, 1971).

Laminar flow prevails under such conditions unlike the turbulent flow in cases of coarse-textured medium when the hydraulic gradients much in excess of unity may render the law unreliable.

Sanchez (1976) reported the observation that the well aggregated oxic families act as sands as far as hydraulic conductivity was concerned.

Talha et al (1978), observed that in the sandy soils of Egypt, calcium carbonate markedly improved the hydraulic conductivity whereas the sodium carbonate reduced the hydraulic conductivity due to its dispersion effects in soils.

In the dynamics of soil water evaluations physicists recognized the decrease in hydraulic conductivity as pore water content decreased, (Richards 1931), Hillel (1971), More (1939), Childs and Young (1974)). It was further pointed out that the hydraulic conductivity and the specific water capacity i.e. rate of change of pore water with pore suction, were soil properties that were dependant upon the water content thus their ration was also dependant on soil water content and analogous to diffusivity, (Childs and Young, 1974).

Kinyali, (1973 and Wilcox, (1966) have pointed out the effect of irrigation water quality on hydraulic conductivity. Both researchers stressed that water quality of more than 2.5 meg/litre of residual sodium carbonate was not suitable for irrigation purposes since the structure of the soil would be adversely affected which in turn would reduce the soil hydraulic conductivity. Water quality of between 1.25 meg/litre of residual sodium carbonate had negligible structural and hydraulic conductivity effects whereas water of less than 1.25 meq/litre of residual sodium carbonate was safe for use as irrigation water.

Ionic species in irrigation water had several effects on hydraulic conductivity. In his study Kinyali, (1973) reported indirect effects of carbonate and bicarbonate ions which precipitate magnesium and calcium ions thus reduce the hydraulic conductivity as a result of the resultant poorer soil structure. Calcium and magnesium promoted the flocculation of soil clay-size particles and thus increased hydraulic conductivity.

Kinyali, (1973) observed that where as the sesquioxides in kaolinites and amorphous dominated soils had very limited influence on saturated hydraulic conductivity, the ESP of 15% to 20% level in the expandable clay minerals notibly Montmorillonite, reduced the saturated hydraulic conductivity. The high level of ESP was probably responsible for the deterioration of structure.

Lagerweiff, Nakayama and Frers (1968), concluded that swelling of soils was limited by the dimensions of pores and that the increase in swelling pressure inside the pores is faster in narrower pores. Swelling rendered smaller pores ineffective as flow channels though they increase at the expense of the large ones. Since most of the water flow is by the large pores, the increasing dominance of the smaller pores as swelling continued effectively reduced the hydraulic conductivity of the soil studied.

Gerard, (1974), revealed that the $\leq .33$ bar suction often used in trickle irrigation caused a reduction in the hydraulic conductivity of the soil due to the microbial gaseous production at low suctions and their subsequent entrapment and the overall reduction in the Macrovoids of the soil. It was further pointed out that the microbial growth formed a physical barrier to water flow, an observation that enhanced the reduction in overall soil permeability.

Talha et al, (1978) found variations in hydraulic conductivity with soil depth, soil compaction, pore size distribution and aggregate stability. Coarse sand fraction correlated positively with the hydraulic conductivity and the relationship was significant. Increased bulk density in the studied Egyptian soils reduced the hydraulic conductivity. This was a result of the altered pore size distribution and the dominance of the smaller-sized but low water conductivity pores.

Sanchez, (1976), reported that organic matter improved the hydraulic conductivity of Andosols as a result of balancing the macro-and micropores' distribution.

Martin and Richards, (1959), used the Hanford sandy loam, Yolo sandy loam and Yolo loam to study the influence of the exchangeable Hydrogen, Calcium, Sodium, Potassium and Ammonium at different hydrogen levels on the aggregation of particles of less than 50 μ as well on the conductivity of the soils. The method involved compaction of the soil into conduction cylinders whilst moist. Exchangeable hydrogen variations between 0 to 80% as well as the exchangeable calcium concentration from 5% to excess had very little influence on aggregation, bulk density and hydraulic conductivity.

Increasing sodium exchangeable percentage adversely affected aggregation and potassium and ammonium slightly distorted the aggregation stability of the soils all of which led to reduced water conductivity.

The high exchangeable hydrogen concentration enhanced the dispersion effects of sodium, potassium and ammonium thus contributing to poorer aggression and reduced hydraulic conductivity (Martin and Richards, 1959).

Sharma and Uehara, (1968) using sieved soils of similar composition but of varying fabric evaluated the capillary conduction and water stability of aggregates and came to conclude that the macrofabric (i.e. the arrangement of soil peds) had more effect on soil water movement in the 0 to 0.2 bar range or saturated range. Identical water flow rates in both Latosols for the water stable aggregates implied that the intraped pores did not significantly contribute to the water flow in this tension range. Sharma and Uehara, (1968) further suggested the possibility of the microfabric (the arrangement of primary particles within a ped) as having great influence on water flow at higher suctions.

Taiha *et al* (1978), investigated the relationship between pore size distribution and salinity, alkalinity and texture of some Egyptian soils and came to the conclusion that the ESP had more effect on the distortion of the pore size distribution in soils than did the Total Soluble Salts, (TSS). As a result, the ESP enhanced soil particles' dispersion and markedly reduced hydraulic conductivity.

2.2 SOIL WATER POTENTIAL

The energy relationships of soil water are commonly described under the term, soil water potential which refers, broadly, to the forces responsible for holding water in the soils matrix, (Taylor, 1972).

Soil water is less free to move in comparison to the free pure water in a pond, so, the soil water potential is conventionally given a negative sign which directly implies that work must be done to detach soil water from the soil particle surfaces into either drainage or uptake by plants, (Hillel,(1971), Taylor, (1972)).

Soil potential has received more consideration than kinetic energy of soil water since the latter, due to motion, is usually at considerably low and insignificant rates especially in the unsaturated conditions commonly prevailing in Soils (Hillel, 1971, Taylor, 1972).

Soil water potential is composed of the

pressure potential, the matrix potential, and the solute or osmotic potential (Taylor, 1972).

Pressure potential

Pressure potential is the portion of water potential that results from an overall pressure that is different from the reference pressure. It is the amount of work that a unit quantity of water in an equilibrium soil - plant or plant-water system is capable of doing when it moves to another equilibrium system identical in all respects except that it is at the reference pressure, Taylor, (1972).

$$\psi_\rho = V_\omega \Delta P = \frac{\delta \ \psi_\omega \nabla P}{\delta P} \qquad \text{------------------}(3)$$

where; ψ_ρ = Pressure potential in suctions or bars
$\bar{V}_\omega$ = Partial specific volume of water
ρ = Pressure
ψ_ω = Water potenial

Matrix Potential

Matrix potential is the proportion of water potential that is attributable to the more or less solid colloidal matrix of the soil or plant system. It is the amount of work that a unit quantity of water in an equilibrium soil water or plant water system is capable of doing when it moves to another equilibrium system identical in all aspects with the exception of absence of matrix (adsorption, capillary) in equilibrium but with opposite sign to the water tension (Taylor, 1972).

$$\psi_m = \xi_\omega \Delta\eta_\omega = \frac{\delta\psi_\omega}{\delta\eta_\omega}\,\Delta\eta_\omega \qquad \text{--------------}(4)$$

where; ψ_m = Matrix potential in suction or bars.

ξ_ω = Some function of water content called soil water characteristic (i.e. slope of the soil water characteristic curve).

η_ω = Mass fraction of water.

ψ_ω = Water potential.

Solute or Osmotic Potential

Solute or Osmotic potential is the portion of water potential that results from the combined effects of all solute species present in the soil or plant system (Taylor, 1972). It is the amount of work that a unit quantity of water in an equilibrium soil-water or plant-water system is capable of doing when it moves to another equilibrium system identical in all aspects except that there are no solutes (Taylor, 1972).

$$\psi_s = \Sigma j \; \pi\omega j \Delta\eta j = \frac{\Sigma\delta\psi_\omega}{\delta\eta j} \Delta\eta j \quad \text{------------}(5)$$

where; ψ_s = Solute or Osmotic potential in suction or bars.

$\pi\omega j$ = Some function of water that expresses the effect of unit concentration of species "j" on water potential.

ηj = The mass fraction of the chemical species "j".

ψ_ω = Water Potential.

Soil water potential is the difference in the chemical potential of water in an equilibrium system, μ_η O, (Taylor, 1972). It is thus the sum of the pressure potential, the matrix potential and the solute or osmotic potential. These components collectively represents the amount of work that a unit quantity of water in an equilibrium soil-water or plant-water system is capable of doing when it moves to a pool of water in the reference state under isothermal conditions (Taylor, 1972).

$$\psi_\omega = (\Delta\mu_\omega)_\tau = \psi_\rho + \psi_m + \psi_s \quad \text{----------}(6)$$

$$= V_\omega \Delta_P + \xi_\omega \Delta\eta\omega + \Sigma j \; \pi\omega j \; \Delta\eta j \quad \text{-------} \tag{7}$$

$$= \frac{\delta\psi_\omega}{\delta P} \Delta P + \frac{\delta\psi_\omega}{\delta\eta_\omega} \Delta\eta_\omega + \frac{\Sigma\delta\psi_\omega}{\delta\eta j} \Delta\eta j \quad \text{---} \tag{8}$$

where; all symbols remain as already given in text and;

$\Delta\mu$ = The difference in chemical potential of water in the system and the water at the same temperature in the reference state.

Gravitational potential is the potential attributable to the gravitational force field and is dependant upon the elevation or vertical location of the water (Taylor, (1972), Hillel, (1971)). It is the amount of work that a unit quantity of water in an equilibrium soil-water or plant-water system at an arbitrary level is capable of doing when it moves to another equilibrium system identical in all respects except that it is at a reference level, Taylor, (1972).

$$\psi_z = \rho_w gz \quad \text{---------------------------} \tag{9}$$

where; ψ_z = Gravitational potential.

ρ_ω = Density of water in gm/cm^3.

g = Acceleration due to gravity in cm or metres per sec^{-2}.

z = Distance measured in the vertical displacement in metres or cm.

Total Soil Water Potential ($\psi\tau$)

Total soil water potential is the sum of all potentials acting on water in an equilibrium system. It is the amount of work that a unit quantity of water in an equilibrium soil-water or plant-water system is capable of doing when it moves to a pool of pure free water at the same temperature located at a reference level and subjected to atmospheric pressure (Taylor, 1972).

The total soil water potential includes both chemical and potentials of external force fields. Normally gravitational force is the only external force field operating on the water in the soil plant-water system (Taylor, 1972). Normally the total soil water potential, $\psi\tau$, is the sum of the water potential, ψ_ω and the gravitational potential, ψ_z, but, if other external forces are existing, they must, too, be included in the equation as separate terms (Taylor, 1972).

$$\psi_\tau = \psi_w + \psi_z = \psi_p + \psi_m + \psi_s + \psi_z + \text{--} \psi_x \quad \text{--}(10)$$

where; ψ_τ = Total soil water potential in suctions or bars.

ψ_w = Soil water potential.

ψ_z = Gravitational potential.

ψ_p = Pressure potential.

ψ_m = Matrix potential

ψ_s = Solute or Osmotic potential.

ψ_x = Other external forces acting upon the soil water.

Details of the terms are already given in text.

Taylor, (1972) pointed out the hydraulic potential, ψ_h comprising all potentials that serve as driving forces, namely pressure, matrix and gravitational potentials but it was not possible to encorporate these potentials, (in conjuction with temperature variations), in the practical analysis. Until more is known about the entropy of adsorbed water, the hydraulic potential concept will continue to be largely a qualitative concept.

Generally, suction numerically equals to the total soil water potential, ψ_T which approximately equals to the matrix potential, ψ_m plus osmotic or solute potential, ψ_s. In this study, the matrix potential, ψ_m, was considered to be the dominant force as far as soil moisture retention was concerned since the adsorption and capillary foces are mainly the forces responsible for soil particles moisture retention.

2.3 Soil moisture retention (RtΘ)

Soil moisture retention is a function of a number of soil factors. Marshall, (1959), reported an important relationship between the soil moisture retention and the particle size distribution and emphasized the greater influence of the structural arrangement of these particles on the soil moisture retention in soils.

Sanchez, (1976), observed that well aggregated oxic family soils held soil moisture in a similar way as clays at high suctions and that such suctions would reduce the ease of moisture availability to plants. A rapid depletion of the pore moisture between 0.01 to 0.1 bar range was attributed to the aggregate size expecially the sand-size water stable aggregates that dominated the soils studied. Low bulk density was proved to account for the high moisture retention (Sanchez, 1976).

Soil organic matter, though a dynamic soil property, was responsible for the increase in the soil moisture retention especially in Andosols where the organic matter percentage was highest (Sanchez, 1976). Through soil aggregation, the organic matter reduces bulk density and increases moisture retention as reported by Sanchez, (1976). This phenomenon was enhanced by the organic matter-allophane binding influence on soil aggregates of Andosols in particular.

Partial sesquioxides in Luvisols (Alfisols) and Acrisols (Ultisols) were responsible for the higher soil moisture retention relative to the Ferralsols (Oxisols), (Sanchez, 1976).

Hillel, (1971), minimized the soil moisture retention improvement ability of organic matter due to the observation that the quantities usually prevalent in most mineral soils in addition to the dynamic nature of the organic matter jointly implied the improvements could be short-lived.

Farm yard manure application for 7 to 8 years on a sandy loam increased the soil moisture retention and reduced the bulk density, a factor that enhanced moisture retention (Salter and Williams, 1963).

Using the incompressible sands and chalk derived soils, the partially compressible silty clay and the fully compressible clays, Croney and Coleman, (1954), revealed that a wide range of moisture values could be in equilibrium with a given suction. The phenomenon was attributed to structural factors and this led to the recommendation that for comparative purposes, the evaluation of both the moisture content and the corresponding suction were necessary requirement in moisture studies.

Pore size distribution was considered a major factor in the soil moisture status. Talha *et al*, (1978) reported that the moisture retention at equilibrium was a function of the size and volume of water-filled pores and thus a function of matrix suction. Retention at low suctions was primarily a function of capillary effect and pore size distribution and thus more influenced by structure than texture.

Moisture retention at high suctions was a function of texture and actually increased with increasing clay percentages (Talha, *et al* 1978)

Childs and Young, (1974), stressed the dependence of soil moisture retention mechanisms in pores, on the activity of the soil particle surfaces. Surface active materials such as clays could have a wide range of moisture

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variations without appreciable corresponding variation in the degree of saturation. This is so because the moisture release takes place with a corresponding shrinkage and the resultant equilibrium is a balance between the pore water suction and the mutual repulsion of interpenetrating Gouy and Stem layers.

Conard, (1968), reported that silt and clay increased moisture retention and especially so at high suctions. Though the observation implied reduced moisture release, it was argued that there was an increase in the soil moisture storage under such circumstances.

The expected variations in soil moisture retention arising from textural variations were often in reverse of what the deductions would imply. Often the soil moisture retention characteristics of soils similar in textural classes were different, an observation that was probably attributable to structural other than textural differences (Conard, 1968).

Salter and Williams, (1965), in their soil moisture retention evaluation in the first 60 cm depth found that the retention at 0.3 and 15 bar suctions increased as soils became finer. Soil texture was an important factor in the soil moisture retention especially at lower suctions when the macropores are more affected, by applied pressure, than the capillary pores.

In the same evaluation, the high Organic matter content was responsible for increasing soil moisture retention in sands and this phenomenon was enhanced in the silt loams due to the higher percentage of the finer silt fraction.

Hill and Sumner, (1967), used disturbed and sieved soil samples to investigate the effect of Bulk density on the soil moisture characteristics in Natal. Mechanical compaction was achieved for a range of Bulk densities. It was revealed that increasing Bulk density, at constant suction, increased moisture retention, but that the magnitude of the effect decreased with higher suctions. Special relationship was illustrated by clay whose increment in moisture retention corresponding to increase in Bulk density actually intensified with rise in suction. For sandy loams and sandy clays, increase in bulk density led to decreased soil moisture retention at low suction though moisture retention increased at higher suctions.

Hill and Sumner, (1967) concluded that compaction reduced the total porosity but increased the number of micropores at the expense of the macropores' volume. It was further argued that where the dominant feature is the reduction in porosity, then the Bulk density effect would be the reduction of soil moisture retention. Alternatively, where the Bulk density alters the macro-to micro-pores' volumes, the soil moisture retention would in effect increase since the compaction could lead to moisture flow into the micropores created, and the resultant overflow could easily reduce the suction within the soil matrix.

In a further analysis, Hill and Sumner, (1967), pointed out that compaction changed the predominance of different pore sizes in different soils to varying extents. In sands, large pores dominated so compaction exerted greater impact at lower suctions where as in clays, where the micropores dominated relative to macropores, there was a wider range of possible compation influece phenomenon, and especially so as the suctions increased.

Volumetric water content was shown to increase linearly over wide Bulk density ranges and that, depending on texture, a maximum or critical Bulk density was reached when further rise in Bulk density would reduce the moisture retention. This observation, made by Archer and Smith, (1972) was reported to occur at a point equivalent to the air capacity value close to zero.

The soil moisture retention at 15 bar had a positive and linear relationship with clay fraction (Lund, 1959). When the attempt was made to compare the 0.3 bar soil moisture content of undisturbed and the disturbed soil samples, it was established that the undisturbed samples held relatively lower moisture compared to the disturbed samples.

Bartelli and Peters, (1959), argued, in their soils study in Illinois, that the use of disturbed soil samples in soil moisture studies, exaggerated the soil moisture status and that this effect was more apparent in previously high bulk density soils. This observation could be linked to the negative effect of bulk density on the soil moisture retention as reported by Hill and Sumner, (1967) and Archer and Smith, (1972). Conditions that reduce Bulk density therefore improve the soil moisture retention of highly compacted soils.

The 0.3 bar moisture content was influenced by all textural fractions thus the moisture retention at low suctions was more of a function of structure than of particle size distribution

(Bartelli and Peters, 1959). In the same study, Organic matter improved the moisture retention of specially the coarse textured soils though the influence was less noticed in high silt and clayey soils.

Junker and Madison, (1967), used Canadian peat in the mixtures of Osoflaco sand in the soil moisture studies and they revealed that the peat reduced the previously high Bulk densities and increased the soil moisture retention by as much as 80% by volume.

Work by Petersen, Cunningham and Matelski, (1968),revealed that with the exception of loamy sands, the 0.3 bar moisture content was strongly associated with Bulk density. The clay content strongly enhanced soil moisture retention at 15 bar with the exception of clay loams. With the exception of coarse-textured soils, the increase in Bulk density lowered the soil moisture retention at 0.3 bar and as clay percentage increased, the 15 bar retention increased to the extent that of very fine clayey class. Where the silt content was the only significant factor, and negatively correlated, the very reduced numbers of such particles could not form aggregates that could influence moisture retention so the overall effect was reduced moisture retention (Petersen, et al, 1968).

The 0.3 bar retention rate of increase with the fineness of texture was at a lower rate in comparison to the corresponding 15 bar moisture retention. It was also concluded from the studies by Petersen et al, (1968), that the finer the texture, the higher were the number of pores for increased moisture retention since the finer particles exposed larger surface active area for increased adsorptive forces.

Organic matter improved soil aggregation and soil moisture retention at 15 bar for the soils studied. A special relationship was illustrated between sandy soils and clay additions whereby the moisture retention at 0.3 and 15 bar significantly increased with corresponding addition of clay but the phenomenon was less effective when the clay percentage exceeded 60% (Petersen, et al. 1968).

Petersen, Cunningham and Matelski, (1968), studied the relationships of morphology and other selected soil properties on moisture retention after equilibrium at 0.3 and 15 bar using a silt loam. They concluded that soil moisture retention was more of a reflection of coarse fraction, than the clay fraction accumulation, structural development or fragipan characteristics. No significant variations were observed between cultivated and non-cultivated areas. The non-fragipan soil had twice as much soil moisture retention capacity relative to the fragipan soil. In general the 0.3 moisture retention was a function of coarseness and bulk density with the magnitude thus C-horizon > B-horizon > A-horizon.

The correlation co-efficients for the 0.3 bar moisture retention and Bulk density were -0.43, -0.58 and -0.89 for A, B, and C horizons respectively. The comparable values in relation to the coarse fractions were 0.24, 0.245 and -0.51 for A, B, and C horizons respectively. The clay fraction was more associated with the 15 bar retention with correlation coefficients of 0.29, 0.662 and 0.775 for A, B, and C horizons respectively.

The slight illuviation of clay into the B-horizon even with low organic matter content had a slight effect of increasing the soil moisture retention at 15 bar.

All sand correlations were negative in relation to the 15 bar and 0.3 bar moisture retention. The 5-2μ fraction correlated with the 0.3 bar moisture content and the relationship was significant at 5% level. The particle size of > 20μ was significantly and positively correlated with the 15 bar retention where as the correlation with the coarse fraction was negative. Also a positive though not significant correlation was established between the 15 bar moisture retention and the particles of < 2μ (Petersen et al, 1968).

Zahner and Hedrich, (1966) studied the soil moisture characteristics of Fluvisols (Entisols) with particular emphasis on the fine and medium sand fractions. Soil moisture retention at 0.3 bar was 0.1% for fine sand, 0.7% for medium sand by weight. The moisture retention at 15 bar was 2.5% for both fine and medium sands. The very fine sand fraction retained more moisture at low suctions than at high suctions but in the final evaluation, this sand fraction had a higher soil moisture retention values than any other sand fractions.

Alexander, (1980), evaluated the relationship between Bulk densities of California soils and organic matter and soil moisture retention. In the range of soils from Vertisols to Fluvisols the moisture content at 0.3 bar was used to predict the Bulk density with the standard error of 0.14 gmcm-3 for upland soils and r^2 of 0.723. In case of alluvial soils the standard error was 0.11 gm cm-3 with r^2 of 0.672.

Organic matter alone predicted the Bulk density for upland soils with the standard error of 0.19 gm cm^{-3} with r of 0.46. Alexander, (1980), concluded that organic matter was the best predicator of bulk density for both aluvial and upland soils using the following equation;

$$BD = 1.66-0.308 * \text{ORGANIC CARBON}^{0.5} \quad ---(11)$$

where; BD = Bulk density in gm/cm^3 and all represented values are constants.

In the same study, Alexander, (1980), stressed that the reliability of the interpretation was dependant upon the contribution to the whole regression of the parameter being evaluated.

The soil moisture retention at 15 bar and the bulk density had a special relationship that held for both upland and alluvial soils. A rise in the retention at 15 bar from 0.068/0.079 to 0.297/0.300 corresponded to a reduction in bulk density of between 7/8% and 30% corresponding to the two categories of 15 bar moisture volumetric retentions respectively.

For the alluvial soils, a rise in the 15 bar volumetric moisture content from 0.27/0.137 to 0.433/0.738 corresponded to the reduction in the bulk density of 13% to 60% respectively, Alexander, (1980).

The Bulk density maxima at low soil moisture retention appear to be related to Bulk density maxima at high sand percentage since the soil retention at 15 bar and clay are highly and positively correlated.

Shetron, (1974), in the study of soil moisture in relation to the distribution of free iron and organic carbon, revealed that organic carbon and free iron in the B_{21} horizon had more influence on retention than did the particle size composition and especially so when considering the specific surfaces. In the C-horizon, low organic matter made it easier for the free iron and, specific surfaces of the particles to be the main factors that influenced the moisture retention.

The regression coefficient of determination, R^2, was 0.58 for organic matter and free iron in the B_{21} horizon where as in the C-horizon the R^2 was 0.73.

Tsuji, Watanabe and Sakai, (1975) in their study of the influence of soil microstructure on water characteristics of Hawaian soils, observed high 15 bar moisture retention for Ferralsols, Acrisols (Ultisols) and Fluvisols (Inceptisols) compared to the Vertisols. The phenomenon was attributed to intra-aggregate void spaces detected by aid of a scanning microscope and were quite distinct in kaolinitic and oxichic minerals though not so with Montmorillonite and Amorphous materials' dominated soils. It was further revealed that the Acrisols behaved as coarse materials at the low suctions with low moisture retention and that at high suctions, they adsorbed the moisture in similar fashion as clay particles. The water holding capacities of the studied soils could be predicted by the mineralogy and soil structure especially as far as these two influenced the inter-and intra-aggregate void spaces' development in these soils. Texture alone could not be reliable in the prediction of the pore size distribution in these soils.

Due to excessive shrinkage resulting from the dry heat of the sun, stable clay aggregates accumulated in the upper horizons in the Lualialei Vertisols and the Montmorillonite that dominated these soils did not show the typical gradual overall variation in moisture content as suction rose, but on the contrary, the variations in moisture as suction rose were more abrupt.

The clay-water system is an important aspect in the soil moisture evaluation. Clay is used as a rock term to describe the 0.002 mm

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or 2 micron size fraction of the fine earth, (Grim, 1968) Brady, (1974)). As such, it is a broad definition due to the wide range of materials that have been classified as clays solemnly on particle size basis. In general, however, the clay fraction applies to a natural finely grained (0.002 mm) material which develops placiticity when mixed with a limited amount of water (Grim, 1968).

Clay mineralogy studies indicate that the most widely occuring clays are the silicate clay which are either octahedral or gibbsite layers attached to the hydroxyl molecules, or the silica tetrahedron composed of silicon atoms together with their corresponding cordination oxygen atoms (Brady, (1974) Grim, (1968)).

The commonly occurring clay minerals are the Kaolinites, Montmorillonite, Illites, Vermiculites and the Allophane or Amorphous group of clay minerals.

Most silicate clays are aluminosilicates composed of silica tetrahedron and aluminium octahedron. Interlocking plane of a series of silica tetrahedra linked together by shared oxygen atoms give a sheet-like tetrahedral layer. Similarly, large number of alumina octahedra are bonded to each other by shared hydroxyl atoms.

Grim, (1968), gave the general formulae for the main unit cells comprising the major groups of clay minerals.

Kaolinite has equal numbers of silicon and alumina atoms with the general formula, $(Al_4Si_4O_{10}\ (OH)_8)$.

Montmorillonite or the smectite group is represented thus, $(Al_2Si_4O_{10}(OH)_2\ .nH_2O)$ and has twice as many silicon atoms as alumina atoms. With the isomorphous substitution, the Montmorillonite formula becomes thus $(Mg_3Si_4O_{10}(OH)_2\ .\ H_2O)$. The aluminium atom could be replaced by either Magnesium or Zinc.

The swelling phenomenon of clay minerals has received considerable attention in as far as the full saturated condition of the soil is concerned. Marshall, (1959), argued that soil moisture retention was related to the clay percentage and that the presence of Montmorillonite led to higher moisture retention in comparison to the lower retention in kaolinite-dominated clay.

Kohnke, (1968), reported that the 2:1 lattice clays dominated by Montmorillonite with the expanding properties on wetting take up water by water-iron attraction into the interspaces.

The valency and the size of the ion determines the extent of such water adsorption. Sodium dominated clay has higher moisture retention than the calcium dominated clay. The non-expanding clay minerals such as Kaolinite, and Illite have lower soil moisture retention. The differences between the expanding and non-expanding clay minerals in their soil moisture retention at 0 bar could be explained by this swelling phenomenon.

The Kaolinite is a 1:1 silicate clay with a single layer of tetrahedron and octahedron units bonded into extensive sheets by hydrogen bonds which though individually weak, are numerous and thus collectively bind successive sheets strongly enough to prevent the expansion of clay platelets, (Grim, (1968) and Brady, (1974).

Montmorillonite, composed of an octahedron or gibbsite layer sandwiched by two tetrahedra layers with exposed oxygen atoms does not have hydrogen bonding. The sheets therefore do not condense easily. Due to unsatisfied negative charges the 2:1 clay minerals are capable of attracting potassium and ammonium ions which, as in Illite, closely fit into the interspaces between successive sheets and firmly hold the clay platelets and so prevent their expansion.

In the case of Montmorillonite, the calcium and Magnesium ions act as hydration foci for attraction of water molecules into the interspaces of the clay platelets thus facilitating expansion resulting from hydration (Taylor, 1972).

Taylor, (1972), stressed that the ionic distribution within the soil solution was a major factor in the swelling phenomenon. Higher ionic concentration in the immediate neighbourhood of colloidal surfaces relative to the external solution causes a drop in the water potential thus leading to high affinity for water which is then drawn towards the clay surfaces and into the inter spaces or lamellae of the clay platelets resulting into swelling. This phenomenon constitutes osmotic swelling.

In the case of Illite, the tightly fitting potassium and ammonium ions act as bridges that mechanically prevent swelling, though they hold successive sheets close together and firmly.
A similar effect in Kaolinites in achieved by the numerous hydrogen bonds.

Based on BET values, (after Brunauer-Emmett-Teller , (1938)) theory of adsorption, Taylor, (1972), and Ochiston, (1955, 1959), reported that the energy of adsorption of water by the clay surface was in the order Magnesium > Calcium > Sodium > Potassium for both Montmorillonite and Illite with the mentioned cation on the exchange surfaces. BET values give the magnitude energy difference between the latent heat of vaporisation and the average heat of adsorption of the first molecular water layer.

Grim and Cuthbert, (1945), related the bonding strength to water content and concluded that the sodium-dominated Montmorillonite, as the exchange site, the non-liquid water had a thickness of three molecular layers and the calcium dominated Montmorillonite had four such layers. It was further noted that the non-liquid to liquid transition was more gradual in the sodium-dominated Montmorillonite than in the calcium-dominated Montmorillonite.

De Witc and Arens, (1950), in their hydration patterns evaluation of clay minerals concluded that lower number of water molecular layers could be expected for Kaolinite and Illite and that higher water molecular layers were feasible in case of Montmorillonite.

White and Pichler, (1959), and White, (1955), stated that there is usually a rapid adsorption rate of water by the clay starting from the dry state up to the near saturated limit. Thereafter, no or very negligible water adsorption takes place and was easily noticed in the clays that had sodium as the dominant exchange site . Lithium had similar effects.

The upper limit of water holding capacity of clays was observed to have been easier to attain in the calcium-dominated clays, and calcium, incidently, is abundant in all natural clays.

Grim, (1962) observed that with drying or moisture reduction at room temperature, the sodium-dominated Montmorillonite tended to develop a single molecular layer between the alumino-silicate sheets whereas the calcium-dominated Montmorillonite developped two molecular layers of water. Noted, too was the higher water absorption for sodium-dominated Montmorillonite compared to the calcium-montmorillonite at high moisture and relative humidity.

Bradley , et. al, (1937), in the study of a hydrogen-dominated Montmorillonite produced by electrodialysis of a Wyoming bentotite indicated the step wise swelling of montmorillonite at cell heights of 12.4 A^{o}, 15.4 A^{o}, 18.A^{o} and 21.4 A^{o}.

Hofmann and Hansdarf, (1942), confirmed that the stepwise hydration of Montmorillonite occurred by formation of successive monomolecular layers of water. In low moisture contents, the presence of hydration nets around calcium and magnesium prevented the orderly development of initial hydration layers so the discrete monomolecular layers' arrangement theory was not manifested at such low moisture levels.

Norish, (1954), using X-ray low angle diffraction methods observed several adsorbed cations in the interspaces taken up during the swelling process of clays. He concluded that hydration was in a stepwise fashion up to a c-spacing of 19 Å and that thereafter regularity ceased. This observation proved that the swelling and the orderly arrangement of successive monomolecular water layers depended on the hydration energy of the cation.

Johanse and Dunning, (1959) determined the surface area of Kaolinite, Montmorillonite and Illite by nitrogen and water vapour adsorption method and revealed that the Water vapor: Nitrogen ratio were Montmorillonite > Illite > Kaolinite.

The higher ratio for Montmorillonite was attributed to the penetration of the basal planes of Montmorillonite by the water vapor.

Desorption values were Kaolinite > Illite > Montmorillonite as a result of the reduced surface area for the enhancement of adsorptive forces in cases of Kaolinite and Illite relative to Montmorillonite where these forces were very effective.

Water vapour adsorption and desorption isotherms were gradual for Illite and Kaolinite as a result of less hydration in contrast with the Montmorillonite isotherms that were steeper as a result of higher hydration of the clay platelets which was enhanced by the adsorbed cations.

Johansen and Dunning, (1959) further concluded that the higher the CEC of the surface, the higher was the adsorption capacity of the clay surface, a phenomenon well illustrated by the three clay mineralogy categories studied.

Barshad, (1955), in his studies on the adsorptive and swelling properties of clay-water systems concluded that for Montmorillonite samples, the higher the charge of the cation, the lower the relative humidity for expansion to occur but that the degree of saturation at which expansion occurs was the same for cations of the same size. Further, Barshad, (1959), pointed out that the larger the ionic radius of the cation, the higher the relative humidity at which expansion occurs though the degree of saturation at which expansion occurs was the same for cations of the same charge but varying in sizes. For varying numbers of cations of the same size, the higher the number of a specific cation, the lower the relative humidity at which the expansion occurs, though the degree of saturation or hydration largely remains the same.

Kaolinite hydration was much less than Montmorillonite on unit-weight basis but was higher on the unit area basis especially in the range when Montmorillonite was in an expanded state which implied greater water-surface activity. Kaolinite has active surfaces that are external so that water vapour directly adsorbs on to them where as Montmorillonite largely has internal active surfaces such that the water vapour adsorbs first on the edges and then gradually penetrates the internal surfaces, a process that retards adsorption.

On the assumption that the ability of a surface to adsorb water is proportional to the CEC per unit area, and regarding the highly expanded state of the Montmorillonite, relative to Kaolinite, the larger charge density in case of Kaolinite could be expected to enhance the higher hydration on the unit area basis, (Barshad, 1959).

Martin, (1960) pointed out that the control of the exchangeable ion was a function of the hydration energy of the ion minus the specific adsorption energy of the ion from the clay surface and that for hydration to occur, the difference had to be positive. It was further argued in the same evaluation that sorption took place at specific sites on the surfaces of clays and that the energy of different sorption surfaces was believed to be different and as a function of the hydrated state of the exchangeable ion.

2.4 SOIL MOISTURE RELEASE (RSθ)

Soil moisture release is an important soil characteristic that gives a general view of how strongly or loosely, the moisture retained by the soil is accessible to plants for uptake. Soil moisture release predominates when the soil moisture retention forces are less in magnitude than the forces of motion,(Hillel, 1971). This energy consideration is a further reflection of the potential energy difference between the soil water at the two points of consideration.

Salter and Williams, (1963), concluded that farm yard manure applications on a sandy loam led to higher soil moisture release for the manured plots. Structural modifications and the resultant well balanced pore size distribution were attributed to the treatment effects that were spread over 7 to 8 years duration.

Conard, (1968), established that the water release depended more on the soil characteristics than on crop or root type. However distinctive relationships between the water release and the specific soil characteristics were not conclusive.

Considerable influence of texture on the water release properties could be feasible but it was not possible to exact the moisture release based on texture considerations. High moisture release at low suctions in sandy soils was attributed to the dominance of macropores in sands as well as the less effective adsorptive forces at low suctions. Reduced moisture release in sandy soils was evident as the adsorptive forces dominated at higher suctions. This phenomenon was evident in all soils studied. In cases of higher silt and clay contents, there was evidence of increased moisture retention and a corresponding reduction in the soil moisture release,(Conard, 1968).

The prediction of soil moisture release using textural data alone could not be reliable and this argument was supported by the observation that expected soil moisture release curves based on textural considerations, were often very different from curves actually plotted. Soils of similar textural classes occassionally had different release curves and this was attributed to structural other than textural variations.

In the same investigation, it was found that the water release variations were highest in the top soil horizon up to 36 cm and minimum variations occurred in the 90-105 cm depths. Differences in sand and silt percentages had no significant influence on moisture release. Conard, (1968), noted that the texture/croptype interaction was significant and logical for irrigation applications.

Hillel, (1971), pointed out that the high Bulk density and the resultant closer particle packing were responsible for the high adsorptive forces that reduce the soil moisture release.

The influence of organic matter on the moisture release at high suctions was established by Salter and Williams, (1965). In sandy soils, the increments were well illustrated even though the magnitudes were small.

Medium textured soils released about 50% of the total soil moisture storage at suctions of less than 1 bar where as the finer and coarse textured soils had correspondingly lower soil moisture release. In the case of the coarse textured soils the moisture release was low and was released at a much lower suction (Salter and Williams, (1965), Junker and Madison, (1967)).

Willatt and Taylor, (1978), in evaluating the soil moisture extraction at different depths by soy beans, observed that though at lower depths there was increased moisture retention, the higher adsorptive forces holding the soil moisture on to the soil particles reduced the ease of moisture release by the soil.

Increased surface area enhances soil moisture adsorption but reduces moisture release, (Johanse and Dunning, 1959). Alternatively the reduced surface area such as in Kaolinite and Illite relative to Montmorillonite, enhances desorption of soil moisture thus leading to high moisture release.

2.5 SOIL MOISTURE RETENTION AND RELEASE CURVES

The soil moisture retention and release curves are used to illustrate the retention and moisture release at corresponding suctions, usually over the 0.0 to 15.0 bar range. As water is released from the soil matrix, the adsorptive forces holding soil moisture on to the surfaces of colloids build up such that successive moisture release requires higher and higher desorption forces as suction rises (Hillel, 1971). The soil moisture retention curve is used to evaluate this phenomenon of soil moisture-energy relationship.

The soil moisture release curve illustrates the volumetric moisture release of the soil matrix in a cummulative fashion and over the 0.0 to a specified bar range, usually the 15 bar. However, the cummulative moisture release could be evaluated up to a selected bar or suction along the release curve in accordance with the purposes of the evaluation, especially in application of irrigation water to either potted or field plants.

Conard, (1968), in evaluating the soil moisture release of California soils came to conclude that where as some predictions of moisture release and retention could be attempted based on texture, they proved unreliable and, surprisingly, soils of similar textures could display different soil moisture retention and release curves.

Further investigation into the structural aspects was suggested as another alternative method of attempting to deduce probable soil moisture relation and release curves. From the same study it was observed that for sandy soils, the slope of the curves were very high at low suctions since most of the moisture release was at low suctions. Similarly moisture retention was low at these same suctions since most of the macropore water had been withdrawn by the applied pressure.

Clayey soils had gradual slopes for both retention and release curves as the dominance of micropores relative to macropores enhanced the adsorptive forces effects in the soil matrix and thus limited moisture release. Similar observations were reported by Hillel, (1971), Taylor, (1972), and Brady, (1974).

Soils with medium textures, lying between the extreme clay and sand textures have been observed to have soil moisture retention and release curves that are intermediate between the clay and sand retention and release curves (Brady, (1974), Hillel, (1971), Taylor, (1972)).

Hillel, (1971), linked the effect of Bulk density on the pore size distribution and thus the soil moisture retention curves. It was argued that compacted and non-compacted soils could, at high suctions display very similar moisture retention curves. This could come about when, for a compacted soil, the intermediate size pores volume is greater than the macropore volume while the interaggregate micropores remains unaffected. In such circumstances, overall moisture retention for both soils would not be significantly different and so would be their curves at high suctions.

Junker and Madison, (1967), in their soil moisture studies using sand peat mixtures, observed that the more uniform moisture-retention curves in pure sands were attributed to uniform pore size distribution and dominated by the macropores. This type of pore distribution was responsible for the more abrupt changes in the moisture tension curves in sands.

Wider pore size distribution variations were manifested in peats which had less abrupt changes in the moisture-retention curves and a similar influence was confirmed when peat-sand mixtures were studied for their soil moisture retention curves.

Petersen, Cunningham and Matelski, (1968), jointly reported that in the Pennyslvania soils with high clay contents, the soil moisture retention curves gradually attained their point of deflexion round about the 0.3 bar mark and that the rest of the curve remained almost constant to the 15 bar mark.

Sharma and Uehara, (1968), studied the soil moisture retention in low Humic Latosols of varying structures with emphasis on both the influence of macrofabric as well as the microfabric aspects of soil peds. . The soil moisture retention curves were used as basis for conclusions which stressed the strong influence of the macrofabric on moisture retention in strongly structured soils and particularly in the 0 to 0.3 ba range. Microfabric was the dominant factor that influenced the moisture retention beyond the 0.3 bar range.

2.6 THE FIELD CAPACITY CONCEPT (FC)

The field capacity concept has for a long time been a controversial soil moisture constant. Most early soil moisture researchers tended to treat the soil moisture status as a static other than a dynamic soil property (Taylor, (1972), Hillel, (1971)).

Early irrigation practices in America generally assumed that as water infiltration continues into the soil; the water holding pores filled and additional water was stored till soil saturation was attained and infiltration ceased, at a soil moisture state which was taken as the field capacity (Taylor, 1972).

This concept was wrong as such soil saturation and the presumed ceasing of infiltration may never be reached in a well drained soil, (Taylor, 1972).

Taylor, (1972), reported that earlier research reports referred to the field capacity as the maximum capillary water capacity equivalent to the amount of soil water retained against gravity.

The FC has been defined as the upper limit of moisture availability to plants (Kohnke, (1968), Taylor, (1972)).

Hillel, (1971), defined the FC as the state of soil moisture when the water flow approaches a static phase after the drainage of gravitational water.

Taylor, (1972), in another approach defined the FC as the quantity of water held against gravity in a well drained soil. This state also referred to the markedly reduced downward water flow.

Currently, the 0.3 bar percentage is commonly used in place of the FC and the 0.3 bar percentage was defined as the moisture equivalent corresponding closely to a water potential of -33 Joules/kg by the soil water content when the out flow ceases from the pressure plate apparatus, (Taylor, 1972). Usage of the 0.3 bar percent or FC takes into consideration the argument that these are approximate equipotential points on the soil water characteristic curve.

The FC concept as the state of soil moisture when water flow has materially ceased to flow is quite subjective,(Hillel, 1971). Flow rates and moisture content decline with time and in the case of water flow, it could become very negligible but not cease entirely. (Alway and Mc Dole, (1971); Richards and More, (1952); Veihmeyer and Hendrickson, (1931)).

Richards, (1960), analysing FC concept came to conclude that the concept may have done more harm than good especially when the determination of the stage when soil moisture redistribution process is considered. Terms such as water flow having "materially ceased", "virtually ceased", "neglibible" or "practically zero" all indicate the lack of universal applicability of the FC concept, (Richards, 1960).

Veihmeyer and Hendrickson, (1949), concluded that FC was equivalent to the moisture retention after excess water had drained off following rain or irrigation application in a pervious and uniform soil. Uniformity here referred to structure and texture. These researchers estimated a period of two days for the attainment of FC in such a soil.

Taylor, (1972), points out that the foregoing concept of FC does not express any exact water content in the soil and assumes that water in excess of the supposed FC value quickly drains away. This approach overlooks the observation that soil water is not held so tightly by the soil matrix as such but that some of the soil moisture can be used by plants while it remains in contact with the plant roots. So the soil moisture content cannot be expected to remain static as had been believed by earlier researchers.

Hillel, (1971), argued that FC was a phase in the soil moisture redistribution process with no marked abrupt breaks or static tendencies. The redistribution rate simply and constantly decreased in absence of a high water table and the phenomenon holds till the equilibrium state is approached as the hydraulic conductivity tends to zero.

For coarse-textured soils, Hillel, (1971) and Kohnke, (1968), indicated that the equilibrium state is approached at a higher rate than for finer textured soils especially those dominated by clays. Clay delays the attainment of or approach to the FC conditions in soils due to the hysteresis phenomenon.

Hillel, (1971), Taylor, (1972) and Kohnke, (1968) stressed the non-equipotential nature of FC of soils and Taylor, (1972) pointed out that the FC represented a range of moisture values on the moisture retention curves and that direct application of the concept of FC was not very reliable though the FC values could give a crude qualitative assessment of the soil moisture status.

The 0.3 bar percentage evaluation encouraged by Taylor, (1972), designates the wet limit of the plant "available" water under general field conditions and allows direct soil moisture comparisons between various soils, (Kohnke, 1968).

Inspite of all the foregoing controversies, FC concept can be dependable to some extent and especially in field conditions as Hillel, (1971) pointed out but then this was on condition that the FC constant had to be measured in the field since no satisfactory method of determining FC constant has proved to be very consistent and the correlations of FC constants as determined in the field with the 0.3 or 0.1 bar percentages tended to depend on specific cases and could not therefore be universally applicable. Moreover, such determinations usually overlooked the dynamic nature of soil moisture status.

The practical implications of the soil moisture content at which the soil moisture redistribution process is considered to have approached an equilibrium or become negligible depend on the purpose of such evaluation.

Hillel, (1971), considered the case of an agriculturalist relying mainly on irrigation farming and pointed out that such a farmer would consider the short-term Soil Moisture Storage Capacity (SMSC) to be crucial. In this case, the soil moisture evaluation within a few days of the period the soil was last saturated would indicate a higher moisture content in comparison to a dryland farmer interested in the long term soil moisture storage capacity. These illustrations clearly appreciate the problems encountered in the attempt to make the FC constant universally applicable since in either case, the farmer has a specific duration which influences the determination as to whether the water flow has markedly reduced or virtually ceased.

From the text, it can be concluded that the evaluation of the moisture content in relation to the practical and specific purpose would be important in the determination of timing of such evaluation. Otherwise for the purpose of general quantitative and qualitative evaluation of soil moisture contents in several soils, the 0.3, or 0.1 bar percentages could serve as standards for comparison of various soils.

2.7 PERMANENT WILTING POINT (PWP) CONCEPT

The Permanent Wilting Point (PWP) concept is yet another soil constant that has for long been a source of argument for many researchers concerned with the soil-water-plant relationships (Hillel, (1971), Marshall, (1959), Kohnke, (1968) Taylor, (1972), Hendrickson and Veihmeyer, (1945), Briggs, (1912)).

Briggs and Shantz, (1912), basing their conclusions on the wilting coefficient concept, defined the PWP as the root zone soil wetness at which the wetted plant could no longer recover its turgidity even when placed in a saturated environment for 12 hours. This was however an arbitrary criterion since the plant-water potential may not reach an equilibrium with the average soil moisture potential in such a short time. Furthermore, plant response depends as much on the intensity and duration of evaporation as on the soil wetness (Hillel, 1971).

Hendrickson and Veihmeyer, (1945), defined PWP simply as the value of soil moisture wetness of the root zone at the time the plant wilted.

Hillel, (1971), argues that the recognition of the particular moment wilting occurs was no easy matter in view of the general observation that wilting could be a temporary phenomenon and that it could occur even at times when the soil was quite wet.

PWP was defined by Marshall, (1959), as the moisture level at which plants wilt and fail to regain their original cell turgidity even when placed in a humid environment for a specied period of time. Although the wilting phenomenon was key to the PWP, allowance was given for the duration of the recovery period.

The PWP is the soil moisture condition at which the ease of release of water to plants is just simply too small to counter balance the transpirational losses (Kohnke, 1968).

Taylor, (1972), defined the PWP as a dynamic range of soil water percentages over which the rate of water supply to plants is not enough to prevent wilting.

Marshall, (1959), stressed that the PWP implied the lower limit of "available" water to plants and that this was misleading since some crops, such as sunflowers, could utilize moisture at suctions higher than the 15 bars considered as the PWP. It was suggested that the plant's osmotic characteristics had to be considered when evaluating PWP. If the PWP value was not independent of the plant used in its determination, then the water content at 15 bars would be equivalent to the soil characteristics, Marshall, (1959).

The 15 bar percentage is commonly used in place of the PWP or the PWP or the Permanent Point Percentage, PPP. Taylor, (1972) defined the 15 bar percentage as the amount of water retained in the soil when subjected to a pressure difference of 15 bars across a water permeable membrane, but cautioned that its usage was limited by its approximate nature as an equipotential point on the soil moisture characteristic curve.

Kohnke, (1968), further pointed out that research by Richards and Weaver, (1943), suggested that for most crops, the PWP was close to the 15 bar percentage though for some plants, the PWP could be lower or even higher than the 15 bar percentage.

For farming purposes the soil moisture content at 15 bar or the 15 bar percentage, is expressed on volume basis or depth of water per given soil thickness or the depth of water within the given depth or volume of soil occupied by the plant roots.

It however, should be appreciated that the PWP evaluation does depend on a number of varied variables namely soil depth, rate of moisture flow to plants' roots, plant roots' osmotic factors, stage of growth of the plants, and the dessicating power of the environment,(Kohnke, (1968), Taylor, (1972)). The environmental and notibly the atmospheric conditions should be closely evaluated in relation to the PWP since wilting could occur even when the soil moisture status would imply the contrary as indeed, Sanchez, (1976), Taylor, (1972), argued.

2.8 AVAILABLE WATER CAPACITY (AWC)

The soil water availability concept has always been a controversial phenomenon in soil-moisture-plant studies and this was appreciated by many researchers (Veihmeyer and Hendrickson, (1927, 1949, 1950, 1955), Hillel, (1971) Taylor, (1972)).

Part of the problem arose from the determination of the critical soil moisture reference points for such AWC considerations. As outlined in sections 2.6 and 2.7, the FC and PWP are the two reference points commonly used in AWC evaluation though they are used with caution as far as universal application is concerned.

Veihmeyer and Hendrickson, (1927, 1949, 1950, 1955), suggested the concept of equal soil moisture availability throughout a definable range of soil wetness, ranging from FC to PWP both of which were characteristic and constant for a given soil. They postulated that plant functions remained largely unaffected by variations in moisture content till PWP was reached. Although this concept remained acceptable for quite a long time, it tended to overlook the dynamic nature of the supposedly constant FC and PWP.

Richards and Wadleigh, (1952), proved that AW decreased as the soil suction increased corresponding to decreased soil wetness. Further, it was observed that, depending on species, plants could suffer stress and growth reductions prior to the long held but controversial PWP constant.

Subsequent research generated a wide range of concepts such as the soil moisture Available Range. AR; Readily Available Water, RAW; Decreasing Available Range, DAR: Readily Available Water Capacity, RAWC; Easily Available Water Capacity, EAWC; Freely Available Water, FAW; and Available Water Storage (Hillel (1971), Riley, (1979), Salter and Williams, (1966)). Riley, (1979), advanced the concept of the Strongly Held Available Water, SHAW; and the Total Available Water, TAW.

All these concepts arose mainly as a result of the search for a critical bar or point along the soil moisture retention curve between the FC and the PWP. This would serve as added criterion for soil moisture availability in view of the arguments for and against the FC and PWP concepts (Hillel, 1971). The soil moisture availability concepts that came up were; the equal moisture availability concept over the FC to PWP range, the equal moisture availability up to a critical moisture and suction point followed by a gradual reduction in moisture availability and, the concept that visualized a gradual and consistent reduction in the soil moisture availability from the FC to PWP (Hillel, 1971).

Soil wetness per se does not imply moisture availability and attempts to correlate the water status in plant and soil moisture potential fell short of fully accounting for the dynamic soil-plant-water relationships as stressed by Hillel, (1971).

Roots growth in the soil environment is varied and as yet the satisfactory microscopic moisture fluxes or gradient measurements are to be treated with caution as evaluation criteria of soil moisture availability. It became increasingly clear that the long held concept of FC, PWP, critical moisture points, gravitational water were often unreliable in the description of the dynamic soil-plant-water system in addition to the lack of fundamental qualitative variation between the soil moisture held at any two suctions (Hillel, 1971).

However, the quantity and rate of moisture uptake depends upon the ability of plant roots to absorb moisture from the soil with which they are in contact. Equally significant is the ability of the soil to supply the water and transmit it to the root zone for absorption to cater for the transpirational as well as related crop needs (Hillel, 1971).

Root density, depth and rate of growth were stressed by Hillel, (1971) as factors that influenced the soil moisture availability to plants. Interlocking root factors such as the root cell sap osmotic pressure and the soil moisture suction were too, considered important.

For practical agricultural moisture evaluation purposes, the PWP as determined using the sunflower trials, and the water content as determined by the pressure plate apparatus at 15 bars, represent the lower limit of available water, AW to plants (Marshall, 1959).

Water is not equally available to plants and actually decreases in availability as suction increases since the drier the soil, the less the permeability and the more restricted is the moisture movement towards the root zone (Marshall, 1959).

It is also believed that the soil moisture at high potential, thus under low suction, is relatively easier for plants to absorb than moisture at low potentials which requires higher energy for extraction by plant roots (Taylor, 1972). Indeed Marshall, (1959), argued that the 0.3 bar was representative of the most suitable suction for most plants' water uptake.

A working definition of the AWC is that moisture held or retained by the soil between the 0.3 and the 15 bars commonly referred to as the Available Water Storage, AWS of the soil (Marshall, (1959), Kohnke, (1968), Hillel, (1971)). This moisture content represents the preserved soil moisture over a long period following infiltration. Such AWS values could exist in several soils in relation to the texture (Croney and Coleman, (1954), Hillel, (1971), Taylor, (1972)).

Some practical observations related to the PWP, FC in evaluation of the AWC or AW to plants have revealed contrasting and often contrary information. The PWP as a measure of lower moisture availability to plants was found to bear little relationship to the permanent wilting condition of even the very moisture sensitive native trees of South Western Alberta plains (Harris, 1974). All trees did not wilt till a much higher than the conventional PWP or 15 bar and lower moisture content were reached. However he pointed out the conviniency of the PWP value as a reference moisture level for the comparison and suitability evaluation purposes when selection of the tree species to plant was required for the soils studied.

Based on the moisture content at 0.3 and 15 bars, Hillel, (1971) using the wilting feasibility considerations concluded that sands had a narrow range of soil moisture for wilting feasibility or susceptibility to wilting where as for clay, there was a wider range of wilting feasibility. The governing considerations were mainly the moisture content at 0.3 and 15 bars both of which were lower for sandy soil than for the clayey soils though these absolute values could not be reliable as far as the availability of this water to plants was concerned. It is to be expected following from sections 2.6 and 2.7 that the moisture stored in the 0.3 to 15 bar range in case of soils dominated by clay would be less easily extractable by plant roots due to the higher adsorptive forces holding the soils moisture on to the colloidal surfaces.

Maclean and Yager, (1972) concluded that the non-universal application of the FC and PWP was largely responsible for the AWC practical usage or the proper soil moisture evaluation problems. In Zambia soils that included Entisols, Oxisols, Inceptisols and Vertisols, the 0.3 bar moisture content underestimated the FC values as determined in the field. However, in most cases, the 0.1 bar moisture content and the FC as determined in the field, correlated well in the fine textured soils with 'r' or 0.969. The 0.05 bar moisture content correlated with FC with r = 0.977. The 15 bar moisture content and the PWP correlated well with r of 0.978 and pointed out that the 15 bar moisture content as determined by pressure plate methods could be applicable as PWP for most plants without serious error.

In the same study, it was reported that AWC determined by direct FC measurements in the field and the 15 bar moisture content ranged from 0.52 cm/dm in sand to 3.53 cm/dm in alluvial silt loam with more than 6% organic matter. A drop in AWC from 2.02 cm/dm in the top soil to 1.25 cm/dm in 130-140 cm depth in the subsoil was observed. AWC variations between the depths and within series were highly significant.

AWC determination based on the 0.3 bar and 15 bar as reference suctions was underestimated by 35% compared with the direct field sampled determinations (Maclean and Yager, 1972).

The usage of the 0.1 and 15 bar as the reference suctions underestimated the AWC by 10% whereas the AWC determined by use of the 0.05 bar and 15 bars as reference suctions was overestimated by 4%. The AWC 0.05-15 and the AWC determined by direct field methods were correlated with r = 0.865. Simple correlation between the AWC and particle size distribution gave highest correlation with USDA silt and the USDA minus the ISSS silt.

Positive and significant correlation was obtained for the AWC and the organic matter in the upper soil horizons and with the ISSS fine sand for the lower depths. Strongly negative correlation between AWC and coarse sand was registered (Maclean and Yager, 1972).

Prediction of AWC, (Vol./vol) using the multiple linear regression slightly overestimated the values in Zambian soils. The r value was 0.75 and was considered high bearing in mind the disparities in the soils genetic properties.

The sample depth gave a small and negative contribution to the regression line and the structural influence on AWC through the organic matter and particle size distribution interaction was not well established. Addition of Bulk density to the regression did not improve the regression line significantly.

Riley, (1979), investigated the relationship between soil moisture retention, texture and organic matter and came to the conclusion that the soil moisture status could be categorized into the Easily Available Water, EAW between 0.1 and 1 bar; the Strongly Held Available Water, SHAW between 1 to 15 bar; and the Total Available Water, TAW between 0.1 to 15 bar. The magnitude of the relationship between moisture and the two soil characteristics were thus EAW < SHAW < TAW.

Marshall, (1959), had earlier emphasized that the quantity of water covered by the available moisture range depended more on structure rather than on texture . Specifically, the importance of the total volume of pores that were full at FC and then emptied at PWP was stressed.

Observations by Marshall, (1959), also indicated that AWS, decreased with high clay content as a result of adsorptive forces and that

AWS increased with coarse silt content. Fine silt had slightly lower positive contribution to AWS because of the higher moisture retention at both 0.3 bar and 15 bars used as the reference suctions

Marshall, (1959) reported that it had further been established that AWS was increased by high organic matter content. A further observation was that since the organic matter was directly related to silt and inversely related to clay, the influence on the AWS could be attributed to structural factors.

Sanchez, (1976), reviewing soil moisture retention in oxic families notibly, Oxisols or Ferralsols, pointed out that at high suctions, these soils, though well aggregated, held moisture with high adsorptive forces similar to the clay fraction. The resulting AWCs could be lower, contrary to the expectations.

The organic matter-allophane aggregation influence soil particles in Oxisols or Ferralsols, and subsequently improve the AWC. In Andosols, the influence was very enhanced by the particularly increased moisture retention at 0.3 bar and a noticebly low moisture retention at 15 bars, (Sanchez, 1976).

In the same study, it was revealed that regardless of actual textural variations, the average AWC was quoted as being 10%. Acrisols or Ultisols had higher AWC and Andosols or Andepts had the highest AWCs.

Sanchez, (1976), further reported that soil organic matter though a dynamic soil property, increased soil moisture retention and AWC in Andosols or Andepts where the influence was particularly marked. The influence was attributed to modifications in pore size distribution in favour of the higher large and medium sized pore size distribution. Organic matter was seen as a positive factor as far as the soil moisture release in Andosols was concerned.

Salter and Williams, (1963), had earlier established that long periods of farm yard manure applications increased AWCs of a sandy loam largely as a result of well balanced pore size distribution and reduction in Bulk density. These factors jointly contributed to the overall 50% to 70% increase in AWC over the 7 to 8 year period.

Conard (1968), revealed that AWS in the studied Californian soils was higher with high silt and clay fractions especially at high suctions. However the AWC viewed from the actual availability of such water to plants was questioned since it was dependant on the soil and plant characteristics. This availability concept was not evaluated in the study.

In the assessment of the influence of sand, silt, clay and organic matter on AWC on 26 soils it was revealed that AWC correlated positively with the International Fine Sand, IFS (American Silt) and organic matter content. The AWC and the Coarse sand were negatively correlated (Salter and Williams, 1966). Variations in the AWCs soils of similar textures were attributed to structural factors and it was further suggested that the FC and not the 0.3 bar percentage should be regarded as the upper limit of available water to plants if the AWC were to be a realistic measure of the total quantity of water available to plants under field conditions.

The AWC evaluation of the top 60 cm of 27 soils of different textures revealed that the medium textured soils had the highest AWC. The reported AWC ranges were 0.008 cm/cm depth for sand, 0.034 cm/cm depth for silt loam, 0.0347 cm/cm depth for peat and 0.0216 cm/cm depth for clay soils (Salter and Williams, 1965). It was also observed that the soil moisture retention increased at both FC and PWP or 15 bar as the soils became finer. FC was determined in the field and the 15 bar moisture percentage was determined using pressure plate method and disturbed soil samples.

The Freely Available Water, FAW, between 0.1 and 0.3 bar or ≤ FC was particularly influenced by the soils structural conditions and it was further established that the FAW was part of the Total Available Water, TAW, and varied with several soil types (Salter and Williams 1965). Consistently low AWCs were reported as soils became finer even at low suctions. Medium-textured soils had about 50% of the AWC held, released at < 1 suction thus a high portion of the Easily Available Moisture Release, EAMR, at low suctions. The finer-textured soils had correspondingly lower AWC and EAMR due to high adsorptive forces.

The coarse-textured soils had lower AWCs and EAMR due to low initial soil moisture retention values resulting from low adsorptive forces and most of the AWC, also a low value, was released at < 1 bar as a result of the macropore dominance in coarse-textured soils (Salter and Williams, 1965).

Pidgeon, (1972), using the Ferralsols Uganda evaluated the AWCs and, using regression equations, attempted to predict the AWCs, EAWCs and FC in these soils.

FC was directly determined in the field and the soil moisture characteristic curves were derived from undisturbed cores. Attempt was made to compare laboratory data determinations of the 0.3 bar percentages with the FC field determined data but these proved unreliable. Actually no single moisture tension value based on the 0.3 bar corresponded to the FC value as determined in the field so the direct use of laboratory determined values should be carefully examined as Pidgeon, (1972) suggested.

Quantitative assessment of the effect of silt, sand, clay and organic matter in the 26 soils on the upper and lower limits of water "availability" to plants was carried out. Also attempt was made to predict the Available Water Capacity AWC, and the Easily Available Water Capacity, EAWC using regression equations obtained. The implications of the predicted FC and PWP values on the AWC was not investigated. However, the accuracy of the upper limit of moisture "availability or FC, ranged from ± 9 to 22% whereas that for the lower limit of moisture availability or PWP ranged from ± 8 to 16%. Though the AWC was not estimated from the FC and PWP regression equations, the accuracy of the AWC if determined could be close to the results corresponding to FC and PWP according to Salter and Williams, (1969).

In his general conclusions, Pidgeon, (1972), stated that the FC, PWP, AWC and EAWC could all be predicted using mechanical analysis data in addition to the organic matter content. The organic matter, in addition to increasing soil moisture retention was most probably contributing to the structural stability of the soils studied.

The regression equations used in the prediction of FC, PWP, AWC and EAWC were as follows;

FC = 7.38 + 0.16 Silt + 0.30 Clay + 1.50 Organic Matter (w/w%). --------------(12)

where FC = Field Capaciety or Upper limit of moisture availability.

PWP = 4.19 + 0.19 Silt + 0.39 Clay + 0.90 Organic Matter (w/w%). --------------(13)

where; PWP = Permanent Wilting Point or Lower limit of moisture availability.

$$\text{AWC} = 169.3 - 1.5\,\text{Clay} + 6.09\,\text{Organic Matter}\ (\text{mm/m}). \quad \text{------} (14)$$

where; AWC = Available Water Capacity.

$$\text{EAWC} = 121.1 - 3.03\,\text{Silt} - 1.38\,\text{Clay} + 6.76\,\text{Organic Matter}\ (\text{mm/m}). \quad \text{------} (15)$$

where; EAWC = Easily Available Water Capacity

Pidgeon, (1972), reported that Hosegood, (1972), had established earlier that the FC and the 0.3 bar percentage moisture in undisturbed soil cores sampled from the B-horizons of the Kikuyu loam soil at Muguga had good agreement. The EAWC was the moisture held between FC as determined in the field, and the 1 bar. The 1 bar reference was taken as the upper limit of moisture availability to plants since at > 1 bar, suctions exerted by the soil matrix lead to growth reduction in most common crops.

Willatt and Taylor, (1978), used the soybean plant to illustrate the importance of effective rooting depth on the utilization of the stored soil moisture in different soil horizons. It was revealed that the depth from which the soybean extracted water was related to the root system and that moisture extraction increased with the more extensive root system. However, water uptake rates decreased as the soil water content decreased attributed to the reduced hydraulic conductivity of the soil.

It was observed that though the soil moisture content could increase with depth, the soil moisture extraction often decreased and this was attributed of to the higher adsorptive forces holding the soil moisture on to the soil particles.

The maximum rate of moisture uptake of the soybean roots was higher per unit length for the deeper penetrating roots compared to the shallow reaching roots.

Salter and Williams, (1969), investigated the soil moisture retention and the AWC in six Rothamsted, Warbwn and Saxmudhan soils of different textures and established that moisture retention was 0.012 cm/cm and 0.031 cm/cm in the surface soil for the sandy loam and silt loam respectively. The silt loam was under permanent grass, a factor that probably improved soil structure and thus improved moisture retention as a direct influence of the well balanced pore size distribution. AWC were also higher for this soil. Comparison of AWCs between the manured and non-manured soils, using farm yard manure, revealed higher AWCs for the manured soils.

Rivers and Shipp, (1972), used disturbed soil samples of sandy soils of North Dakota to investigate AWCs which revealed that the AWCs were lower in the sand to the loamy sand range of textural classes. Higher AWCs were reported for the loamy sand to the loam range of textural classes. AWC and silt correlations were significant at 5% level. Coarse sand and AWC correlations were low but positive.

In all cases the FC was underestimated by the 0.1 bar moisture percentage by 1.2% and 1.7% for fine and coarse sand respectively and so the AWC based on the FC as determined in the field and the 15 bar percentage as determined by laboratory pressure plate method, was more reliable.

Sykes and Loomis, (1967), evaluated the plant and soil factors that related closely to the Permanent Wilting Percentage and the Field Capacity Storage, and designated the moisture retained after 2 days by a previously partially wet soil, as the Field Capacity Storage.

It was stated that the FCS did represent the Maximum Storage Capacity of the soil with about 50% of this moisture assumed to be available to plants. Storage Capacity, it was stipulated, was the moisture retained under the same conditions after a period of several weeks. It was a soil moisture property that could be of importance in drought or in insignificant rain periods, (Sykes and Loomis, 1967).

Further, the FC values were established to be primarily dependant on texture whereas the Storage Capacity depended on structure. The continuity of the moisture films along successive soil particles was necessary for high moisture conductivity at high suctions if the actual moisture availability to plants were to be improved (Sykes, Loomis,(1967).

Bartelli and Peters, (1959), established that the A-horizon in the Illinois silt loam soils had higher AWCs and that the AWC correlated highly with the 0.3 atmosphere moisture percentage but less so with the 15 bar moisture content. The silt percentage principally controlled the AWC as the investigation revealed. The AWC tended to be related to the total moisture content at any suction but in case of the clayey soils, the particularly high moisture retention at the 15 bar reduced the potentially AWC.

Junker and Madison, (1967), proved that Ganadian peat mixed with sandy soils improved the moisture retention. The AWC increased by as high as 80%. The influence of the peat was particularly significant bearing in mind the usually low saturation value of about 40-44% for sand.

The Practically Available Water was defined as the moisture retained between the near-saturated range of the soil and the moisture retained slightly in excess of the value resulting in the first wilting symptoms.

Petersen, Cunningham and Matelski, (1968), established that the clay-rich or fine textured Pennyslvania soils had higher AWCs compared to the sand-rich coarse textured soils. Maximum AWCs were in the medium textured silt-rich soils.

The AWC for most samples decreased with > 70% sand and > 40% clay content due to low and very high adsorption forces respectively which, in case of sand, implied potentially low AWC and, in the case of clay, led to less desorption of the soil moisture. Particular emphasis on the silt loam class moisture status revealed that AWC increased with the silt fraction. Similarities in the silt contents for the clay loam and silt clays led to similar AWCs in these textural classes (Petersen, et al, 1968).

The dominance of large or macropores in sandy soils could not favour high soil moisture retention and noting that the AWC was determined using the 0.3 bar moisture percentage as upper limit of availability, it can be visualized that most of the macropore water had drained at this suction so the difference between the 0.3 bar moisture percentage and the 15 bar percentage would be expected to be small thus the low AWC in such soils.

Petersen, Cunningham and Matelski, (1968), made the general conclusion that increasing bulk density, sand and clay, (40%) reduced the AWCs whereas the silt fraction was reported to have increased water availability capacities for the soils studied. It was further recommended that the Bulk density had to be included in all AWC prediction equations.

Investigating the soil moisture retention within the silt loam textural class in particular, Petersen, Cunningham and Matelski, (1968), reported higher AWC for the A-horizon compared to either B-or-C-horizons and that the increased soil moisture retention at 15 bars in the B-horizons markedly reduced AWC thus limiting moisture availability to plants. Also the coarseness of the texture, which actually increased with depth led to reduced moisture availability resulting from lowered AWC in such situations.

Soil organic matter significantly improved the AWCs and particularly of coaser fractions of the silt loam class. As the finer fractions became dominant, the AWCs gradually attained constant magnitudes and were, thereafter, functions of the fine fractions other than of the organic matter content.

Often the AWCs were negatively correlated with clay mineral types but since most soils had mixed clay mineralogy no significant influence by any clay type was outstanding (Petersen, Cunningham and Matelski, 1968).

Gardner, Petersen, Cunningham and Matelski, (1971), basing their determinations on laboratory methods, established as AWC, the moisture content between 0.1 and 1 bar and that this AWC could be reliable for the A- and B-horizons. For the C-horizon, the plant rooting habits and the water table considerations had to be carefully reviewed.

The four researchers concluded that due to lack of well proven and reliable soil physicists' backed evidence to establish the true upper and lower moisture availability reference points, the 0.3 and 15 bar moisture percentages shall continue to be used in AWC evaluations.

Zahner and Hedrick, (1966), evaluating the FAO/UNESCO Fluvisols, with emphasis on the medium and fine sand textural classes, established that AWC was higher for the fine sand compared to the medium sand. Closely investigating the soil moisture status in the fine sand textural class, it was revealed that the very fine sand fraction had the greatest influence on the AWC and that the AWC for very fine sand fraction was 12% compared with 2% for the medium sand texture. The fine sand retained slightly less than x2½ the AWC of the medium sand at low suctions.

In relation to the RAWC, Readily Available Water Capacity between 0.06 and 6 atmospheres according to Zahner and Hedrich, (1966), the very fine sand fraction had a value of x5 any other textural class.

In the soil moisture evaluations the Kenya Soil Survey accepts in principle that FC is at the PF 2.3 (approximately 0.3 bar) and that PWP is at PF of 4.2 (approximately 15 bars). But the KSS appreciates the limitations of the PWP reference PF of 4.2 noting that moisture retained at this PF value is strongly adsorbed on to the soil particles. So the KSS uses the "conservative" moisture lower limit of PF 3.7 (approximately 9 to 10 bars) and estimates the Productive Available Water, PAW as the moisture retained between PF 2.3 and 3.7 or approximately 0.3 and 9 to 10 bars.

In the previously studied Kenyan soils, it was reported that the moisture storage ranged from 10 mm/10 cm in loamy sands to 5 mm/10 cm in sands (Siderius and Muchena, 1977). It was also appreciated that the subsoil moisture is not readily available to plants due to reduced root density such that only the moisture close enough to the existing root system was potentially available or exposed to plants' roots uptake.

Shetron, (1974), evaluating the AWC of some forested sandy soils recommended that soils of low AWCs should be used for low moisture requiring species.

The influence of the soil moisture storage on various aspects of crops' performance have been investigated by several researchers. Ranjodh and Chadha, 1977), studied the effects of phosphorus fertilizer, initial profile water storage and seasonal rainfall, on yield and water use by dry dryland wheat on a loamy sand and sandy loam over a two-year period. The most significant correlation was between the yield and Available Water Storage, AWS, + seasonal rainfall received, r = 0.991.

Other correlations were as follows;

The yield versus AWS + seasonal rainfall received between tillering to jointing, r = 0.881.

The yield versus AWS + seasonal rainfall received between jointing to heading, r = 0.931.

The yield versus AWS + seasonal rainfall received between tillering to heading, r = 0.948. These results emphasized the importance of soil AWS at planting.

The importance of high AWC was stressed by Kohnke, (1968), as having the advantage of reducing supplementary irrigation requirements, an observation that is more pronounced in fine textured soil. For the same suction, the fine-textured soil has higher moisture retention than a coarse-textured soil. It therefore follows that supplementary irrigation frequency would be higher for the coarse-textured soil compared to the fine-textured soil.

From the foregoing arguments on the concepts of FC, PWP, AWC, the author appreciates the various handicaps of the mentioned concepts and in particular, the overall hinderance of these limitations to the universal application of the FC, PWP and AWC concepts. The AWC concept in particular is limited by the dynamic nature of the reference moisture points on the soil moisture retention curve such that the FC or the 0.1, 0.3, or 0.05 bar moisture contents cannot always be true for all plants as the upper value of moisture availability. Also the PWP or the 15 bar moisture content cannot always hold for all plants as the lower value or limit of moisture availability

The overall evaluation of the AWC has limitations of plant and soil factors but the author would agree with the theory that asserts that not all the AW, Available Water (as determined by any two reference points on the soil moisture retention curve is equally available to all plants over the same moisture-tension range. For any plant, the author would agree with the concept that the availabilty of moisture would vary along the moisture-tension curve and that the moisture availability would be governed by the various stages in the physiological development of the plant in question. In this study, the soil moisture content between any specified suction was referred to as Soil Moisture Storage (SMSθ), (Hillel 1971).

Further, the author, appreciates the argument that the atmospheric factors, and in particular the transpirational factors could be vital in the determination of the PWP, of the plant in question.

It should also be appreciated that the soil moisture conductivity does play a role in the availability of soil moisture to plants. The link up between the transpirational requirements of the crop and the ability of the soil to make the moisture available at the right rate was considered a key argument by the author.

In conclusion, the author agreed with the advanced suggestions of more critical investigations on the FC, PWP and the AWC concepts for universal application purposes.

CHAPTER 3

MATERIALS AND METHODS

3.1 SOILS STUDIED

The soils types selected were to represent as far as possible, a varied range of soil textures between clay and sand as the two extreme textural classes. This was intended to give a wider choice of the investigation to the author thus providing fairly balanced conclusions from the study. The soils studied are given in Table 1.

3.2 METHODS

Field Work

Field work comprised selection of four sites for each of the six soil types. Such sites were selected such that they were within close range of each other so as to minimize, as far as possible, the usually drastic variations common in soil studies. Representativeness and consistence in sites' selection per soil type were further improved by limiting of slopes for the sites within the 2 to 5% range. The precaution was intended to minimize variations attributable to slope factors.

To represent, as far as possible, the natural state of the soil moisture relationships of the soil samples, virgin areas were selected as sampling sites. Where virgin areas were either non-representative or non-existent, relatively less disturbed or cultivated but otherwise representative sites with secondary growth were selected.

3.3 SAMPLING TECHNIQUE

Each site was sampled at 0-6, 30-36 and 60-66 cm depths for the determination of moisture relationships, hydraulic conductivity, textural determinations and organic matter. The selected site was cleared of growing vegetation and a profile, dug out in a terrace-like fashion to correspond to the three depths, was made.

A core sampler was used for obtaining the undisturbed soil samples for all soils studied. After fitting the protector rings on top and bottom of the main ring, the whole retainer components were inserted into the core sampler head which was screwed on to the handle. The core sample was then hammered into the soil at each appropriate depth.

The whole component was carefully removed from the soil, unscrewed and the main soil sample in its retainer ring was trimmed at the junctions of the two protector rings. The sample was then sealed with two metal (aluminium) lids for safe transfer to the laboratory. Simultaneously, disturbed soil samples were augered within a short range of each of the core sampler sites and composite samples were made from these for the laboratory determination of texture, clay mineralogy and organic matter.

3.4 SATURATED HYDRAULIC CONDUCTIVITY (K_{sat})

The constant head method as outlined by Black (1965), Kinyali (1973), was used in the saturated hydraulic conductivity determinations. Each soil sample bottom was capped with cheese cloth filter using rubber bands while the top was trimmed to the ring volume. A second empty ring was connected to the top of the sample and the two rings were firmly sealed at the junction using water·proof adhesive tape.

Samples were placed in a tray and tap water was introduced to cover the samples' rings up to about 1 cm from the top of the empty ring. Saturation was allowed for at least 24 hours at room temperature. To minimize evaporation and thus facilitate full and faster saturation, polythene covers were placed over all such samples.

Soil cores were then carefully and vertically mounted and supported on porous outflow surfaces connected to funnels leading to water receivers below each sample.

A shallow column of water was maintained over the soil surface by a siphon tube from a constant level reservoir. The system was given approximately ten minutes to attain both a steady water column level over the soil surface and a steady water flow through the soil core. It was also established that no air bubbles were in the system and this ensured constant and consistent water flow.

At the appropriate moment, a water receiver was placed under the funnel and simultaneously a stop clock was started. Collection of the outflowing water continued for the predetermined time (t) of 60 minutes. The quantity of water collected (Q) was measured in cubic centimetres and the shallow water column height (δh) above the soil surface was measured in centimetres both at the beginning and at the end of the 60 minutes for each sample.

Saturated hydraulic conductivity (Ksat) in cm/minute was calculated thus and according to Darcy's Law.

$$K_{sat} = \frac{Q}{At} * \frac{L}{\Delta H} \quad \text{---------------------} (16)$$

where; Q = Quantity of water in cm^3, collected.

t = Time of water flow in minutes.

A = Cross-sectional area of the soil-core in cm^2.

L = Length of soil core in cm.

ΔH = Hydraulic head difference or gradient across the soil core.

$\Delta H = L + \delta h$, where δh is the water column level over the soil surface.

For each core sample, dry Bulk density in gm/cm^3 was determined after oven drying for at least 48 hours at 105°C.

$$\rho_B = \frac{Ms}{Vt} \quad \text{------------------------------} (17)$$

where; Ms = Weight in gms of the oven dry soil sample.

Vt = Field volume in cm^3 of the soil sample which was equivalent to the volume of the ring.

3.5 SOIL MOISTURE RETENTION AND RELEASE DETERMINATION

The pressure chamber method was used in the soil moisture studies in the 0.0 to 15.0 bar range.

The lower end of the core samples were capped with cheese cloth filter using rubber bands. The top was trimmed to the core volume and excess cloth was trimmed off to allow firm grip of the rubber bands.

Samples were placed in a tray and tap water was introduced to soak the samples up to about 1 cm from the top of each soil sample. Saturation was allowed for at least 24 hours and polythene covers were used to minimize evaporation from the soil surfaces thus enhancing full saturation of the soil samples. A previously examined ceramic plate of 1 bar was soaked for the same period of time before it was placed on metal supports inside the pressure chamber.

For each sample, the full saturation or the zero bar weight was quickly but accurately recorded. The procedure was intended to minimize possible drainage of some macropores once samples were lifted out of the saturating water for weighing. Samples were then firmly placed on the ceramic plates to maintain continuous water film through the soil core and the ceramic plate.

Out flow rubber tubing leading from underneath the ceramic plate and in connection with the pressure membrane was connected to a fine metal side pipe leading to the chamber exterior thus providing the only outlet for the released water once the pressure was applied on to the core samples inside the pressure chamber. The chamber was firmly closed to avoid any pressure leakages.

Automated pump with the pressure adjustment system fixed on to the wall had a main pressure tube leading into the adjustment system. The operation of the pressure adjustment system was such that for low tensions, up to 3 bars, the high tension nobs were locked while the low tension nobs were carefully adjusted to the desired tension. Once attained, the nobs were locked to guard against undesirable pressure excesses.

A water receiver was placed below the metal side pipe to collect the released water from the samples. Once the water out-flow ceased, it implied that the equilibrium between the applied pressure and the soil matrix suction had been attained so samples were then weighed.

Prior to weighing at any bar, pressure control nobs were locked to cut off the pressure supply to the chamber and then the exhaust nob was slowly opened to release pressure from the chamber. Samples were placed on trays and covered with polythene sheets to avoid moisture absorption. They were immediately weighed and then placed back in the chamber on moistened plates for the next stage of the experiment. Weighings were made at 0, 0.1, 0.3, 0.5, 0.7, 1, 3, 5, 7, 10, 13 and 15 bar and ceramic plates of 1, 3 and 15 bar markings were used in the study at the appropriate stage of the experiment.

After the 15 bar readings, samples were oven-dried for at least 48 hours at 105°C and then, soil moisture retention, release and the dry Bulk density were determined.

$$Rt_{\Theta} = \frac{Wt_{(i)} - Wt_{(O.D)}}{Vs * \rho_{w}} \quad \text{---------------} \quad (18)$$

where; Rt_{Θ} = Soil Moisture retention (volume fraction) in cm^3 per unit volume of soil.

$Wt_{(i)}$ = Weight in gms of the soil sample at a given tension.

$Wt_{(OD)}$ = Oven dry weight of the soil sample in gms.

Vs = Field volume of the soil sample in cm^3 equivalent to volume of ring.

ρ_{w} = Density of tapwater in gm/cm^3

(In this study ρ_w was taken to be 1 gm/cm^3.

Soil moisture release was determined thus;

$$Rs_\theta = \frac{Wt_{(O)} - Wt_{(\tau)}}{Vs * \rho_w} \quad \text{---------------} (19)$$

where; RS_θ = Soil moisture release equivalent to volume fraction water occupying space in soil and now at the specified suction, (τ), is released by the soil.

$Wt(O)$ = Initial weight of the soil system in gms at O (zero) bar tension.

$Wt_{(\tau)}$ = Soil system subsequent weights in gms corresponding to the suction (τ) in every case.

Vs = Field volume of the soil sample in cm^3 equivalent to the volume of the ring.

ρ_w = Density of water in gm/cm^3 (In this study, ρ_w was taken to be 1 gm/cm^3).

For each of the moisture study samples, the dry Bulk density was determined thus;

$$\rho_B = \frac{Wt_{(O.D)}}{Vt} \text{ ------------------------ } (20)$$

where; ρ_B = Dry bulk density in gm/cm^3.

Wt (O.D) = Oven-dry weight of the soil sample in gms.

Vt = Field volume of the soil sample in cm^3 equivalent to the volume of the ring.

3.6 SOIL TEXTURE DETERMINATION

The particle size distribution was determined by the pipette method with slight modifications in the silt and sand determinations using Ahn's, (1973) procedure. Constant temperature was maintained by placement of the sedimentation cylinders in a giant water tank.

Samples were air-dried and then sieved through a 2 mm sieve and 10 gms were used in all determinations which were made in duplicates. A third sample in each case was used for oven-dried and organic matter-free weight of the soil.

Organic matter for each sample was oxidized using portions of hydrogen peroxide till no reaction was observed.

Dispersion was carried out using 25 ml portions of sodium hexametaphosphate (Calgon) added by pipette to each sample free of organic matter. The suspension was transferred into a dispersion can using "policeman" glass rods and the volume was made up to about 300 mls with distilled water followed by electric stirring for 10 minutes.

A 63 mm sieve was used to separate the sand fraction from the silt and clay which collected in a 500 ml sedimentation cylinder and this was made up to the mark with distilled water. The sand oven-dried at 105°C for 24 hours.

The sedimentation cylinders plus contents were placed in the constant temperature water tank overnight and were covered with aluminium foil. Prior to sampling, the temperature of the water was checked to establish the corresponding sampling time. Stirring using brass stirrer was for about two minutes and immediately the stirrer was removed from the suspension, a stop clock was simultaneously started to time the three samplings per sample i.e. T_1, T_2, and T_3 using a 10 ml capacity automatic pipette. The sampled suspensions were emptied into weighted tins and covered to avoid foreign bodies' entry prior to oven drying at 105^{o}C for 24 hours. Oven-dried samples were placed in a dessicator and after cooling, were weighed less the weight of empty tins.

The sampling times T_1, T_2, T_3 corresponded to Clay + Medium Silt + Fine Silt + Coarse Silt; Fine Silt + Clay; and Clay alone respectively. Correction had to be made for Calgon by pipetting 25 ml of calgon into 500 ml of distilled water and then pipetting 10 ml as for the actual samples.

Calculations for the percentages of various textural seperates were as follows.

SAND FRACTIONS

The set up of 600 micron sieve atop the 200 micron sieve and a receiver below was used to separate the Coarse, Medium and Fine Sand fractions in that order. The direct weights of the sand fractions were expressed as percentages of the oven dry, organic matter-free soil sample.

CLAY FRACTION

The clay percentage was determined by the T_3 oven-dry weight expressed over the organic-free soil sample.

SILT FRACTIONS

The Fine Silt weight was given by T_2-T_3 and the Medium Silt weight was given by T_1-T_2.

The conversion of the weights obtained from the 10 ml a liquot into the amount contained in the 500 ml was by a multiplication factor of x 50 in each case and all weights were expressed as percentages of the oven dry organic matter-free soil samples.

Finally, the coarse silt percentage was obtained thus;

$$Csi = 100-(Clay + Fsi + Msi + CS + FS) \qquad -----(21)$$

where; Csi = Coarse Silt %
CS = Coarse Sand %
FS = Fine Sand %
Fsi = Fine Silt %
Msi = Medium Silt %

3.7 ORGANIC MATTER DETERMINATION

The Walkey Black method as outlined by Ahn,(1973) was followed in the organic matter determination. 0.5 gm of air-dried fine earth used in all duplicate determinations. 10 mls of

IN Potassium dichromate were used as oxidizing reagent 20 mls of concentrated sulphuric acid were used to digest the organic bonds thus rendering them exposed to oxidation and conversion to carbon dioxide by the dichromate. The suspension was left to cool, then about 200 mls of distilled water were added followed by 5 ml of diphenylamine indicator. Titration was done using 0.5N freshly prepared ferrous sulphate against excess dichromate. A blank sample was run in the same way. Organic matter was calculated from the organic carbon percentage using the 1.724 multiplication factor.

3.8 CLAY MINERALOGY DETERMINATION

Clay mineralogy for each composite sample per sampled depth was carried out using the Xray diffraction method using sedimented organic matter-free samples. Calcium carbonates had been removed using hydrochloric acid and dispersion was achieved by use of sodium hexametaphosphate (Calgon).

Xray analysis was carried out on samples saturated with Potassium and Magnesium using standard clay minerals.

CHAPTER 4

RESULTS AND DISCUSSIONS

The data was presented in several broad sections covering the selected soil characteristics, the simple linear correlation and regression relationships between the selected soil characteristics and the evaluated soil moisture parameters and, finally, the overall soil moisture status evaluation of each soil type.

The selected soil sites characteristics comprised Texture, Bulk density and Organic matter and it was noticed that variations within the soils' depths were often insignificant in comparison to the variations between the soil types studied.

4.1.1 TOTAL SAND (TS)

The Total Sand ranges were represented by Mwea soil (Vertisol) at the lower end and by Mariakani soil (Arenosol) at the upper end. The TS ranges were; 437% to 78.43%; 3.78% to 78.50%; and 4.31% to 75.73% for the 0-6, 30-36 and 60-66 cm depths respectively as shown in Table 2. The TS values were highly significant at 0.1% level.

Table 2: Particle Size Analysis data

Depth (CM)	Soil Site	Clay Mineralogy	Total Sand	Coarse Sand	Medium Sand	Fine Sand	Total Silt	Coarse Silt	Medium Silt	Fine Silt	Clay	Organic Matter (%)	Textural Class
0-6	Kabete	K	13.53	2.09	3.32	8.12	24.46	1.58	13.30	9.50	62.01	3.03	Clay
	Kambes	K	61.79	12.20	25.96	23.63	16.67	1.87	8.11	4.69	23.54	2.26	Sandy Clay Loam
	Longonot	A	45.23	4.06	15.77	25.40	24.26	1.04	17.34	5.88	30.51	3.72	Sandy Clay Loam
	Mariakani	I/K	78.43	0.38	11.50	66.55	11.54	0.84	2.53	8.17	10.03	1.30	Sand
	Mazeras	K	68.21	10.92	34.81	22.48	9.34	2.70	4.01	2.63	22.45	1.30	Sandy Clay Loam
	Mwea (Thiba)	M	4.37	1.41	0.67	2.29	15.93	0.30	10.70	4.93	79.70	2.33	Clay
30-36	Kabete	K	8.01	0.53	2.20	5.28	24.74	1.66	6.78	16.30	67.25	2.11	Clay
	Kambes	K	58.80	7.64	27.47	23.69	11.08	1.11	5.39	4.58	30.12	0.78	Sandy Clay Loam
	Longonot	A	50.13	3.40	17.39	29.34	23.04	1.56	14.91	6.57	26.63	2.12	Sandy Clay Loam
	Mariakani	I/K	78.50	0.33	11.72	66.45	13.44	1.75	5.54	6.15	8.06	0.76	Loamy Sand
	Mazeras	K	65.11	12.21	33.60	19.30	14.11	3.24	5.72	5.15	20.78	1.15	Sandy Clay Loam
	Mwea (Thiba)	M	3.78	0.64	0.60	2.54	16.00	1.38	9.38	5.24	80.22	1.97	Clay
60-66	Kabete	K	8.10	0.46	2.08	5.56	22.57	1.46	12.11	9.00	69.33	1.69	Clay
	Kambes	K	59.87	11.33	23.86	24.68	12.75	1.16	6.17	5.42	27.38	0.51	Sandy Clay Loam
	Longonot	A	63.91	10.24	26.03	27.64	17.49	1.23	11.29	4.97	18.60	0.77	Sandy Loam
	Mariakani	I/K	75.73	0.17	11.14	64.42	11.63	2.35	3.99	5.29	12.64	0.50	Loamy Sand
	Mazeras	K	63.94	10.98	33.72	19.24	19.06	4.26	6.62	6.12	17.00	1.23	Sandy Loam
	Mwea (Thiba)	M	4.31	1.42	0.54	2.35	15.29	1.16	7.91	6.22	80.40	1.90	Clay
	F test-Depths		ns	ns	ns	ns	ns	ns	ns	ns	ns	**	
	F test-Soils		***	***	***	***	**	**	**	*	***	*	

ns = Not significant; * = Significant at 5%; ** = Significant at 1%; *** significant at 0.1%.

A = Amorphous; I = Illite; K = Kaolinite; M = Montmorillonite;

4.1.2 COARSE SAND (CS)

The Coarse Sand, as given in Table 2 were; 0.38%, Mariakani (Arenosol) to 12.20%, Kambes (Nitosol) for the 0-6 cm; 0.33%, Mariakani (Arenosol) to 12.21%, Mazeras (Luvisol/Acrisol) for the 30-36 cm and 0.17%, Mariakani to 11.33%, Kambes for the 60-66 cm depth. The CS values were significant at 0.1% level.

4.1.3 MEDIUM SAND (MS)

The Medium Sand ranges were thus; 0.67%, Mwea (Vertisol) to 34.81%, Mazeras (Luvisol/Acrisol) in the 0-6 cm; 0.60%, Mwea to 33.60% Mazeras, in the 30-36 cm; 0.54%, Mwea to 33.72%, Mazeras, in the 60-66 cm depth. The MS values were significant at 0.1% level.

4.1.4 FINE SAND (FS)

The Fine Sand were represented, as given in Table 2, by Mwea soil (Vertisol) at the lower level and by Mariakani soil (Arenosol) at the upper level. These FS values were; 2.29% to 66.55%, 2.54% to 66.45% and 2.35% to 64.42% in the 0-6, 30-36 and 60-66 cm depths respectively. The FS variations between soils were significant at 0.1% level.

4.2.1 TOTAL SILT (TSi)

The Total Silt fraction ranges were, as given in Table 2; 9.34%, Mazeras (Luvisol/Acrisol) to 24.46%, Kabete (Nitosol) in the 0-6 cm; 11.08%, Kambes (Nitosol) to 24.74% Kabete (Nitosol) in the 30-36 cm; 11.63%, Mariakani (Arenosol) to 22.57%, Kabete in the 60-66 cm depth and these values were significant at 1% level.

4.2.2 COARSE SILT (CSi)

The Coarse Silt values ranged between 0.30%, Mwea (Vertisol) to 2.70%, Mazeras (Luvisol/Acrisol) in the 0-6 cm; 1.11%, Kambes (Nitosol) to 3.24%, Mazeras, in the 30-36 cm; 1.16%, Kambes to 4.26%, Mazeras, in the 60-66 cm depth. The Csi variations between soils were significant at 1% level.

4.2.3 MEDIUM SILT (MSi)

The Medium silt values were; 2.53%, Mariakani (Arenosol) to 17.34%, Longonot (Andosol) in the 0-6 cm; 5.54%, Mariakani to 14.91%, Longonot, in the 30-36 cm; 3.99%, Mariakani, to 12.11%, Kabete (Nitosol) in the 60-66 cm depth. These values were significant at 1% level.

4.2.4 FINE SILT(FSi)

The Fine Silt ranges as given in Table 2, were; 2.63%, Mazeras (Luvisol/Acrisol) to 9.50%, Kabete (Nitosol); 4.58%, Kambes (Nitosol) to 16.30%, Kabete in the 30-36 cm; 5.29%, Mariakani (Arenosol) to 9.00%, Kabete in the 60-66 cm depth. The Fsi values were significant at 5% level.

4.3.1. BULK DENSITY (K_{sat} Samples)

The Bulk density ranges were, as given in table 3; 0.83 gm/cm^3, Kabete (Nitosol) to 1.45 gm/cm^3, Mazeras (Luvisol/Acrisol) in 0-6 cm; 0.95 gm/cm^3, Kabete to 1.49 gm/cm^3 Mazeras, in the 30-36 cm; and 1.02 gm/cm^3, Mwea (Vertisol), to 1.43 gm/cm^3, Mariakani (Arenosol) in the 60-66 cm depth. Depths and Soils' variations were significant at 5% and 0.1% respectively.

4.3.2 BULK DENSITY (Moisture Samples)

The moisture samples had Bulk density ranges of 0.76 gm/cm^3, Kabete (Nitosol) to 1.30 gm/cm^3 Mazeras (Luvisol/Acrisol) in the 0-6 cm; 0.95 gm/cm^3, Kabete to 1.39 gm/cm^3, Mazeras in the 30-36 cm; 1.01 gm/cm^3 Longonot (Andosol) to 1.42 gm/cm^3, Mazeras in the 60-66 cm depth

The depths and soils' variations were significant at 0.1% level.

4.4 ORGANIC MATTER (%) (OM)

The Organic matter values were given in Table 2 and had the following ranges; 1.30%, Mariakani (Arenosol) and Mazeras (Luvisol/Acrisol) to 3.83%, Kabete (Nitosol) in the 0-6 cm; 0.76%, Mariakani to 2.12%, Longonot (Andosol) in the 30-36 cm; and 0.50%, Mariakani to 1.90%, Mwea (Vertisol) in the 60-66 cm depth. The OM depths' and soils' variations were significant at 1% and 5% levels respectively.

4.5 SATURATED HYDRAULIC CONDUCTIVITY (K_{sat})

The K_{sat} values as given in Table 3, ranged from 0.0027 cm/min for Mwea soil (Vertisol) to 0.8601 cm/min for Kabete soil (Nitosol) in the 0-6 cm; 0.0019 cm/min, Mwea soil to 0.5487 cm/min, Kabete soil in the 30-36 cm; 0.0002 cm/min, Mwea soil to 0.0863 cm/min for the Mazeras (Luvisol/Acrisol) in the 60-66 cm depth. The K_{sat} depths variations were significant at 5% level. Further K_{sat} separation was as shown in Table 4.

The simple linear correlation coefficients as given in table 10 revealed that K_{sat} was best correlated with Coarse Silt (Csi), r=0.53 in the 0-6 cm depth and it was probable that the lower Csi fractions of Mwea soil (Vertisol) and Mariakani soil (Arenosol) were the likely cause of lower

Table 3: Saturated Hydraulic Conductivity (K_{sat}) for the 6 Soils

Depth (CM)	Soil Site	Clay Mineralogy	K_{sat} (cm/min)	Bulk Density (gm/cm^3)
0-6	Kabete	K	0.8601	0.83
	Kambes	K	0.5724	1.17
	Longonot	A	0.1910	0.88
	Mariakani	I/K	0.1480	1.33
	Mazeras	K	0.3205	1.45
	Mwea (Thiba)	M	0.0027	0.96
30-36	Kabete	K	0.5487	0.95
	Kambes	K	0.2624	1.38
	Longonot	A	0.0634	0.96
	Mariakani	I/K	0.1144	1.33
	Mazeras	K	0.0645	1.49
	Mwea (Thiba)	M	0.0019	0.96
60-66	Kabete	K	0.0324	1.07
	Kambes	K	0.0312	1.38
	Longonot	A	0.0619	1.08
	Mariakani	I/K	0.0494	1.43
	Mazeras	K	0.0863	1.40
	Mwea (Thiba)	M	0.0002	1.02
	F-test-Depths		*	*
	F-test-Soils		ns	***

ns = Not significant; * Significant at 5%

A = Amorphous; I = Illite; K = Kaolinite; M = Montmorillonite.

Table 4: Separation of K_{sat} values using Duncan's Multiple Range Test

Soil Site	0-6 cm	30-36 cm	60-66 cm
Kabete (Nitosol)	k	t	e
Kambes (Nitosol)	b	a	c
Longonot (Andosol)	l	n	n
Mariakani (Arenosol)	m	s	r
Mazeras (Luvisol/Acrisol)	z	o	y
Mwea (Vertisol)	v	v	v

Only the K_{sat} values for individual soils' depths' were separated.

Statistically similar K_{sat} values are represented by identical letters.

DMRT's Least Significant Range (LSR) at 5% Level was 0.0335.

K_{sat} values compared to the Nitosols and the Luvisol/Acrisol in the 0-6 cm depth. The Organic matter and K_{sat} were positively correlated, r=0.44 but for both Csi and OM, these correlations were not significant though there were noticeable trends due to their influence on K_{sat}. In the 30-36 cm depth, the Fine Silt (Fsi) fraction had the highest and significant r of 0.86* with K_{sat} and in invariably all soil types, the high Fsi fractions led to high K_{sat} values with Kabete (Nitosol) showing the best relationship.

The regression coefficient of determination, r^2 was 0.74 and the regression line was not statistically significant. The Bulk density had a low and negative correlation with K_{sat}.

In the 60-66 cm depth, the K_{sat} was positively and significantly correlated with Medium Sand, r=0.81*. Other important correlations were with Csi, r=o.76, TS, r=0.72 and the negative correlation with the Clay fraction, r=-0.79.

From the simple linear correlation values, it was established that the positively correlated variables were the factors that were very likely to have led to higher K_{sat} values for especially the Nitosols and the particularly low K_{sat} values for the Vertisol whose low K_{sat} was most probably enhanced by the negatively correlated Clay fraction. The Clay effect was seen as a possible explanation for the K_{sat} variations between the Kambes (Nitosol) and the Longonot soil (Andosol) where the former had higher Clay fraction but lower K_{sat} value.

The simple regression coefficients of determination as given in table 11 were 0.66 for MS, 0.63 for Clay , 0.58 for Csi and 0.52 for TS and were not significant.

Following from the observations by Lagerweiff et al. (1968) it was probable that the swelling phenomenon of particularly the montmorillonitic clay in the Vertisol was largely responsible for the lowest K_{sat} values throughout the 0 to 60 cm depth. The swelling phenomenon led to reduction of moisture conducting pores.

4.6.1 SOIL MOISTURE RETENTION AT 0.1 BAR ($Rt_{\theta_{0.1}}$)

The $Rt\theta_{0.1}$ volume fractions were represented by Mariakani soil (Arenosol) at the lower end and by Mwea soil (Vertisol) at the upper end as given in Tables 5 and 6. The ranges were; 0.1715 to 0.5545; 0.1128 to 0.5415; 0.1967 to 0.5708 for the 0-6, 30-36 and 60-66 cm depths respectively. Soils' variations were significant at 0.1% level.

The Clay fraction and the Msi fraction were positively correlated with $Rt\theta_{0.1}$ values, $r=0.91^*$

Table 5: Soil Moisture Retention (Rt9) for the 6 soils (Volume Fraction)

Depth (CM)	Soil Site	Clay Mineralogy	0-Bar	0.1	0.3	0.5	0.7	1.0	3.0	5.0	7.0	10.0	11.0	15.0
0-6	Kabete	K	0.7073	0.3679	0.3545	0.3455	0.3403	0.3260	0.3058	0.2757	0.2670	0.2630	0.2487	0.245[illegible]
	Kambes	K	0.5499	0.3213	0.2540	0.2482	0.2421	0.2261	0.2106	0.2021	0.1896	0.1849	0.1794	0.1762
	Longonot	A	0.5617	0.3601	0.3158	0.2948	0.2833	0.2376	0.2236	0.2005	0.1945	0.1891	0.1834	0.1773
	Mariakani	I/K	0.4564	0.1715	0.1200	0.1074	0.1026	0.0929	0.0833	0.0723	0.0681	0.0652	0.0610	0.0567
	Mazeras	K	0.4473	0.2539	0.2117	0.1959	0.1901	0.1844	0.1683	0.1613	0.1569	0.1543	0.1525	0.1517
	Mwea (Thiba)	M	0.6205	0.5545	0.5381	0.5335	0.5307	0.5191	0.5061	0.5[illegible]	0.4909	0.4819	0.4763	0.4707
30-60	Kabete	K	0.6855	0.4178	0.3978	0.3918	0.3833	0.3713	0.3508	0.3238	0.3180	0.3078	0.2969	0.2960
	Kambes	K	0.4269	0.2126	0.1901	0.1813	0.1746	0.1655	0.1534	0.1392	0.1362	0.1336	0.1312	0.1306
	Longonot	A	0.4980	0.2825	0.2550	0.2455	0.2370	0.2163	0.1960	0.1773	0.1683	0.1615	0.1565	0.1533
	Mariakani	I/K	0.4295	0.1128	0.0968	0.0898	0.0850	0.0763	0.0673	0.0625	0.0594	0.0558	0.0539	0.0521
	Mazeras	K	0.3941	0.2088	0.1738	0.1661	0.1591	0.1425	0.1375	0.1274	0.1232	0.12[illegible]0	0.1191	0.11[illegible]
	Mwea (Thiba)	M	0.6210	0.5415	0.5132	0.5097	0.5093	0.4972	0.4841	0.4786	0.4687	0.4627	0.4565	0.4531
60-66	Kabete	K	0.6515	0.4744	0.4519	0.4441	0.4347	0.4290	0.4017	0.3812	0.3696	0.3621	0.3459	0.3436
	Kambes	K	0.4690	0.2610	0.2356	0.2270	0.2206	0.2087	0.1939	0.1767	0.1723	0.1690	0.1674	0.1666
	Longonot	A	0.4981	0.3060	0.2812	0.2613	0.2540	0.2475	0.2233	0.2038	0.1955	0.1844	0.1826	0.177[illegible]
	Mariakani	I/K	0.3917	0.1967	0.1422	0.1319	0.1267	0.1185	0.1092	0.0964	0.0936	0.0908	0.0894	0.0887
	Mazeras	K	0.3923	0.2199	0.1809	0.1756	0.1698	0.1580	0.1429	0.1333	0.1258	0.1217	0.1195	0.1181
	Mwea (Thiba)	M	0,6370	0.5708	0.5467	0.5428	0.5408	0.5238	0.5152	0.5101	0.5023	0.4963	0.4836	0.4[illegible]

A = Amorphous; I = Illite; K = Kaolinite; M = Montmorillonite;

and 0.60 respectively. The dominance of the Clay fraction as far as $Rt\theta_{0.1}$ volume fractions were concerned was well illustrated by Mwea soil (Vertisol), Kabete soil (Nitosol) and Longonot (Andosol) which had higher $Rt\theta_{0.1}$ values.

The negatively correlated variables were TS, $r=-0.90^{*}$, FS, $r=-0.83^{*}$, Bulk density, $r=-0.66$ and these were seen as the factors that led to lower $Rt\theta_{0.1}$ values for the Mariakani (Arenosol), Mazeras (Luvisol/Acrisol) and Kambes (Nitosol) as shown in Tables 5, 6 and 8. Simple regression coefficients of determination, r^2 were, in the 0-6 cm, 0.81^{*} for TS, 0.83 for Clay, 0.69 for FS, 0.44 for Bulk density and 0.36 for Msi.

In the 30-36 cm depth the $Rt\theta_{0.1}$ was positively correlated with the Clay fraction and Organic matter, $r=0.98^{**}$ and 0.79 respectively. The important and negatively correlated site characteristics were TS, FS and MS with $r=-0.97^{**}$, -0.83^{*} and -0.69 respectively. Bulk density too, had a negative influence on $Rt\theta_{0.1}$, $r=-0.78$. The high but negatively correlated sand fractions were probably the factors that led to lowered $Rt\theta_{0.1}$ values in the Arenosol, the Luvisol/Acrisol and the Kambes (Nitosol) where as the positively correlated Clay and Organic matter were seen as the factors that increased the $Rt\theta_{0.1}$ in the Kabete

Table 6: Evaluation table for Soil Moisture Retention (RLO) and Soil Moisture Storage (SMS_g), (Volume Fraction)

Depth (CM)	Soil Site	Clay Mineralogy	Moisture Retention (0.1)	Moisture Retention (0.3)	Moisture Retention (15)	Moisture Storage (0.1-15 Bar	Moisture Storage (0.3-15Bar)	Moisture Storage at low suction (0.1-1 Bar)	Moisture Storage at low suction (0.3-1Bar)	Moisture Storage at high suction (1-15 Bars)	Bulk Density (g/cc³)
0-6	Kabete	K	0.3679	0.3545	0.2450	0.1229	0.1095	0.0419	0.0285	0.0810	0.76
	Kambes	K	0.3212	0.2540	0.1762	0.1451	0.0778	0.0950	0.0277	0.0501	1.17
	Longonot	A	0.3601	0.3158	0.1773	0.1828	0.1385	0.1225	0.0782	0.0603	0.91
	Mariakani	I/K	0.1715	0.1200	0.0587	0.1128	0.0613	0.0785	0.0271	0.0342	1.27
	Mazeras	K	0.2539	0.2117	0.1507	0.1032	0.0610	0.0725	0.0303	0.0307	1.32
	Mwea (Thiba)	M	0.5545	0.5381	0.4707	0.0838	0.0674	0.0354	0.0190	0.0484	0.95
30-60	Kabete	K	0.4178	0.3978	0.2960	0.1218	0.1018	0.0465	0.0265	0.0753	0.95
	Kambes	K	0.2126	0.1901	0.1306	0.0820	0.0595	0.0471	0.0246	0.0349	1.20
	Longonot	A	0.2825	0.2550	0.1533	0.1292	0.1017	0.0662	0.0387	0.0630	0.97
	Mariakani	I/K	0.1128	0.0968	0.0533	0.0595	0.0438	0.0365	0.0205	0.0230	1.35
	Mazeras	K	0.2088	0.1739	0.1179	0.0909	0.0559	0.0593	0.0243	0.0316	1.39
	Mwea (Thiba)	M	0.5415	0.5132	0.4534	0.0881	0.0598	0.0443	0.0160	0.0438	1.03
60-66	Kabete	K	0.4744	0.4519	0.3436	0.1308	0.1083	0.0514	0.0289	0.0794	1.05
	Kambes	K	0.2610	0.2356	0.1666	0.0944	0.0690	0.0523	0.0269	0.0421	1.28
	Longonot	A	0.3060	0.2812	0.1771	0.1289	0.1041	0.0685	0.0437	0.0604	1.01
	Mariakani	I/K	0.1967	0.1422	0.0887	0.1080	0.0535	0.0782	0.0237	0.0298	1.40
	Mazeras	K	0.2199	0.1809	0.1182	0.1013	0.0620	0.0619	0.0229	0.0399	1.42
	Mwea (Thiba)	M	0.5708	0.5467	0.4864	0.0844	0.0603	0.0420	0.0179	0.0424	1.02
	F-test-Depths		ns	ns	*	ns	ns	ns	ns		
	F-test-Soils		***	***	***	*	***	ns	**		

ns = Not significant; * = Significant at 5%; ** = Significant at 1%; *** = Significant at 0.1%.

A = Amorphous; I = Illite; K = Kaolinite; M = Montmorillonite.

Table 7: Separation of Moisture Retention and Storage values using Duncan's Multiple Range Test

Soil Moisture Parameter	Depth (cm)	LSR at 5% Level	Kabete (Nitosol)	Kambes (Nitosol)	Longonot (Andosol)	Mariakani (Arenosol)	Mazeras (Luvisol/ Acrisol)	Mwea (Vertisol)
Moisture Retention (0.1 Bar)	0-6	0.0566,	s	s	s	r	z	w
	30-36		b	m	l	v	m	t
	60-66		k	e/g	g	o	O/e	i
Moisture Retention (0.3 Bar)	0-6	0.0423,	k	b	l	r	z	w
	30-36		t	e	g	i	e	a
	60-66		u	m	o	n	n	v
Moisture Retention (15 Bars)	0-6	0.0379,	k	s	s	s	y	w
	30-36		t	m	m	m	z	i
	60-66		e	r	r	r	r	O
Moisture Storage (0.1-15 Bars)	0-6	0.0290,	z/b	b	l	z	z/w	w
	30-36		o	m/r	O	m	r	m/r
	60-66		n	a	n	a/n	a/n	a
Moisture Storage (0.3-15Bars)	0-6	0.0122,	t	b	l	m	m	m/b
	30-36		t	w	t	r	w/r	w
	60-66		t/o	t	o	i	i/t	i
Moisture Storage (0.3-1 Bar)	0-6	0.0122,	s	s	l	s	s	s
	30-36		x	x	o	x	x	x
	60-66		r	r	o	r	r	r
Moisture Storage (1-15 Bars)	0-6	0.0070,	t	w	l	z	z	w
	30-36		g	m/b	g	o	o/b	m
	60-66		e	y	n	r	y	v

For each parameter, Statistically significant volume fractions were represented by different letters and those which were insignificant, were represented by identical letters.

Evaluations were based on DMRt's Least Significant Range (LSR) at 5% level.

Table 8. Simple linear correlation results (r, values) between the Soil Water movement , Moisture Retention (Rtθ), Moisture Storage (SMSθ), Moisture Release (RSθ), and the Selected Soil Characteristics.

		Investigated Parameter	Total Sand	Coarse Sand	Medium Sand	Fine Sand	Total Silt	Coarse Silt	Medium Silt	Fine Silt	Clay	Bulk Density	Organic Matter
(+)	1	Saturated	-0.12	0.28	0.07	0.27	0.38	0.53	0.18	0.39	0.04	-0.23	0.44
		Hydraulic	-0.72	-0.21	-0.25	-0.25	0.43	-0.22	-0.34	0.86*	0.27	-0.20	0.15
		Conductivity	0.72	0.54	0.81*	0.38	0.22	0.76	-0.09	-0.25	-0.79	0.52	-0.42
	2	Moisture	-0.99**	-0.22	-0.55	-0.83*	0.42	-0.48	0.60	-0.12	0.91*	-0.66	0.47
		Retention	-0.97**	-0.42	-0.69	-0.83*	0.46	-0.30	0.33	0.35	0.98**	-0.78	0.79
		(0.1 Bar)	-0.97**	-0.51	-0.76	-0.77	0.39	0.53	0.55	0.56	0.97**	-0.80	0.86*
	3	Moisture	-0.93**	-0.29	-0.60	-0.84*	0.45	0.48	0.60	-0.06	0.95**	-0.70	0.48
		Retention	-0.98**	-0.45	0.71	-0.81*	0.47	-0.33	0.32	0.37	0.96**	-0.79	0.79
		(0.3 Bar)	-0.97**	-0.46	0.73	-0.79	0.40	-0.56	0.58	0.56	0.97**	-0.82*	0.85*
	4	Moisture	-0.88*	-0.26	-0.56	-0.80	-0.25	-0.47	0.41	-0.14	0.94**	-0.55	0.29
		Retention	-0.95**	-0.43	-0.70	-0.78	-0.34	-0.31	0.23	0.28	0.98**	-0.69	0.69
		(15 Bars)	-0.96**	-0.49	-0.75	-0.76	0.31	-0.52	0.46	0.51	0.97**	-0.75	0.86*
	5	Moisture	0.22	0.19	0.21	0.13	0.57	0.08	0.58	0.12	-0.39	-0.24	0.57
		Storage	-0.49	-0.07	-0.16	-0.55	0.88*	-0.04	0.67	0.54	0.37	-0.77	0.83*
		(0.1-15)	0.07	-0.06	0.03	0.09	0.58	-0.09	0.68	0.36	-0.15	-0.31	-0.09
	6	Moisture	-0.32	-0.17	-0.22	-0.26	0.92**	-0.12	0.90*	0.35	0.14	-0.73	0.91*
		Storage	-0.50	-0.23	-0.30	0.44	0.93*	-0.21	0.62	0.68	0.36	-0.82*	0.81*
		(0.3-15)	-0.29	0.06	-0.06	-0.38	0.71	-0.39	0.94**	0.47	0.20	0.67	0.18
	7	Moisture	0.62	0.37	0.53	0.44	0.09	0.18	0.17	-0.22	-0.72	0.27	0.08
		Storage	0.08	0.52	0.48	-0.27	0.38	0.37	0.64	-0.12	-0.17	-0.20	0.40
		(0.1 - Bar)	0.83*	0.07	0.41	0.89*	-0.29	0.37	-0.33	-0.48	-0.84*	0.50	-0.72
	8	Moisture	0.11	-0.02	0.14	0.07	0.55	-0.05	0.64	-0.01	-0.26	-0.27	0.51
		Storage	-0.18	0.14	0.27	0.06	0.58	-0.01	0.66	0.18	-0.31	-0.33	0.36
		(0.3-1 Bar)	0.31	0.41	0.37	0.11	0.25	-0.30	0.60	-0.18	-0.37	-0.40	-0.38
	9	Moisture	-0.68	-0.29	-0.54	-0.53	0.93**	-0.16	0.80	0.61	0.54	-0.93**	0.94**
		Storage	-0.68	-0.37	-0.47	-0.57	0.94**	-0.26	0.53	0.77	0.56	-0.90*	0.87*
		(1-15 Bars)	-0.54	-0.12	-0.27	-0.56	0.82*	0.38	0.95**	0.72	0.46	-0.69	0.43
	10.	Moisture	0.33	0.01	0.10	0.39	0.39	0.32	0.12	-0.62	-0.47	-0.13	0.36
		Release	0.35	-0.20	0.02	0.50	0.40	-0.01	-0.07	0.56	-0.46	-0.02	-0.09
		(0-15 Bar)	0.60	0.22	0.46	0.48	0.13	0.10	0.14	-0.03	-0.65	-0.27	-0.67
	11	Moisture	0.48	0.06	0.20	0.52	0.24	0.37	-0.0034	0.56	-0.60	0.03	0.20
		Release	0.54	-0.11	0.14	0.67	0.18	0.06	-0.21	0.39	-0.63	0.21	0.32
		(0-1 Bar)	0.78	0.35	0.56	0.67	-0.12	0.21	-0.14	-0.24	-0.81*	0.48	-0.82*
	12	Moisture	-0.67	-0.27	-0.51	-0.54	0.96**	-0.17	0.87*	0.55	-0.53	-0.94**	0.98**
		Release	-0.68	-0.36	-0.47	-0.57	0.91**	-0.25	0.54	0.77	0.56	-0.90*	0.87*
		(1-15 Bars)	-0.53	-0.11	-0.26	-0.56	0.82*	-0.37	0.95**	0.72	0.45	-0.69	0.43

(+) Each set of 3 'r' values corresponding to a specific Investigated Parameter and a specific Soil characteristic correspond to 0-6 cm, 30-36 cm and 60-66 cm depths in that order.

* = Significant at 5%; ** = Significant at 1%; n-2 = 4. Critical 'r' values 0.81 = 5% Significant
0.92 = 1% Significant

The values were calculated using the Hp-25 Programme.

soil (Nitosol); Mwea soil (Vertisol) and Longonot soil (Andosol).

The simple regression coefficients of determination r^2 were, 0.95^{**} for TS, 0.68 for FS, 0.47 MS, 0.95^{**} Clay, 0.61 for Bulk density and 0.62 for Organic matter in the 30-36 cm depth.

In the 60-66 cm depth, the positively correlated site characteristics were as given in Table 8 , Clay, $r=0.97^{**}$, OM $r=0.86^{*}$ and Msi plus Fsi with r=0.55 and 0.56 respectively. The negatively correlated variables were TS, $r=-0.97^{**}$, FS, r=-0.77 and MS, r=-0.76. Bulk density again had a negatively correlated 'r' of -0.80.

The low $Rt\theta_{0.1}$ values could be associated with the higher percentages of the negatively correlated variables as the Mariakani soils (Arenosol), Mazeras (Luvisol/Acrisol) and Kambes (Nitosol) illustrated.

Similarly, the high $Rt\theta_{0.1}$ values were closely associated with the positively correlated variables notibly in Kabete, (Nitosol), Mwea, (Vertisol) and Longonot (Andosol) soils. The swelling properties of the montmorillonitic clay fraction in the Mwea soil was viewed as a factor that greatly enhanced such high moisture retention.

The r^2 values that were significant in the 60-66 cm depth corresponded to TS, $r^2=0.94^{**}$ and Clay, $r^2=0.95^{**}$. The other r^2 values were, as shown in Table 9 , 0.74 for OM, 0.59 FS, 0.58 MS but these could not be relied upon as far as the regression line was concerned. Representative $Rt\theta_{0.1}$ values were represented by the regression lines in Figures 1 and 2.

4.6.2 SOIL MOISTURE RETENTION AT 0.3 BAR($Rt\theta_{0.3}$)

The $Rt\theta_{0.3}$ ranges were represented by Mariakani (Arenosol) and Mwea (Vertisol) at the lower and upper ends respectively. These values were; 0.1200 to 0.5381; 0.0968 to 0.5132 and 0.1422 to 0.5467 in the 0-6, 30-36 and 60-66 cm depths respectively. As indicated in Table 6, these values were significant at 0.1% level. Further separation of the $Rt\theta_{0.3}$ values was illustrated using DMRT as shown in table 9.

Simple linear correlation revealed important relationships between $Rt\theta_{0.3}$ and Clay, $r=0.95^{**}$, Msi, $r=0.60$, TS, $r=-0.93^{**}$, FS, $r=-0.84^{*}$ and Bulk density, $r=-0.70$. for the 0-6 cm depth as given in Table 8 . The effect of the negatively correlated variables were evident in the lower $Rt\theta_{0.3}$ values for the Mariakani (Arenosol), Mazeras (Luvisol/Acrisol) and the Kambes (Nitosol). The higher $Rt\theta_{0.3}$ values for Mwea (Vertisol), Kabete (Nitosol) and Longonot (Andosol) were most

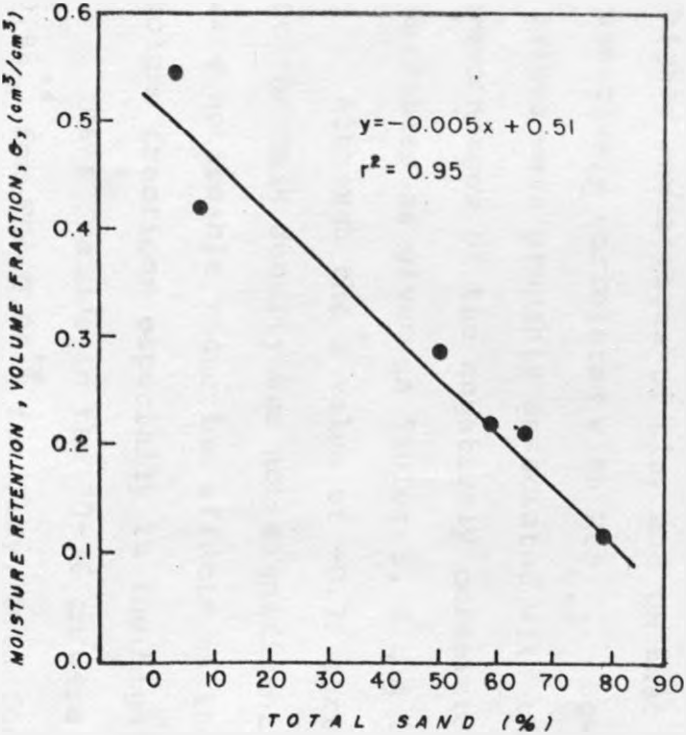


FIGURE I: RELATIONSHIP BETWEEN MOISTURE RETENTION AT 0.1 BAR AND TOTAL SAND (30−36cm)

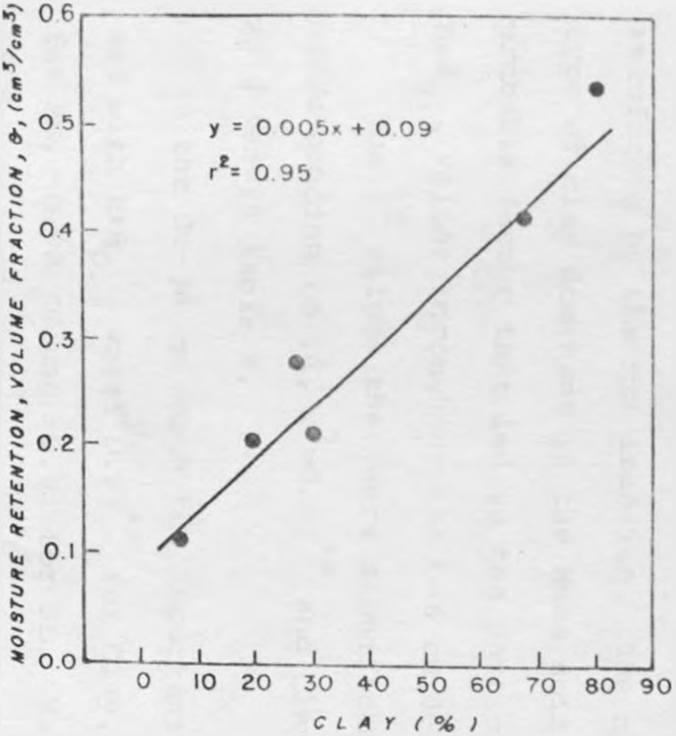


FIGURE 2: RELATIONSHIP BETWEEN MOISTURE RETENTION AT 0.1 BAR AND CLAY (30–36 cm)

probably the result of the Clay fraction which was reinforced by the Msi fraction. The montmorillonitic type of clay dominant in the Mwea soil was the probable factor that led to the particularly high $Rt\theta_{0.3}$ values throughout the 0-6 cm depth.

The r^2 values that were significant were corresponding to TS, $r^2=0.83^{**}$ and Clay $r^2=0.90^{**}$ as given in Table 9.

In the 30-36 cm depth the important r values associated with $Rt\theta_{0.3}$ were; 0.97^{**} for Clay, 0.79 for OM, 0.71 for MS, -0.98 TS and -0.81 for FS. Variations between the Kabete soil (Nitosol), Mwea soil (Vertisol) and Longonot soil (Andosol) on one hand and the remaining soils studied, were explained by the higher percentages of clay and OM that were positively correlated with $Rt\theta_{0.3}$. Lower $Rt\theta_{0.3}$ values were probably associated with the higher percentages of the negatively correlated variables as given in Tables 5, 6 and 8 .

Although the r value of -0.79 corresponding to the Bulk density was not significant, there were noticeable reduction effects on the $Rt\theta_{0.3}$ volume fractions especially in the high sand soils.

The r^2 values in the 30-36 cm were; 0.98^{**} for TS, 0.96^{**} for Clay, 0.62 for both OM and Bulk density as given in Table 9.

In the 60-66 cm depth, the important and

Table 9. Simple Regression Coefficients of Determination (r^2, values) corresponding to the simple linear correlations in Table 10.

	Investigated Parameter	Total Sand	Coarse Sand	Medium Sand	Fine Sand	Total Silt	Coarse Silt	Medium Silt	Fine Silt	Clay	Bulk Density	Organic Matter
(+) 1	Sturated Hydraulic Conductivity	0.01 0.11 0.52	0.08 0.04 0.30	0.008 0.06 0.66	0.07 0.06 0.14	0.15 0.18 0.04	0.28 0.05 0.58	0.03 0.12 0.008	0.15 0.74 0.06	0.002 0.08 0.63	0.06 0.04 0.27	0.19 0.02 0.19
2	Moisture Retention (0.1 Bar)	0.81* 0.95** 0.94**	0.05 0.17 0.26	0.31 0.47 0.58	0.69 0.68 0.59	0.18 0.21 0.15	0.23 0.09 0.29	0.36 0.11 0.31	0.01 0.12 0.32	0.83 0.95** 0.95**	0.44 0.61 0.64	0.22 0.62 0.74
3	Moisture Retention (0.3 Bar)	0.83** 0.96** 0.93**	0.08 0.20 0.21	0.36 0.51 0.54	0.71 0.66 0.63	0.20 0.22 0.16	0.23 0.11 0.31	0.36 0.10 0.34	0.003 0.14 0.32	0.90** 0.96 0.93**	0.49 0.62 0.68	0.23 0.52 0.73
4	Moisture Retention (15 Bars)	0.78 0.91** 0.92**	0.06 0.19 0.24	0.32 0.49 0.56	0.61 0.61 0.58	0.06 0.11 0.09	0.22 0.10 0.27	0.17 0.05 0.21	0.02 0.08 0.26	0.88** 0.95** 0.95**	0.30 0.48 0.56	0.38 0.48 0.73
5	Moisture Storage (0.1-15)	0.05 0.24 0.004	0.04 0.004 0.004	0.05 0.03 0.001	0.02 0.30 0.008	0.33 0.78 0.34	0.007 0.002 0.01	0.34 0.45 0.46	0.01 0.33 0.13	0.15 0.13 0.02	0.06 0.60 0.10	0.33 0.70 0.008
6	Moisture Storage (0.3-15)	0.10 0.24 0.10	0.03 0.06 0.004	0.05 0.09 0.004	0.07 0.19 0.15	0.34** 0.87** 0.51	0.02 0.04 0.16	0.82* 0.39 0.88**	0.12 0.45 0.23	0.02 0.13 0.04	0.53 0.67 0.45	0.83 0.65 0.03
7	Moisture Storate (0.1-1Bar)	0.38 0.007 0.69	0.14 0.27 0.005	0.29 0.23 0.17	0.19 0.07 0.79	0.008 0.15 0.08	0.03 0.14 0.14	0.03 0.40 0.11	0.05 0.01 0.23	0.52 0.03 0.70	0.07 0.04 0.25	0.006 0.11 0.11
8	Moisture Storage (0.3-1Bar)	0.01 0.03 010	0.0002 0.02 0.17	0.02 0.08 0.14	0.006 0.003 0.01	0.31 0.34 0.06	0.002 0.0006 0.09	0.41 0.44 0.35	0.0001 0.03 0.03	0.07 0.10 0.13	0.07 0.11 0.16	0.28 0.13 0.14
9	Moisture Storage (1-15 Bars)	0.46 0.47 0.29	0.08 0.13 0.01	0.30 0.22 0.07	0.27 0.32 0.31	0.86** 0.68** 0.67	0.03 0.07 0.14	0.65 0.28 0.90**	0.37 0.60 0.52	0.30 0.32 0.21	0.86 0.82 0.48	0.89 0.76 0.19
10	Moisture Release (0-15 Bars)	0.11 0.12 0.36	0.0001 0.04 0.10	0.01 0.0004 0.21	0.15 0.25 0.23	0.15 0.16 0.02	0.10 0.0001 0.01	0.01 0.005 0.02	0.39 0.31 0.0007	0.22 0.21 0.42	0.02 0.0003 0.07	0.13 0.01 0.44
11	Moisture Release (0-1 Bar)	0.23 0.29 0.61	0.004 0.01 0.13	0.04 0.02 0.31	0.27 0.45 0.44	0.06 0.03 0.01	0.13 0.003 0.04	0.001 0.04 0.02	0.31 0.15 0.06	0.36 0.39 0.66	0.001 0.05 0.23	0.04 0.10 0.68
12	Moisture Release (1-15 Bars)	0.45 0.46 0.28	0.07 0.13 0.01	0.26 0.21 0.07	0.29 0.32 0.31	0.92** 0.88** 0.68	0.03 0.06 0.13	0.75 0.29 0.90*	0.30 0.59 0.51	0.28 0.31 0.20	0.88** 0.81* 0.48	0.95 0.76 0.18

(+) Each set of 3 'r' values corresponding to a specific Investigated Parameter and a specific Soil Characteristic correspond to 0-6 cm, 30-36 cm and 60-66 cm depths in that order.

Regression Equation is; $y = a_1x+a_o$ where a_1 and a_o are constants.

n-2 = 4, * = Significant Regression line at 5%
** = Significant Regression line at 1%

The values were calculated using the Hp - 25 Programme.

positively correlated variables were; Clay, $r=0.97^{**}$ Organic matter (OM), $r=0.85^{*}$, MS, $r=0.73$. The negatively correlated variables were; TS, $r=-0.97^{**}$, Bulk density, $r=-0.82^{*}$, FS, $r=-0.79$. The positive influence of the Clay and OM on the $Rt\theta_{0.3}$ was evident in the higher values of Kabete soil (Nitosol), Mwea (Vertisol) and Longonot (Andosol) in comparison to the Mariakani (Arenosol) and the Mazeras (Luvisol/Acrisol). The TS, Bulk density and FS were the most probable factors that reduced the $Rt\theta_{0.3}$ volume fractions in notibly the Mazeras and Mariakani soils.

The simple regression coefficients of determination (r^2) values were; 0.94^{**} for Clay, 0.93^{**} for TS, 0.73 for OM, 0.63 for FS and 0.54 for MS as given in Table 9. Representative $Rt\theta_{0.3}$ were plotted as shown in Figures 3 and 4.

03

4.6.3 SOIL MOISTURE RETENTION AT 15 BAR ($Rt\theta_{15}$)

As given in Tables 5 and 6, the $Rt\theta_{15}$ volume fractions ranges were represented by Mariakani (Arenosol) at the lower level and by Mwea (Vertisol) at the upper level. The ranges were 0.0587 to 0.4707; 0.0533 to 0.4534 and 0.0887 to 0.4864 in the 0-6, 30-36 and 60-66 cm depths respectively. Soils' variations were significant at 0.1% level.

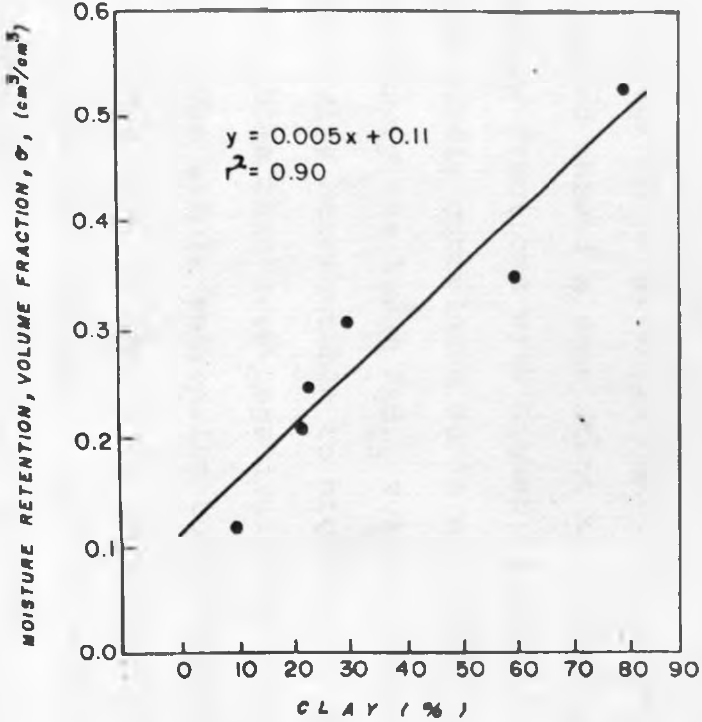


FIGURE 3: RELATIONSHIP BETWEEN MOISTURE RETENTION AT 0.3 BAR AND CLAY, (0-6cm)

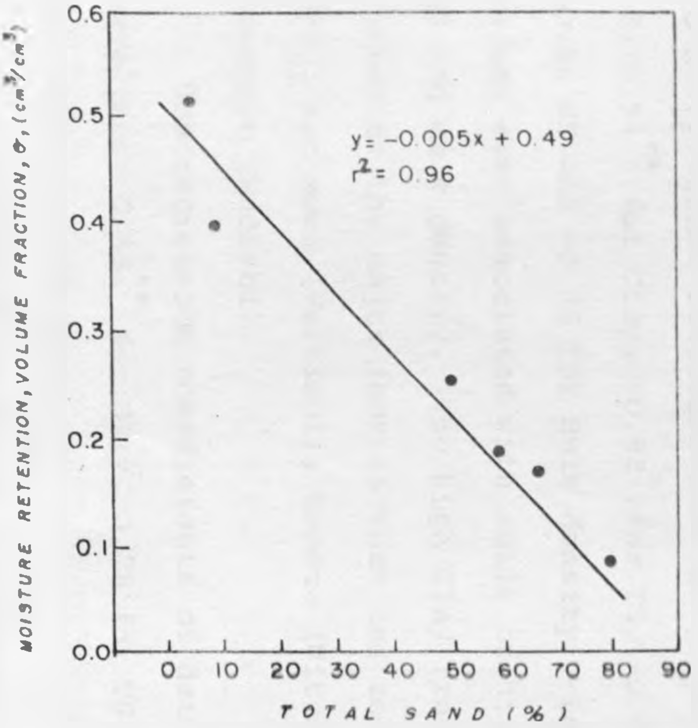


FIGURE 4: RELATIONSHIP BETWEEN MOISTURE RETENTION AT 0.3 BAR AND TOTAL SAND, (30–36 cm)

In the 0-6 cm depth, the r values corresponding to $Rt\theta_{15}$ volume fractions were as given in Table 8; 0.94^{**} for Clay, -0.88^{*} for TS, -0.80 for FS, -0.56 MS and -0.55 for Bulk density. Lower $Rt\theta_{15}$ values were associated with soils of high TS, FS MS and Bulk density. The high Clay fractions were viewed as the major factors that led to higher $Rt\theta_{15}$ for Mwea (Vertisol), Kabete (Nitosol) and Longonot (Andosol).

The regression coefficients of determination were thus; 0.88^{**} for Clay, 0.78 for TS, 0.64 for FS in the 0-6 cm depth.

For the 30-36 cm depth, the simple linear correlations with $Rt\theta_{15}$ were; 0.98^{**} Clay, -0.95^{**} TS, -0.78 FS, -0.70 MS, -0.69 Bulk density and 0.69 for OM as given in Table 8. The soils studied showed a consistent trend of higher $Rt\theta_{15}$ volume fractions with higher fractions of the positively correlated soils as Tables 5,6,8 show. Similarly the lower $Rt\theta_{15}$ volume fractions were generally attributable to higher percentages of the variables that were negatively correlated.

The simple regression coefficients of determination in the 30-36 cm corresponding to $Rt\theta_{15}$ and the textural fractions were 0.95^{**} for clay, 0.91^{**}, for TS, 0.61 for FS.

In the 60-66 cm depth, the important r values were; 0.97** for Clay, -0.96** for TS, 0.86* for OM, -0.76 FS, -0.75 MS and -0.75 for Bulk density as given in Table 8. The negatively correlated variables, to magnitudes corresponding to their percentages in the various soils, invariably led to lower $Rt\theta_{15}$ volume fractions particularly in the Mariakani (Arenosol)and Mazeras (Luvisol/Acrisol) as given in Tables 5, and 6.

Similarly, the positively correlated Clay and OM were probably the factors that led to a generally consistent trend of higher $Rt\theta_{15}$ values in the Kabete (Nitosol), Mwea (Vertisol), Longonot (Andosol) and Kambes (Nitosol). The magnitude of the influence was observed to have been a function of the percentages of the variables concerned.

The r^2 values were, 0.95** for Clay, 0.92** for TS, 0.73 for OM 0.58 for FS and 0.56 for Bulk density as given in Table 9.

The moisture retention, evaluated with the clay mineralogy bias came within reasonable agreement with the observations by Barshad, (1955), De witc, (1950), Johanse (1959), Marshall, (1959) and Kohnke, (1968) whose findings indicated higher moisture retention for the montmorillonitic Clay type as in Mwea soil. Lower moisture retention was reported for the kaolinitic-dominated clays and a similar trend was noticed in the study.

From the textural point of view, the observed higher moisture retention corresponding to particularly the finer textural fractions was similar to findings by Slater et al (1965), Junker, (1967), Petersen et al. (1968), Hill and Sumner, (1967). The negative influence of the Bulk density on moisture retention came in close agreement with findings by Hill and Sumner, (1967), Junker, (1976) and Petersen et al. (1968).

The positive influence of OM on soil moisture retention in the soils studied could be supported by the findings of Slater and Williams, (1965), Sanchez, (1976) and Petersen et al., (1968). Representative $Rt\theta_{15}$ were plotted as shown in Figures 5 and 6.

4.7.1 SOIL MOISTURE STORAGE 0.1-15 BAR ($SMS\theta_{0.1-15}$)

As given in Table 6, the $SMS\theta_{0.1-15}$ values were overall higher compared to the $SMS\theta_{0.3-15}$ values for all soils. The ranges were; 0.1032, Mazeras (Luvisol/Acrisol) to 0.1828, Longonot (Andosol) in the 0-6 cm; 0.0595, Mariakani (Arenosol)to 0.1292, Longonot (Andosol) in the 30-36 cm;

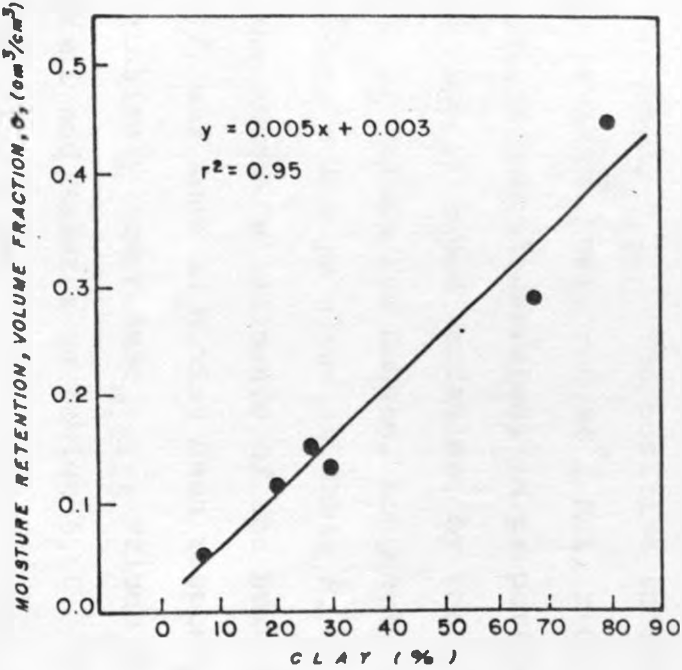


FIGURE 5 : RELATIONSHIP BETWEEN MOISTURE RETENTION AT 15 BAR AND CLAY (30 – 36 cm)

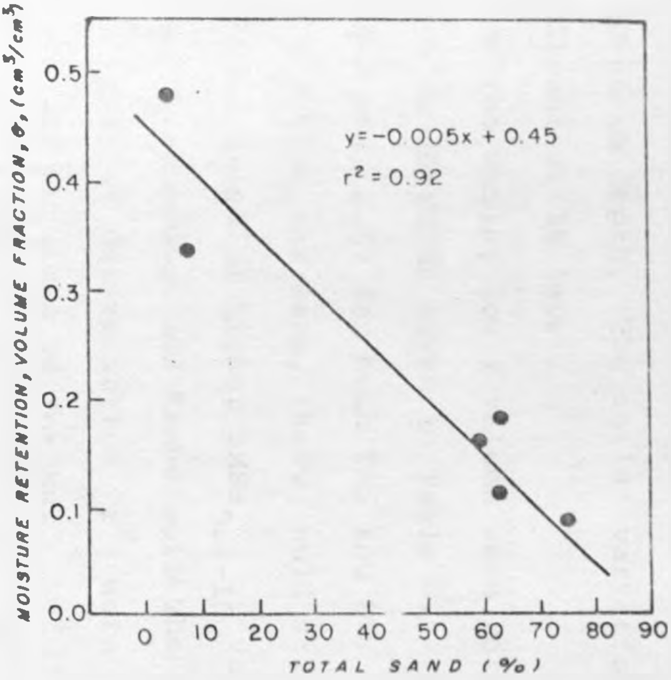


FIGURE 6: RELATIONSHIP BETWEEN MOISTURE RETENTION AT 15 BAR AND TOTAL SAND, (60 − 66 cm)

0.0844, Mwea (Vertisol) to 0.1308, Kabete (Nitosol) in the 60-66 cm depth. The soils' variations were significant at 5% level.

On the whole, low r values were recorded in the 0-6 cm depth as given in Table 8. These were 0.58 for Msi, 0.57 for both Tsi and OM. Low as these correlations were, there could still be a noticeable trend of higher $SMS\theta_{0.1-15}$ values among the Kabete, Longonot and Kambe soils The regression coefficients of determination r^2 were 0.33 for both Tsi and OM and 0.34 for Msi.

In the 30-36 cm depth there was a marked improvement in the correlation values associated with the $SMS\theta_{0.1-15}$. The positive influence of the OM, $r=0.83^*$, Tsi, $r=0.88^*$, Msi, r=0.67 and Fsi, r=0.54 was illustrated, in proportion to the percentages of these variables, by the higher $SMS\theta_{0.1-15}$ values for Kabete, Longonot, Mazeras and Kambes soils as given in Table 6.

The negative influence of the Bulk density, r=-0.77, was seen as having been responsible for the relatively lower $SMS\theta_{0.1-15}$ values for the Mariakani and Mazeras as Tables 6, 8, show.

The simple regression coefficients of determination r^2 were; 0.78 for Tsi, 0.70 for OM, 0.60 for Bulk density, 0.45 Msi though they were not significant.

In the 60-66 cm depth there was a marked reduction in the r values and the highest values associated with $SMS\theta_{0.1-15}$ were; 0.68 for Msi and 0.58 for Tsi. These correlations were low though there were noticeable positive trends associated with higher $SMS\theta_{0.1-15}$ values with higher MSi and Tsi fractions. Longonot and Kabete soils were outstanding in this depth. The r^2, values were 0.46 for Msi and 0.34 for the Tsi.

4.7.2 SOIL MOISTURE STORAGE, 0.3-15 BARS ($SMS\theta_{0.3-15}$)

The $SMS\theta_{0.3-15}$ volume fractions, as given in Table 6, ranged between 0.0613, Mariakani (Arenosol) to 0.1385, Longonot (Andosol) in the 0-6 cm; 0.0438, Mariakani to 0.1018, Kabete (Nitosol) in the 30-36 cm; 0.0535, Mariakani to 0.1083, Kabete in the 60-66 cm depth. The soils' variations were significant at 0.1% level, and the depths' variations were significant at 5% level.

The important correlations coefficients r in the 0-6 cm depth were with Tsi, $r=0.92^{**}$, Msi, $r=0.90^{*}$, OM, $r=0.91^{*}$ and Bulk density, r=-0.73 as given in Table 8. The corresponding regression coefficients of determination r^2 were; 0.84^{**} for

Tsi, 0.82^{*} for Msi, 0.83 for OM and 0.53 for Bulk density as given in Table 9.

In the 30-36 cm depth, outstanding r values associated with $SMS\theta_{0.3-15}$ were; 0.93^{**} for Tsi, 0.81^{*} for OM, -0.82^{*} for Bulk density, 0.68 for Fsi and 0.62 for Msi. Corresponding r^2 values were; 0.87^{**} Tsi, 0.65 for OM, 0.67 for Bulk density, 0.45 for Fsi and 0.39 for Msi.

The highly positive Silt fractions together with the OM were the likely factors that led to higher $SMS\theta_{0.3-15}$ volume fractions in notibly the Kambes (Nitosol), Longonot (Andosol) Kabete (Nitosol) and Mwea soils (Vertisol) as given in Table 6. It was noted that the magnitude of the influence was related to the percentages of the positively correlated variables. The negative influence of the Bulk density was evident in the $SMS\theta_{0.3-15}$ values for notibly the Mazeras (Luvisol/Acrisol) and the Mariakani (Arenosol).

In the 60-66 cm depth, outstanding simple linear correlation values r were; 0.94^{**} for Msi, 0.71 Tsi and 0.67 for Bulk density as given in Table 8. Corresponding r^2 values were 0.88^{**} for Msi, 0.51 for Tsi and 0.45 for Bulk density as given in Table 9.

The positive influence of the Msi and Tsi was closely associated with high $SMS\theta_{0.3-15}$ volume fractions with the influence more pronounced in Kabete (Nitosol) and Longonot (Andosol) soils. Lower and negatively correlated TS fractions could have been responsible for low $SMS\theta_{0.3-15}$ values in especially the high Sand content soils such as Mariakani (Arenosol) and Mazeras (Luvisol/Acrisol) but, by judgement of the low r value, this factor could not be very reliable. Representative $SMS\theta_{0.3-15}$ were plotted as shown in Figures 7 and 8.

4.7.3 SOIL MOISTURE STORAGE, 0.1-1 BAR ($SMS\theta_{0.1-1}$)

As given in Table 6, the $SMS\theta_{0.1-1}$ volume fractions ranged between 0.0354, Mwea (Vertisol) to 0.1225, Longonot (Andosol) in the 0-6 cm; 0.0365, Mariakani (Arenosol) to 0.0662, Longonot in the 30-36 cm; 0.0420, Mwea to 0.0782, Mariakani in the 60-66 cm depth.

The Soils' and depths' variations were not significant.

The r values in the 0-6 cm were on the whole low. Outstanding r values were; 0.62 for TS, 0.53 for MS and -0.72 for the Clay fraction as given in Table 8 . Corresponding r^2 values were 0.38, TS, 0.29 MS and 0.52 for Clay as given

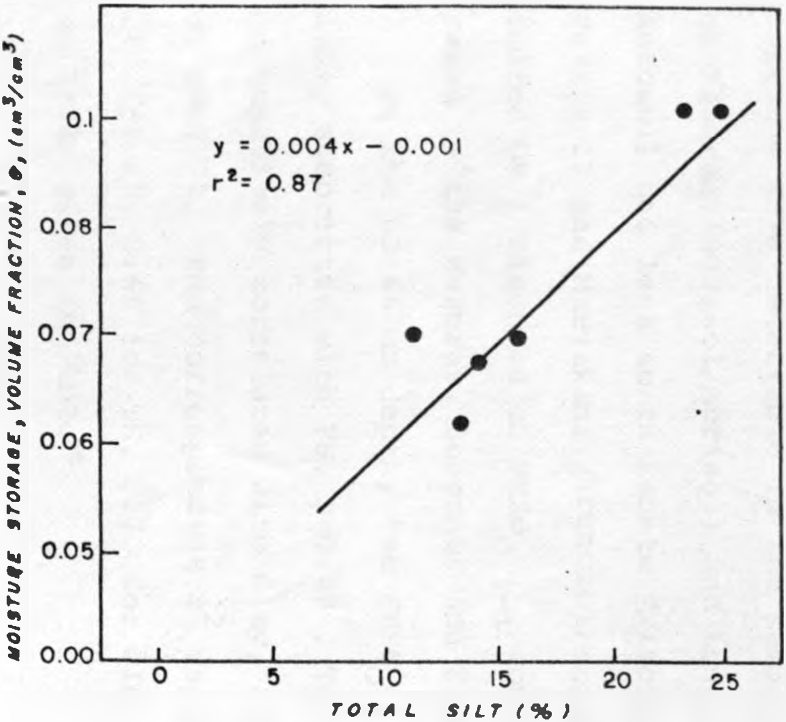


FIGURE 7: RELATIONSHIP BETWEEN MOISTURE STORAGE 0.3-15 BARS AND TOTAL SILT, (30-36 cm)

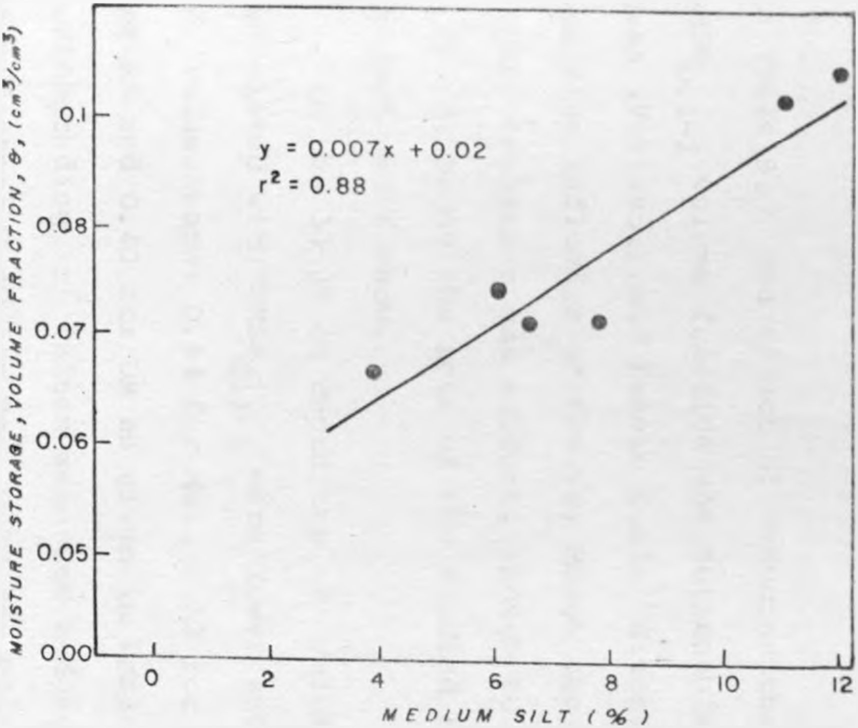


FIGURE 8 : RELATIONSHIP BETWEEN MOISTURE STORAGE, 0 3 – 15 BARS AND MEDIUM SILT, (60 – 66cm)

in Table 9. The effect of reducing the $SMS\theta_{0.1-1}$ volume fraction was noticeable in the Mwea (Vertisol) and Kabete soils (Nitosol) and the positive influence of the TS, MS on the $SMS\theta_{0.1-1}$ volume fractions was evident, though to varying extents, among the rest of the studied soils as Tables 5 and 6 show.

In the 30-36 cm depth the r values associated with $SMS\theta_{0.1-1}$ were lower and outstanding r values were; 0.64 for Msi, 0.52 for CS, 0.48 for MS and 0.40 for OM as given in Table 8. Corresponding r^2 values were low and not significant; 0.40 for Msi, 0.27 for CS, 0.23 for MS and 0.36 for OM as given in Table 9.

The positive influence of the CS, MS and Msi fractions were detectable in the Kambes (Nitosol), the Mazeras (Luvisol/Acrisol) and Longonot (Andosol) and less so in Kabete (Nitosol), Mwea (Vertisol) and Mariakani (Arenosol) soils. The limited OM influences on $SMS\theta_{0.1-1}$ could be traced in the Mazeras, Longonot and Kabete soils.

In the 60-66 cm depth, the $SMS\theta_{0.1-1}$ was highly associated with FS, $r=0.89^*$, TS, $r=0.83^*$ and negatively correlated with Clay, $r=0.84^*$, and OM, $r=-0.72$. The corresponding r^2 values were 0.79 for FS, 0.69 for TS, 0.70 for Clay and 0.36 for OM as given in Table 9.

In invariably all soils, the positively correlated variables enhanced higher SMS$\theta_{0.1-1}$ with the magnitude of the effect dependant upon the percentages of these variables. However the negatively correlated Clay and OM, had marked effect on Mwea (Vertisol) and Kabete soil (Nitosol) in this Moisture Storage range.

4.7.4 SOIL MOISTURE STORAGE, 0.3-1 BAR (SMS$\theta_{0.3-1}$)

The ranges of SMS$\theta_{0.3-1}$ as given in Table 6 were; 0.0190, Mwea (Vertisol) to 0.0762, Mazeras (Luvisol/Acrisol) in the 0-6 cm; 0.0160, Mwea to 0.0387, Longonot (Andosol) in the 30-36 cm depth; 0.0179 Mwea, to 0.0437, Longonot in the 60-66 cm depth. Soils' variations were significant at 1% level.

On the whole, low correlation coefficients were revealed. The outstanding r values were; 0.64 for Msi, 0.55 for Tsi and 0.53 for OM as given in Table 8. Corresponding r^2 values were 0.41 for Msi, 0.31 for Tsi and 0.28 for OM, clearly low values though their limited positive influences on the SMS$\theta_{0.3-1}$ could be detected in nearly all soils studied with the magnitude of the effect dependant on the percentage of the variable in consideration.

In the 30-36 cm depth, outstanding correlation coefficients r associated with $SMS\theta_{0.3-1}$ were; 0.66 for Msi, 0.58 for Tsi and the negatively but low r values for Bulk density, OM and clay as given in Table 8. Corresponding r^2 values were; 0.44 for Msi and 0.34 for Tsi as given in Table 9. The correlations were not significant but, as Table 6 shows, the positive influence of Tsi and Msi fractions could be noticeable and were relatively more evident in the Longonot soil (Andosol). The low and negatively correlated variables' influence on the $SMS\theta_{0.3-1}$ was far less distinct.

Nearly all r values in the 60-66 cm depth were low, Table 8; The Msi fraction with r=0.60 was the outstanding variable associated with $SMS\theta_{0.3-1}$ volume fractions. The Msi fraction positive influence on these values was related to the percentages of the Msi fraction per soil type and the maximum effect was illustrated by the Longonot soil (Andosol). The simple regression coefficient of determination for Msi was 0.35 in the 60-66 cm depth as shown in Table 9.

4.7.5 SOIL MOISTURE STORAGE, 1-15 BAR ($SMS\theta_{1-15}$)

The $SMS\theta_{1-15}$ volume fractions were significant at 0.1% level. The ranges were, as given in table 6; 0.0307, Mazeras (Luvisol/Acrisol) to 0.0810, Kabete (Nitosol) in the 0-6 cm; 0.0230, Mariakani (Arenosol) to 0.0753, Kabete in the 30-36 cm; and 0.0298, Mariakani to 0.0794, Kabete in the 60-66 cm depth.

The outstanding r values in the 0-6 cm associated with $SMS\theta_{1-15}$ volume fractions were; 0.94^{**} for OM, -0.93^{**} for Bulk density, 0.93^{**} for Tsi, 0.80 for Msi, 0.61 Fsi, -0.68 for TS, 0.54 for clay and -0.54 for MS as given in table 10. The corresponding r^2 values were; 0.89 for OM, 0.86 for Bulk density, 0.86^{**} for Tsi and 0.65 for Msi. Other r^2 values, as given in Table 9 were low.

The positive influences of the OM, Tsi, were well illustrated in nearly all soils and a clear contrast could be established between the bulk of the investigated soils and the Mazeras (Luvisol/Acrisol) and Mariakani (Arenosol) that had lower $SMS\theta_{1-15}$, an observation attributable to low Tsi and OM fractions. It was also evident that the negative influence of the Bulk density and Sand fractions could have contributed to the lower $SMS\theta_{1-15}$ values in the Mazeras and Mariakani relative to the remaining soils studied.

In the 30-36 cm depth, the SMSθ_{1-15} volume fraction was positively correlated with the following variables, Tsi, r=0.94**, OM, r=0.87*, Fsi, r=0.77, Clay, r=0.56 and Msi, r=0.53 as given in Table 8. The negatively correlated variables were thus, -0.090* for Bulk density, TS, r=-0.68 and FS, r=-0.57. The corresponding simple linear regression on coefficients r^2 were as follows, 0.88** for Tsi, 0.82 for Bulk density 0.76 for OM, 0.60 for Tsi, 0.47 for TS, 0.32 for FS and the Clay fraction, 0.28 for Msi as given in Table 9. The higher SMSθ_{1-15} volume fractions for Kabete soil (Nitosol) and Longonot soil (Andosol) was most probably due to the high Tsi, OM and Tsi which enhanced this phenomenon and less so in the other soils studied. The negatively correlated Bulk density, TS were seen as the probable factors that led to lower SMSθ_{1-15} in the particularly high Bulk density and TS soils of Mariakani (Arenosol) and the Mazeras (Luvisol/ Acrisol) as Table 6 shows.

In the 60-66 cm depth, the outstanding simple correlation values associated with SMSθ_{1-15} volume fractions were, the following, 0.95** for Msi, 0.82* for Tsi, 0.72 for Fsi, -0.69 for Bulk density, -0.54 for TS. The corresponding r^2 values were, as given in Table 9 ; 0.90** for Msi, 0.67

for Tsi, 0.52 for Fsi, 0.48 for Bulk density and 0.29 for TS. The positive influence of the Silt fractions were closely associated with the higher SMSθ_{1-15} values in Kambe, Kabete, Longonot an Mwea soils. The Sand fractions and Bulk density were more associated with the lower SMSθ_{1-15} values in the Mazeras and Mariakani soils. It was noticed that the magnitude of the influence of both the positively or negatively correlated soil site characteristics depended upon the percentages of the characteristic or variable being considered.

In this study, the Soil Moisture Storage (SMSθ) term was used instead of the commonly used "Available Water Capacity" (AWC), since, following from the controversies as regards AWC concept pointed out in Chapter 2, the SMSθ concept could give allowance for the actual moisture availability and not lead to the assumption that the moisture in consideration is wholly available to plants or other soil life forms.

Findings by Hillel, (1971), Taylor, (1972) and Marshall, (1959) pointed out the reduction in AWC or SMSθ as the clay fraction increased and that the increase in the Silt fraction was associated with higher AWC or SMSθ. The study's findings came to closer agreement with these previous findings.

The positive influence of the OM on the AWC or SMSθ were similar to findings by Maclean et al, (1972), Slater et al, (1963) and Junker, (1967).

The satisfactory SMSθ associated with the Medium textured soils such as the Sandy Clay Loams and Sandy Loams such as the Longonot (Andosol) and Kambes (Nitosol) were supported by findings by Salter and Williams, (1965), Petersen et al. (1968). The major factor here was that the macropores associated with coarser textured soils could empty fast at low suctions leaving the tittle moisture strongly held by the adsorption forces where as in the case of medium textured sois, the adsorption forces are strong enough to retain sufficient moisture that constitutes the SMSθ. The medium textured soils are likely to have well balanced pore size distribution to enhance such SMSθ as Salter and Williams, (1969) pointed out. That the pore size distribution could be improved too, by the grass cover was evident in the Kabete (Nitosol) that had dense grass roots' system especially in the 0-36 cm depth as revealed by the field observations. Representative $SMS\theta_{1-15}$ values were plotted as shown in Figures 9 and 10.

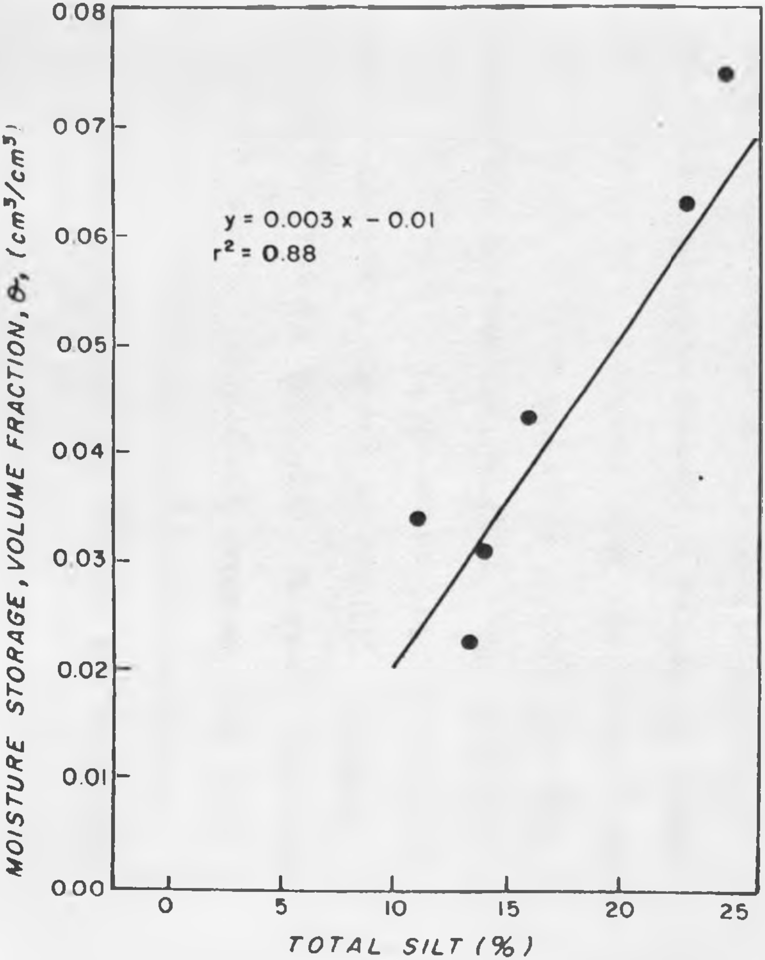


FIGURE 9 : RELATIONSHIP BETWEEN MOISTURE STORAGE, 1–15 BARS AND TOTAL SILT

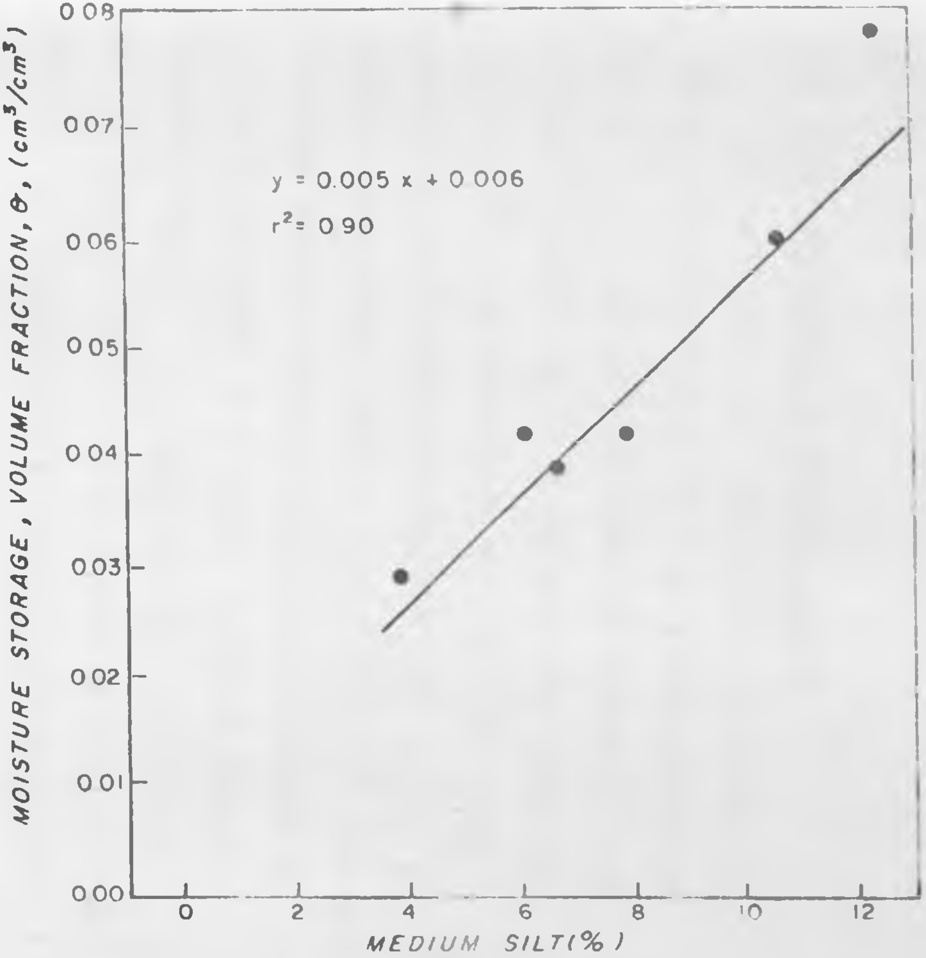
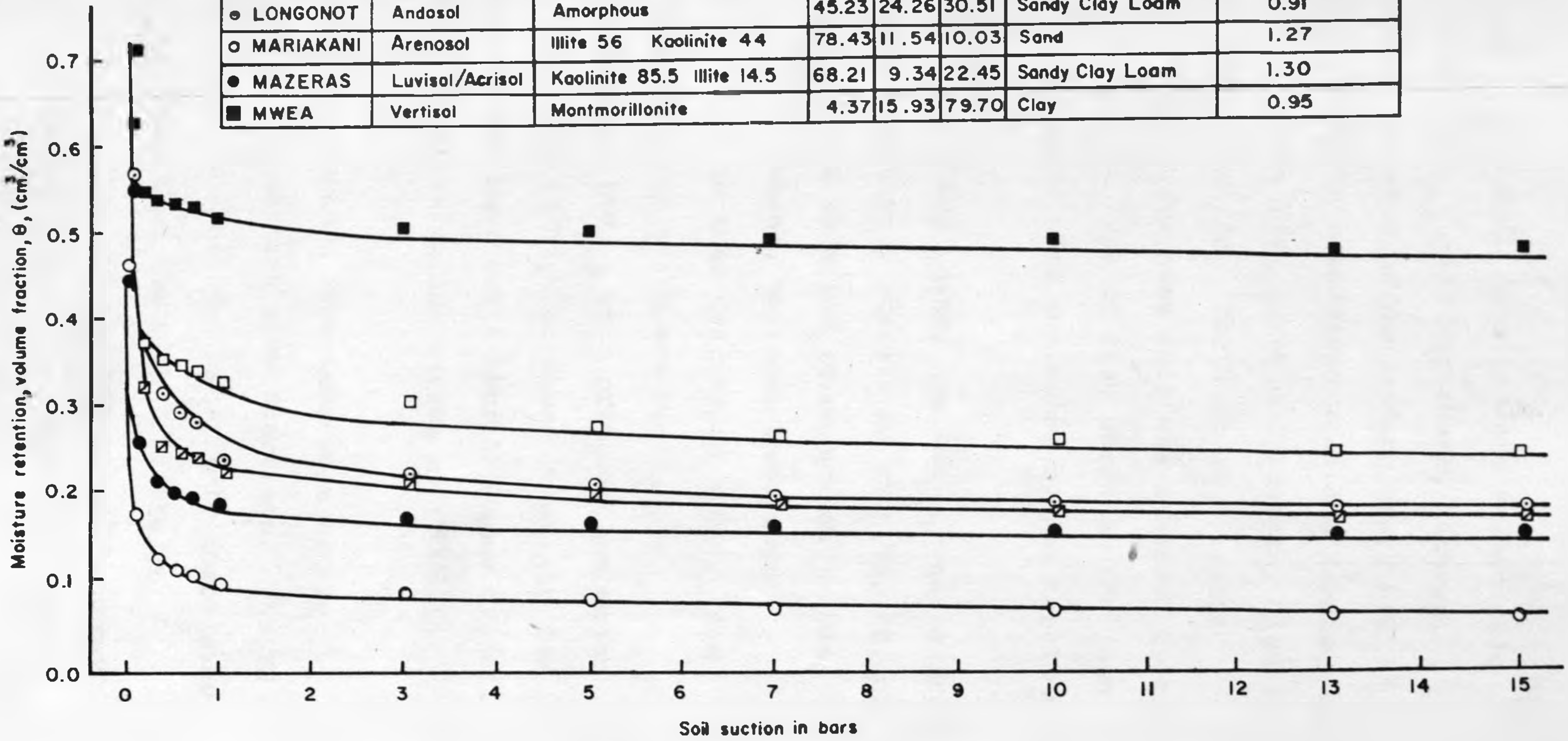


FIGURE 10: RELATIONSHIP BETWEEN MOISTURE STORAGE, 1-15 BARS AND MEDIUM SILT. (60-66 cm)

4.8 SOIL MOISTURE RETENTION CURVES

The soil textural separates had varying effects on the various soil moisture retention curves. The influences were not constant both along the curves as well as with the changing depths. The variations in the soil moisture retention curves were explained with aid of the simple correlation values associated with the key suctions and corresponding volume fractions at 0.1, 0.3, 15, Bars and the 1 to 15 bar range. Most changes in the slopes occurred in the 0 to 1 bar range and there on the slope variations were minimal in invariably all soils as Figures 11to13 show.

The moisture retention curves for the 6 soils in the 0- 6 cm were shown in figure 11. The 0-Bar moisture retention values as given in Table 5 showed that the highest value was that of Kabete (Nitosol) 0.7073 and the lowest was of Mazeras, 0.4473. The overall descending order of the retention curves were Mwea (Vertisol), Kabete (Nitosol), Longonot (Andosol), Kambes (Nitosol), Mazeras (Luvisol/ Acrisol) and the Mariakani (Arenosol) as in Figure 11. The negatively correlated Sand fractions and notibly the TS and FS fractions



SAMPLING DEPTH 0–6 cm

LOCATION	SOIL TYPE	CLAY MINERALOGY %	TEXTURE % Sand	TEXTURE % Silt	TEXTURE % Clay	TEXTURAL CLASS	BULK DENSITY (g/cm³)
□ KABETE	Nitosol	Kaolinite	13.53	24.46	62.01	Clay	0.76
⧄ KAMBES	Nitosol	Kaolinite	61.79	14.67	23.54	Sandy Clay Loam	1.17
⊙ LONGONOT	Andosol	Amorphous	45.23	24.26	30.51	Sandy Clay Loam	0.91
○ MARIAKANI	Arenosol	Illite 56 Kaolinite 44	78.43	11.54	10.03	Sand	1.27
● MAZERAS	Luvisol/Acrisol	Kaolinite 85.5 Illite 14.5	68.21	9.34	22.45	Sandy Clay Loam	1.30
■ MWEA	Vertisol	Montmorillonite	4.37	15.93	79.70	Clay	0.95

FIGURE II SOIL MOISTURE CHARACTERISTICS

enhanced by the Bulk density were responsible for the low $Rt\theta_{0.1}$ thus Mariakani, Mazeras, Kambes and Longonot in descending order had sharper slopes in comparison with the Kabete and Mwea soils whose $Rt\theta_{0.1}$ was particularly high due to the Clay fraction. The highest moisture retention curve for Mwea soil was enhanced by the montmorillonitic type of Clay where as the rest of the studied soils were dominated by the kaolinitic type of Clay.

At the 0.3 bar point, the $Rt\theta_{0.3}$ volume fractions were negatively correlated with TS, FS and Bulk density and this led to reduction in the $Rt\theta_{0.3}$ for Mariakani, Mazeras, Kambes and Longonot soils in that descending order. The high Clay fraction which was positively correlated with $Rt\theta_{0.3}$ were probably the major factor that led to high moisture retention for both Kabete and Mwea soils thus the more gradual slopes of their retention curves as shown in Figure 11.

The $Rt\theta_{15}$ volume fractions were mainly functions of TS and the clay fractions. The TS was, as given in Table 8, negatively correlated with $Rt\theta_{15}$ such that the high TS soils of Mariakani, Mazeras, and the Kambes and Longonot to some extent had lower lying retention curves.

The Clay fraction enhanced $Rt\theta_{15}$ volume fractions leading to higher retention curves for Mwea and Kabete soils. The order of the moisture retention curves over the 1 to 15 bar range was maintained by the positive influence of the Tsi, Msi and OM and the negative influence of the Bulk density and TS. The positive factors enhanced higher moisture retention thus curves for Mwea and Kabete soils where as the negative factors led to lower retention curves for Mariakani and Mazeras. Longonot and Kambes retention curves had middle of the course tendencies probably as a result of the balance of the positively and negatively correlated variables as given in Tables 2 and 6. This could be attributed to structural influences other than any single factor.

In the 30-36 cm depth, the moisture retention curves, as shown in Figure 12, were overall in the following descending order of magnitude, Mwea, Kabete, Longonot, Kambes, Mazeras and Mariakani. The $Rt\theta_{0.1}$ volume fraction was negatively correlated with TS, MS, FS and Bulk density as discussed in section 4.6.1, such that high percentages of these fractions particularly in the Mariakani and Mazeras were the probable factors that led to the sharp drop in $Rt\theta_{0.1}$ thus lower

SAMPLING DEPTH 30-36 cm

LOCATION	SOIL TYPE	CLAY MINERALOGY %	TEXTURE			TEXTURAL CLASS	BULK DENSITY (g/cm^3)
			% Sand	% Silt	% Clay		
☐ KABETE	Nitosol	Kaolinite	8.01	24.74	67.25	Clay	0.95
☒ KAMBES	Nitosol	Kaolinite	58.80	11.08	30.12	Sandy Clay Loam	1.32
⊙ LONGONOT	Andosol	Amorphous	50.13	23.04	26.83	Sandy Clay Loam	0.99
○ MARIAKANI	Arenosol	Illite 52 Kaolinite 48	78.50	13.44	8.06	Loamy Sand	1.35
● MAZERAS	Luvisol/Acrisol	Kaolinite 76 Illite 24	65.11	14.11	20.78	Sandy Clay Loam	1.39
■ MWEA	Vertisol	Montmorillonite	3.78	16.00	80.22	Clay	1.03

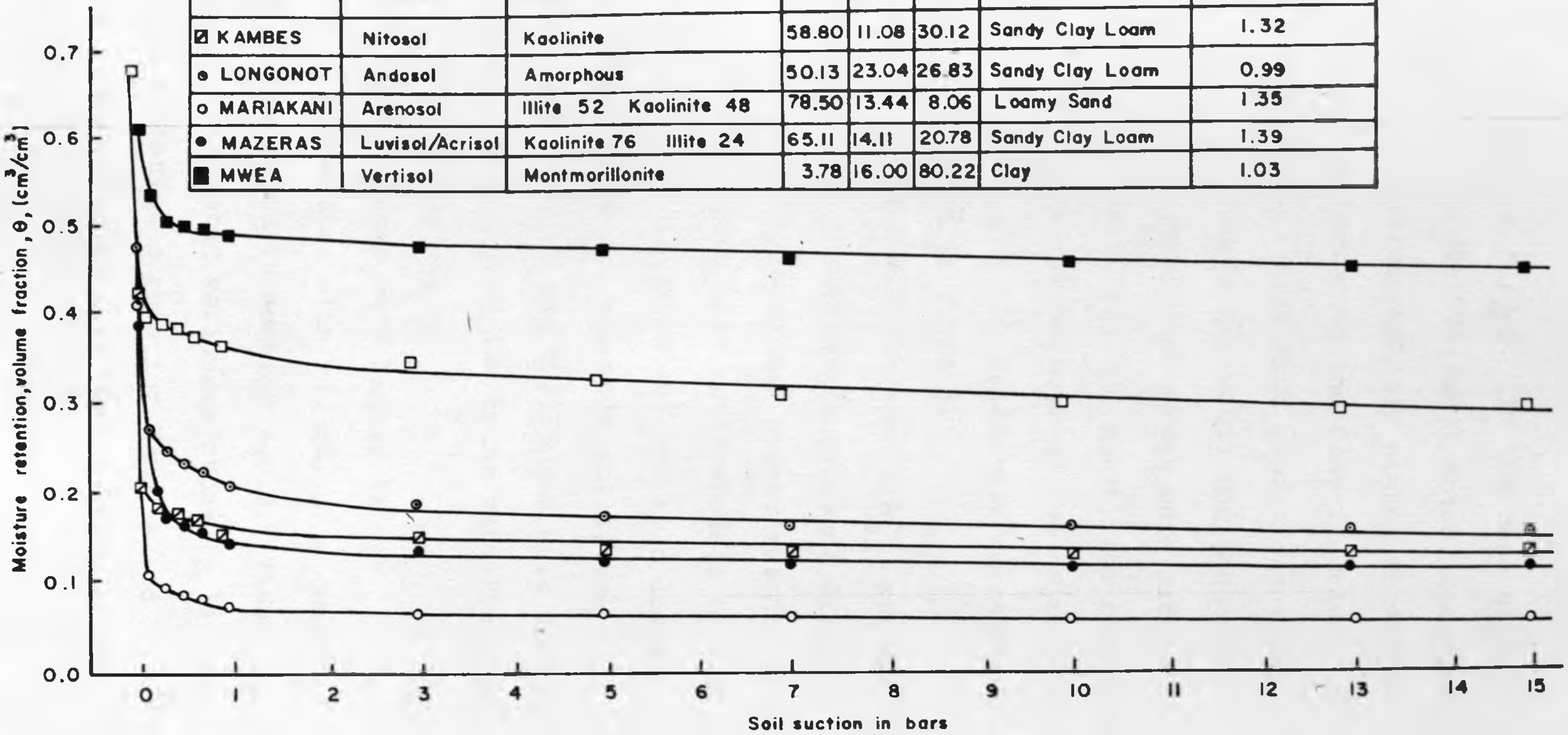


FIGURE 12 SOIL MOISTURE CHARACTERISTICS

moisture retention curves. In the case of Mwea (Vertisol) and Kabete (Nitosol) soils, the higher $Rt\theta_{0.1}$ and the correspondingly higher retention curves were attributed to the Clay fraction. The slopes were in this case more gradual as shown in Figure 12. The Kambes (Nitosol) and Longonot (Andosol) soils' retention curves were midway between the two extremes, and again, the observation could be linked to the balance of the major textural fractions and notibly the positively correlated variables as given in Table 8.

At the 0.3 bar suction, the $Rt\theta_{0.3}$ was mainly a function of the positively correlated Clay and OM content with the resultant higher retention curves for Kabete and Mwea soils whereas in the case of the Mazeras, Mariakani and to a lesser extent, the Kambes and Longonot soils, the negative influence of the TS, FS and Bulk density led to lower $Rt\theta_{0.3}$ thus low lying retention curves at this bar, Figure 12.

The $Rt\theta_{15}$ values were highly though negatively correlated with TS, MS, Bulk density and FS as discussed in section 4.6.3. These negatively correlated variables probably let to low lying retention curves for Mazeras and Mariakani in particular, at the 15 bar mark.

The higher percentages of the Clay and Organic Matter were the probable factors that enhanced high $Rt\theta_{15}$ for Mwea and Kabete soils and the resultant higher retention curves as shown in Figure 12.

In the 1-15 bar range, the dominant and negatively correlated variable was the TS, Bulk density and positively correlated with Tsi, Fsi and OM as discussed in Section 4.7.5. From the findings, it was evident that the high percentages of the negatively correlated variables contributed to the lower retention curves in cases of Mazeras, and Mariakani and less so in case of Longonot and Kambes. For the Kabete and Mwea, retention curves were higher mainly because of the high Clay and OM factors. The lower retention curve for Kabete soil was most probably attributable to the dominance of the kaolinitic type of clay as opposed to the montmorillonitic type in the Mwea soil.

In the 60-66 cm depth, the retention curves up to the 0.1 bar mark were in the following descending order, Mwea, Kabete, Longonot, Kambes, Mazeras and Mariakani, as shown in Figure 13. The $Rt\theta_{0.1}$ volume fractions were, as given in Table 8, negatively correlated with TS, CS, MS, FS, and Bulk density and positively correlated with Clay, OM and, to a limited extent, with the Silt

SAMPLING DEPTH 60-66 cm

LOCATION	SOIL TYPE	CLAY MINERALOGY %	TEXTURE			TEXTURAL CLASS	BULK DENSITY (g/cm³)
			% Sand	% Silt	% Clay		
□ KABETE	Nitosol	Kaolinite	8.10	22.57	63.33	Clay	1.05
▨ KAMBES	Nitosol	Kaolinite	59.87	12.75	27.38	Sandy Clay Loam	1.28
● LONGONOT	Andosol	Amorphous	63.91	17.49	18.60	Sandy Loam	1.01
○ MARIAKANI	Arenosol	Illite 55 Kaolinite 45	75.73	11.63	12.64	Loamy Sand	1.40
● MAZERAS	Luvisol/Acrisol	Kaolinite 79.5 Illite 20.5	63.94	19.06	17.00	Sandy Loam	1.42
■ MWEA	Vertisol	Montmorillonite	4.31	15.29	80.40	Clay	1.02

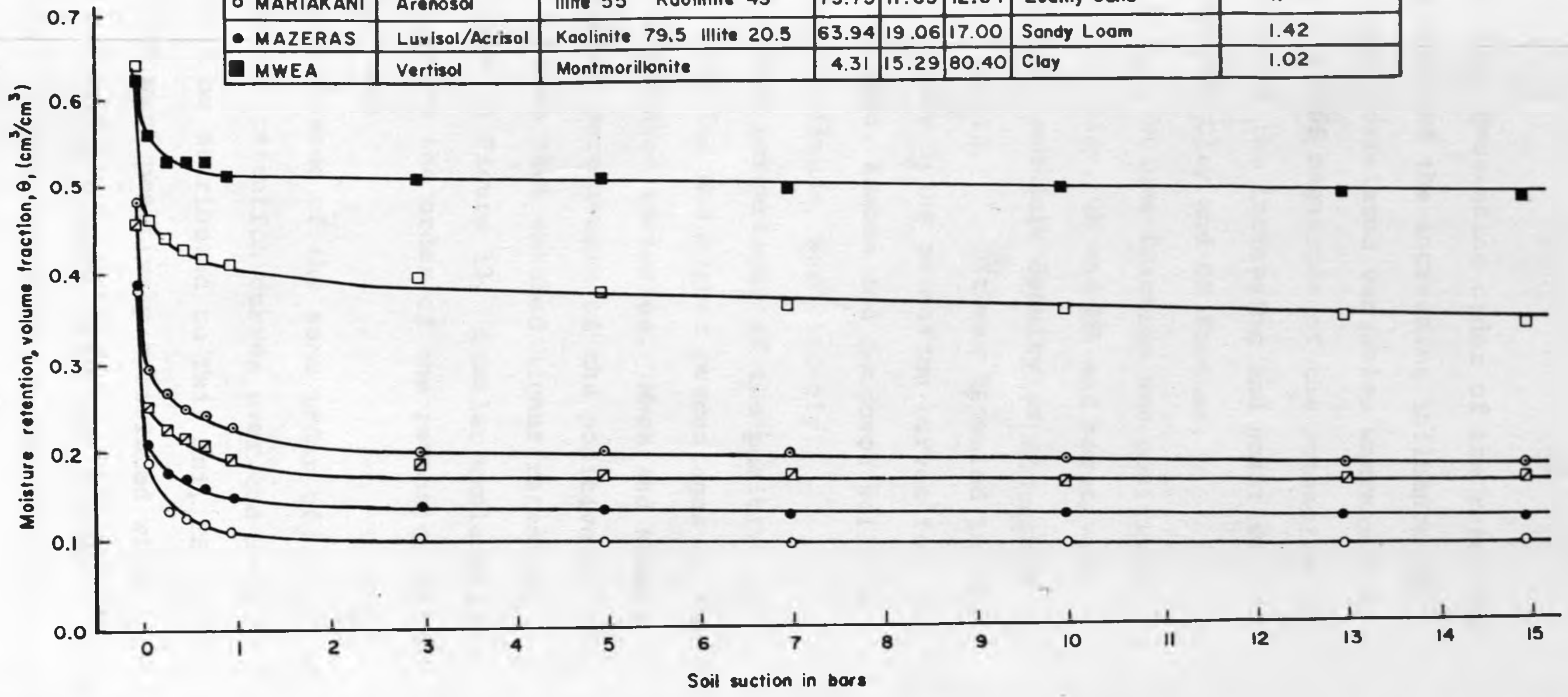


FIGURE 13 SOIL MOISTURE CHARACTERISTICS

fractions. The descending order of the retention curves represented the increasing influence of the negatively correlated variables whereas the ascending order of magnitude of the retention curves reflected the increasing and positive influence of the Clay and OM factors.

The $Rt\theta_{0.3}$ volume fraction was positively correlated with Clay, OM and MS and negatively so with TS, Csi, and Bulk density as discussed in section 4.2.3. It was revealed in the study that the low lying retention curves for Mariakani, Mazeras, Kambes and Longonot soils in the ascending magnitude, were largely a result of lower percentages of the positively correlated variables and higher percentages of the negatively correlated variables. Mwea and Kabete soils had higher percentages of the positively correlated factors that ensured higher retention curves as shown in Figure 13. Similar explanations were applicable to the order of the retention curves at the 15 bar mark.

The maintainance of the same order of Magnitude for the retention curves over the 1-15 bar range could be attributed to Tsi, Msi, FS fractions which were positively correlated with $SMS\theta_{1-15}$ values and the lower retention curves were attributed to the negatively correlated

TS, FS and Bulk density.

It was noted that though the positively correlated variables were high for Mwea (Vertisol) and Kabete (Nitosol) soils, the initially high moisture retention at 1 bar enhanced higher moisture retention points along the curves. For the case of Mwea soil the phenomenon was strengthened by the montmorillonitic clay type where as kaolinite dominated the Kabete clay fraction.

Special linkage was made between the Kambes (Nitosol) and Longonot soil (Andosol) which had closely related soil moisture retention curves, Figures 11 to 13. Noted too was the similarity of the textural class of the two soils as Table 2 shows.

The major variations between the Kabete (Nitosol) and the Mwea soil (Vertisol) were most probably due to the clay mineralogy difference as well as the far more balance textural fractions in Kabete soil relative to the Mwea soil, thus structural differences were implied in this case.

4.9.1 SOIL MOISTURE RELEASE, 0-15 BAR ($RS\theta_{0-15}$)

The $RS\theta_{0-15}$ volume fractions as given in Tables 10 and 11 ranged as follows; 0.1497, Mwea (Vertisol) to 0.4575, Kabete (Nitosol) in the 0-6 cm; 0.1683, Mwea to 0.3893, Kabete in the

Table 10 Soil Moisture Release (RSB) for the 6 Soils (Volume Fraction)

Depth (CM)	Soil Site	Clay Mineralogy	0-Bar	0.1	0.3	0.5	0.7	1.0	3.0	5.0	7.0	10.0	13.0	15.0
0-6	Kabete	K	-	0.3391	0.3528	0.3611	0.3668	0.3783	0.4013	0.4314	0.4358	0.4395	0.4511	0.4575
	Kambes	K	-	0.2284	0.2959	0.3017	0.3078	0.3237	0.3374	0.3473	0.3603	0.3650	0.3703	0.3733
	Longonot	A	-	0.2017	0.2459	0.2669	0.2782	0.3165	0.3405	0.3580	0.3610	0.3636	0.3751	0.3812
	Mariakani	I/K	-	0.2825	0.3364	0.3470	0.3538	0.3633	0.3731	0.3841	0.3861	0.3908	0.3912	0.3955
	Mazeras	K	-	0.1934	0.2356	0.2517	0.2572	0.2656	0.2730	0.2860	0.2907	0.2930	0.3318	0.3165
	Mwea(Thiba)	M	-	0.0660	0.0823	0.0869	0.0897	0.1013	0.1143	0.1205	0.1295	0.1356	0.1441	0.1427
30-36	Kabete	K	-	0.2678	0.2873	0.2938	0.3023	0.3143	0.3343	0.3518	0.3670	0.3758	0.3883	0.3893
	Kambes	K	-	0.2143	0.2366	0.2459	0.2524	0.2614	0.2735	0.2837	0.2904	0.2913	0.2957	0.2961
	Longonot	A	-	0.2155	0.2440	0.2525	0.2610	0.2813	0.3070	0.3215	0.3293	0.3363	0.3407	0.3443
	Mariakani	I/K	-	0.3168	0.3328	0.3374	0.3442	0.3531	0.3620	0.3676	0.3700	0.3746	0.3756	0.3762
	Mazeras	K	-	0.1853	0.2203	0.2280	0.2352	0.2445	0.2566	0.2667	0.2709	0.2732	0.2755	0.2765
	Mwea (Thiba)	M	-	0.0801	0.1084	0.1119	0.1123	0.1241	0.1376	0.1431	0.1530	0.1588	0.1651	0.1681
60-66	Kabete	K	-	0.1759	0.1996	0.2075	0.2168	0.2283	0.2498	0.2706	0.2822	0.2872	0.3051	0.3064
	Kambes	K	-	0.2090	0.2334	0.2402	0.2484	0.2603	0.2751	0.2921	0.2967	0.3000	0.3016	0.3020
	Longonot	A	-	0.1914	0.2169	0.2369	0.2444	0.2601	0.2748	0.2946	0.3026	0.3099	0.3157	0.3212
	Mariakani	I/K	-	0.1950	0.2493	0.2597	0.2640	0.2733	0.2820	0.2930	0.2980	0.3008	0.3022	0.3029
	Mazeras	K	-	0.1724	0.2114	0.2159	0.2228	0.2344	0.2496	0.2530	0.2668	0.2706	0.2728	0.2745
	Mwea (Thiba)	M	-	0.0667	0.0903	0.0941	0.0961	0.1032	0.1212	0.1269	0.1347	0.1405	0.1481	0.1503

A = Amorphous; I = Illite; K = Kaolinite; M = Montmorillonite.

Table 11. Evaluation table for Soil Moisture Release (Rsθ)

Depth (CM)	Soil Site	Clay Mineralogy	Moisture Release (0-15 Bar)	Moisture Release (0-1 Bar)	Moisture Release (1-15 Bar)
0-6	Kabete	K	0.4575	0.3783	0.0792
	Kambes	K	0.3733	0.3237	0.0496
	Longonot	A	0.3812	0.3165	0.0647
	Mariakani	I/K	0.3955	0.3633	0.0322
	Mazeras	K	0.2965	0.2656	0.0309
	Mwea (Thiba)	M	0.1497	0.1013	0.0484
30-36	Kabete	K	0.3893	0.3140	0.0753
	Kambes	K	0.2964	0.2614	0.0350
	Longonot	A	0.3448	0.2813	0.0635
	Mariakani	I/K	0.3762	0.3531	0.0231
	Mazeras	K	0.2765	0.2445	0.0320
	Mwea (Thiba)	M	0.1683	0.1244	0.0439
60-66	Kabete	K	0.3084	0.2288	0.0796
	Kambes	K	0.3020	0.2603	0.0417
	Longonont	A	0.3212	0.2603	0.0609
	Mariakani	I/K	0.3029	0.2733	0.0296
	Mazeras	K	0.2745	0.2344	0.0401
	Mwea (Thiba)	M	0.1503	0.1082	0.0421
	F-test-Depths		***	**	ns
	F-test-Soils		***	***	***

ns = Not significant; * = Significant at 5%; ** = Significant at 1%;
*** = Significant at 0.1%

A = Amorphous; I = Illite; K = Kaolinite; M = Montmorillonite.

Table 12: Separation of Moisture Release values using Duncan's Multiple Range Test

Soil Moisture Parameter	Depth (cm)	LSR at 5% Level	Kabete (Nitosol)	Kambes (Nitosol)	Longonot (Andosol)	Mariakani (Arenosol)	Mazeras (Luvisol/ Acrisol)	Mwea (Vertisol)
Soil Moisture Release (0-15 Bars)	0-6		t	s	o	s	s	w
	30-36	0.0295,	e	b	g	r	b	v
	60-66		t	i/z	i	i	z	O
Soil Moisture Release (0-1 Bar)	0-6		t	1	1	r	z	.w
	30-36	0.0364,	e	b	o	a	b	i
	60-66		k	x	9	m	x	x
Soil Moisture Release (1-15 Bars)	0-6		t	b	1	z	z	b
	30-36	0.0063,	k	r	O	m	r	v
	60-66		e	y	g	a	y	y

For Each parameter, Statistically significant volume fractions were represented by different letters and those which were insignificant were represented by identical letters. Evaluations were based on DMRT's Least Significant Range (LSR) at 5% Level.

30-36 cm; and 0.1503, Mwea to 0.3212, Longonot (Andosol) in the 60-66 cm depth. Both soils' and depths' variations were significant at 0.1% level.

The simple linear correlation values r were generally low as given in Table 8. The highest r value was that associated with Fsi, r=0.62 and the rest of the textural and other soil characteristics were low and nearly within the same range which would indicate a lack of overall dominance by any single factor in the $RS\theta_{0-15}$ volume fractions. The Fsi positive influence was probably the major factor in the high $RS\theta_{0-15}$ value of Kabete soil. In the case of Mwea soil that was predominantly montmorillonitic the negatively though low correlation value associated with the Clay fraction may have been responsible for the lowest $RS\theta_{0-15}$ values since the adsorption forces in the Montmorillonite clay reduced the moisture release. The r^2 value corresponding to the Fsi fraction was 0.39 as given in Table 9.

In the 30-36 cm depth, $RS\theta_{0-15}$ values were associated with quite low r values and the outstanding ones were, for Fsi r=0.56, FS, r=0.50 and for Clay, r=-0.46 as given in Table 8. Corresponding r^2 values were; 0.31 for Fsi; 0.25 for FS and 0.21 for the clay fraction. Though the r and r^2 values were low, some positive influence of the Fsi and FS on the RSθ_{0-15} could be detected to some limited extent and was pronounced in the Kabete (Nitosol) soil. The magnitudes of the influences were generally related to the percentages of the variables under consideration. The Clay fraction could have been closely related to the lower RSθ_{0-15} volume fractions for Mwea soil.

In the 60-66 cm depth, the correlation coefficients r associated with RSθ_{0-15} were; 0.60 for TS, 0.48 for FS, 0.46 MS, -0.67, OM, -0.65 for Clay. The corresponding regression coefficients of determination were 0.44 for OM, 0.42 for Clay fraction, 0.36 for TS, as given in Table 9.

Though the TS r value was low, there was a limited influence on the RSθ_{0-15} volume fractions especially in the Mariakani, (Arenosol), Kambes (Nitosol) and Longonot (Andosols) soils. The lowest RSθ_{0-15} volume fractions associated with the Mwea soil (Vertisol) were most probably related to the negative influence of the Clay fraction.

The Kabete soil (Nitosol) was peculiar in that both the Clay and Organic Matter values were high and could have been expected to limit

$RS\theta_{0-15}$ but the high $RS\theta_{0-15}$ could be explained by the relative influence of the remaining textural fractions that might have collectively overwhelmed the negative influence of the clay and OM. In this urgument, structural other than textural factors were implied.

The findings by Johanse and Dunning, (1959) that the moisture release was higher for the kaolinitic Clay type compared to the montmorillonitic type was consistent with the results of this study.

4.9.2 SOIL MOISTURE RELEASE, 0-1 BAR ($RS\theta_{0-1}$)

The $RS\theta_{0-1}$ volume fractions as given in Tables 10 and 11 ranged between 0.1013, Mwea (Vertisol) to 0.3783, Kabete (Nitosol) in the 0-6 cm; 0.1244, Mwea, to 0.3531, Mariakani (Arenosol) in the 30-36 cm; 0.1082, Mwea to 0.2733, Mariakani in the 60-66 cm depth. The $RS\theta_{0-1}$ values were significant for depths' and soil types' variations at 1% level and 0.1% level respectively.

The outstanding simple linear correlations r associated with $RS\theta_{0-1}$ volume fractions were; 0.56 for Fsi, 0.52 for FS and -0.60 for the Clay fraction as given in Table 8. The corresponding though low regression coefficients of determination r^2 were 0.31 for Fsi, 0.27 for FS and 0.36 for the Clay fraction in the 0-6 cm depth. There was a general tendency of the soils that had higher fractions of the positively correlated Fsi and FS to have higher $RS\theta_{0-1}$ values. The influence was closely associated with the relative variations of the Fsi and TS and Kabete soil that had the highest $RS\theta_{0-1}$ in the 0-6 cm had the highest Fsi fraction compared to other soil types.

The negative influence of the clay fraction was largely responsible for the low $RS\theta_{0-1}$ in the case of Mwea soil (Vertisol). The Kabete (Nitosol) soil again had a peculiar $RS\theta_{0-1}$ in the sense that the Clay fraction could have lowered the $RS\theta_{0-1}$ volume fraction. It would be urgued that it was probably the relative balance between the TS, FSi and the Clay fraction that, to some extent, modified the negative influence of the Clay fraction alone. There were some indications of structural factors in this observation.

In the 30-36 cm depth, the outstanding, though statistically insignificant simple linear correlations associated with $RS\theta_{0-1}$ were; 0.67 for FS, 0.54 for TS and -0.63 for the Clay fraction, as given in Table 8. The corresponding simple regression coefficients of determination r^2 were, 0.45 for FS, 0.29 for TS and 0.39 for the Clay fraction as given in Table 9. The positively correlated TS and FS, to varying magnitudes enhanced moisture release in the 0-1 bar range in nearly all soils with the Mariakani (Arenosol) showing the maximum effect. The lowest $RS\theta_{0-1}$ value for Mwea, a Vertisol, was attributable to the high Clay fraction and enhanced by the montmorillonitic type of the Clay fraction. Structural considerations together with the dominance of the kaolinitic Clay type instead of the montmorillonitic type could have been the factors that explained the higher $RS\theta_{0-1}$ for Kabete compared to the Mwea soil.

In the 60-66 cm depth, Table 8, clearly shows that the simple linear correlation values r associated with $RS\theta_{0-1}$ were higher relative to the 0-36 cm depth . The outstanding r values were, 0.78 for TS, 0.67 for FS, 0.56 for MS, -0.82^{*} for OM and 0.81^{*} for the Clay fraction. The corresponding r^2 values as given in Table 9 were; 0.61 for TS, 0.44 for FS, 0.31 for MS, 0.68 for OM and 0.66 for the Clay fraction regression coefficient of determination. The positively correlated TS, FS and MS, to some extent led to varying increments in the $RS\theta_{0-1}$ volume fractions in nearly all soils.

The negatively correlated OM and Clay fractions had the net reduction in $RS\theta_{0-1}$ in, notibly, the Mwea soil (Vertisol) and Kabete soil (Nitosol), though the reduction in the case of Kabete soil was relatively lower due to the kaolinitic nature of the clay fraction together with the fairer balance of the positively correlated variables compared to the Mwea soil that was predominantly montmorillonitic.

4.9.3 SOIL MOISTURE RELEASE, 1-15 BARS ($RS\theta_{1-15}$)

The soil moisture release at higher suctions (1-15) ranged as given in Tables 10 and 11 between 0.0309, Mazeras (Luvisol/Acrisol) to 0.0792, Kabete (Nitosol) in the 0-6 cm; 0.0231, Mariakani (Arenosol) to 0.0753, Kabete, in the 30-36 cm; 0.0296, Mariakani to 0.0796, Kabete in the 60-66 cm depth. The soils' variations were significant at 0.1% level.

In the 0-6 cm depth, the outstanding r values associated with $RS\theta_{1-15}$ were; 0.96^{**} Tsi, 0.87^{*} Msi, and 0.98^{**} for OM. Negatively correlated variables were; -0.94^{**} for Bulk density, -0.67 TS. The corresponding r^2 values were; 0.92^{**} for Tsi, 0.75 Msi, 0.95 OM, 0.88^{*}; Bulk density, and 0.45 for TS as given in Table 9.

The high and positively correlated TSi, Msi and OM factors enhanced $RS\theta_{1-15}$ in all soils in proportion to the amounts of these variables in these soils reaching a maximum in Longonot (Andosol) and Kabete soil (Nitosol). The negative influence of the TS in conjuction with the Bulk density were largely the factors that were seen to have reduced the $RS\theta_{1-15}$ for notibly, the Mazeras (Luvisol/ Acrisol) and the Mariakani soil (Arenosol) The Kambes (Nitosol) had values that were about midway between the two extremes and this could be attributable to the more balanced soil variables of Texture, Organic Matter and Bulk density as given in Table 2,

In the 30-36 cm depth, the outstanding r values associated with $RS\theta_{1-15}$ were; 0.94^{**} for Tsi, 0.87^{*} for OM, 0.77 for Fsi, -0.90^{*} for Bulk density, -0.68 for TS, as given in Table 8. Corresponding r^2 values were; 0.88^{**} Tsi, 0.76, OM, 0.59 for Fsi, 0.81^{*} for Bulk density and 0.46 for TS, as given in Table 9.

The positively correlated Silt and Organic Matter factors were viewed as the major factors that led to higher $RS\theta_{1-15}$ volume fractions in particularly Longonot soil (Andosol) and Kabete (Nitosol) soils which had the highest of these factors, Table 2. Other soil types were also influenced to varying magnitudes related to the quantities of these factors. The negatively correlated Bulk density and TS could explain the low $RS\theta_{1-15}$ values in, notibly the Mazeras (Luvisol/Acrisol) and the Mariakani (Arenosol) as given in Tables 10 and 11. The Kambe (Nitosol) again displayed a midway trend between the two extreme $RS\theta_{1-15}$ values.

In the 60-66 cm depth, the outstanding simple linear correlation values r were; 0.95^{**} Msi, 0.82^{*} Tsi, 0.72 Fsi, -0.69 for Bulk density, -0.56 for FS and -0.53 for TS as given in Table 8. The outstanding r^2 values were; 0.90^{**}, Msi, 0.68, Tsi, 0.51 for Fsi, 0.48, Bulk density in the 60-66 cm depth.

The positively correlated Silt and Organic matter invariably enhanced $RS\theta_{1-15}$ volume fraction in nearly all soils with the magnitude of the influence related to the quantity or percentages of the variables concerned. Longonot, Kabete and Mwea soils were at the upper level where as the Mazeras and Mariakani represented the lower level group. The Kambes (Nitosol) had $RS\theta_{1-15}$ values about midway between the two soil groups, reflective of its medium textured nature.

The negatively correlated sand fractions and Bulk density were the probable factors that led to the lower $RS\theta_{1-15}$ for, notibly the Mazeras (Luvisol/Acrisol) and the Mariakani (Arenosol).

The positive influence of the OM on the RSθ as revealed by the study came in close agreement with findings by Salter and Williams, (1963) who attributed the effect to improved pore size distribution.

The lowest RSθ values for the montmorillonitic Mwea soil compared to the predominantly kaolinitic dominated clay fractions in the rest of the studied soils were similar to previous revelations by Johanse and Dunning, (1959).

Also the moisture release of the medium-textured soils such as the Longonot (Andosol) and Kambes (Nitosol) taking a midway position relative to other soil types was an expected observation reported by Hillel, (1971), Taylor, (1972) and Brady, (1974). Generally too, was the reduction in moisture release down the profiles which was similar to earlier work by Willatt and Taylor, (1978). The representative $RS\theta_{1-15}$ values were represented by Figures, 14, 15 and 16.

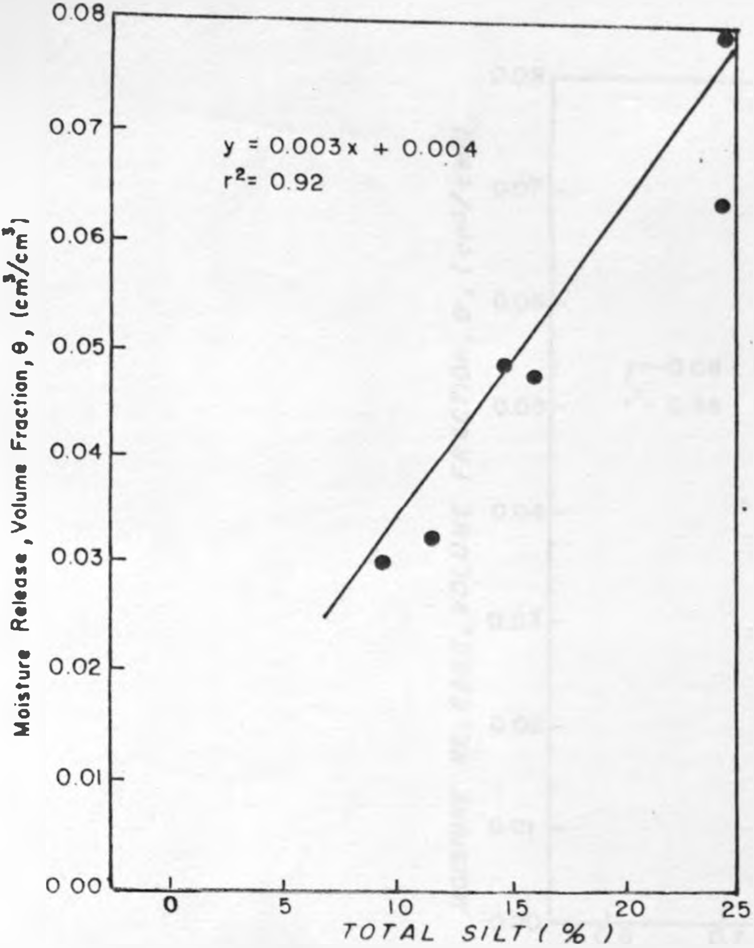


FIGURE 14 : RELATIONSHIP BETWEEN MOISTURE RELEASE, 1–15 BARS AND TOTAL SILT (0–6 cm.)

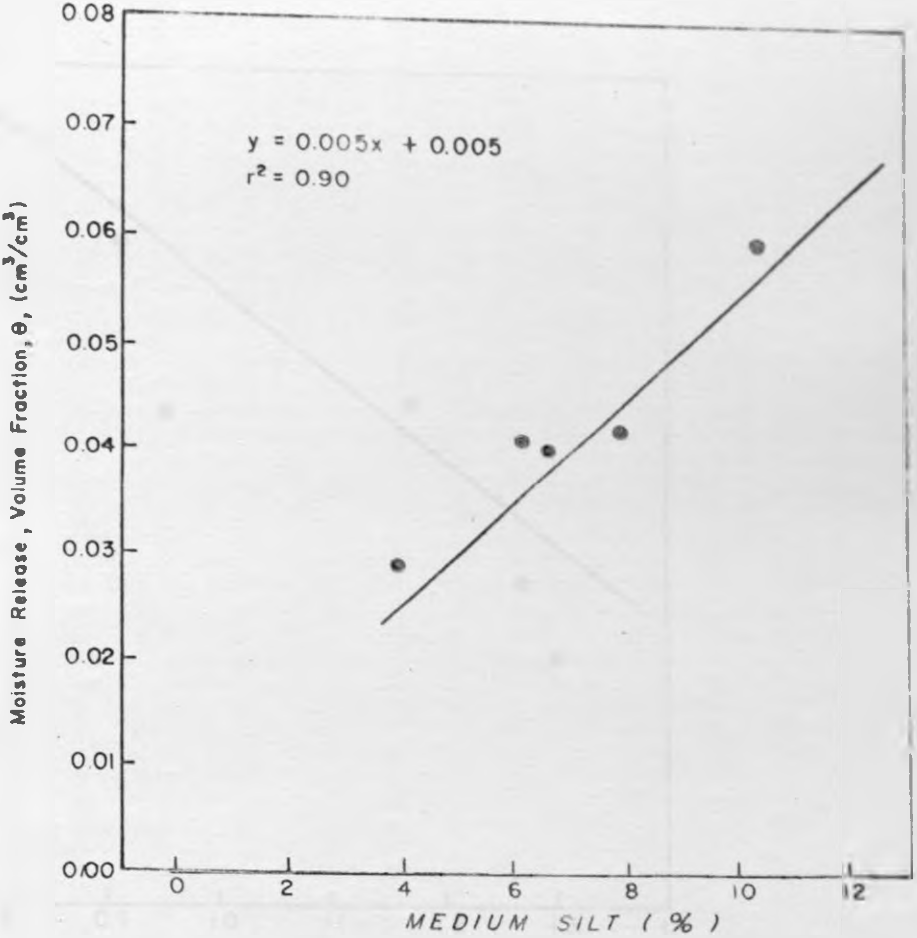


FIGURE 15: RELATIONSHIP BETWEEN MOISTURE RELEASE 1–15 BARS AND MEDIUM SILT, (60-68cm.)

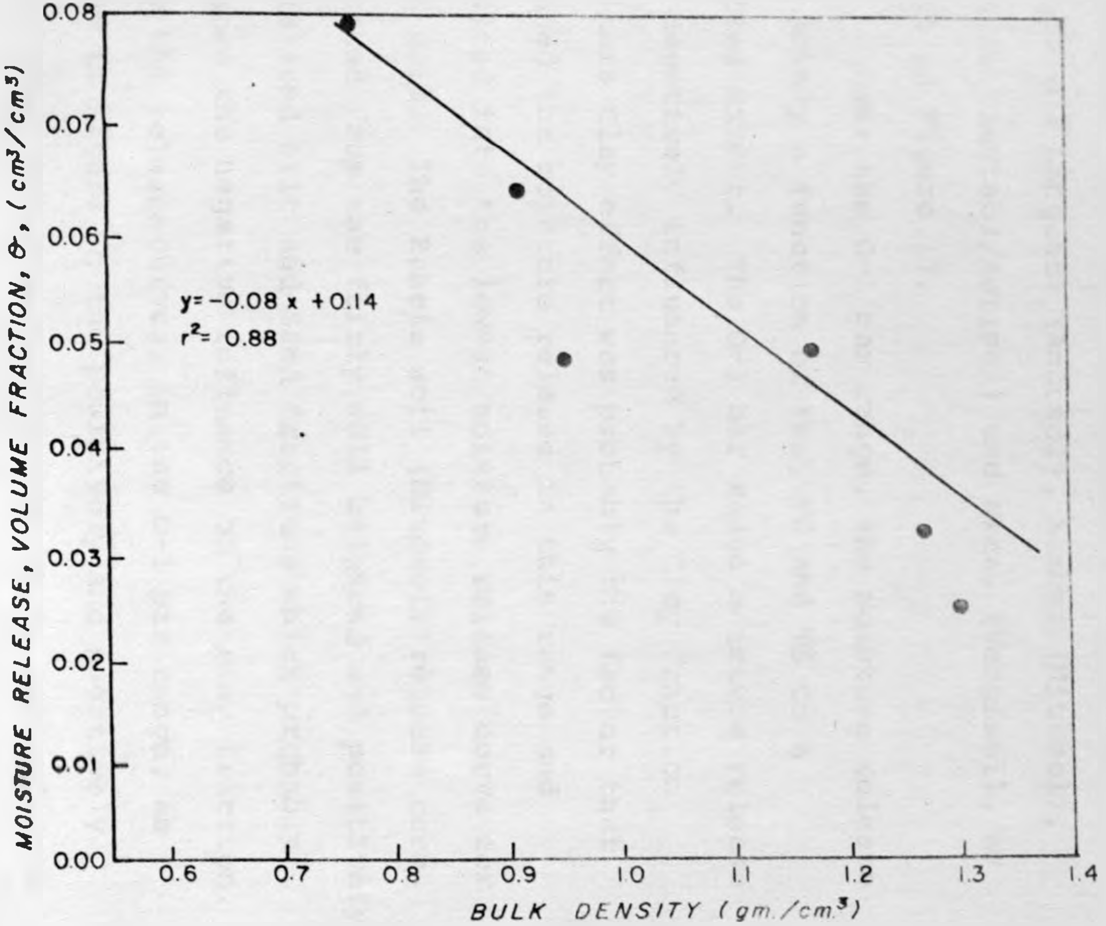
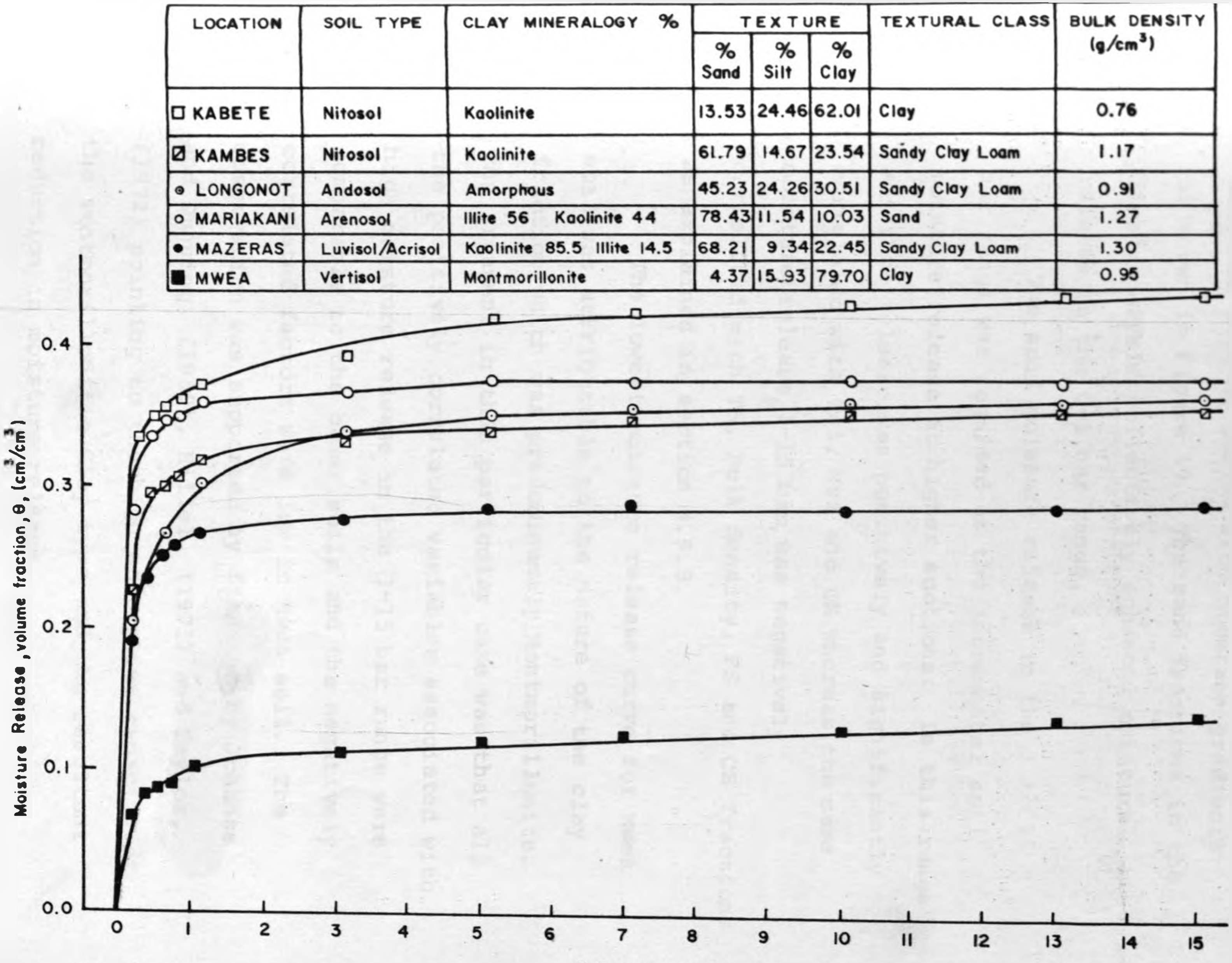


FIGURE 16: RELATIONSHIP BETWEEN MOISTURE RELEASE, 1–15 BARS AND BULK DENSITY, (0–6 cm)

4.10 SOIL MOISTURE RELEASE CURVES

The soil moisture release curves in the 0-6 cm depth were in the following descending order, of magnitude Kabete (Nitosol), Mariakani (Arenosol) Longonot (Andosol), Kambes (Nitosol), Mazeras (Luvisol/Acrisol) and Mwea, (Vertisol), as shown in Figure 17.

Over the 0-1 bar range, the moisture release was mainly a function of Fsi, FS and TS to a limited extent. The 0-1 bar range moisture release was negatively influenced by the Clay fraction and this Clay effect was probably the factor that reduced the moisture release in this range and resulted into the lowest moisture release curve for Mwea soil. The Kabete soil (Nitosol) release curve resulted from the fairly well balanced and positively correlated Silt and Sand fractions which probably reduced the negative influence of the clay fraction. From the release curves, in the 0-1 bar range, as shown in Figure 17, the positively and negatively correlated variables were on the whole low and none alone could account for the variations in the $RS\theta_{0-1}$, an observation that would suggest a strong structural influence in this low suction range. It was also noted that the soil types with fairly well balanced textural fractions such as the



LOCATION	SOIL TYPE	CLAY MINERALOGY %	TEXTURE			TEXTURAL CLASS	BULK DENSITY (g/cm^3)
			% Sand	% Silt	% Clay		
□ KABETE	Nitosol	Kaolinite	13.53	24.46	62.01	Clay	0.76
▨ KAMBES	Nitosol	Kaolinite	61.79	14.67	23.54	Sandy Clay Loam	1.17
⊙ LONGONOT	Andosol	Amorphous	45.23	24.26	30.51	Sandy Clay Loam	0.91
○ MARIAKANI	Arenosol	Illite 56 Kaolinite 44	78.43	11.54	10.03	Sand	1.27
● MAZERAS	Luvisol/Acrisol	Kaolinite 85.5 Illite 14.5	68.21	9.34	22.45	Sandy Clay Loam	1.30
■ MWEA	Vertisol	Montmorillonite	4.37	15.93	79.70	Clay	0.95

FIGURE 17 SOIL MOISTURE RELEASE

Longonot (Andosol) and Kambes (Nitosol) had soil moisture release curves with moderate gradients as shown in Figure 17. The sand fractions in the final analysis collectively enhanced moisture release in the 0-1 bar range.

The soil moisture release in the 1 to 15 bar range was regarded as the incremental soil moisture release at higher suctions. In this range moisture release was positively and significantly correlated with Tsi, Msi and OM whereas the same moisture release, 1-15 bar, was negatively correlated with TS, Bulk density, FS and CS fractions as explained in section 4.9.3.

The lowest moisture release curve for Mwea soil was attributable to the nature of the clay fraction which was predominantly Montmorillonite. The urgument in this particular case was that all the positively correlated variables associated with high moisture release in the 1-15 bar range were comparable to the other soils and the negatively correlated factors were low in Mwea soil. The observation was supported by findings by Johanse and Dunning, (1959), Hillel, (1971) and Taylor, (1972) pointing to the high adsorptive capacity of the montmorillonitic Clay type and the resultant reduction in moisture release.

The moisture release curves in descending order over the 1-15 bar range were thus, Kabete (Nitosol), Mariakani (Arenosol), Longonot (Andosol), Kambes (Nitosol), Mazeras (Luvisol/Acrisol), and Mwea (Vertisol) as given in Figure 17.

The lower release curve for Mazeras was attributed to the negative influence of the Bulk density and the TS, fraction whereas the varying but increasing magnitudes of the rest of the moisture release curves in other studied soils were attributable to the increasing fractions of Tsi, Msi and Organic matter content, the influence being maximum in the Kabete (Nitosol) soil as shown in Figure 17.

The similarities in the release curves for Kambes and Longonot soils were attributed to their similar textural fractions and the rest of the positively correlated variables that enhanced moisture release in the 1-15 bar range. In the 30-36 cm depth, the descending order of magnitude of the moisture release curves were, in the 0-1 bar range; Mariakani (Arenosol), Kabete (Nitosol), Longonot (Andosol), Kambes (Nitosol), Mazeras (Luvisol/Acrisol) and Mwea soil (Vertisol), as shown in Figure 18.

The only outstanding linear correlation values

SAMPLING DEPTH 30-36 cm

LOCATION	SOIL TYPE	CLAY MINERALOGY %	TEXTURE			TEXTURAL CLASS	BULK DENSITY (g/cm³)
			% Sand	% Silt	% Clay		
□ KABETE	Nitosol	Kaolinite	8.01	24.74	67.25	Clay	0.95
▨ KAMBES	Nitosol	Kaolinite	58.80	11.08	30.12	Sandy Clay Loam	1.32
⊙ LONGONOT	Andosol	Amorphous	50.13	23.04	26.83	Sandy Clay Loam	0.99
○ MARIAKANI	Arenosol	Illite 52 Kaolinite 48	78.50	13.44	8.06	Loamy Sand	1.35
● MAZERAS	Luvisol/Acrisol	Kaolinite 76 Illite 24	65.11	14.11	20.78	Sandy Clay Loam	1.39
■ MWEA	Vertisol	Montmorillonite	3.78	16.00	80.22	Clay	1.03

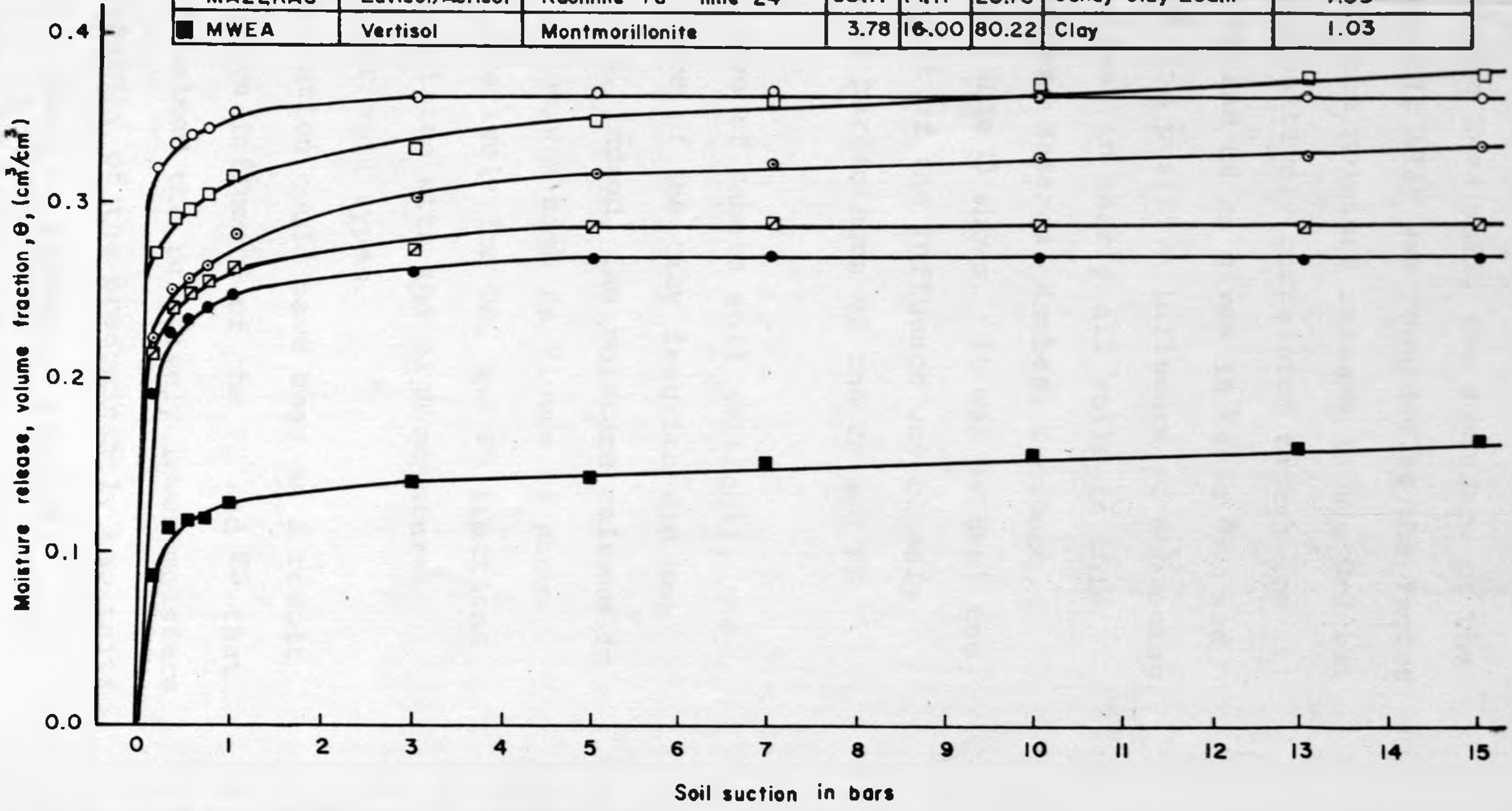


FIGURE 18 SOIL MOISTURE RELEASE

in this range were quite low, r=0.67 for FS, r=0.54 TS and r=-0.63 for the Clay fraction . In the case of the Mwea soil, the dominance of the montmorillonitic Clay was regarded as the factor that lowered the moisture release in the 0-1 bar range. The positively correlated though low r values for TS and FS as given in Table 8, had a noticeable and positive influence of enhancing moisture release in nearly all soils in this ascending order, Mazeras, Kambes, Longonot, Mariakani as Table 11 shows. It was evident too, that the extent of the influence was closely related to the percentages of the TS and FS fractions.

In the case of Kabete soil (Nitosol), the likely influence of the Clay fraction did not take place, and, indeed, the moisture release in the 0-1 bar range was high as Figure 18 shows despite the relatively low TS, and FS fractions that were associated with the high moisture release in other soil types.

The observation could have been as a result of the collective influence of the TS and FS that may have overwhelmed the relatively lower moisture adsorption capacity of the predominantly kaolinitic clay fraction. The r values in Table 8 indicate a highly positive and significant correlation between the OM and $RS\theta_{0-1}$ though the corresponding regression coefficient of determination r^2 was low. It was probable that the influence of the OM was by way of enhancing a well balanced pore size distribution with the resultant high moisture release over the 0-1 bar range.

For the explanation of the highest moisture release curves' slopes in the 0-1 bar range, there was good evidence to attribute this to the macrofabric factors (arrangement of the soil aggregates) at this low suction thus strong implication of the structural factors as Sharma and Uehara, (1968), reported.

In the 1-15 bar range the order of the moisture release curves in descending order of magnitude were; Mariakani (Arenosol), Kabete (Nitosol), Longonont (Andosol), Kambes (Nitosol) Mazeras (Luvisol/Acrisol) and Mwea soil (Vertisol) as Figure 18 shows. Above the 10 bar mark, the Kabete soil (Nitosol) moisture release curve took the lead.

The outstanding positively correlated variables associated with the moisture release in the 1-15 bar range were Tsi, $r=0.94^{**}$, OM, $r=0.87^{*}$, Fsi, r=0.77, Clay, r=0.56 and Msi r=0.54 as given in

Table 8. The outstanting though relatively lower and negatively correlated variables were; Bulk density, r=-0.90*, TS, r=-0.68 and FS, r=0.57.

The negatively correlated TS, Bulk density and FS could explain to a reasonable degree the lower $RS\theta_{1-15}$ of notibly the Kambes, Mariakani and Mazeras which had relatively higher percentages of these factors as Table 2 shows. In the 1-15 bar range these three soils in effect attained their constant slopes earlier than the other studied soils. The effect was enhanced by the relatively higher Bulk densities.

For Mwea soil (Vertisol), the positive Clay fraction influence could have been limited by the highly adsorptive nature of the dominant Montmorillonite Clay fraction as reported by Johanse and Dunning, (1959), Taylor, (1972) and Hillel, (1971). The would-be positive influences of the Tsi, Fsi and Msi, by way of enhancing moisture release was overwhelmed by the montmorillonitic clay fraction. Such limitation was minimal in the case of Kabete soil that had Kaolinite dominating the Clay fraction and whose moisture adsorption was relatively lower in comparison to the Montmorillonite Clay type.

Kabete (Nitosol) and Longonot (Andosol) soils well illustrated the positive influence of the positively correlated variables as Figure 18 shows. These two soils had the highest soil moisture curves' gradients compared to the other soils studied. In the case of Kabete soil, the effectiveness of the positively correlated variables could further have been reinforced by the Clay fraction to the extent that the moisture release curve for Kabete soil intersected the Mariakani curve at around the 10 bar mark and was above the moisture release curves of all soils beyond this range as shown in Figure 18. The Clay fraction contribution in the 1-15 bar range was largely to maintain the continuous soil moisture films on the successive soil particles thus enhancing moisture release.

In the 60-66 cm depth, the descending order of magnitude of the soil moisture release curves were, Mariakani (Arenosol), Kambes (Nitosol) and Longonot (Andosol), Mazeras (Luvisol/Acrisol), Kabete (Nitosol) and Mwea soil (Vertisol), as shown in Figure 19, and over the 0-1 bar range.

The moisture release in the 0-1 bar range was mainly influenced, positively, by TS, r=0.78, FS, r=0.67 and MS, r=0.56. The outstanding though negatively correlated factors were OM, r=-0.82*

SAMPLING DEPTH 60-66 cm

LOCATION	SOIL TYPE	CLAY MINERALOGY	TEXTURE			TEXTURAL CLASS	BULK DENSITY (g/cm^3)
			Sand %	Silt %	Clay %		
□ KABETE	Nitosol	Kaolinite	8.10	22.57	69.33	Clay	1.05
■ KAMBES	Nitosol	Kaolinite	59.87	12.75	27.38	Sandy Clay Loam	1.28
● LONGONOT	Andosol	Amorphous	63.91	17.49	18.60	Sandy Loam	1.01
○ MARIAKANI	Arenosol	Illite 55 % Kaolinite 45 %	75.73	11.63	12.64	Loamy Sand	1.40
● MAZERAS	Luvisol/ Acrisol	Kaolinite 79.5 % Illite 20.5 %	63.94	19.06	17.00	Sandy Loam	1.42
■ MWEA	Vertisol	Montmorillonite	4.31	15.29	80.40	Clay	1.02

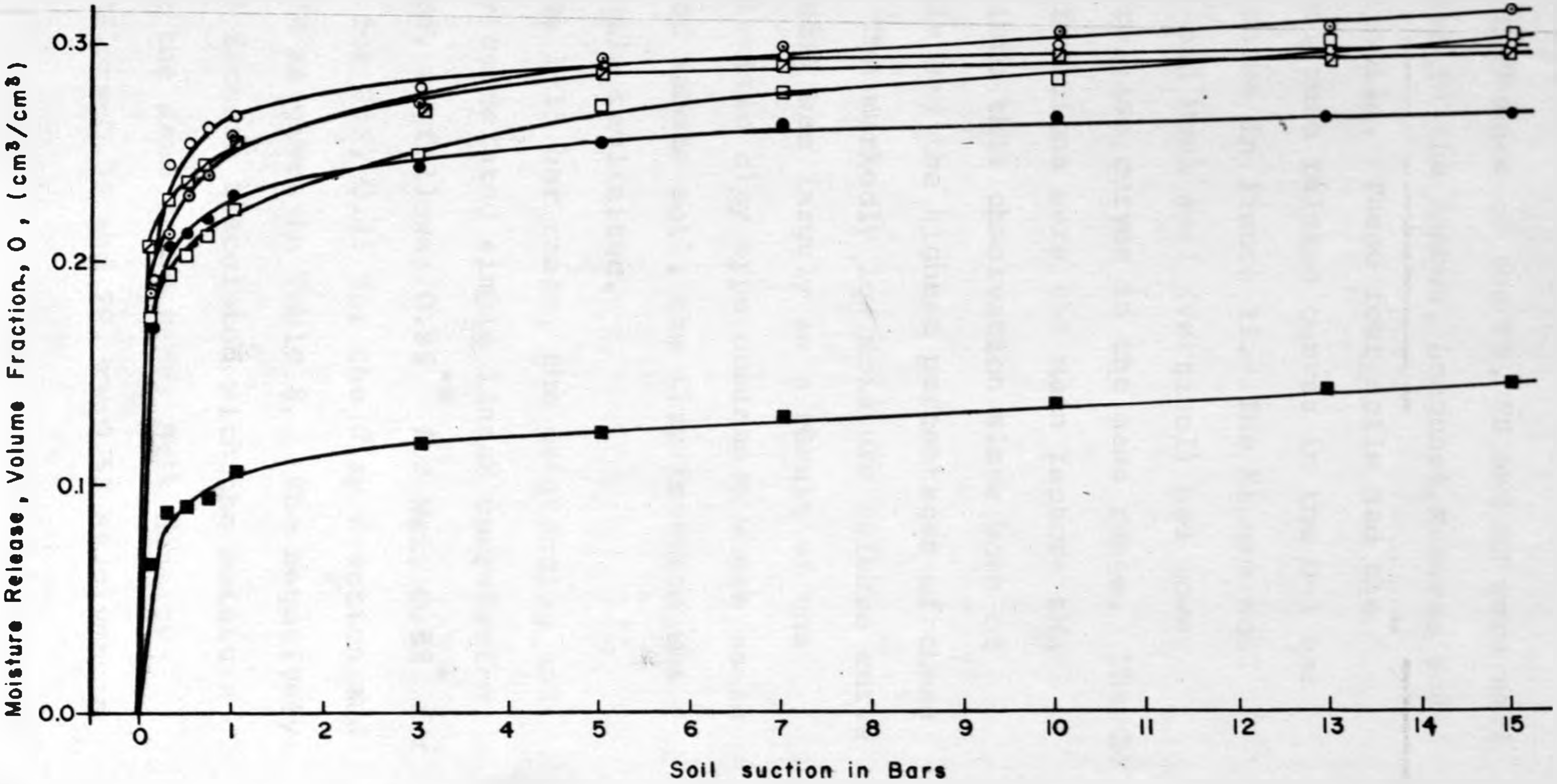


FIGURE 19 SOIL MOISTURE RELEASE

and the Clay fraction, r=-0.81* as discussed in Section 4.9.2.

The influence of the TS, FS and MS were well illustrated in the Kambes, Longonot, Mazeras and Mariakani soils. These four soils had the highest moisture release curves in the 0-1 bar range as shown in Figure 19. The Kabete soil (Nitosol) and Mwea soil (Vertisol) had lower moisture release curves in the same range. The OM and Clay fractions were the main factors that resulted into this observation since both of these soils had the highest percentages of these factors. The markedly low moisture release curve for Mwea soil was largely as a result of the montmorillonitic clay type dominance where as in the case of Kabete soil, the Clay fraction was predominantly kaolinitic.

In the 1-15 bar range, the outstanding and positively correlated simple linear correlation values were, as follows; 0.95** for Msi, 0.82* for Tsi, 0.72 for Fsi, 0.45 for the Clay fraction and 0.43 for OM as given in Table 8. The negatively correlated factors associated with the moisture release in the same range were; Bulk density r=-0.69, FS, r=-0.56 and TS, r=-0.53 as given in Table 8.

The negatively correlated TS, FS and Bulk density were largely responsible for the reduced gradients in the 1-15 bar range of notibly the Mariakani and Mazeras as shown in Figure 19.

The lowest moisture release curve for the Mwea (Vertisol) was most probably a result of the dominance of the Montmorillonite type of clay which, according to Johanse and Dunning, (1959), Taylor, (1972) and Hillel, (1971) would reduce the moisture release due to the particularly strong adsorptive forces. The Msi, Tsi and Fsi fractions in Mwea soil apparently could not overcome the montmorillonitic clay effect.

The high and consistent influence of the Tsi, Msi and Fsi fractions on the moisture release curves in the 1-15 bar range was well illustrated by Kabete (Nitosol) and Longonot (Andosol) soils. These fractions were on the whole higher in these two soils and Kabete moisture release curve had the highest gradient in the 1-15 bar range and the successive influence of the Tsi, Msi and Fsi fractions enabled the moisture release curve for Kabete to overide the Mazeras one at the 2 bar mark and the Mariakani (Arenosol) curve as well as the Kambes' (Nitosol) at the 12 bar mark as shown in Figure 19.

The Longonot soil (Andosol) maintained a consistently high gradient over the 1-15 bar range largely due to the high Tsi, Msi and Fsi fractions that enhanced moisture release.

The Kambes (Nitosol) and Mariakani (Arenosol), moisture release curves came midway between the Kabete (Nitosol) and the Mazeras (Luvisol/Acrisol) as shown in Figure 19. Similarities in the Tsi, Fsi and Msi were reflected in their closely associated moisture release curves in the 1-15 bar range.

The Mazeras, though having comparable Silt fractions with the Kambes and Mariakani soils, had a lower moisture release curve probably due to the influence of the negatively correlated Bulk density in conjuction with the sand fractions.

The Mariakani and Kambes were similarly affected by TS and FS fractions which reduced their moisture release curves' gradients but the Bulk density influence was less marked in the 1-15 bar range. The overall resultant gradients were lower compared to those of Kabete and Longonot but higher than those of Mazeras and Mwea soils as shown in Figure 19. The overall descending order of magnitude of the moisture release curves beyond the 10 bar mark was thus; Longonot

(Andosol), Kabete (Nitosol) Mariakani (Arenosol), Kambes (Nitosol), Mazeras (Luvisol/Acrisol) and Mwea (Vertisol).

General agreement with the observations by Taylor, (1972), Hillel, (1971), Brady, (1974) that the medium textured soils such as the Kambes, Longonot, displayed moisture release and retention curves taking the intermediate position was established in this study as the textural data in Table 2 and the Moisture Retention and Release curves show, Figures 11 to 13 and 17 to 19

The dominance of the microfabric factors (arrangement of primary particles within the soils aggregates) at high suctions as revealed by Sharma and Uehara, (1968) was probably the explanation for the tendency of the finer textural fractions notibly of silt becoming dominant features in the moisture release 1-15 bar range.

The linkage between the textural data or class and the moisture release and retention could not be very reliable. It could for instance suggest similarities between the Kabete (Nitosol) and Mwea (Vertisol) as far as moisture retention and release are concerned. Though these two soil types are of the Clay textural class, differences were revealed in their moisture release and retention.

In some cases such as the Kambes (Nitosol) and Longonot (Andosol) the similarities in textural data were closely associated with the nature of the moisture retention and release curves.

There were, too, strong indications of the structural influences in the moisture retention and release evaluations.

4.11 OVERALL SOIL MOISTURE STATUS EVALUATION OF INDIVIDUAL SOIL TYPES

A comprehensive assessment of the Moisture Retention, Release and Water Movement of individual soils was carried out to give a general moisture status evaluation of these soils based on the findings of the study.

The various moisture categories were ranked thus; Average; High; Low; Moderate; Very High; and Very Low; basing the ranking on the quantitative assessment of the specified moisture categories as summarized in Table 13. The ranking was primarily limited to the soils studied

4.11.1 KABETE SOIL (NITOSOL)

The textural class was Clay and was predominantly Kaolinite. The moisture retention,

Table 13 Comprehensive table of Moisture Retention (Rtθ) Soil Moisture Storage (SMSθ), Moisture Release (RSθ) and Saturated Soil Water Movement Evaluations

Soil Site	Kabete			Kambon			Longonot			Marinkani			Mazeras			Mwea (Thiba)		
Clay Mineralogy	Kaolinite			Kaolinite			Amorphous			Illite/ Kaolinite			Kaolinite			Montmorillonite		
Depths (cm)	0-6	30	60	0-6	30	60	0-6	30	60	0-6	30	60	0-6	30	60	0-6	30	60
Water Movement	VH	VH	A	VH	H	A	L	L	H	L	A	A	A	L	H	VL	VL	VL
(+) Moisture Retention (Rtθ)																		
0.1 Bar	H	VH	VH	A	M	H	H	A	A	L	VL	L	M	H	L	VH	VH	VH
0.3 Bar	H	VH	VH	M/L	M	M	H	M	M	VL	VL	L	M	L	L	VH	VH	VH
15 Bar	A	A/H	H	M	M/L	M/L	H	H/L	M	VL	VL	VL	M	L	L	VH	VH	VH
Moisture Storage (SMSθ)																		
0.1-1 Bar	M/A	A	M	H	A	M/A	VH	H	A	A	M/A	A	M/A	A	A	L	A	H
0.3-1 Bar	M/A	A	H	M/A	A	A	VH	H/A	VH	M/A	A	A	A	A	A	VL	L	M
0.1-15 Bar	H	H	H	H	A	M/A	H	H	H	A	L	A	H	A	A	L	H	L
0.3-15 Bars	H	H	H	A	L/H	A	H	H	H	M	L	L	M	L	A	L	L	L
1-15 Bars	M/A	A	M	H	A	M/A	VH	H	A	A	H/A	A	M/A	A	A	L	A	H
Moisture Release (RSθ)																		
0-15 Bars	VH	H	H	A/H	A	A/H	H	H	H	H	H	H	M	H	A	VL/L	L	L
0-1 Bar	A/H	H	A	A/H	A	A/H	A/H	A/H	A/H	VH/H	VH/H	H	M	L	A	VL	VL	VL
1-15 Bars	A/H	A/H	A/H	M/A	M/A	M/A	A	A/H	A/H	L/M	L	VL	L/M	H/A	H/A	A/H	A	A/M

A = Average; H = High; L = Low; M = Moderate;
VH = Very High; VL = Very low;
(+) All moisture values are volume fractions

Rtθ at low suctions was High to Very High and at high suction, notibly $Rt\theta_{15}$ it was Average to High which led to the overall Moderate to High Soil Moisture Storage (SMSθ) at both low and high suctions. The overall moisture release (RSθ) was High and the RSθ at both low and high suctions was Average to High. To link up the RSθ and Rtθ with SMSθ and K_{sat}, it was probable that the Average to Very High K_{sat} would not be a limitation to the potential soil moisture availability. Soil water movement was stressed as vital by Hillel, (1971) and Taylor, (1972), in the soil moisture availability considerations. It was noted that figures for Kabete soils were slightly higher compared to standard ones.

4.11.2 THE KAMBES (NITOSOL)

The textural class was Sand Clay loam and the clay fraction was predominantly Kaolinite. The Rtθ at low suctions was Average to Moderate and was Low to Moderate at high suctions with the resultant Average to High SMSθ at both low and high suctions. The overall RSθ was Average to High where as the RSθ at low and high suctions was Average to High and Moderate to Average respectively. The Average to Very High K_{sat} would not cause limitations to the potential moisture availability.

4.11.3 LONGONOT SOIL (ANDOSOL)

The textural class was Sandy Clay Loam to Sandy Loam and the clay fraction was Amorphous. The Rtθ at low suctions was High to Moderate and was Moderate at high suctions. The SMSθ at both low and high suctions was High to Very High. The overall RSθ was high where as the RSθ at both low and high suctions was Average to High. The K_{sat} was Low to High and was seen as a potential limitation to moisture flow especially in the 0-36 cm depth.

4.11.4 MARIAKANI SOIL (ARENOSOL)

The textural class was Sand to Loamy Sand and the Clay mineralogy was nearly balanced between Illite and Kaolinite. The Rtθ at low suctions was Low to Very Low and at high suctions, notibly at the 15 bar, ($Rt\theta_{15}$), it was Very Low. The SMSθ at low suctions was Average and at high suctions was Average to Moderate. The RSθ was overall high. It was however noted that RSθ was High to Very High at low suctions and Low to Very Low at high suctions. The K_{sat} was Low to Average and, the probable soil moisture movement limitations could be feasible in the unsaturated conditions.

4.11.5 MATERAS (LUVISOL/ACRISOL)

The textural class was Sandy Clay Loam to Sandy loam in the 60 - 66 cm. . The Rtθ was Low to Moderate at both low and high suctions. The SMSθ was Average at low suctions and Moderate to Average at high suctions. The overall RSθ was Average to Moderate. RSθ at low suctions was overall Moderate where as at high suctions, it was Moderate to Average. The K_{sat} was Average to High and was not considered a possible limitation to moisture movement thus potential moisture availability could be satisfactory.

4.11.6 MWEA SOIL (VERTISOL)

The textural class was Clay and the Clay fraction was predominantly Montmorillonite. The Rtθ at both high and .low suctions was Very High. The SMSθ at low suctions was Low to Very Low in the 0-36 cm depth and was Moderate in the 60-66 cm depth. SMSθ, overall, and at high suctions was Low to Moderate. The overall RSθ was low and the RSθ at low suctions was Very Low. At high suctions, the RSθ was Moderate to Average. The K_{sat} was Very Low throughout the 0-66 cm depth and could seriously limit satisfactory soil drainage as stressed by Kohnke, (1968).

CHAPTER 5

CONCLUSIONS

Based on simple linear correlations between the Rtθ, RSθ, SMSθ, K_{sat}, and the Selected Soil Characteristics of Texture, Bulk Density, Clay Mineralogy and Organic Matter, the following conclusions were drawn from, and within the limitations of the study;

5.1 SATURATED HYDRAULIC CONDUCTIVITY (K_{sat})

(i) The K_{sat} varied much with depth and was mainly a function of the Fine Silt and Medium Sand fractions in the 30 and 60 cm depths respectively. The Total Sand and Coarse Silt became important in the 60-66 cm depth.

(ii) The outstanding factors that negatively influenced the K_{sat} were Total Sand and the Clay fraction in the 30 and 60 cm depths respectively. The Clay influence was more pronounced in the Mwea soil which was predominantly Montmorillonite.

5.2 SOIL MOISTURE RETENTION (Rtθ)

(i) The Clay fraction consistently and significantly enhanced Rtθ at 0.1, 0.3, and 15 bars. The influence was particularly pronounced in the case of the Montmorillonitic clay type compared to the Illite or Kaolinitic - dominated clay fractions.

(ii) Organic Matter (OM) content enhanced Rtθ especially in the 30 and 60 cm depths. The Medium Silt (Msi) and Medium Sand (MS) fractions had limited though positive influence in enhancing $Rt\theta_{0.3}$.

(iii) Total Sand (TS), Fine Sand (FS) and Bulk Density were the major soil characteristics that were largely associated with low Rtθ in invariably all soils studied.

There was a consistent increase in the magnitudes of both the negative and positive variables associated with Rtθ, down the profiles.

5.3 SOIL MOISTURE STORAGE (SMSθ)

(i) The overall or total Soil Moisture Storage (SMSθ), 0.3-15 bars and 0.1-15 bars was raised by Total Silt (Tsi), Medium Silt (Msi), and Organic Matter (OM).

(ii) The $SMS\theta_{0.1-1}$ was positively influenced by the Total Sand and Fine Sand and negatively so by OM and the Clay fraction. The influences were outstanding in the 60-66 cm depth. The $SMS\theta_{0.3-1}$ was mainly a function of the positively correlated Total Silt (Tsi) and Medium Silt (Msi).

(iii) The SMSθ at higher suctions (1-15 bars) was mainly a function of the positively correlated Total Silt (Tsi), Medium Silt (Msi) and the Organic Matter (OM) content. Lower SMSθ over the same suction range were associated with high Bulk density, Total Sand (TS) and Fine Sand, (FS).

(iv) High gradients of the moisture retention curves were associated with the Total Sand (TS), Fine Sand (FS) and the high Bulk Density which were often negatively correlated with Rtθ such that lower moisture retention was recorded at successive bars and especially so at lower suctions along the curves.

Low gradients of the retention curves were often associated with Organic matter, (OM), Medium Silt (Msi), Medium Sand (MS) and the Clay fraction all of which enhanced Rtθ along the retention curves. The influence was more pronounced in the Montmorillonitic-dominated clay fractions. The gradients' variations were more pronounced in the O-3 bar range.

5.4 SOIL MOISTURE RELEASE (RSΘ)

(i) The total Soil Moisture Release $RS\Theta_{0-15}$, was mainly enhanced by the positively correlated Fine Silt (Fsi), Fine Sand FS), and Total Silt TSi) in the 0-36 cm depth. In the 60-66 cm depth, Total Sand (TS) and FS, dominated the moisture release processes. The low overall Moisture release was associated with high Clay fraction and particularly Montmorillonite. OM, negatively influenced moisture release in the 60-66 cm depth.

(ii) The RSΘ and the curves' gradients at low suctions (0-1) were positively influenced by TS, FS and to some extent the Fsi fractions. The clay fraction limited the RSΘ with the magnitude increasing with depth. The OM negatively influenced RSΘ in particularly the 60-66 cm depth. Lower release curves' gradients resulted.

(iii) High RSΘ and the corresponding high curves' gradients in the high suctions range (1-15 bars) were a funtion of Tsi, Msi, OM, Fsi and the Clay fraction to a limited extent. Lower RSΘ in the same range was associated with high Bulk Density, TS and FS fractions. The release curves' gradients were similarly low.

5.5 OVERALL MOISTURE STATUS EVALUATION

It was appreciated in the soil moisture evaluations that the SMSθ was a function of the Rtθ at the lower and higher reference suctions and that SMSθ could be increased by having a lower Rtθ at the higher suction. This phenomenon was however limited in the soils that had higher Sand fractions and thus correspondingly lower Rtθ at both reference suctions. Similarly limiting was the predominance of the Montmorillonitic Clay fraction that enhanced very high Rtθ at all suctions.

Clay mineralogy variations did not feature very prominently in Rtθ, SMSθ, RSθ and K_{sat} evaluations in most soils except in the outstanding case of Mwea soil that was predominantly Montmorillonitic.

Overall textural classes could often be misleading as far as moisture status evaluations are concerned so thorough textural fractions' examination proved useful in this study. A combination of Textural, OM and Bulk Density in relation to the moisture status evaluation strongly indicated that structural factors could not be overlooked.

It was further appreciated that K_{sat} was a vital link between the SMSθ and RSθ as far as the overall soil moisture availability to the varied plant and other soil life forms are concerned.

Within the limitations of the findings of this study, there were indications of the possibility of assessing the potential soils' productivity based on their observed soil moisture release, an aspect of the soil moisture evaluation suggested by Richards (1968).

5.6 SCOPE FOR FUTURE WORK

The author was of the opinion that the findings of the study could further be tested in green house studies involving potted and specified moisture-sensitive plants with the aim of evaluating their performances in the studied soils. The suggested study should cover a wide range of moisture suctions and further attention, too, ought be given to the Structural and Clay Mineralogy aspects of the soils.

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APPENDIX 1

Soil Sites' Characteristics

Site Characteristics	Kabete	Kambes	Longonot	Mariakani	Mazeras	Mwea (Thiba)
Location	Kabete Ridge ½ km along farm road, 200 m off the road	50 m South of Banda La Salama (Mwarakaya Kilifi)	½ km from Ereri range Farm office (Longonot)	Kizurini ¼ km from sub-road (country) to Kaloleni (Kilifi)	200 m from Mariakani school (Kilifi)	½ km from main Thiba rice Research Station
Parent Material	Kabete Trachyte	Oolitic Limestone	Tertiary Volcanic Ash	Mariakani Sand stone	Coarse Sand stone	Volcanic Tuffs and Agglomerates
Macro relief	None	Undulating	None	None	None	None
Macro relief	None	None	None	None	None	Occasional Gilgai
Slope (%)	2 - 8%	3 - 4%	2 - 3%	1 - 2%	2%	0 - 1
Slope length	50 m	100 m	100 m	100 m	100 m	100 m +
Shape of slope	Convex	Linear	Linear	Linear	Linear	Linear
Slope pattern	Regular	Gently undulating	Regular	Regular	Regular	Regular
Surface sealing	None	None	Very slight	Slight	None	None
Surface Cracking	None	None	None	None	None	Common
Drainage	Adequate	Adequate	Satisfactory	Adequate	Adequate	Poor
Erosion	None	None	None	None	None	None
Flooding	None	None	None	None	None	Likely
Vegetation cover	Pennisetum spp. (Kikuyu grass) + Chloris gayana	Grass + scattered Coconuts	Chloris gayana + scattered Acacia	Mixture of Palms + Herbs	Lantana camara Bushes	Cypress Species
Land use	Grazing including Long duration of Rotation	Cultivation (coconuts mangoes maize	Range land	Cultivation (Palms + Cashew plants)	Cultivation of Cashew nuts	Rice Cultivation

APPENDIX II . Sites' Characteristics for the 6 Soil Types.

Depth (cm)	Soil Site	Soil Color		Mottling	Structure	Cutans	Pores		Consistence			Roots' Distribution	pH	
		Dry	Moist				Macro	Micro	Dry	Moist	Wet		H_2O	$CaCl_2$
0-6	Kabete	2.5 YR 4/4 Reddish Brown	2.5 YR 3/4 Dark reddish brown	None	Granular	None	Many	Few	Hard	Friable	SS/NP	Numerous	5.9	4.8
	Kambes	5 YR 4/4 Reddish brown	5 YR 3/4 Dark reddish brown	None	Crusty	None	Many	Few	Hard	Very Friable	S/P	Many	6.7	6.0
	Longonot	2.5 YR 3/2 Very dark greyish Brown	2.5 YR 3/2 Very dark greyish Brown	None	Massive	None	Few	Many	Soft	Friable	NS/NP	Common	6.2	5.4
	Mariakani	10 YR 4/3 Brown	10 YR 3/3 Dark brown	None	Pr to Sub.	None	Many	Few	Soft	Friable	NS/NP	Common	5.5	5.0
	Mazeras	5 YR 5/3 Reddish brown	5 YR 4/3 Reddis brown	None	Pr.	None	Few	Few	Slightly Hard	Very Friable	NS/SP	Common	5.7	4.6
	Mwea (Thiba)	7.5 YR 3/0 Very dark grey	7.5 YR 3/0 Very dark grey	None	Massive	None	Scarse	Many	Hard	Firm	SS/P	Few	7.9	7.0
30-36	Kabete	2.5 YR 4/6 Red	2.5 YR 3/6 Dark red	None	Sub. Blocky	Traces	Few	Many	Hard	Friable	S/SP	Common	6.5	5.9
	Kambes	2.5 YR 4/6 Red	2.5 YR 3/6 Dark red	None	Pr to Sub.	Common	Many	Few	Hard	Slightly firm	S/P	Common	6.6	6.0
	Longonot	2.5 YR 5/4 Light olive brown	2.5 YR 4/4 Olive brown	None	Massive	None	Many	Many	Slightly Hard	Friable	SS/NP	Scarce	6.4	6.0
	Mariakani	10 YR 4/3 Brown	10 YR 3/3 Dark brown	None	Pr. to Sub.	None	Many	Few	Soft	Friable	NS/NP	Few	5.9	5.0
	Mazeras	10 YR 4/8 Red	10 YR 4/8 Red	None	Pr.	None	Common	Common	Slightly Hard	Friable	S/SP	Few	5.8	4.6
	Mwea (Thiba)	7.5 YR 4/0 Dark grey	7.5 YR 4/0 Dark grey	None	Massive	None	Scarce	Numerous	Very hard	Firm	S/VP	Scarce	8.1	7.4
60-66	Kabete	2.5 YR 5/6 Red	2.5 YR 4/6 Red	None	Sub. Blocky	Traces	Scarce	Numerous	Hard	Friable	S/P	Scarce	6.7	6.0
	Kambes	10 R 4/6 Red	10 R 3/6 Dark red	None	Pr. to Sub	Common	Common	Many	Hard	Very Friable	S/P	Scarce	6.2	5.1
	Longonot	5 Y 5/1 Grey	5 Y 4/2 Olive grey	None	Porous and Massive	None	Common	Few	Loose	Friable	NS/NP	Scarse	6.8	6.1
	Mariakani	10 YR 6/6 Yellow brownish	10 YR 6/6 Yellow brown	None	Pr to Sub.	None	Many	Few	Slightly Hard	Friable	NS/NP	Scarce	5.4	4.3
	Mazeras	10 YR 5/8 Red	10 YR 4/8 Red	None	Sub. Blocky	None	Few	Common	Slightly Hard	Friable	S/P	Scarce	5.5	4.1
	Mwea (Thiba)	7.5 YR 4/0 Dark grey	7.5 YR 4/0 Dark grey	None	Massive	None	Scarce	Numerous	Extremely Hard	Very firm	VS/VP	Scarce	8.3	7.6

Structural Abbreviations:
Pr = Prismatic
Sub = Subangular (Blocky)

Consistence Abbreviations
NP = Non plastic
NS = Non sticky
SS = Slightly Sticky
S = Sticky
P = Plastic
VP = Very plastic
VS = Very Sticky

APPENDIX III

X - Ray diffraction identification of the Principal clay minerals (<2µ) of oriented mounts in separated clay fraction of soils from Mr. Sam M. Sessanga

Our Ref No.	Your Ref No.	Lab. No.	Depth	Clay minerals Present	Remarks
190/81	Aug. 1981-A 11	6227/81	0-6 cm	Kaolin and Illite	Both Kaolin and Illite occur at basal spacings of 7.25A° and 10.04A° respectively. They are moderately crystalized. Illite constitutes 56% of the crystalline material, whereas, kaolin accounts for 44%. Kaoline collapses to an amorpheous material on heating whereas Illite intensifies in this condition.
1991/81	Aug. 1981-A 12	8628/81	30-36 cm	-do-	As 190/81 above but kaoline constitutes 48% whereas, Illite accounts for 52%.
192/81	Aug. 1981-A 13	8629/81	60-66 cm	-do-	As 190/81 and 191/81 but Illite accounts for 55% whereas, kaolin constitutes 45% of the crystalline material.

APPENDIX III cont.

Our Ref No.	Your Ref No	Lab. No.	Depth	Clay minerals Present	Remarks
193/81	Aug. 1981-Z 14	8630/81	0-6 cm	Kaolin and Illite	Kaolin is the predominant clay mineral. It occurs at a basal spacing of 7.19-7.20A^{o} and is very well crystallized. It is however, rendered armorphous by heat. Kaolin accounts for 85.5% of the crystalline material whereas, Illite constitutes only 14.5%. Illite occurs at a basal spacing of about 10A^{o} and intensifies slightly on heating.
194/81	Aug. 1981-Z 15	8631/81	30-36 cm	Kaolin and Illite	As 193/81 above but kaolin accounts for 76% whereas, Illite constitutes 24% of the crystalline material.
195/81	Aug. 1981-Z 16	8632/81	60-66 cm	-do-	As 193/81 and 194/81 but kaolin constitutes 79.5% of the crystalline material whereas, Illite accounts for only 20.5%.

APPENDIX III cont.

Our Ref No.	Your Ref No	Lab. No.	Depth	Clay Minerals present	Remarks
196/81	Aug. 1981-B 17	8633/81	0-6 cm	Kaolin and traces of Illite	Kaolin is the Predominant clay mineral in this sample. It occurs at a basal spacing of 7.25A°. It is very well crystallized. On heating the clay, traces of Illite are revealed by the presence of tiny peak at about 10A°, whereas, kaolin collapses to an amorphous material.
197/81	Aug. 1981-B 18	8634/81	30-36 cm	-do-	As 196/81 above but, with higher peak intensities.
198/81	Aug. 1981-B 19	8635/81	60-66 cm	-do-	As 196/81 above.
199/81	Aug. 1981-K 20	8636/81	0-6 cm	Kaolin and Traces of Illite	Kaolin occurs as a poorly crystallized mineral at basal spacings 7.19A° - 7.41A°. A heat treatment condition collapses it to an amorphous material. Traces of Illite are revealed by the presence of a small peak of about 10A°.

APPENDIX III cont.

Our Ref No.	Your Ref No	Lab. No.	Depth
200/81	Aug. 1981-K 21	8637/81	30-36 cm
202/81	Aug. 1981-K 22	8638/81	60-66 cm
202/81	Aug. 1981-T 23	8639/81	0-6 cm
203/81	Aug. 1981-T 24	8640/81	30-36 cm
204/81	Aug. 1981-T 25	8641/81	60-66 cm
211/81	Aug. 1981-(M)		0-6 cm

Clay Minerals present	Remarks
Kaolin and Traces of Illite	As 199/81 above.
-do-	-do-
Entirely amorphous	No d reflections of definite basal spacings. Amorphous material is predominant.
-do-	-do-
-do-	-do-
Montmorillonite	Montmorillonite is the predominant clay mineral in this sample. It occurs at a basal spacing of 15.22A°. There is also a fairly broad peak of low intensity occuring in the region of 7.13A° to 8.19A°. This reveals the 2nd order of Montmorillonite is much pronounced in a Mg treatment condition and very much reduced in a K treatment

APPENDIX III cont.

Our Ref No.	Your Ref No	Lab. No.	Depth	Clay Minerals present	Remarks
					condition. On glycolation, montmorillonite expands to a basal spacing of 19.19A$^{\circ}$ and the 7.13-8.19A$^{\circ}$ peak is improved.
212/81	Aug. 1981-(M) No. 8	8649/81	30-36 cm	Montmorillonite	As 211/81 above.
213/81	Aug. 1981-(M) No. 9	8650/81	60-66 cm	-do-	-do-

A = Mariakani, B = Kambes, K = Kabete, M = Mwea, T = Longonot, Z = Mazeras