Journal of Soil Science and Environmental Management Vol. 2(12), pp. 411-421, 22 December, 2011
Available online at http://www.academicjournals.org/JSSEM
ISSN 2141-2391 ©2011 Academic Journals

Full Length Research Paper

Soil water content profiling using EnviroSMART^{TM} in Northern Ghana

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Accepted 14 November, 2011

Soil moisture is very important in crop cultivation. Farmers in Ghana usually cultivate crops by guessing the available moisture content of the soil by means of observation and feeling. Major drawbacks with these methods are that estimation is subjective and not exact. These methods normally lead to either soil water deficits or water logging on crop fields. The need for soil moisture profiling to understand the moisture levels at different depths of soil is therefore very important. The study assessed the moisture levels at different depths of the soil profile of the Cheshegu community in the Tolon-Kumbungu District of northern Ghana. Soils of the area are predominantly dystric planosols. EnviroSMART^{TM} recorded soil moisture at depths of 10, 20, 40, 60 and 80 cm whilst tipping bucket rain guage was used to record rainfall amounts. Results indicated an increase in clay and soil moisture content across the soil profile. The average soil moisture content was 21.22% with a standard deviation of 12.10 for 10 cm depth whilst at 20 cm depth 27.67% soil moisture with a standard deviation of 7.20 was recorded. Average volumetric moisture content at the 40 cm depth was 30.78% with a standard deviation of 5.31 whilst the 60 cm depth recorded 43.93% and a standard deviation of 2.62. The 80 cm depth of the soil profile had 49.37% as the average moisture content with a standard deviation of 1.97%. It was only for the 10 cm depth that there was no significant difference in soil moisture variation but the rest had significant difference ($p<0.001$) indicating much soil moisture during the months under study. Soil moisture conservation is therefore considered to be very important in the area.

Key words: Soil, water, volumetric, profile, moisture.

INTRODUCTION

Soil moisture as a basic requirement for plants has been defined as the amount of water in an unsaturated soil expressed as a volume of water per unit of porous media (Alemaw et al., 2006). Hanks (1992) defined soil moisture as a mass of water per oven dry mass of soil. In the soil below the water table, all the pores are generally filled with water and this region is the saturated zone. When the water table is lowered by drainage, in a waterlogged soil, the upper part of the soil becomes unsaturated, meaning that the pores contain both air and water. Water in the unsaturated zone generally originates from infiltrated precipitation and from capillary rise of groundwater (Kabat, 1992).

The process of water movement in the unsaturated part of the soil profile plays a central role in the study of irrigation, drainage, evaporation from the soil, water uptake by roots and the transport of salts and fertilizers. The unsaturated zone is of fundamental importance for plant growth. Soil-water conditions in the upper part of the soil profile have a distinct influence on accessibility and workability of fields. Physical and chemical properties of soil have been noted to vary with the moisture content (Kabat and Beekma, 1994).

According to Bouma (1992), the amount of water available for plants is the amount of water held by a soil between field capacity and wilting point. Below the wilting point, water is too strongly bound to the soil particles. Above the field capacity, water either drains from the soil without being intercepted by roots, or too wet conditions causing aeration problems in the root zone, which restricts water uptake. The ease of water extraction by roots is the same over the whole range of available

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water. Bouma (1992) also indicated that at increasing desiccation of the soil, the water uptake decreases progressively. For optimum plant production, it is better not to allow the soil to dry out to the wilting point.

In northern Ghana, rain fed farming under an erratic mono-modal rainfall pattern is the dominant practice. About 90% of the rainfall occurs between June and September and only within these humid months that soil moisture surplus occur. During the dry periods of October to May, potential evapotranspiration exceeds precipitation accompanied by mean day time temperature of 38°C. Both the onset and cessation of the rain are irregular, and the temporal and spatial variability in rainfall are well marked. Even within the humid months of June to September, 10 to 14 days of dry spells are common (Kasei and Sallah, 1993).Farmers in the Tolon-Kumbungu District cultivate various crops by guessing the available moisture content of the soil by means of observation and feeling methods. Moisture needs of a crop vary from one stage of growth to the other. The local farmers only use soil 'feel' and appearance for their moisture monitoring and measurement. One of the major drawbacks with this method is that the estimation of soil moisture is subjective and not exact (Schneekloth et al., 2007). This method leads either to soil water deficits or water logging. Water logging reduces aeration in the soil by decreasing the oxygen content, increasing the carbon dioxide level, and the accumulation of hydrogen sulphide, methane and hydrogen concentrations as by-products of anaerobic decomposition. These kill the roots and reduce crop yield (Russell, 2003).

The main objective of the study was to determine the soil water content across the soil profile in the Cheshegu community. The specific objectives were to assess the volumetric water content across the soil profile, monitor soil moisture level at different soil depths and assess the relationship between rainfall and soil moisture at different depths.

METHODOLOGY

Study area

The study was conducted in the Cheshegu community farmlands and located on latitude 09°28'18.6"N, longitude 01°03'29.5 W and at an altitude of 168 m in the Tolon-Kumbungu District of the Northern Region of Ghana. The area is 183 m above sea level (TKDA, 2006).

The area experiences one rainy season in a year, lasting from April to October with an annual mean of 1,000 mm and mean monthly temperature ranges between 17 and 40°C (TKDA, 2006). The EnviroSMART™ instrument was installed in the meteorological station at the southern part of the community (Figure 1).

Data collection

Materials

The field instruments used includes:

i. EnviroSMART™ (Figures 2 and 3)
ii. Tipping bucket rain gauge

Methods

This study used the indirect method to determine the soil moisture variation across the soil profile by means of the EnviroSMART™ instrument. This instrument provides soil water content profile and/or soil volumetric ion content (VIC) for irrigation and fertilization management operations. It operates with minimum soil disturbance and has been recommended for higher accuracy research measurements. The EnviroSMART™ is beneficial in the following ways; it has multiple sensors with flexible depth placement (10 cm increments), it can monitor from shallow depths (0 to 10 cm) to deep installations (up to 30 m), length of EnviroSMART™ probe can be customized to suit a wide range of applications up to 16 sensors per probe and, minimized soil and root disturbance.

The EnviroSMART™ instrument was buried at a depth of 80 cm and readings were taken at five minutes interval for a period of nine months. The readings were taken at the depths of 10, 20, 40, 60 and 80 cm. Data were collected from January to October, 2008 and analyzed by means of Genstat software. Each month was divided into three sections and treated as "treatments" and the nine months were treated as "replicates" and an ANOVA was run.

RESULTS AND DISCUSSION

Soil texture of different depths of the study area

The results of the soil particle size analysis of the samples taken from the experimental site, Cheshegu community, using the Bouyoucos or hydrometer method is summarized in Table 1. Also presented in Table 1 is the soil moisture content at the time of sampling. This information therefore is to indicate clearly the soil type and or particle size distribution across the depths.

The results obtained from the field analysis indicated an increase in the clay content across the soil profile while the quantity of sand decreased across depth. The clay content at the 20 cm depth was 10.00% and increased to 47.50% at the depth of 88 cm, but decreased to 27.50% at the 90 to 110 cm depth. The amount of sand at the 20 cm depth was 50.30% and decreased to 21.97 % at the depth of 88 cm but increased to 42.25% at the 90 to 110 cm depth. The first 88 cm of the soil profile can therefore be said to be in the zone of eluviation (Horizon A). This is the layer of fast weathering (organic or inorganic) accelerated by chemical and physical actions of abiotic and biotic life. Clay particles are produced in the largest quantity (Scott, 2000). This indicates that the 90 to 110 cm depth lies within the zone of illuviation (Horizon B). This layer is composed of particles that are mostly sand-sized (Scott, 2000).

The amount of the soil particles at their respective depths influences the water holding capacity of the soil. From Table 1, it can be seen that soil moisture generally increased with depth. The moisture content of the soil particle analysis increased from 2.20% at the 20 cm

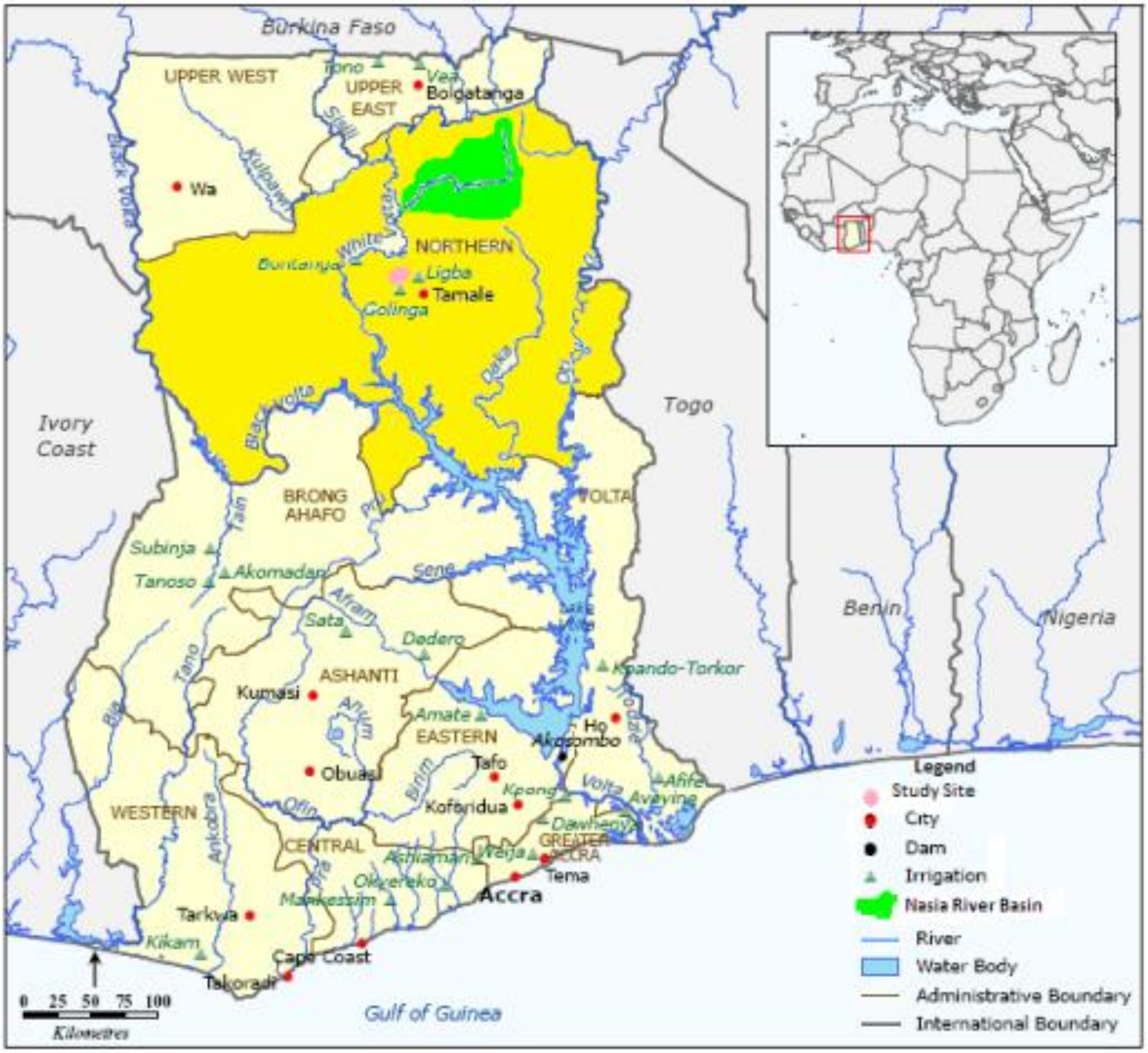

Figure 1. Map of Ghana showing the study site.

depth to 14.50% at the 63 to 83 cm depth. This could be ascribed to the increasing amount of clay content across the soil profile whilst the amount of sand decreases. Clay particles have smaller pore spaces and larger total porosity, and hence the property to store much water. Sand particles on the other hand have larger pores due to the large individual particle sizes (Ley et al., 1994).

The moisture content at an average depth of 78 cm decreased from 14.50% at the average depth of 73 cm to 11.90%. It increased to 14.50% at the average depth of 98 cm and decreased again to 12.40% at the average depth of 100 cm. This is attributable to the increase in soil moisture content as the average depth increases at a decreasing rate.

Relationship between rainfall and soil moisture content

The onset of rains had effect on the amount of moisture in the soil at the various layers across the soil profile. This caused moisture variations within the soil profile during the dry and wet periods of the year as shown in Figure 4.

In Figure 4, it can be noted that moisture variation across the soil profile increased at the onset of rain. The soil moisture across the soil profile before the start of the rains was low. This means that the presence or absence of rains drastically affects the volumetric moisture content at the various soil depths. This moisture variation across

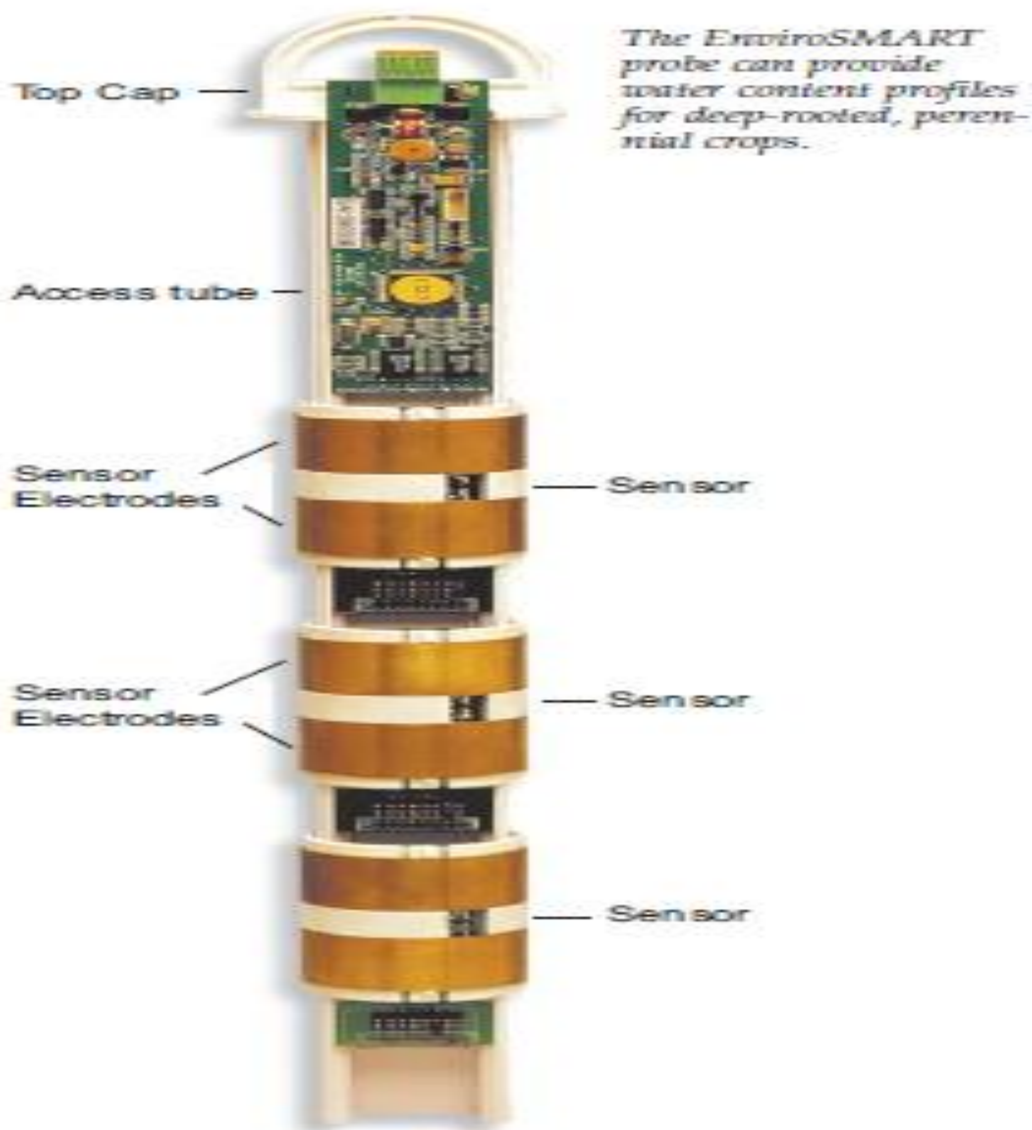

Figure 2. EnviroSMART^{TM} instrument (Courtesy: Campbell Scientific Inc, 2008).

the soil profile is confirmed by Kabat (1992) who indicated that water in the unsaturated zone generally originates from infiltrated precipitation.

In the month of January, there was little soil moisture variation across the profile due to the dry periods. The moisture contents at the depths of 40, 60 and 80 cm were relatively high even though there were no rains for January. This could credibly be attributed to the moisture retention capability of the high clay content at these depths according to Hendrickx et al. (1988).

The volumetric moisture content at the 10 cm depth drastically reduced from 18.7% in January to 2.4% in February. This is attributable to the rapid evaporation from the surface of the soil as well as percolation into the 20 cm layer of the soil. Also, despite the fact that there was a general decrease in moisture content at the various soil depths, a good amount of moisture was retained at the depths of 40, 60 and 80 cm. The influence of high clay content may therefore be affecting this phenomenon.

March experienced a total rainfall of 50.16 mm and had a significant moisture variation at the 10 cm depth (moisture content increased from 2.4% in February to 10.8% in March) as shown in Figure 4. At the 10 cm layer of the soil high moisture content of sand particles with larger pores as shown in Table 1 were realized.

The moisture content of the soil increased gradually across the soil profile from the month of April to the month of August. The moisture content at the 10 cm depth increased from 12.5% in the month of April to 35.8% in the month of August. It increased at the depth of 20 cm from 20.31% in April to 36.83% in August. The moisture content further increased at the 40 cm depth from 24.39% in April to 37.43% in August while soil

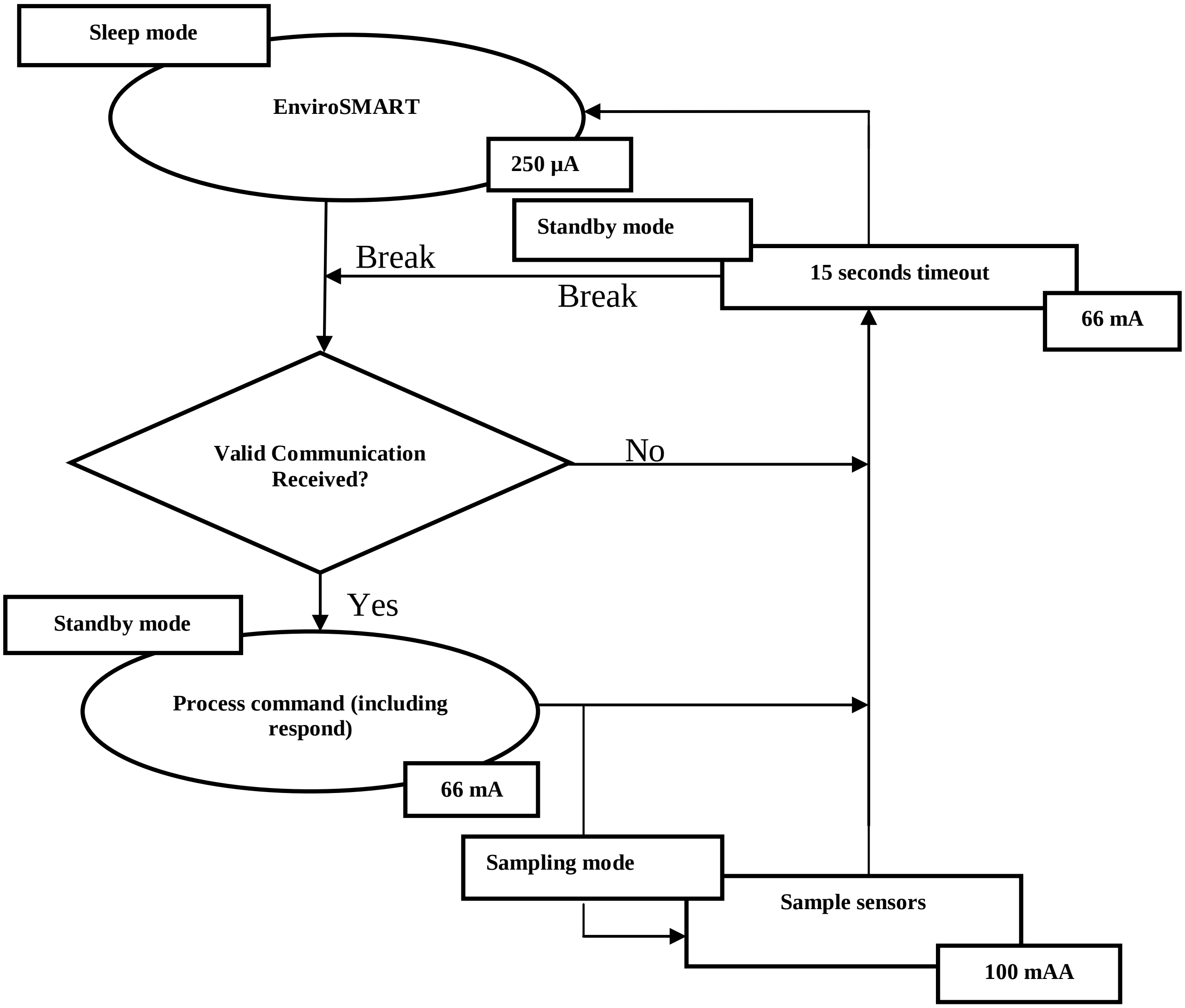

Figure 3. EnviroSMART[TM] probe interface (Courtesy: Campbell Scientific Inc, 2008).

moisture increased at the 60 cm depth from 39.94 to 46.46%. The 80 cm depth also recorded an increase in soil moisture content from 46.53% in the month of April to 51.48%. Infiltration and lateral inflow as the rainfall increased from 77.33 mm in April to 229.95 mm in August are factors that can cause this soil moisture increase. This variation across the soil profile is confirmed by Kabat (1992) who indicated that water in the unsaturated zone generally originates from infiltrated precipitation.

In the month of September, the amount of soil moisture content at the 10 cm depth exceeded the moisture contents at the depths of 20 and 40 cm while the moisture contents of the inner layers of the soil remained the same as compared to November. This may be due to increase surface run-off as the 10 cm depth becomes saturated.

Soil moisture variation at 10 cm depth of soil

Soil moisture at the topmost layer is very crucial for plant development especially at the initial stage of growth. Shallow rooted crops cannot develop well without the required moisture content at this depth. Figure 5 shows the soil moisture variation at the 10 cm depth of the soil profile.

There were no significant differences in the moisture content in the months of January, February, March, April, May and June. A significant difference ($p < 0.001$) in the moisture content in the months of July, August and September was observed suggesting that there was much moisture in the soil during these months. From Figure 5, a high variation in moisture content was recorded for January and this could be attributed to high

Table 1. Soil particle size across depths

Depth (cm)	Average depth (cm)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Moisture content (%)
0 – 20	10	10.00	39.70	50.30	0.00	2.20
20 – 40	30	22.50	37.38	40.12	0.00	7.10
30 – 50	40	30.00	25.80	44.20	0.00	8.40
40 – 60	50	40.00	23.25	36.75	0.00	10.70
48 – 68	58	45.00	24.98	30.02	0.00	11.70
63 – 83	73	47.50	28.00	24.50	0.00	14.50
68 – 88	78	47.50	30.53	21.97	0.00	11.90
88 – 108	98	45.00	33.93	21.07	0.00	14.50
90 – 110	100	27.50	30.25	42.25	0.00	12.40
Particle size (USDA)		< 0.002 mm	0.002 – 0.50 mm	0.05 – 2.0 mm	>2.0 mm	

(Dystric Planosols, sampled on 8th January, 2008)

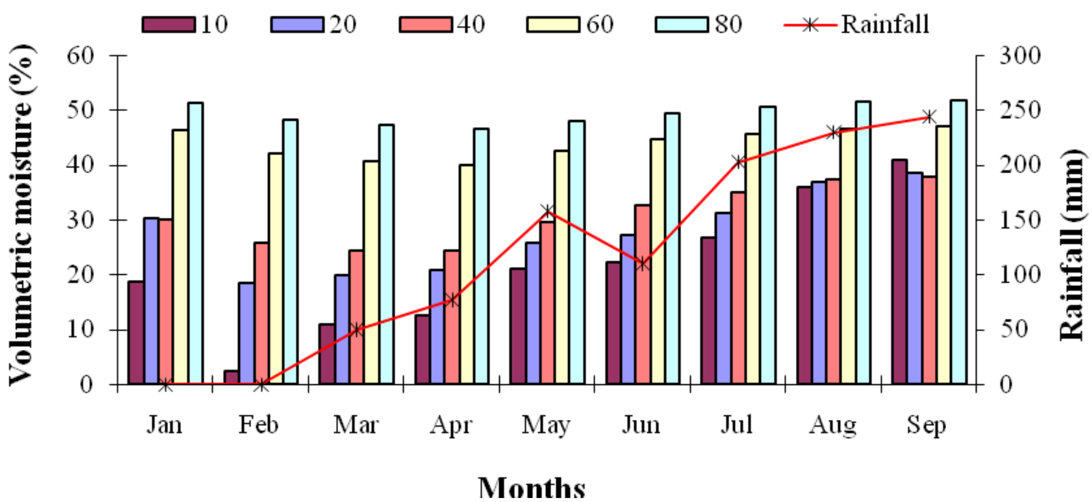

Figure 4. Rainfall pattern and moisture variations at different soil depths within months.

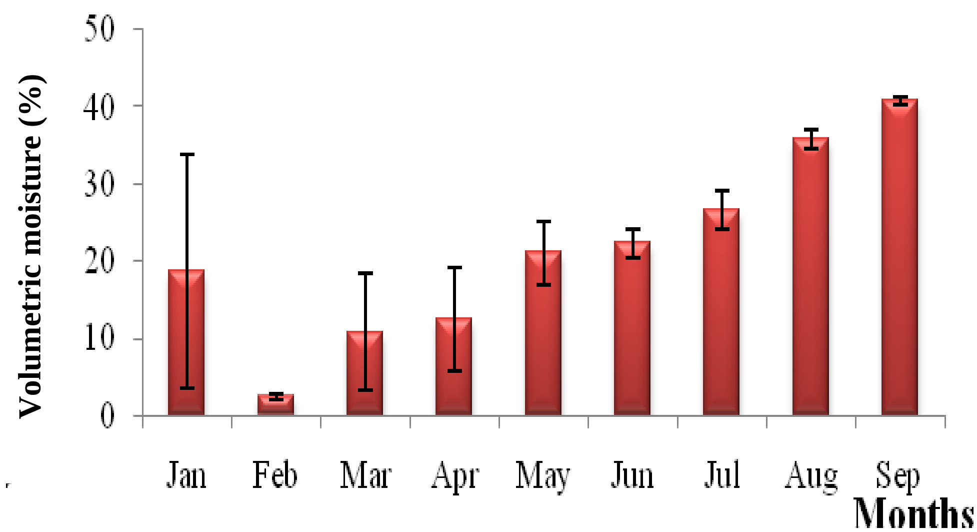

Figure 5. Soil moisture variation at 10 cm depth.

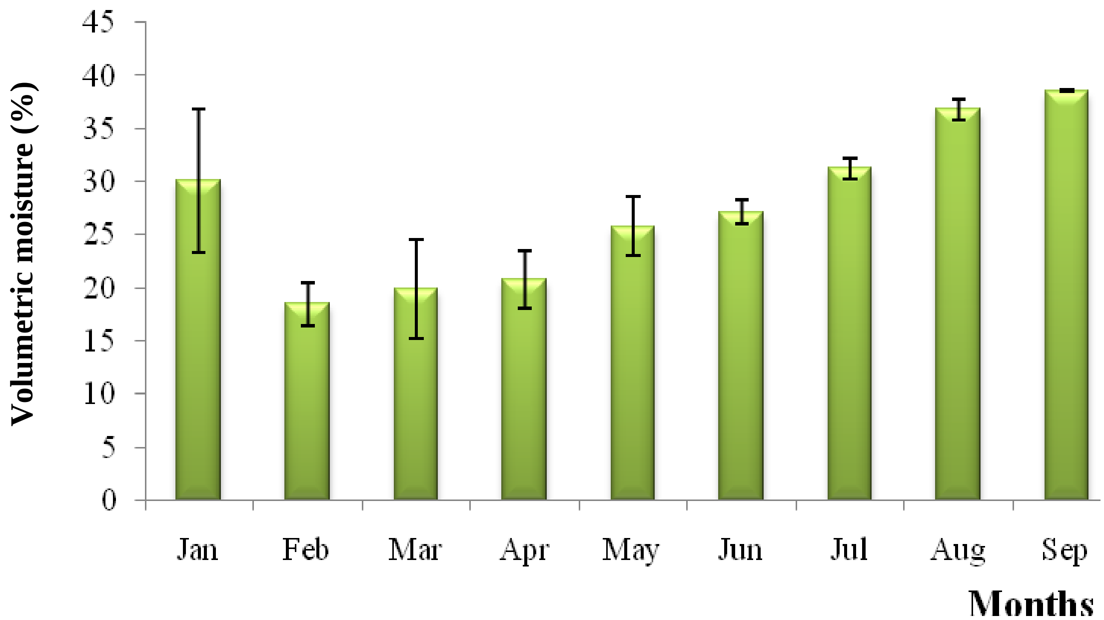

Figure 6. Soil moisture variation at 20 cm depth.

evaporation rate during the dry periods coupled with no rainfall for moisture replenishment. According to Walley (1983), if the rate of capillary rise falls below the potential evaporation rate the moisture content of the surface layers decreases.

There was very little variation in moisture content at the depth of 10 cm for the month of February. This could be attributed to high evaporation from the surface layers of the soil in the absence of rainfall.

The variations of the soil moisture content gradually reduced from the month of March to September which could be due to the onset of rainfall and reduction in evaporation. September recording the highest moisture content of 40.8% and rainfall amount of 243.93 mm with very little variation could suggest possible surface run-off of excess water.

Soil moisture variation at 20 cm depth of soil

Higher soil moisture content values were recorded at the 20 cm depth of the soil profile compared to those recorded for the 10 cm depth for the nine months. Infiltration at the 10 cm depth and reduced or no evaporation from the 20 cm depth resulted in this increase. Figure 6 shows the soil moisture variation at the 20 cm depth of the soil profile in the various months.

There was a significant difference ($p < 0.001$) in the moisture content in all the nine months. From Figure 6, high soil moisture variation was recorded in January and this is probably as a result of high evaporation during the dry periods and the absence of rains.

The month of March recorded a higher soil moisture variation compared to that of February. There was a gradual decline in the soil moisture variation from the month of March to September indicating increased moisture resulting from onset and intensification of rainfall. Also, the filling of the soil pore spaces by the water from the effective rainfall as well as minimum evaporation from the soil are contributory factors. September recorded the highest moisture content of 38.53% with rainfall amount of 243.93 mm with very little variation.

Soil moisture variation at 40 cm depth of soil

Figure 7 presents the soil moisture variations at the 40 cm depth of the soil profile of the various months. From Figure 7, higher soil moisture values were recorded at the 40 cm depth for all the nine months with little variations as compared to the moisture values at the 10 and 20 cm depths in their respective months. Low infiltration and high soil moisture retention will result due to the presence of high clay and silt contents (Table 1). According to Bilskie (2001), both soil structure and texture determine soil moisture characteristics. There was a significant difference ($p<0.001$) in the moisture content in all the nine months, that is, January to September, suggesting that there was much moisture in the soil during these months.

Figure 7 showed that the highest soil moisture variation was recorded in the month of May. The sudden increase in rainfall in late April and early May, and the sudden decline in rainfall mid of May maybe the cause of this wide variation. This moisture variation across the soil profile is confirmed by Kabat (1992) who indicated that water in the unsaturated zone generally originates from

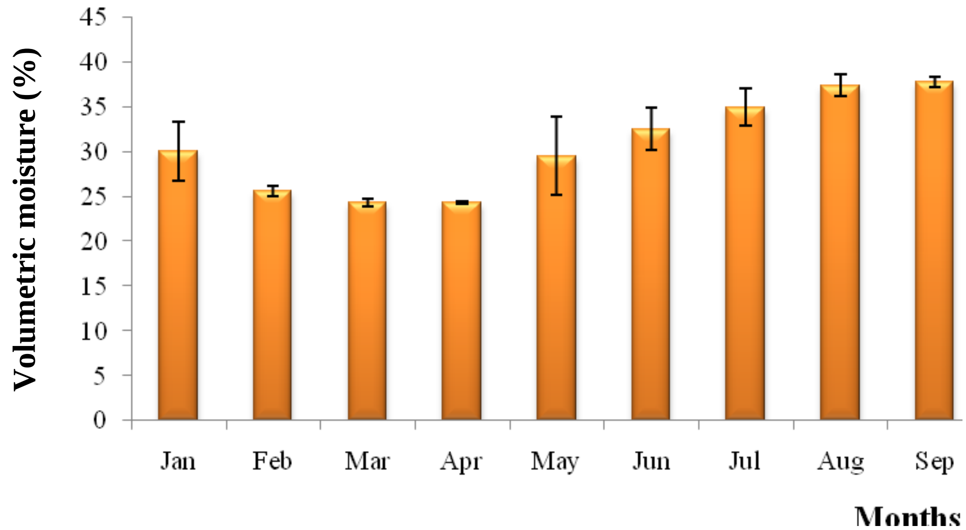

Figure 7. Soil moisture variation at 40 cm depth.

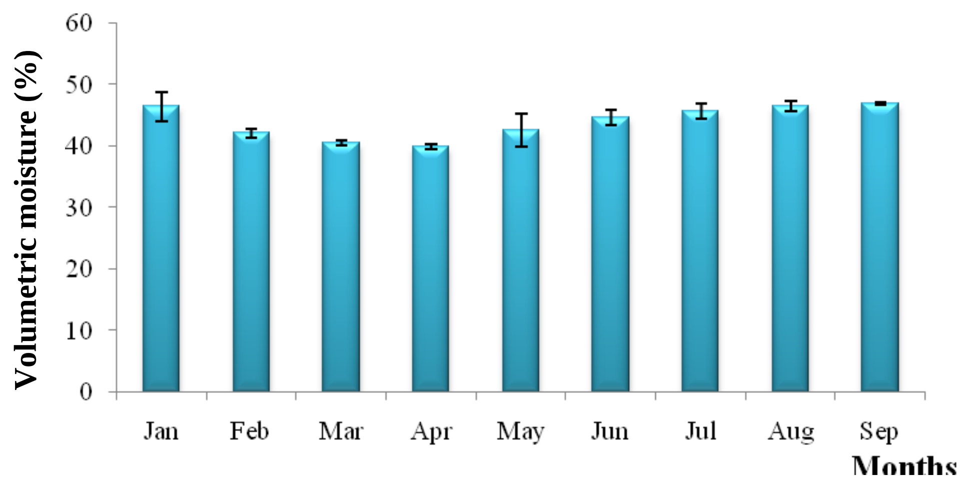

Figure 8. Soil moisture variation at 60 cm depth.

infiltrated precipitation.

Soil moisture variation at 60 cm depth of Soil

The soil moisture variations in the various months in the 60 cm depth are very minimal as shown in Figure 8 and this appeared uniform as compared to the 10, 20 and 40 cm depths. This variation is as a result of the high water retention capability of the clay particles at this depth, with their smaller pore spaces and larger total porosity. Figure 8 shows the soil moisture variation at the 60 cm depth of the soil profile in the various months.

Figure 8 indicates that the highest soil moisture values were recorded at the 60 cm depth of the soil profile compared to the other depths. Infiltration, lateral inflow and high soil moisture retention of the clay and silt particles in the soil profile will cause high water retention as noted in the results. There was a significant difference ($p<0.001$) in the moisture content in all the nine months, thus January to September, which suggest that there was much moisture in the soil during these months.

Soil moisture variation at 80 cm depth of soil

Figure 9 shows the soil moisture variations at the depth of 80 cm from the month of January to the month of September.

From Figure 9, it can be observed that relatively lower moisture content was recorded at the 80 cm depth as compared to the depths at 40 and 60 cm. This might

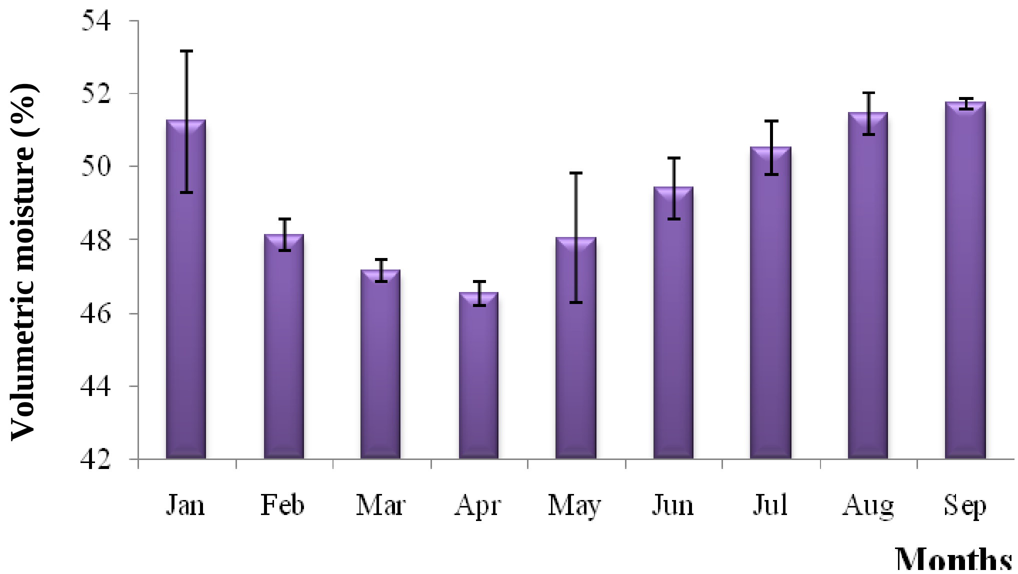

Figure 9. Soil moisture variation at 80 cm depth.

have resulted from the high clay content at the 40 and 60 cm depth of the soil profile forming an impervious layer thus retaining the moisture in those layers and limiting the rate of infiltration into the soil.

The amount of soil moisture drastically decreased from 51.25% in the month of January to 46.53% in the month of April, and these might have resulted from the dry spells experienced at the study site during the period under consideration. The moisture content gradually increased from 48.06% in the month of May to 51.74% in the month of September and this increase may be attributable to the intensification of rains as experienced in the month of May.

There was a significant difference ($p<0.001$) in the moisture content in all the nine months, thus January to September, implying that there was much moisture in the soil during these months.

Volumetric soil moisture variation across soil depths and time

The volumetric moisture contents of the soil at the different depths of the soil profile have been noted to generally increase with increase depth. The moisture content values recorded at the 60 and 80 cm depths were far higher than the values recorded at the upper layers of the soil profile as shown in Figure 10. This is attributable to the increase in clay and silt content as depth increases as presented in Table 1. According to Ley et al. (1994), clay and silt particles have the capability to store and retain much moisture due to their small pore spaces.

From Figure 10, the moisture variations of the various soil depths decreased as the depth increased. The increase in soil temperature affects evaporation of soil moisture especially for the upper most layers of the soil. Figure 10 shows the variation of volumetric soil moisture across the profile of the soil of the study area.

The volumetric moisture contents as shown in Figure 10 increased with time as from the dry spells to the wet months and this is attributable to the inception and intensification of the rainfall with time.

Figure 10 indicates that the volumetric moisture content at the 10 cm depth exceeded the volumetric moisture contents at the 20 and 40 cm depths of the soil profile in the month of September (243.93 mm). The increase in rainfall in late August and September as well as increase surface run-off due to saturation of the upper layers of the soil would cause this.

Relationship and variability of soil moisture content and soil depth

As presented in Figure 11, soil moisture content increases across the soil profile with little moisture variations. The average soil moisture content of the soil of the study site at the 10 cm depth was 21.22% with a standard deviation of 12.10. The average soil moisture content at the 20 cm depth was realized to be 27.67% with a standard deviation of 7.20 whilst average volumetric moisture content at the 40 cm depth was 30.78% with a standard deviation of 5.31. At the 60 cm depth the average soil moisture content of 43.93% had a standard deviation of 2.62 with the 80 cm depth of the soil profile being 49.37% with a standard deviation of 1.97. The variations in the soil moisture content are attributable to variation in rainfall, soil infiltration, evaporation and

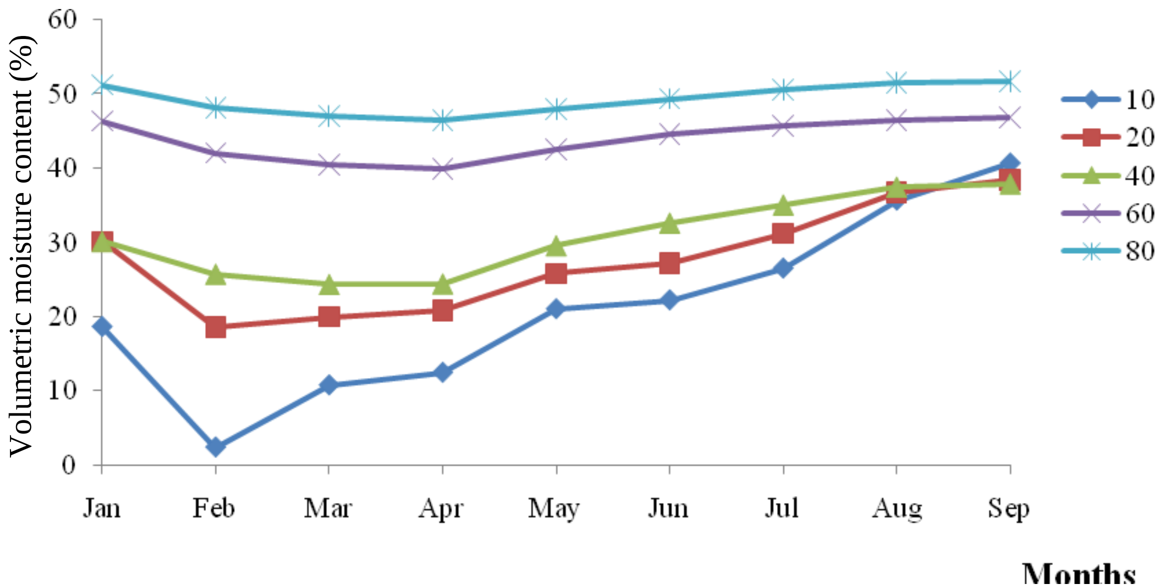

Figure 10. Volumetric soil moisture variation across soil depths.

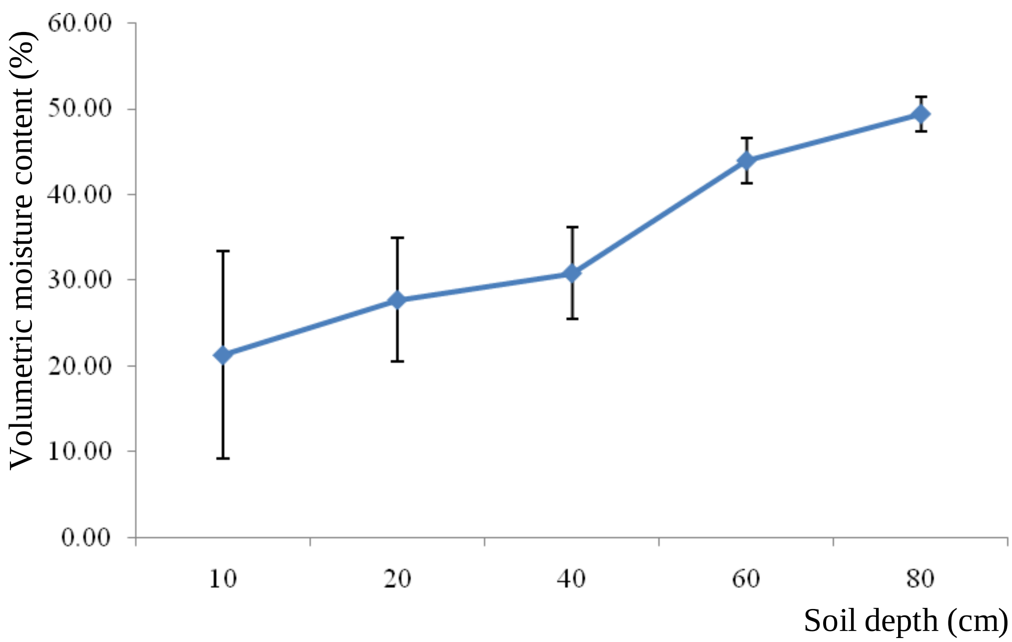

Figure 11. Relationship between volumetric moisture and soil depth.

difference in soil temperature at the various layers of the soil profile.

Conclusions

The study revealed that soil moisture generally increases with soil depth and also it is clear that the upper layers of the soil profile of the study area had higher percentages of sand with low moisture contents. The content of clay particles increased with respect to soil depth and thus resulted in high soil moisture retention.

The onset and increase in the amount of rains caused variations of the soil moisture across the soil profile. From the study, it was realized that much soil moisture was retained in the soil at the depths of 40 and 60 cm with minimum variations. The highest volumetric water content values were recorded at these depths.

The average soil moisture content of the study site at the 10 cm depth was 21.22% with a standard deviation of 12.10. The average soil moisture content at the 20 cm depth was 27.67% with a standard deviation of 7.20 whilst average volumetric moisture content at the 40 cm depth was 30.78% with a standard deviation of 5.31. At the 60 cm depth the average soil moisture content of 43.93% and a standard deviation of 2.62 with the 80 cm depth of the soil profile being 49.37% with a standard deviation of 1.97. The variations in the soil moisture content are attributable to variation in rainfall, soil infiltration, evaporation and difference in soil temperature at the various layers of the soil profile.

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