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MOISTURE RETENTION CHARACTERISTICS OF SOILS USED FOR VEGETABLE CROP PRODUCTION IN THE TOLON-KUMBUNGU DISTRICT, GHANA

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ABSTRACT

Most soil moisture measurements make use of the direct method with its associated disadvantages. Farmers in the study area particularly use the direct observation and feel methods in the determination of the required moisture level for most farming activities even though this is subjective and normally inaccurate. This study employed the indirect method (tensiometer and theta probe) of soil moisture measurements and determined the available soil moisture and force of suction of soil water by existing capillary force at different depths and locations. The study was conducted at the University farm of the University for Development Studies, Gung and Gizaa in the Tolon-Kumbungu District. Vegetable crops commonly grown in these areas include Capsicum spp, Lycopersicon esculentum, Solanum melongena, Abelmoschus esculentus and Hibiscus cannabinus. Ferric acrisols, dysteric planosols and dystric plinthosols are soils commonly found in this area and have varying soil moisture characteristics. An inverse soil matric potential-rainfall relationship was determined for all three (3) study areas. Soil suction therefore increased as the soil moisture content increased coupled with lower matric potentials when high rainfall was recorded. A direct relationship was established between volumetric moisture content and rainfall for the study period. Drier periods (dry season) recorded lower volumetric moisture content and increased with the intensification of the rains reaching its peak in September. August and September 2007, recorded the lowest pF values ranging from 0.43 at Gizaa (40 cm) to 0.80 at 15 cm depth in the University Farm. These indicated a saturated soil condition of the study areas thus exerting soil moisture suction stress on the vegetable crops grown. Soil moisture characteristic curves however varied with varying soil texture. Root rot resulting in the lodging of vegetable crops was observed during the period of study. Moisture stress and excessive moisture in the study areas resulted in low yields of crops as a result of root stock rotting, plant lodging as well as fruit rotting.

INTRODUCTION

Rainfall is the principal means for replenishing moisture in the soil water system and this recharge depends upon the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth and the soil type. According to Schippers (2000), indigenous vegetables play an important role in income generation and subsistence. They also present an opportunity for the poorest people to earn a living as producers and/or traders without requiring large capital investments. Most practical techniques for soil water monitoring are indirect (Robinson *et al.*, 1999), and these methods estimate soil moisture by a calibrated relationship with some other measurable variable (Muñoz-Carpena and Dukes, 2005). According to Muñoz-Carpena and Dukes (2005), the suitability of each method depends on several issues such as cost, accuracy, response time, installation, management and durability of the instrument. Indirect methods of soil water content measurements are however classified as volumetric and tensiometric methods which give volumetric soil moisture and soil suction or water potential. The two are related through the soil water characteristic curve which is specific to a given soil type. According to Evett (2007), the soil water status affects the transpiration stream of crops and their ability to uptake nutrients from the soil and CO_2 from the atmosphere for yield formation. Because soil water status is reflected in crop water status, there are many links between soil water status and crop physiological response, including leaf turgor and orientation, growth through cell expansion and division, rooting, fruiting, stomatal size, chemical (hormonal) processes, flowering, canopy temperature, etc. The cultivation of vegetable crops such as tomatoes, kenaf, pepper, etc for their leaves or fruits therefore presents a very important area that wide variations in soil moisture during cultivation will greatly affect.

Kasei and Sallah (1993) indicated that rainfed farming under erratic monomodal rainfall pattern is the dominant practice in the northern regions of Ghana when 90% of the rainfall is received between June and September and only within these humid months that soil moisture surplus occurs. Even though there exist several dugouts are used for vegetable crop cultivation during the dry season, cultivation during the rainy season is the preferred practice.

Field observations showed that, farmers in the Tolon-Kumbungu District in the Northern Region of Ghana usually cultivate crops without taking cognizance of crop-moisture related characteristics of the soil. Direct observation (appearance) and feel methods are mostly used in soil moisture determination by farmers in these areas. One of the major drawbacks with this method according to Schneekloth *et al.*, (2007) is that the estimation of soil moisture is subjective and not exact.

The objective of the study was to determine the available soil moisture content of the soils and the force of suction of soil water by existing capillary force in the soil, at different depths and locations in soils used for vegetable crop production in the Tolon-Kumbungu District.

MATERIALS AND METHODS

Study Area

The study was carried out in the Tolon-Kumbungu District of the Northern Region of Ghana. The instruments were located in the University Experimental Farm at the western side of the Faculty of Agriculture, University for Development Studies, Ghana and two communities – Gung and Gizaa at 14 and 12 km respectively from the University Experimental Farms. The study area experiences one rainy season in a year, lasting from April to October with an annual mean of 1,000 mm while the mean monthly temperature ranges between 17°C and 40°C (TKDA, 2006).

Methods

The instrumentation for the various sites, the soil classification and geographic location of the study areas are presented in Table 1. Tensiometric readings were taken after every rainfall event with time interval of four hours within daylight time. Period for data collection was from May to October, 2007.

Soil Textural Analysis – Hydrometer Method

The soil texture of the sites were determined in the laboratory using the hydrometer method and classified according to the USDA classification. The America Hydraulic Properties Calculator (http://hydrolab.arsusda.gov/spoilwater/Index.htm, 2008) software which automatically calculates the soil texture class, wilting point, field capacity, saturated hydraulic conductivity, bulk density and available water of the soils was used for the different depths.

Soil Moisture Characteristics

Soil moisture characteristic (pF) curves of the soils of the study sites were plotted to obtain the relationship between the matric potential and available water content of the soil. Reading from tensiometers in kilopascal (kPa) were converted into picofarad (pF). pF is generally used as one of the pressure units and it is expressed as;

$pF = \log(\text{value in } kPa \times 10.197)$

The height of the water column is however related to pF as described in equation 2.

$pf = \log /h/$

Soil Matric Potential

The soil moisture condition (matric potential) at the various depths was compared graphically with their months of incidence. Monthly averages of the pF readings were computed for the various depths and the force of suction for the various months was determined.

Hydraulic Properties Calculator was used together with the sand and clay percentages from the laboratory analysis to obtain the soil texture and other hydraulic properties of the soils for the various depths as presented in Table 2.

Wilting point of crops was 0.09 cm^3/cm^3 for sandy loam soil at the Gung study site whilst the other sites recorded a wilting point of 0.1 cm^3/cm^3. At this stage of soil water, the crops wilted as the available water for extraction became limited. This has a great effect on especially the vegetables cultivated for their leaves and even resulted in a low market value. Fruit vegetables also produced smaller fruits as the plants were not able to carry out most metabolic processes.

Table 1: Soil Type, Depth and Geographic Location of Instruments used for Data Collection

Location	Geographic Location	Type of Instrument	Sampling Depth (cm)	FAO Soil Classification	Local Classification
University Farm	Latitude: 09°24'49.7" N Longitude: 00°59'17.3" W	Tensiometer Theta Probe	15 and 35	Ferric Acrisols	Techiman-Tampu
Gung	Latitude: 09°29'57.1" N Longitude: 00°59'17.3" W	Tensiometer Theta Probe	15	Ferric Acrisols	Techiman-Tampu
Gizaa	Latitude: 09°27'28.0"N Longitude: 01°02'.38" W	Tensiometer Theta Probe	40	Dysteric Planosols/ Dystric Plinthosols	Lima Volta and Sambu-Pasga

RESULTS AND DISCUSSION

Hydraulic Properties of the Study Area Soils

According to Amati *et al.* (1989), soil for vegetable crops like tomatoes and pepper need to be permeable and no puddles should remain on the ground. They indicated that leaves of vegetable crops such as pepper and sweet pepper cannot endure more than a couple of hours of saturated soils. The American

According to Amati *et al* (1989), yields of tomato and pepper decreased considerably after short periods of water deficiency and watering is recommended for periods of flowering and fruiting. The soils however got saturated when the soil water was within the range of 0.42 cm^3/cm^3 at the Gung area to 0.45 cm^3/cm^3 at the Gizaa area. At saturation, the vegetable crops encountered a difficulty in the absorption of soil water and this affected the growth of the crops greatly. Results from Table 2 indicate

Table 2: Soil Texture and Hydraulic Properties of Soils of the Study Areas

Site		**University Farm**		**Gung**	**Gizaa**
Soil Depth (cm)		0-15	15-35	0-15	15-40
		Input Data			
Sand (%)		50.96	52.96	56.96	36.96
Clay (%)		11.72	11.72	9.72	13.72
		Calculated Results			
Silt (%)		37.32	35.32	33.32	49.32
Texture Class (USDA System)		Loam	Sandy loam	Sandy Loam	Loam
Wilting Point (cm^3 water/cm^3 soil)		0.1	0.1	0.09	0.1
Field Capacity (cm^3 water/cm^3 soil)		0.23	0.22	0.21	0.26
Bulk Density (g/cm^3)		1.51	1.51	1.55	1.46
Saturation (cm^3 water/ cm^3 soil)		0.43	0.43	0.42	0.45
Saturated Hydraulic Conductivity (cm/hr)		2.13	2.12	2.74	1.81
Available Water	cm^3 water/cm^3 soil	0.13	0.13	0.12	0.15
	inches water/foot soil	1.54	1.50	1.45	1.82

that, the soil texture of the University Farm at depth of 0 – 15 cm is loam but sandy loam at 15 – 35 cm depth. The available water as indicated in Table 2 shows that enough water is available for absorption by the vegetable crops during the rainy season. This shows soil texture difference across depths as confirmed by Ley *et al.* (1994) that, soil layers resulting from deposition generally vary in texture with depth in the soil profile.

Soil Moisture Characteristics

The soil moisture tension or suction for the tensiometer and the theta probe for the various sites were related to obtain the soil moisture characteristic curves. The moisture characteristic curves only showed the normal wet basis of the soil during the rainfall period from May to October 2007. The difference in the plots of Figures 1, 2, 3 and 4 could be attributed to the variations in the soil particles both spatially and across the various depths. This also shows the soil moisture available to the various vegetable crops grown in the study area which has a direct relationship on fruit and leaf yield of the crops.

At 15 cm depth the University Farm soil had a comparatively lower sand percentage (50.96%) and higher silt percentage of 37.32% than the Gizaa soil, whilst the Gung site (15 cm depth) recorded 33.32% silt content. The difference in soil particles for these two sites presents different moisture characteristic curves as shown in Figures 1 and 2.

The Gizaa area recorded a low percentage of sand particles of about 36.96% and a high of 49.32% at the depth of 40 cm. Figure 3 presents inverse soil suction – volumetric moisture content relationship of the Gizaa study area.

The 35 cm depth moisture retention curve of the University Farm recorded sand particle size of 52.96% and silt of 35.32% with the curve exhibiting a characteristic 'chair-shaped' structure (Figure 4). The 'chair-shaped' curve for the University Farm (35 cm depth) is an indication of the rapid loss of water with increasing pF and of which is largely due to the high percentage of macro pores that exist in the soil as a result of high proportion of sand particles.

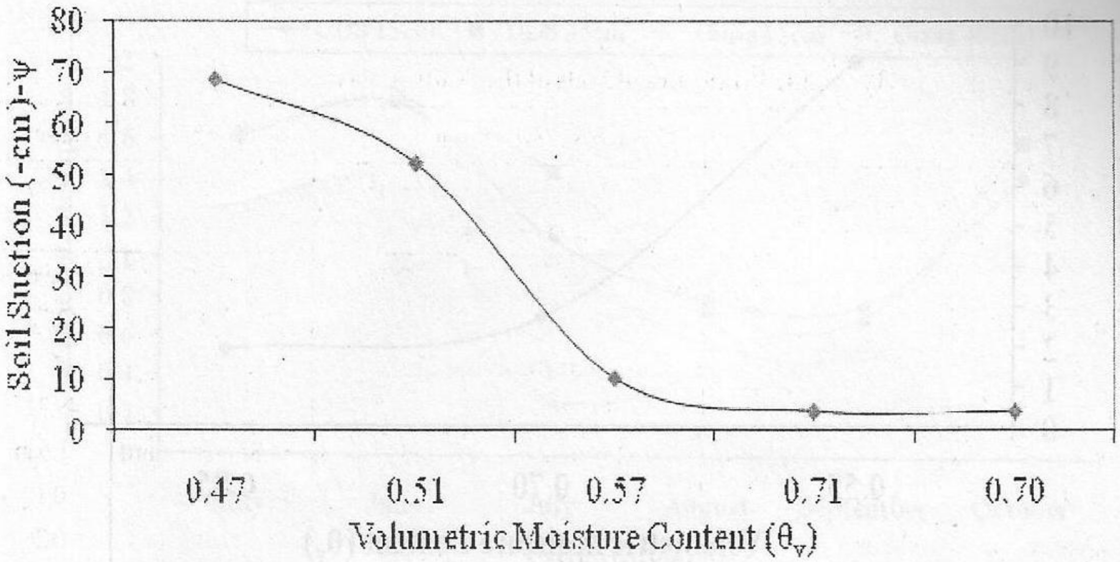

Figure 1: Soil Moisture Characteristics of Gung (15 cm Depth)

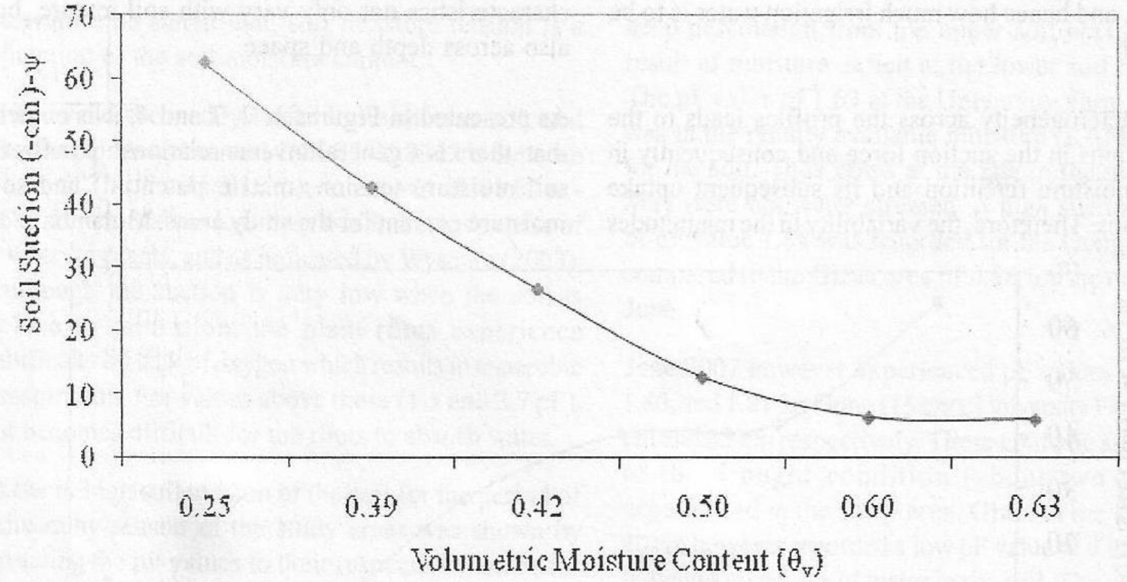

Figure 2: Soil Moisture Characteristics of the University Farm (15 cm Depth)

The difference in soil particle size distribution across depth and spatially was realised to have led to differences in pore size distribution along the soil profile and thus results in the differences in the shapes between the various soil moisture characteristic curves (Figure 1, 2, 3 and 4). Bilskie (2001) pointed out that both soil texture and structure determine the soil moisture characteristics curve of any particular area. Also, Miyazaki (1993) attributed the differences in soil moisture characteristics curves primarily to the differences in pore size distribution among soils. These curves are sensitive to the changes in bulk densities and disturbances of soil structures. The moisture characteristic curves are very important especially if one needs to know how much water is deficit in the effective root zone of

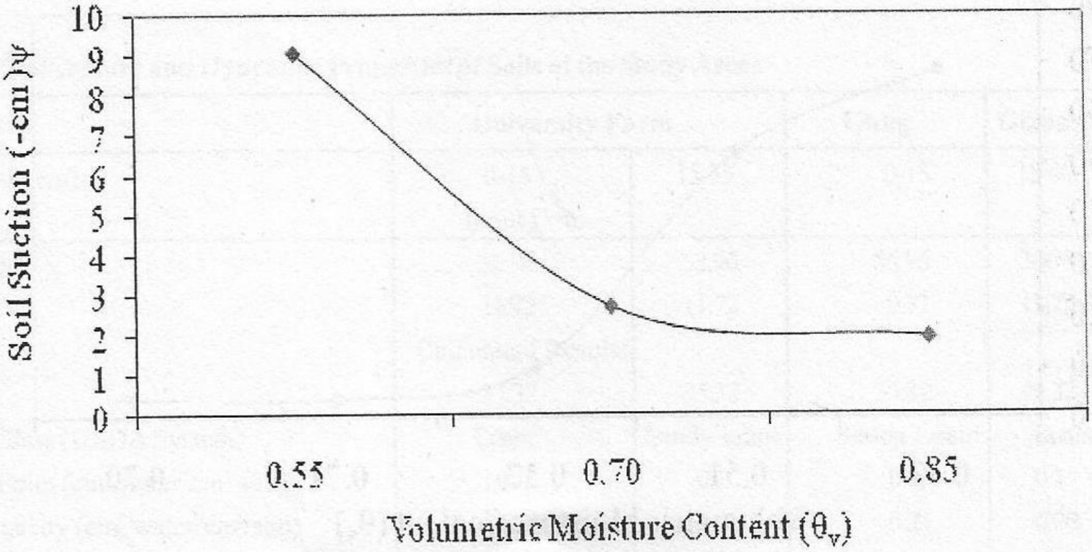

Figure 3: Soil Moisture Characteristics of Gizaa (40 cm Depth)

crops, and hence how much irrigation water is to be added.

Soil heterogeneity across the profiles leads to the variations in the suction force and consequently in soil moisture retention and its subsequent uptake by crops. Therefore, the variability in the magnitudes of moisture contents at any given tension reflects the variability in soil texture and porosity as indicated by Kumar and Purandara (2003). However, the results of the study indicate that, soil moisture characteristics not only vary with soil texture, but also across depth and space.

As presented in Figures 1, 2, 3 and 4, it is evident that, there is a general inverse relationship between soil moisture tension (matric potential) and soil moisture content for the study areas. Mulamba *et al.* (2002) stated that, there is an opposite relationship existing between soil moisture tension and soil moisture content since applying suction (tension) to the soil diminishes the soil moisture. It can

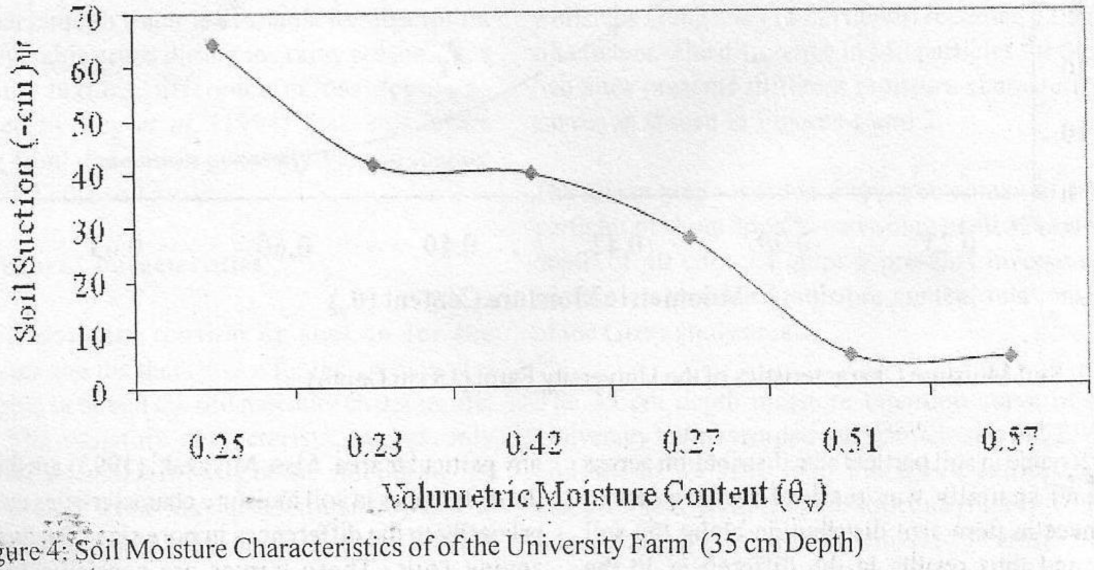

Figure 4: Soil Moisture Characteristics of of the University Farm (35 cm Depth)

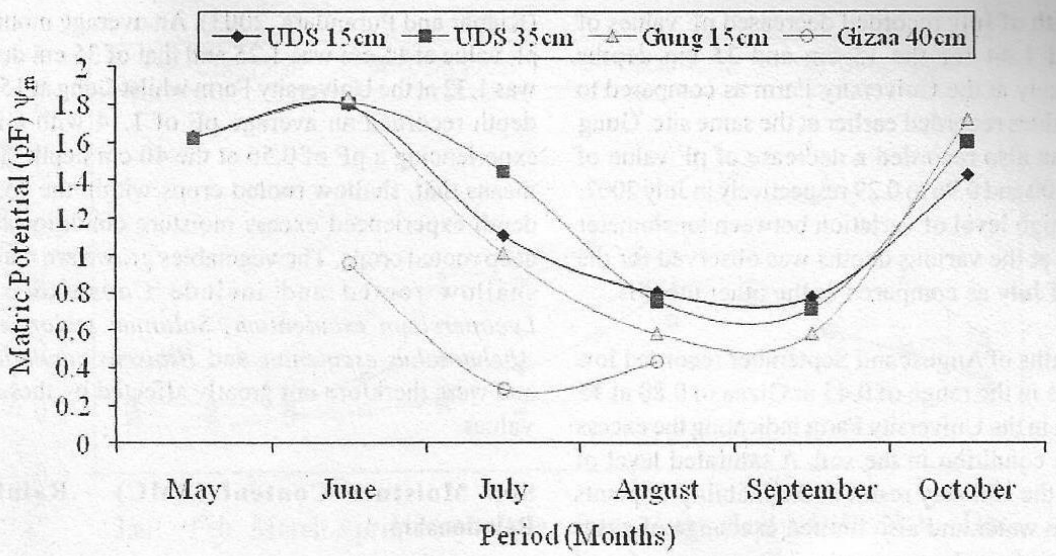

Figure 5: Monthly soil matric potential of the sturdy Areas

therefore be stated that, soil moisture tension is a function of the soil moisture content.

In the field, the readily available moisture as indicated by the pF-Meter manual-DIK 8332, 8342 is between 1.5 and 2.7 pF values i.e. pressure head of -31.62 to -501.19 cm. Values less than this indicates excess of water for plants, and as indicated by Wyseure (2003), although the suction is very low when the soil is close to saturation, the plant roots experience difficulty by lack of oxygen which results in anaerobic respiration. For values above these (1.5 and 2.7 pF), it becomes difficult for the roots to absorb water.

Low or high soil tension of the soil for the period of the rainy season of the study areas was shown by relating the pF values to their respective months for the 2007 wet season. As can be seen in Figure 5, tensiometric measurements at the various depths present the average matric potential or force of suction of soil water by capillary force for the months of May to October 2007.

At the beginning of the rains in May, the matric potential or suction force for the 15 cm depth tensiometer at pF value of 1.63 was slightly higher than the 35 cm depth tensiometer at pF value of 1.62 at the University Farm. This difference is attributed to the evapotranspiration loss coupled with the rapid deep percolation from the upper soil horizon as a result of moisture deficit at the lower soil horizon. The pF value of 1.63 at the University Farm in May was in the readily available moisture (RAM) range for the soil. Thus crops at the site in the month of May were not water stressed. A high suction force of pF value 1.84 was recorded for the Gung area as compared to the Gizaa area of 0.96 for the month of June.

June 2007 however experienced pF values of 1.84, 1.80, and 1.81 for Gung (15 cm), University Farm at 15 cm and 35 cm respectively. These could be attributed to the drought condition (about two weeks) experienced in the study area. Gizaa at the depth of 40 cm however recorded a low pF value of 0.96 which indicates an excess of water in the soil. The month of June was noted to have recorded the highest soil moisture tension for the six (6) month wet season under study. Even though these values except, Gizaa are within the RAM range, vegetable crops at Gizaa would be water stressed and thus have to apply a greater force to suck moisture from the soil. Wysuere (2003) indicated that, the suction of soil moisture increases with decreasing water content or increasing empty pore space and this is evident in the results of the study due to the drought that was experienced.

The month of July recorded decreased pF values of 1.10 and 1.44 for the 15 cm and 35 cm depths respectively at the University Farm as compared to the pF values recorded earlier at the same site. Gung and Gizaa also recorded a decrease of pF value of 1.84 to 1.00 and 0.96 to 0.29 respectively in July 2007. Quite a high level of variation between tensiometer readings at the various depths was observed for the month of July as compared to the other months.

The months of August and September recorded low pF values in the range of 0.43 at Gizaa to 0.80 at 15 cm depth in the University Farm indicating the excess moisture condition in the soil. A saturated level of water in the soil may result in the inability of plants to absorb water and also limited exchange of gases necessary for plant growth. The excess of soil moisture in the soils under study also points to the fact that the year 2007 recorded a high level of rainfall which resulted in the flooding of some areas in northern Ghana. The Gizaa study site and its instruments got flooded in the month of September 2007 and so readings of instruments could not be undertaken. August and September recorded the lowest suction force or matric potential due to the high rainfall recorded in those months. The saturated moisture condition experienced is clearly shown in the low pF values recorded for the two months. It was evident during this period that there was excess water than the vegetable crops could absorb from the soil at the sites.

As the rains tailed off, the soil moisture tension increased in October 2007. Except for the 15 cm depth at the University Farm which recorded a pF value of 1.42, the 35 cm depth at the University Farm and the Gung area at the depth of 15 cm recorded 1.60 and 1.72 pF values respectively. The Gizaa area had no reading due to the flooding. Since there was reduced amount of rainfall in this month (October), the higher sand percentage within the 35 cm zone at the University Farm and the Gung site and the sandy loam type of soil could have facilitated the fast emptying of moisture from the soil pores in the absence of recharge from the rains. The transition from saturation to dryness generally entails a steep drop in hydraulic conductivity, which may decrease by several orders of magnitude as suction increases (Kumar and Purandara, 2003). An average monthly pF value at 15 cm was 1.25 and that of 35 cm depth was 1.32 at the University Farm whilst Gung at 15 cm depth recorded an average pF of 1.14 with Gizaa experiencing a pF of 0.56 at the 40 cm depth. This means that, shallow rooted crops within the 15 cm depth experienced excess moisture condition than deep rooted crops. The vegetables grown are mainly shallow rooted and include *Capsicum spp, Lycopersicon esculentum*, *Solanum melongena*, *Abelmoschus esculentus* and *Hibiscus cannabinus* and were therefore not greatly affected by these pF values.

Soil Moisture Content (SMC) – Rainfall Relationship

Rainfall as the main source of water for rainfed agriculture significantly plays a unique physiological role in the growth and development of vegetable crops. The established relationship between rainfall and the soil moisture content for the year 2007 is therefore important in this respect.

In the months of January to March, when there was virtually no rain, the volumetric moisture content for each study area experienced little variation. Gung recorded the highest soil moisture content as compared to the University Farm at the same depth whilst a wide variation was experienced between the University Farm at 35 cm depth and the Gizaa site at 40 cm depth. The water holding capacities of the various soils however could have contributed to these differences. A gradual increase in the soil moisture content was realised from the month of April through to September. Even though the rate of increase in the soil moisture was realised to be increasing gradually for the various study areas, Gizaa experienced sharp rise in soil moisture content from April to May. The top layers of the soil at 15 cm depth for the two sites (University Farm and Gung) also recorded relatively higher soil moisture content. The difference in moisture content across depth may be due to the horizon having a good water holding capacity to retain moisture.

June recorded a decrease in SMC as indicated by the two instruments at the University Farm with the

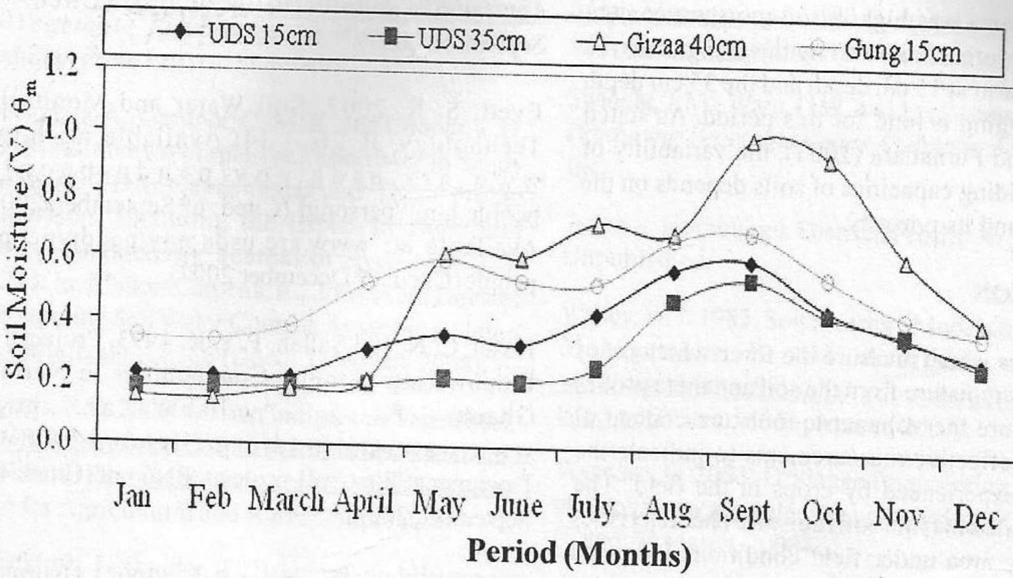

Figure 6: A Typical Annual Soil Moisture Content Variation of the Study Areas

35 cm depth moisture content of 0.21 lagging behind the 15 cm depth moisture content of 0.33. Gung recorded a decline in SMC to 0.53 whilst Gizaa also experienced a decrease of 0.61 SMC for the same month. This decrease was as a result of the two week drought condition experienced in that month. Moisture stress (Swinder *et al,* 1992) during flowering will cause blossoms to abort but result in high incidence of blossom-end rot during fruit development. This is common with pepper and garden egg which are widely cultivated in the study areas.

September experienced the highest amount of rainfall in the year resulting in high soil moisture contents at all the study sites. The vegetable crops grown are also sensitive to excess soil moisture conditions thus resulting in damping-off as a result of root stock rotting. Rice *et al* (1990) indicated however that *Abelmoschus esculentus* is tolerant to a wide variation in rainfall. Excessive moisture and water logging during periods of high rainfall and soil moisture content resulted in low vegetable fruit yield as a result of root stock rotting as well as plant lodging. Thin leaves as well as leaf rot become common in leafy vegetables.

A decline in the SMC as a result of receding rains in the year characterised the month of October. SMC of 0.45, 0.44 were experienced at the University Farm at the 15 cm and 35 cm depth respectively with Gung recording 0.56 and Gizaa 0.94. These relatively high values could be attributed to the saturated condition of the soils in the previous months and some few rainfall events in the month of October. November experienced no rain but with a higher amount of SMC than the months of January, February and March because of the residual moisture retained in the soil from the previous months. Surprisingly, this was the only month with the 35 cm SMC value at the University Farm being greater than the 15 cm depth SMC value. This could be attributed to deep percolation of moisture from the upper soil boundary to the lower depth coupled with the lower rate of soil moisture drift from these zones to the lower horizons. According to Walley (1983), if the rate of capillary rise falls below the potential evaporation rate the moisture content of the surface layer decreases.

December continued the decrease in the SMC in both depths due to the absence of rain coupled with high wind speeds and hot day time temperatures which cause loss of water through evapotranspiration. The

Gizaa study area was high in soil moisture content than the other areas followed by the Gung area, the University Farm at 15 cm depth and the 35 cm depth generally lagging behind for this period. As stated by Kumar and Purandara (2003), the variability of the water holding capacities of soils depends on the soil texture and its porosity.

CONCLUSION

Tensiometers which measure the force which crops exert to suck moisture from the soil and theta probes which measure the volumetric moisture content of the soil are effective measurements to indicate the conditions experienced by crops in the field. The results revealed that the soil moisture characteristics of the study area under field conditions indicated different curves at different depths resulting from differences in soil textural classes. The moisture characteristic curves showed inverse relationship between soil moisture tension and soil moisture content. This implied soil suction decreases as the moisture content increases.

Moisture stress and excessive moisture in the study areas resulted in low yields of crops as a result of root stock rotting, plant lodging and fruit rotting. Soil moisture content generally increased with increasing rainfall even though variations may result from differences in soil texture and consequently the water holding capacities of the soils. A general inverse relation was noted for the soil matric potential as it was realised that lower matric potentials were recorded for higher rainfall events during the period of study.

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