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Hydrological and Physical Changes of Soils Under Cocoa Plantations of Different Ages During the Dry Season in the Transition Zone of Ghana

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Abstract
The study was conducted at the University of Education, Winneba, Mampong Campus from October, 2007 to March, 2008 to assess the hydrological and physical changes that take place in soils under cocoa plantations of different ages as climate changed through the dry season. The treatments were T_1 (control, representing an adjoining grass fallow land), T_2 (5-year old cocoa plantation), T_3 (4-year old cocoa plantation) and T4 (3-year old cocoa plantation). The parameters measured were: Bulk density, Total porosity, organic matter, gravimetric moisture content, potential evaporation and Net Litter Accumulation (NLA) of the plants. From the results, T_2 recorded the highest gravimetric moisture content, porosity, litter fall, organic matter and lowest bulk density and potential evaporation. T_1 recorded the lowest and highest values for gravimetric moisture content (3.5%) and evaporation loss of water (249.0mm), respectively, at day 84. Correlation analysis revealed that soil moisture was highly influenced by bulk density, total porosity, potential evaporation and net leaf litter accumulation. Soil moisture storage negatively correlated with potential evaporation (r = -0.987) and bulk density (r = -0.985) but positively correlated with Total porosity (r =0.984) and net litter accumulation (r = 0.941). The proper manipulation of these parameters would ensure good soil moisture retention and better adaptations of cocoa to unfavourable conditions driven by climate change in the Transition Zone of Ghana.
Keywords: Gravimetric moisture, potential evaporation, porosity, leaf litter, correlation

1. Introduction

Cocoa is ranked the most important commercial crop in Ghana. It contributes about 33% of the Country's foreign exchange earnings and about 12% of the Gross Domestic Product (GDP). (http://storea.mnesty.ie/home/cocoa.letion). The crop provides more than 40% of the total Government revenue and employs about 17% of the country's labour force. (Manu and Tetteh, 1987). Are and Gwynne-Jone (1973) observed that, cocoa has become a major foreign exchange earner for the West African countries. Akinsammi (1988) reported that, cocoa oil, cocoa butter, cocoa powder, chocolate; wine and shoe polish can be produced from cocoa. The by-products, according to Wood and Lass (1985), are made into cocoa jelly and soft drinks. The development of the crop is therefore jealously being guarded.

Cocoa is a plant of tropical lowland rainforest. It grows well in a wide range of rainfall, between 1000-3000mm per annum. In Ghana, cocoa is mostly grown in the forest areas of Ashanti, Brong Ahafo, Eastern, Western and Volta Regions, where rainfall is between 1010mm and 1500mm per annum (Addo-Quaye *et al.*, 1993).

Soil moisture influences most soil processes and plant growth. Fluctuating continually in response to changing climatic forces. Soil moisture availability is one of the most changeable soil properties that influence cocoa production in Ghana. Most areas in the Transition Zone of Ghana, including Asante Mampong, are marginal for cocoa production in terms of rainfall, compelling most of the crops, especially the younger ones to die out during the peak of the dry season. The solution lies in the identification, and adoption of relevant soil water conservation measures.

The main objective of this study was to determine how various soil parameters, driven by climate change, could affect soil moisture storage under cocoa plantations of different ages in the dry season in Mampong Ashanti. This study would let us know the stage of growth of young cocoa trees at which soil water management is critical.

2. 2. Materials and Methods

2.1 The Study Area

The experiment was carried out at the cocoa plantation of the University of Education, Winneba, Mampong Campus from the start of the dry season (October, 2007) to the beginning of the raining season (March, 2008). Mampong Ashanti is located between latitude 7^o and 8^{o}N of the equator and longitude 01^{o}24'W of Greenwich and on an elevation of 457.5m above sea level (see Figure 1 for location).

Mampong is found within the Transitional Zone between the Guinea Savanna belt in the north and the

Deciduous Rainforest belt of the middle portion of Ghana. The site falls within an area with a bimodal rainfall with about seven months of rainfall and five months of dry season each year. The major rainy season begins from March and ends in July, with a short dry spell in August. The minor season begins in September and ends in mid-November. The mean monthly rainfall of the area is about 91.2mm with a mean temperature of about 25-30°C (Meteorological Service Department, Mampong Ashanti, 2004). The soil of Mampong is locally classified as the Bediesi series which is well drained, friable, and permeable with moderate organic matter and good water holding capacity. The soil is classified by the FAO/UNESCO legend as Chromic Luvisol and derived from Voltaian sandstone of the Afram Plains (Asiamah, 1998).

Cocoa plantations at various ages of growth at the Demonstration Farm of the University of Education, Mampong Campus, which comprised five-year old, four-year old, three-year old plantations with the adjoining grass fallow land as the control, were selected as treatments for the experiment.

The Completely Randomized Design (CRD) was used. Quadrants of 3m x 2m were randomly made under each treatment for data collection.

2.2 Data Collection

The following parameters were measured in the experimental plots: Bulk density, total Porosity, organic matter content of the soil, gravimetric soil moisture content, Potential evaporation and Net litter accumulation. The core sampler method was used for bulk density (Blake, 1965). Determination of soil organic matter was done using the Walkley–Black method while the gravimetric soil moisture content was determined by the destructive sampling method (Gardner, 1965). Total Porosity was calculated using the relationship:

$$f = (1 - BD/PD) \times 100 \qquad \text{(Hillel, 1980)}$$

Where f = Total Porosity
BD = Bulk Density.
PD = Particle Density .

An assumed value of 2.65g/cm^3 was used for the particle density (Hillel, 1980). Improvised Evaporators were used to estimate potential evaporation of water on the various treatments. Empty cylindrical containers of 10 litre capacity were graduated and placed in the soil at ground level. They were filled with water to the mark and covered with a wire mesh to prevent animals from drinking it. The change in depth of water level was recorded for each treatment from the graduated scale at two weekly intervals. This represented the potential evaporation of water and was expressed in centimetres of water.

Measurement of Net accumulation of leaf litter was done at the end of the experiment. Wooden quadrant measuring 1m x 1m, which were open at both ends were constructed. The quadrants were each placed within the area demarcated for data collection for all treatments and replications, respectively and the litter within each quadrant was collected in sampling bags and weighed to obtain the net litter accumulation per unit area.

Analysis of variance (ANOVA) method was used to statically analyze all the data taken and the significant differences between the means were determined by the Dancan's Multiple Range Test.

3. Results and Discussion

3.1 Bulk Density

Soil bulk density values for the various treatments are presented in Table 1. The control field recorded the highest bulk density of 1.62 g/cm^3 while the other treatments showed a steady reduction in bulk density as age of cocoa plantation increased. For mineral soils, lower bulk density is an important productivity index as it enhances water infiltration and root penetrability among other soil properties (Asiedu et al., 1997). This is in line with Devis and Freitas (1970) who observed that the lower the bulk density, the more productive the soil is, as it allows for easy root penetration. Wild (1995) reported that bulk density below 1.60g/cm has those features that allow root penetration as well as support of good growth of plants. In soils with higher bulk density, plant root growth is restricted because such soils serve as mechanical resistance to root penetration and limit the amount of air and water. In such soils, roots must exert greater force to penetrate, thereby lowering root length (UMES, 2001).

3.2 Total Porosity

Data from the experiment showed an increase in total porosity with age of plantation. Total porosity values recorded were 49, 45 42 and 39% for the 5-year, 4-year, 3-year old plantations and the control, respectively. Differences between the porosity values were significant ($p = 0.05$).

Porosity and pore size distribution, as observed by Thien and Graveel (2003), influence many important processes that impact on plant growth and quality of root environment such as: aeration, drainage, infiltration, root distribution, water storage and nutrient availability. If total porosity is high, infiltration could also be high. In effect, higher porosity implies lower bulk density, which promotes microbial activities in the soil for proper plant growth. In general, the proper growth of roots, leaves, stems and even yield of crops are good indicators of adequate porosity.

3.3 Net Leaf Litter Accumulation

Table 1 shows the mean net leaf litter accumulation values for all the treatments. The 5-year old plantation recorded the highest mean litter accumulation value of 12,744.30kg/ha. This was significantly higher than mean values of the other treatments (p = 0.05). It was followed by the 4-year old and the 3-year old plantations and the control with values of 3,967.30, 1,901.00 and 1,052.70kg/ha, respectively. This could probably be attributed to the fact that the 5-year old plantation, being the oldest plantation, possessed a lot of biomass, with many branches and leaves forming thicker canopy and consequently resulting in higher litter fall. The lower value of net litter accumulation for the 3-year old plantation suggests that the canopy was not well established, leading to low biomass and potential physiological activities. The younger plantations had many shade trees. This is in agreement with an observation by Wood and Lass (1985) that shade is not only needed to reduce light intensity but also to buffer the micro-environment so that excessive moisture stress in the young plant is avoided.

3.4 Organic matter Content

Figure 2 shows that the 5-year old plantation recorded the highest percentage organic matter with a value of 3.2%. This could be attributed to the fact that the highest leaf litter drop (Table 1) had decomposed over the years to increase the soil organic matter content. This was followed by the 4-year old plantation and the control in a decreasing order with the 3-year old plantation recording the least value of 2.54%. The high organic matter content recorded by the 5-year old plantation could also be attributed to the creation of suitable micro-climate which mitigated the adverse climatic effects of the dry season. This could have been achieved through canopy development, soil moisture retention by leaf litter which acted as mulch, improved biological activity and reduced evaporation. The work of Thien and Graveel (1997) confirmed that the origin of organic matter in soil is plant residue. Soil organic matter is known to play a very important role in soil moisture storage and retention. Humus as identified by Thien and Graveel (2003) is the active component of soil organic matter which enhances water retention, nutrient adsorption, aggregate stability and pesticide adsorption.

3.5 Soil Moisture Storage

Changes in gravimetric soil moisture content at 14-day interval over a period of 126 days in the dry season between November, 2007 and February, 2008 is presented in Fig. 3. The 5-year old plantation recorded the highest gravimetric soil moisture storage throughout the dry season (84 days). This was followed by the 4-year old plantation, the control and the 3-year old plantation in that decreasing order. The high gravimetric soil moisture storage in the 5-year old plantation throughout the dry season could be attributed to the heavy leaf litter accumulation (Table 1) which served as mulch, thicker canopy cover which prevented the direct heating effect of the sun, high organic matter content (Fig. 2) and low potential evaporation (Fig. 4). According to Wood and Lass (1985) shade is not only needed to reduce light intensity, but also to buffer the micro-environment so that excessive moisture stress in young plants is avoided. According to Brady (1969) mulches are highly effective in checking evaporation and are most practical for home garden use and for high-valued crops. This is confirmed by Thien and Graveel (2003) who explained that weather, soil use, management activities, plant growth and landscape features all influence water balance in soil. It was, however, observed when it rained after 84 days of soil moisture data collection, gravimetric moisture of the 4-year old plantation became higher than that of the 5-year old plantation. This could be explained by the fact that the thick ground leaf litter cover of the 5-year old plantation might have impeded water entry into the soil.

3.6 Potential Evaporation

Figure 4 represents the data on Potential Evaporation of water taken at a two (2) weekly intervals**.** From Fig. 4, the Control field recorded the highest loss of water (249.5mm), followed by 3-year, 4-year and 5-year old plantations which recorded potential evaporation values of 245, 180 and 130mm of water respectively. The results suggest that, because of the heavy canopy on the 5-year old plantation, direct heat of the sun onto the soil was reduced, thereby reducing the rate of water loss. The heavy canopy of the 5-year old plantation also helped to increase relative humidity which slowed down evaporation.

3.7 Correlation Analysis

Table 2 shows the relationship between soil gravimetric moisture content and bulk density, porosity, potential evaporation and net litter accumulation. Table 2 indicates that gravimetric soil moisture showed negative correlation with bulk density (r = - 0.985) and potential evaporation (r = - 0.987). A positive correlation existed between gravimetric soil moisture and Total porosity (r = 0.984) and gravimetric soil moisture and net litter accumulation (r = 0.941). This could be explained by the fact that increasing porosity improved water intake capacity of the soil. The litter also acted as mulch to reduce evaporation loss of water thereby enhancing moisture storage in the soil. As the thickness of canopy increased, more moisture is retained in the soil and less water is likely to be lost as potential evaporation. Also, as the bulk density is increased, the tendency is for less moisture to enter the soil.

4. Conclusion

The study shows that the older the plantation, the higher the soil moisture storage, organic matter content, total porosity and net leaf litter accumulation. These parameters are expected to reduce with reducing age of the cocoa plantation. Conversely, bulk density and potential evaporation are lowest in the older cocoa plantations and increase with reducing age of the plantations. Values recorded from the control field confirmed that the changes in the physical and hydrological properties were due to biological and micro-climatic changes induced by the cocoa plantations which increased with age of the cocoa trees. High and significant correlations existed between soil moisture and bulk density, potential evaporation, total porosity and net leaf litter accumulation, respectively. This suggests that the proper manipulation of these parameters would ensure good soil moisture retention and better adaptations of cocoa to unfavourable conditions driven by climate change in the Transition Zone of Ghana and also soil moisture storage is critical for the growth of young plantation in the fringes of the Transition Zone of Ghana.

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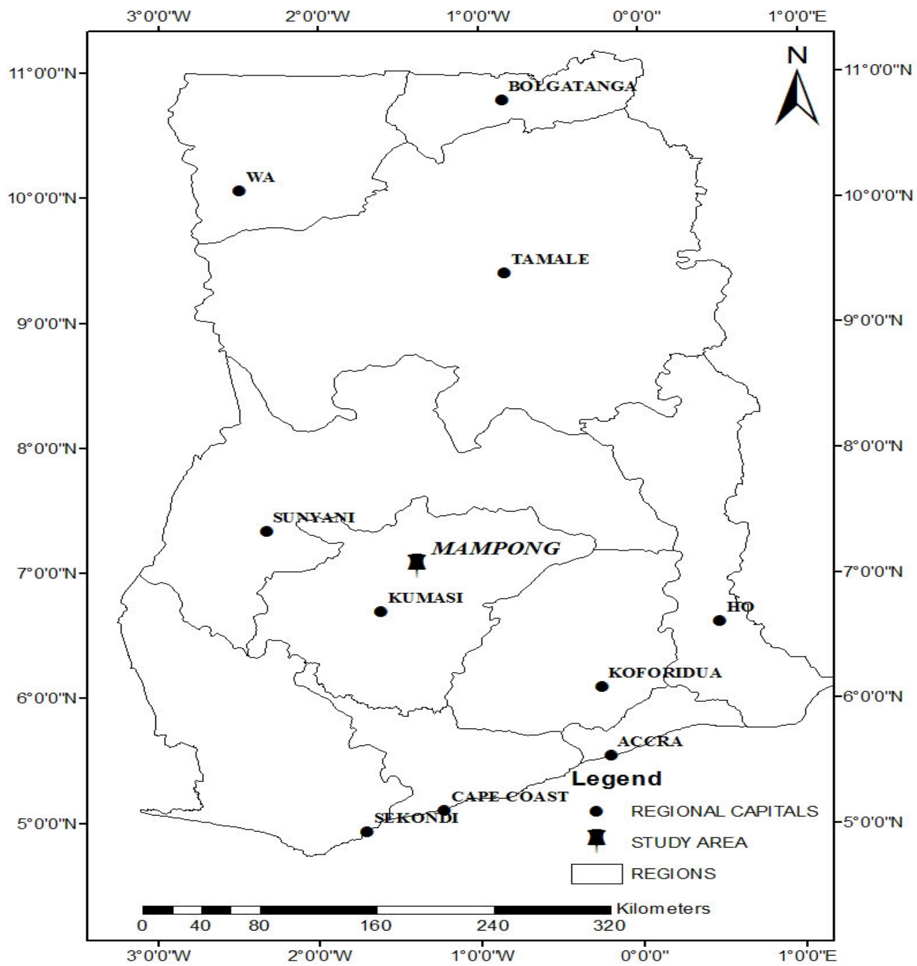

Figure 1. Map of Ghana showing the location of the study area.

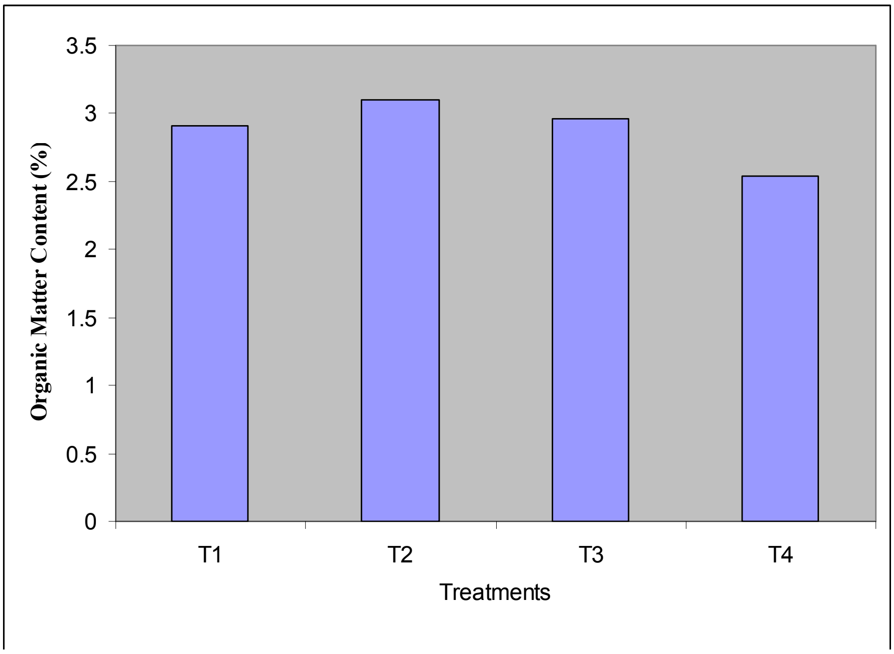

Figure 2. Organic matter content of soils under cocoa plantations of different ages

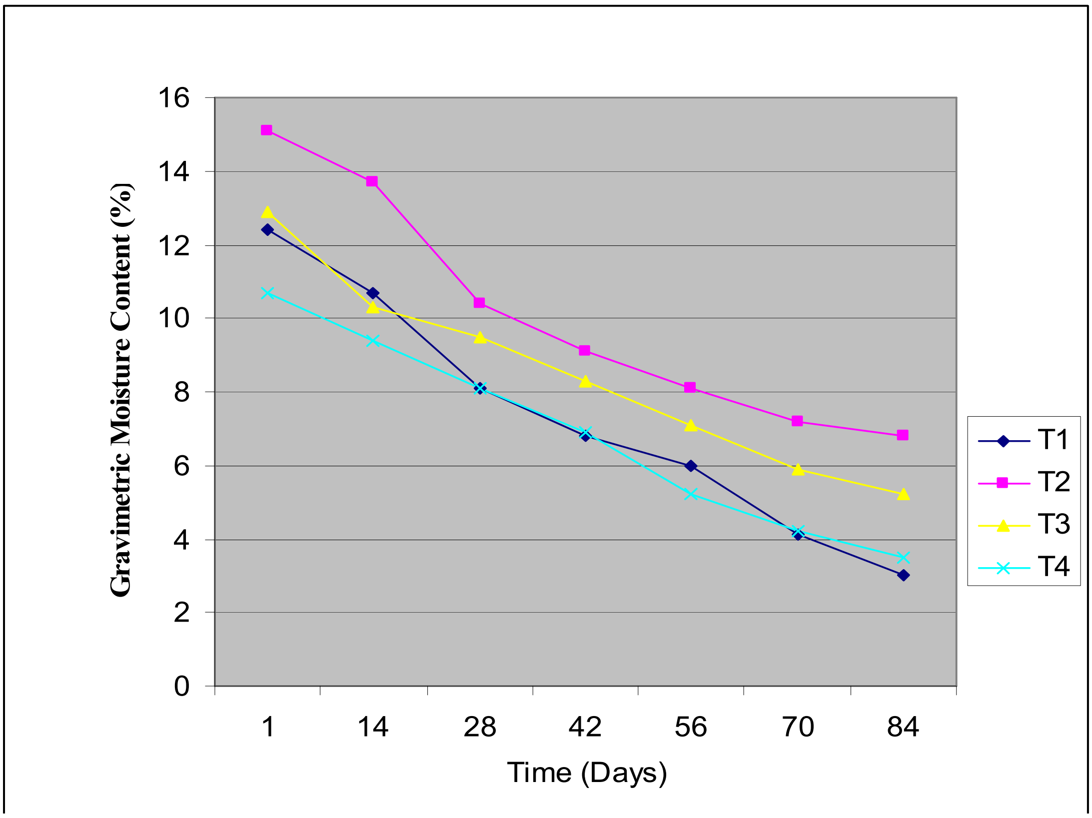

Figure 3. Seasonal Changes in Soil Gravimetric Moisture Content

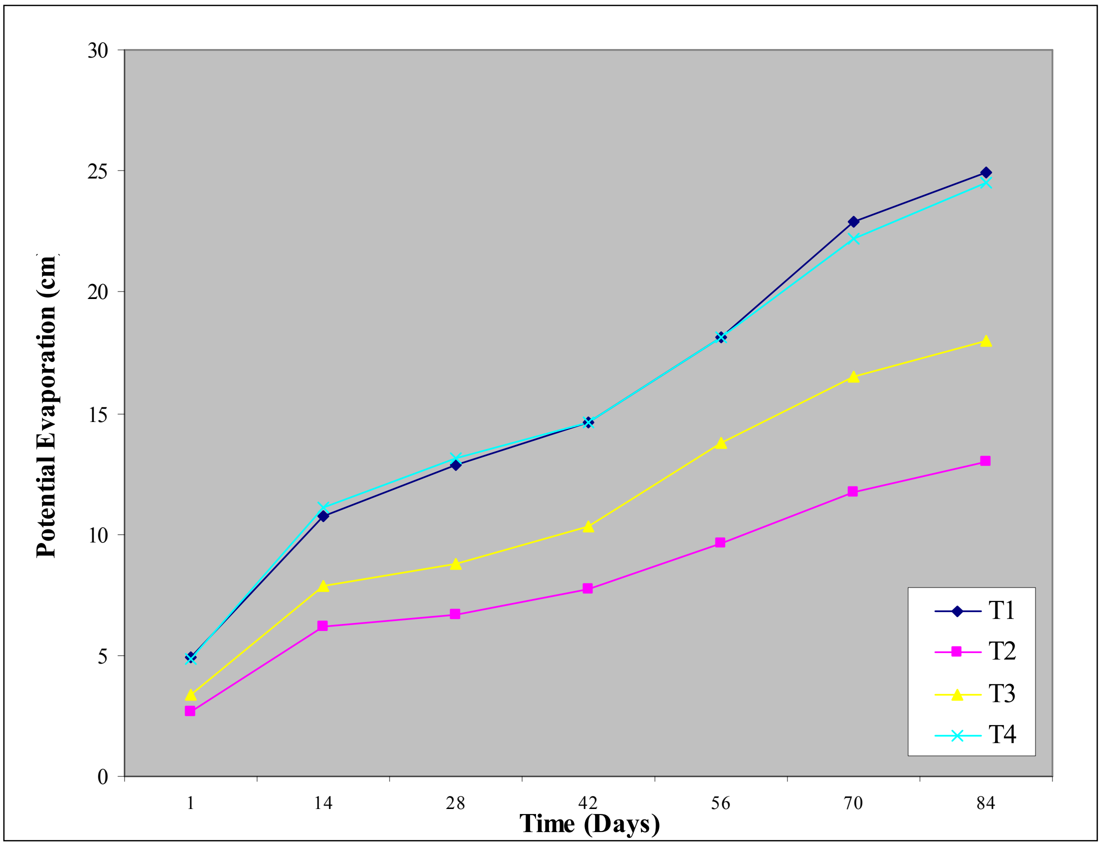

Figure 4. Potential Evaporation behaviour of the Treatments

Table 1. Bulk Density, Total Porosity and Net Litter Accumulation on soils under Cocoa Plantations of different ages

Treatments	Bulk Density (g/cm^3)	Total Porosity (%)	Net Leaf Litter Accumulation (Kg/ha)
T1 (Control)	1.62	39.0	1,052.7
T2(5-year plantation)	1.35	49.0	12,744.3
T3 (4-year plantation)	1.46	45.0	3,967.3
T4 (3-year plantation)	1.54	42.0	1,901.0
CV	2.49%	3.31%	55.44%
LSD (0.05)	0.063	2.883	5,446

Table 2. Correlation Analysis of some Parameters

Correlation	Correlation Coefficient (r)
Gravimetric Moisture versus Bulk Density	-0.985 **
Gravimetric Moisture versus Porosity	0.984 **
Gravimetric Moisture versus Net litter accumulation	0.941 *
Gravimetric Moisture versus Potential Evaporation	- 0.987 *

* Significant ($P \leq 0.05$)
** Highly Significant ($P \leq 0.01$)