Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.7, No.9, 2016 www.iiste.org

# Characterizing Soil Physical Properties and Their Influence on Moisture Retention in Eastern Mau, Kenya

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## Abstract

The study was undertaken to determine site specific physical properties of soil in the plains of Eastern Mau Escarpment for the purposes of enhancing agricultural productivity. Soil physical characteristics are a function of soil moisture retention which has an important influence on agricultural productivity. Topography was found to be 1-1.65%. The soil profile of the *mollic andosols* was defined as; well drained, moderately deep with varied structure across the profile as supported by the trend of moisture content analysis down the profile which revealed that the moisture content variation was a third order quadratic function that increased with depth. It is characterized by coarse texture, low organic matter status, deep and well-drained profiles. The sieve analysis revealed that it is a rich gradation which refers to a sample of aggregate with a high proportion of particles of small sizes. The weighted means of soil fractions were 82.1, 2.7 and 15.2% for sand, silt and clay respectively. Bulk density, (BD), varied from 1.04-1.37 gcm$^{-3}$ within the top soil. The highest BD in the study profiles was found to occur between 20 and 40cm depths, suggesting the existence of a plough pan. Particle density ranged from 1.61 to 2.18gcm$^{-3}$. Mean particle density was 2gcm$^{-3}$ with high density particles dominating the top 20cm. The pF curves for samples from soil depths; 10, 20, 30, 40, 50 and 60 cm had unique SWCC though the soil texture was found to be similar in all sampled profiles. It was revealed that the plough pan layer retained more moisture than above and below it.

**Keywords;** *mollic andosols,* physical characteristics, rich gradation, plough pan

## *Introduction*

The objective of the study was to characterize volcanic soils of Eastern Mau in relation to moisture retention. Most soil characteristics can be modified through tillage to improve their moisture retention capacity. It was observed that a consistent pattern of little or no rain in the month of June every year (Meteorological Department of Kenya 1929-2011, data) existed and the shortfall has increased in recent times. The main planting period in the area lasts from late March to early May. A partial drought in June which marks the end of the first and main rain season always poses a danger to crop yield since it occurs when most crops are at their critical growth stage. Drought during this period is reported to reduce for example; corn yields by 10 to 50 percent (Heininger, et. al., 2001). The amount of yield loss that occurs during dry weather depends on the growth phase of the crop and the extent of the dry conditions. Severity of moisture deficit in *mollic andosols* is worsened by the inherent high drainage rate. This calls for the understanding of target soil properties and how they affect moisture retention, in order to allow manipulation for improved moisture retention. According to Payne et al., (1990) the proportion of moisture retained in crops root zone could even be more crucial to increased productivity than the total rainfall. Poor moisture retention in these soils stems more from the ensuing unfavourable pore size distribution. Tillage systems modify soil structure, temperature and water distribution (Waddell and Weil, 1996). The implication of these peculiarities is that future crop production by the resource-poor farmers in Eastern Mau may remain water-constrained if no viable soil and water conservation practices are devised and the first step towards attaining these is through soil characterization. Eastern Mau is dominated by *mollic andosols* (Mainuri, 2004). At present, no site specific works have been undertaken to complement management practices on the soil moisture retention.

## *Material and methods*

Some of the soil properties that were studied included soil profile, soil elements associated with water holding capacity, texture, infiltration rate, permeability, soil water characteristic curve, hydraulic conductivity, bulk density and porosity with respect to their influence to moisture retention. The soil profile was analyzed using the profile pit technique. A gravimetric method (SOP METHOD 1.00) was used in bulk density determination.

In determining spatial variability of soil elements, the experimental site was subdivided into 5×5m grids to form sampling quadrants. Samples were obtained from the centre of each quadrant. Soil samples were subjected to soil primary macronutrient element tests using relevant laboratory protocol to investigate any systematic variation within the plots. The purpose was to detect if there existed any relationship between known water holding elements and their concentrations in the study area soil. To determine soil textural composition, the texture analysis chart method was used. The soil infiltration rate was determined by the modified Kostiakov's method and permeability was determined by the falling head method using a procedure described by Eijkelkamp. Soil Water Characteristic Curve was determined using the pressure plate extraction method. Pore-size distribution and plant available water plant available water, (PAW), content were computed based on the data for soil water retention, (SWR). Plant available water was computed as the difference between volumetric water content at -2 and -4.2pf. Soil physical characteristics were monitored after tillage treatment application.

## ***Results and discussions***

The soil elements known to affect moisture retention are; Nitrogen, Phosphorous, Potassium, calcium, manganese, and sulphur. Soil sampling was systematically undertaken and none of the chemicals had a significant effect on moisture retention. It is important to note that their spatial concentration variability was over 50% in all cases but did not attain critical masses to have any corresponding effect on the moisture retention.

### *Soil Chemical Distribution*

The primary macronutrients, i.e., N.P.K secondary macronutrients, i.e., Ca, Mg, S and some micronutrients were analyzed due to their known direct or indirect effect on soil moisture retention. Carbon was found to range from 1.7 to 3.4% and decreased down the profile. Nitrogen was found in quantities of 0.12 to 0.26%. Both Nitrogen and Carbon are used by bacteria during decomposition of organic matter which is responsible for moisture retention arising from its effect on soil aggregation and pore size distribution. The pH level was found to lie between 5.04 and 6.18, the range described as moderate to slightly acid soil. Potassium was 213.7 to 494.7ppm being concentrated more on elevated parts of the experimental site than the depressed ones.

Potassium influences soil stability due to increasing the soil's water retention properties. The precipitated potassium salts causes bridging between the soil precipitated potassium salts, significantly increasing the soil's water retention properties. The precipitated potassium salts causes bridging between the soil particles, reducing the size of the macro pores and increasing the water retention capacity.

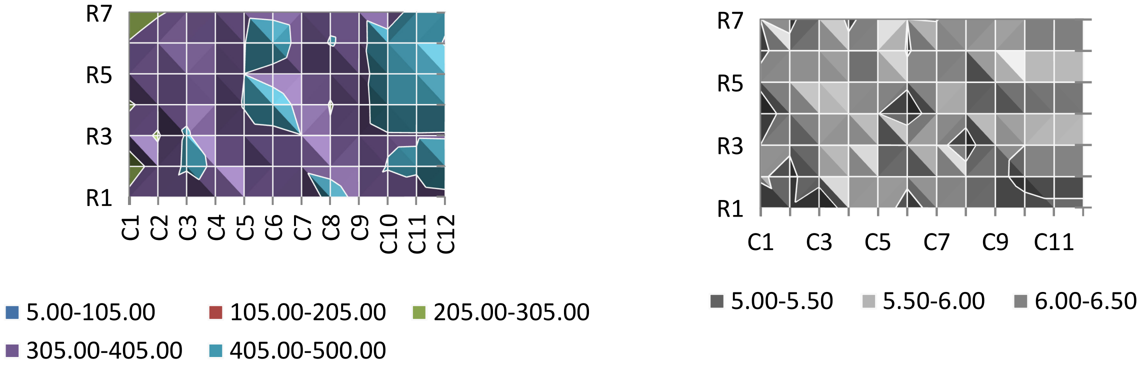

**Figure 1: 4.1 Potassium (Left) and Phosphorous concentrations on the research site**

### *Soil Profile*

Well drained, moderately deep and with varied structure across profile pockets of soil were noticed in the weathered rocks. Root distribution was normal but was more concentrated in the top 40cm depth of the soil layer.

$Ap_1$ 0-13cm Dark reddish brown (5 YR 2.5/2) moist, (7.5 YR 4/4) dry and (5YR 3/2) rubbed; clay loam, strong fine to coarse crumb and granular, slightly hard dry, friable moist, sticky and plastic wet; common micro, very fine and fine interstitial pores; many very fine and fine roots; pH 5.4; abrupt and smooth boundary to:

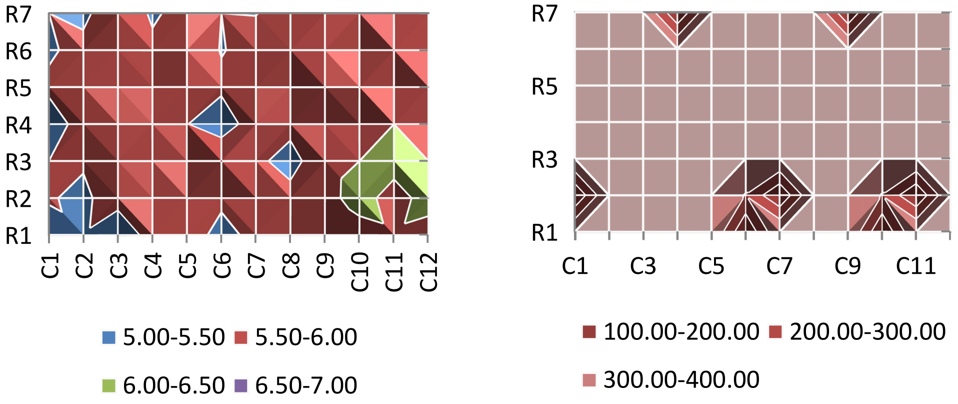

Figure 2: Figure: 4.2 pH left and Manganese concentrations

$Ap_2$ 13-27cm Dark reddish brown (5 YR 2.5/2) moist, (7.5 YR 4/4) dry (5YR 3/2) rubbed; Clay loam, weak very coarse prismatic structure falling apart to weak fine to coarse angular blocky structure; very hard (dry) friable moist, sticky and plastic wet; common micro, very fine interstitial pores; common very fine and fine roots; pH 5.61; clear and smooth boundary to:

$Bw_1$ 27-40cm Dark reddish brown (5 YR 3/2) moist, (5 YR 3/3) dry (5YR 3/3) rubbed; Clay; moderate fine to coarse sub angular blocky structure; slightly hard dry, friable moist, sticky and plastic wet; common micro, very fine, fine and medium interstitial pores; very few fine and fine roots; pH 5.02; gradual and smooth boundary to:

$Bw_2$ 40-60cm Dark reddish brown Dark reddish brown (5YR 3/3) moist, (5YR 4/4) dry, (5YR 3/3) rubbed; clay; moderate fine to coarse sub-angular and angular blocky structure, slightly hard dry, friable moist, sticky and plastic wet; many micro, very fine, fine and medium interstitial pores; rare very fine roots; pH 5.96; abrupt irregular boundary to weathered vitric tuff, beyond 60cm falls outside the scope of this study.

The soil profile of the *mollic andosols* was defined as well drained, moderately deep with varied structure across the profile as supported by the trend of moisture content analysis down the profile which revealed that the moisture content variation was a third order quadratic function that increased with depth. Though there were distinct abrupt and smooth soil profile boundaries, $Ap_1$, $Ap_2$, $Bw_1$ and $Bw_2$ this was not illustrated in a quadratic curve and the moisture content change was entirely due to depth suggesting that the texture between profile boundaries was gradual.

*Soil Textural Analysis*

Soil from the study area belongs to Phaeozems series and has been classified as *mollic andosols*. It is characterized by coarse texture, low organic matter status, deep and well-drained profiles. The sieve analysis revealed that it is a rich gradation which refers to a sample of aggregate with a high proportion of particles of small sizes. The weighted means of soil fractions were 82.1 2.7 and 15.2% for sand, silt and clay respectively. The high quantity of sand is responsible for the low saturation time of 4-20 minutes, some clay soils take up to 72hrs to saturate. Sandy particles were found to be more concentrated in the topsoil which can be attributed to the previous land use. The grading curve (Figure 4.8) describes the test sample as poorly graded medium sand. $D_{10}$ of 0.3 is of fine sand, not well graded as the value for $C_u$ is 5 both which explain the high infiltration of 10-30mmhr$^{-1}$.

**Figure 3: Grading Curve**

*Bulk Density(BD)*

BD was found to vary from 1.04-1.37 gcm$^{-3}$ within the top soil. The highest BD in the study profiles was found to occur from 20 to 40cm depths, suggesting the existence of a plough pan. This can be accredited to previous land use practices where soil was frequently worked at 20-30cm deep by heavy machinery, below which existed a plough pan. At that depth, porosity was lowest and the highest bulk density occurred here (Figure 4.9).

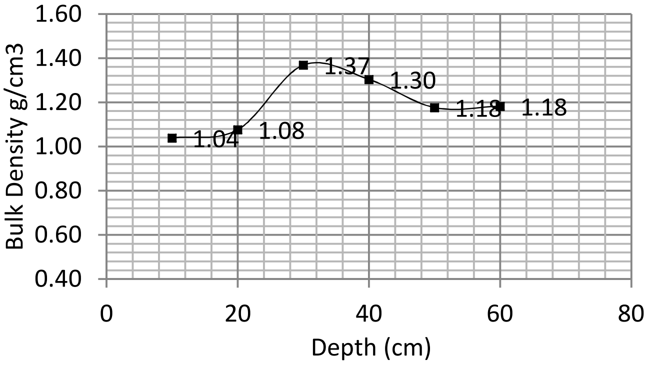

**Figure 4: Variation of BD down the profile**

*Moisture Content*

The soil moisture content in the top 10cm was 7.88%. It was found to geometrically increase with depth to 31.7% at 60cm, (Figure 7). The top soil looses water to 7.88% during the dry season representing ¼ of the wilting point as earlier observed from the pF curves; available moisture at wilting point was 34%, within the top soil (0-30cm). After a long spell of drought, the soil develops deep cracks from the surface to a depth of 25-30cm. This enhances moisture loss through evaporation. At 60cm depth, there is a sudden change in the soil profile to pumice rock that has a low permeability that explains increasing moisture towards the 60cm depth. The relationship of depth and moisture content evaluated by regression revealed that the significant best fit occurs at the third order (quadratic) function (figure 10).

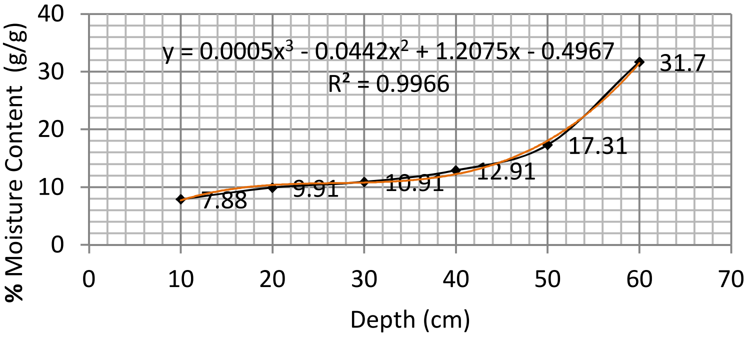

**Figure 5: Variation of Moisture Content down the profile before onset of rains**

*Porosity*

A decrease in porosity (Figure 12) and hydraulic conductivity (Figure 4.18), increase in bulk density between 25 and 40 cm depth are accredited to the existence of a plough pan confirming an earlier stated case. Beyond 50cm, porosity was found to decrease as the depth approached the pumice rock which is semi permeable with a low bulk density.

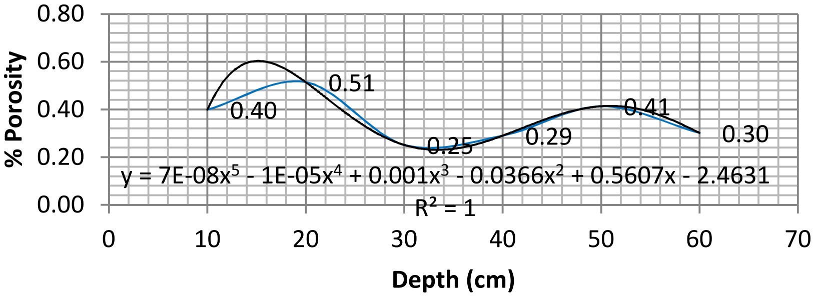

**Figure 6 Variation in porosity down the profile**

*Infiltration*

Results showed how infiltration rates varied amongst the treatments due to different soil surface conditions. Infiltration rates under different tillage systems were in the order MT>CT>NT>ZT. The infiltration rate observed in the MT treatment was attributed to the shallow pulverization by the harrow that left a finer tilth compared to that in ZT treatment in which infiltration was hastened.

The tilled soil depth in CT is deeper than in MT. In CT soil receives more passes packing soil particles more closely than in MT. Thus, the voids are considerably reduced and the BD increased as established above, hence, accounting for a lower infiltration rate. The BD was found to be in the order of MT>CT>NT>ZT immediately after treatments which corresponds to the infiltration rates. The soil surface in NT had cracks that led to increased infiltration rate right from the surface hence higher than that in ZT. ZT had a lower infiltration rate because while chiselling, the chisel tool compressed the soil reducing crack size while being dragged through the soil. Soil surfaces in the chisel opening were found to have smeared reducing the water inflow and inhibiting infiltration.

The smear effect was caused by the higher soil moisture content that was found to increase with depth. Soil tillage can initially improve infiltration and, sometimes benefit drainage over time. Tillage favours degradation of the soil structure and a reduction of the infiltration rate due to the high soil water aggregation of the sandy loam.

Basic infiltration rates varied from 10.8, 14.1, and 21.6 to 30.6 mmh$^{-1}$ for ZT, NT, CT and MT respectively, Figure 4.14. Infiltration rates for CT and MT ranged between 20 to 60mmh$^{-1}$ and are distinguished as moderately rapid class according to ASTM D338-94. The high infiltration rate may be attributed to the high sand percentage, 82.1%. The curves Figure 4.15 can be used to estimate the amount of cumulated water in the soil for a given duration of wetting. The initial higher rate of infiltration observed in ZT over NT was due to the channel by the chisel in the sandy soil which tends to stabilize after 40 minutes when the effect of the treatment is overtaken by ponding. The gradients for the infiltration rate curves were similar (0.6684, 0.6684, 0.6348, and 0.6619) with coefficients 1, 1, 0.99 and 0.95 for MT, CT, ZT and NT respectively. The phenomenon of coefficient similarity is credited to the identical soil type whose physical characteristics are varied only by tillage treatments.

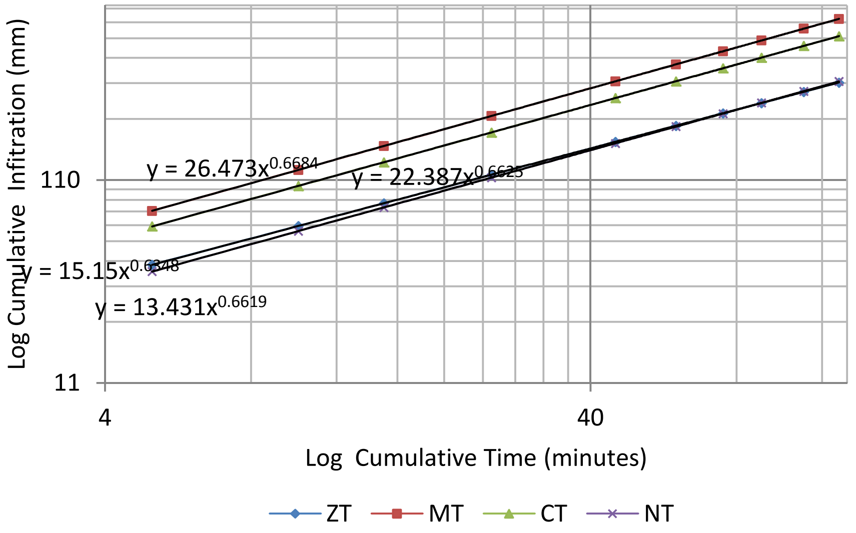

**Figure 7 Logarithmic plot of cumulative Infiltration ($I_{cum}$) versus time ($T_{cum}$) for selected Tillage Systems on *mollic andosols of* Eastern Mau**

**Table 1: Infiltration depth after 40cm**

| Tillage Treatment | Time in Minutes | Accumulated Depth(cm) |
|---|---|---|
| **MT** | 40 | 31.08 |
| **CT** | 40 | 25.37 |
| **ZT** | 40 | 16.50 |
| **NT** | 40 | 14.74 |

Table 4.1 is a summary of the amount of infiltrated water in the soil after 40 minutes under the four tillage systems and Figures 4.14a-4.14d are respective prediction curves.

*Hydraulic Conductivity (Double ring)*

The $K_s$ value determined from the infiltrometer method was found to be 22.4mm/hr. The double ring infiltrometer method tends to exaggerate the IR. Hydraulic conductivity reduces with increasing bulk density as can be observed from (Table 4.2) and (Figure 4.15). The variation in hydraulic conductivity may be due to the different bulk densities within the soil profile.

**Table 2 pF Hydraulic conductivity analysis by constant head (Laboratory Method)**

| Depth (cm) | Average K($ms^{-1}$) |
|---|---|
| **10** | $1.44\times10^{-5}$ |
| **20** | $7.87\times10^{-6}$ |
| **30** | $1.52\times10^{-6}$ |
| **40** | $9.31\times10^{-6}$ |
| **50** | $1.36\times10^{-5}$ |
| **60** | $1.07\times10^{-5}$ |

*pF Curves at Different Depths*

The pF curves for samples from soil depths; 10, 20, 30, 40, 50 and 60cm had unique SWCC though the soil texture was found to be similar in all sampled profiles. The upper moisture limit considered to be field capacity i.e. pF=2 and the lower soil moisture limit also called “wilting point”, pF=4.2 were used to determine the amount of water retaining capacity in relation to crop requirement. Volumetric available moisture in the top 10cm soil was found to be 8% (Figure 4.19a). The low amount could be attributed to high hydraulic conductivity (Figure 18), low Bulk density (Figure 4.9) and high organic matter content as compared to the results at 40cm depth with 34%.

The available moisture reduced from 15% to 13% at soil depths 20cm and 30cm respectively corresponding to the bulk density associated with the plough pan at the depth. The available moisture at 40 and 50cm depth did not exhibit a notable difference, 33, 34% respectively. At the 60cm depth, the hydraulic conductivity reduced because it is at this depth that the soil changes in structure and texture as it approaches the underlying prominent distinct dark yellowish mottles (10YR 3/4) which occur from soil depth 56cm. Similar results were reported by (Kimotho, 1990). The storage coefficients (the slope of soil-water characteristic curve) of the six pF curves from respective depths, do not exhibit significant difference after air entry point (Figure .16a-f). From the figure it can be observed that the high bulk density soil depth stored more water and dewater for a longer period in which, the air entry value refers to the matrix suction value when the water in surface meniscus of soils body skeleton begins to move (Jin-yu Li, 2010). The absolute water storage capacity is 11.7cm, 19.5% by volume.

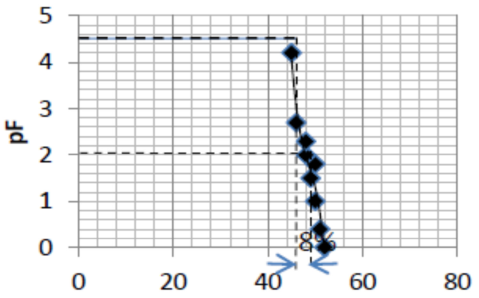

**Figure: 8.a Vol % Water(10cm)**

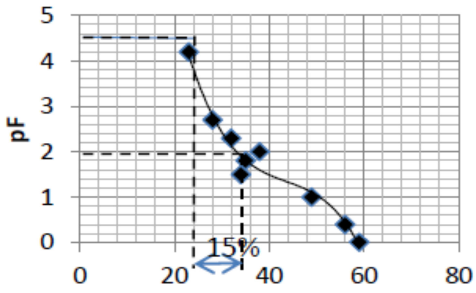

**Figure: 8.bb Vol % Water (20cm)**

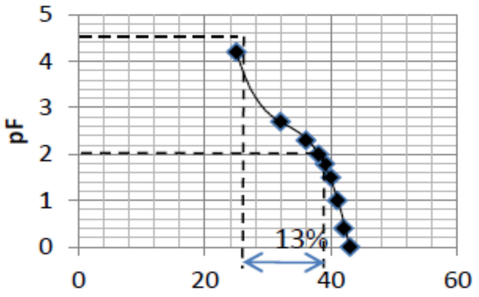

**Figure: 8.c Vol % Water (30cm)**

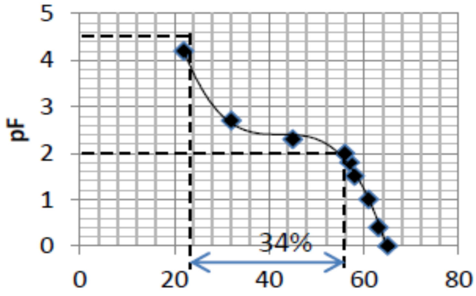

**Figure: 8.d Vol % Water (40cm)**

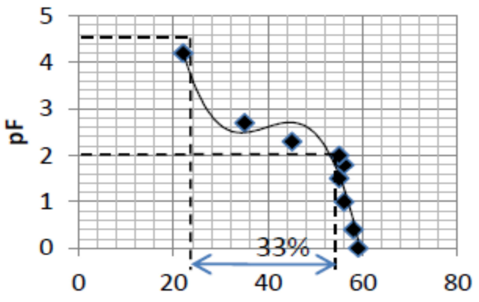

**Figure :8.e Vol % Water (50cm)**

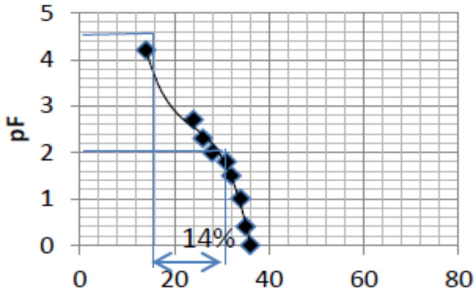

**Figure: 8.f Vol % Water (60cm)**

**Figure 8 pF curves at 10, 20, 30, 40, 50 and 60cm**

*Statistical Analysis*

While infiltration rate was in the order of MT>CT>ZT>NT, immediately after the treatments were applied, mean moisture retention over the test period was in the order of CT>ZT>NT>MT. Infiltration rate was high in MT but with the lowest moisture retention as there was excessive percolation due to the large undisturbed cracks that were observed below the tilled profile. The rapid infiltration rate of the sandy loam (*mollic andosols)* and evaporation at the surface led to moisture storage increasing with depth as the top soil served as an insulator.

## *Conclusions*

Based on the laboratory and field results of this study, the following conclusions were drawn: Soil retention curves and water holding capacity were affected by the type of tillage due to change in structure. Bulk density of *mollic andosols* on Eastern Mau Plains is was found to be below 1.40 g/cm$^3$ with a porosity of up to 41% that lead to high infiltration and hydraulic conductivity and infiltration rates. These characteristics compounded by the partial draught that occurs in June renders the study area a moisture deficient one. It was revealed that the high bulk density retained more moisture than the lower ones.

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