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Effect of Phyisco-chemical Parameters on the Thermal Diffusivity and Soil Heat Flux over Ayadi, Ondo State, Nigeria

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Abstract: This study assesses the effect of some soil physical properties on the thermal diffusivity and soil heat flux over Ayadi in Ondo State, Nigeria. Physical properties of the soil at different depths were determined using laboratory techniques. In-situ measurement of air temperature and surface soil temperature were carried out. The phase lag method was used to determine the thermal diffusivity of the soil, while the subsoil heat flux was determined from values obtained for the thermal diffusivity. The result showed that the subsoil heat flux values during the dry season ranged between 0.58 and 52.84 W/m^2, while that of the wet season ranged between -0.77 and 98.50 W/m^2. The average thermal diffusivity values at the different depths had values between 0.74 × 10^{-7} and 238.7 × 10^{-7} m^2/s for the dry season, while the wet season had a range of 1.97 × 10^{-7} to 238.7 × 10^{-7} m^2/s.

Keywords: soil moisture content, air temperature, soil temperature, soil heat flux, thermal diffusivity.

1. INTRODUCTION

The exchange of heat in the soil is very essential for the redistribution of moisture and nutrients in the soil. This exchange originates from the net solar radiation received at the earth surface which is absorbed in the ground in the form of soil heat flux. Soil heat flux is the energy received by the soil to heat it per unit of surface and time. Soil heat flux, together with sensible heat flux and latent heat flux are important in atmospheric physics because they are principally responsible for the re-allocation of energy across the earth surface [1]. The significance of surface energy balance extends towards various fields of application and it has been explored by several researchers [2 – 6]. The effects of soil heat flux on chemical and biological processes are conspicuous. Soil heat flux affects process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants [7].

Thermal properties of soils are a component of soil physics that has found important uses in climatology, engineering and agriculture. Soil temperature is an important factor for plant growth like air, water and nutrients. The temperature of the soil can affect plant growths directly or indirectly by influencing moisture, aeration, structure, microbial and enzyme activities, organic matter decomposition, nutrient availability and other soil chemical reactions. Different crops adapt to specific temperatures. The movement of heat in the soil can be defined in terms of the thermal conductivity and diffusivity. Thermal diffusivity measures the rate at which heat is transferred from the hot to the cold side. It is defined as thermal conductivity divided by density and specific heat capacity [8].

Several factors can influence the thermal diffusivity and soil heat flux, among which are soil moisture content, soil temperature, vegetation cover, air temperature, soil texture and porosity. This study aims at assessing the impact of all these factors on the thermal diffusivity and soil heat flux over Ayadi, an agrarian community in Irele Local Government Area of Ondo State, Nigeria. Ayadi community falls between the bitumen sand belt of Nigeria. The geological formation of the area is the Precambrian basement complex rocks overlaid by the Eastern Dahomey basin. The area is located within the tropical rain forest and woodland belt of Nigeria thus, having a humid climate [9]. Crops commonly cultivated in the region include yam, okro, cassava, etc.

2. MATERIALS AND METHODS

A Davis Vantage Pro Weather Station equipped with data logger and tiny sensors from the Federal University of Technology Akure, installed at the experiment sites were used to acquire daily soil temperature data at depths 30, 40 and 50 cm. The device consists of a solar panel, alternative battery source, and the wireless console which serve as the receiver from the integrated sensor suite (ISS). The ISS houses the temperature, pressure, relative humidity, and radiation shield sensors. The sensor interface module (SIM) transmits the measured values of the atmospheric parameters to the data logger. In-situ measurements of air temperature for 1 m above the soil surface were taken during the dry and rainy months. The choice of soil depths was due to the fact that most cereal crops cultivated at these locations have roots densities at these depths at their reproductive stage.

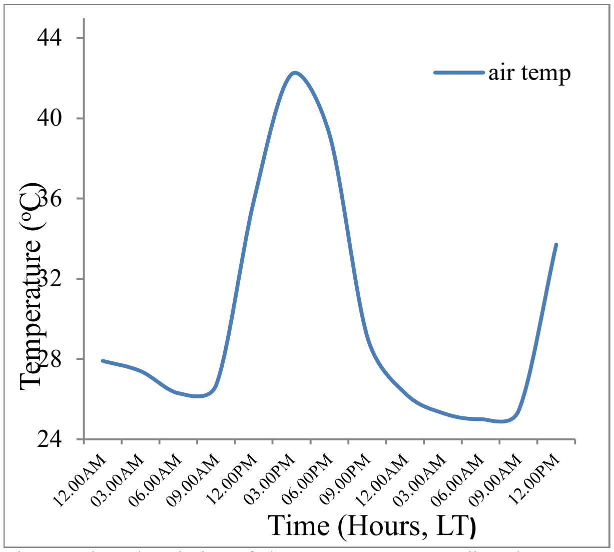

Fig. 1. Diurnal variation of air temperature at Ayadi, Irele L.G.A. during the dry season.

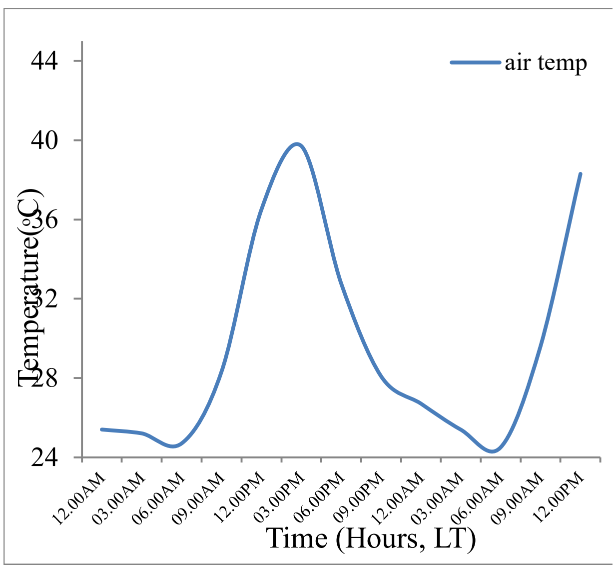

Fig. 2. Diurnal variation of air temperature at Ayadi, Irele L.G.A. during the wet season.

The measuring assembly is composed of different sensors that measure moisture content and temperature of the soil as well as the air temperature. The sensors were placed at 30, 40 and 50 cm depths in the soil. The air temperature and soil temperature at the sites were measured at 3-hour intervals. Other physico-chemical parameters of the soil such as bulk density, specific heat capacity, porosity and moisture content were determined using laboratory methods. The calorimetric method was used to determine the specific heat capacity of the soil. The experimental research was carried during March to April, 2012 for the dry season, and at mid June, 2012 for the wet season.

Thermal Diffusivity of the Soil

The thermal diffusivity of the soil was determined using the phase lag method. The phase lag between the thermal waves at two depths was used. The thermal diffusivity, D, of the soil was determined using the equation [10]

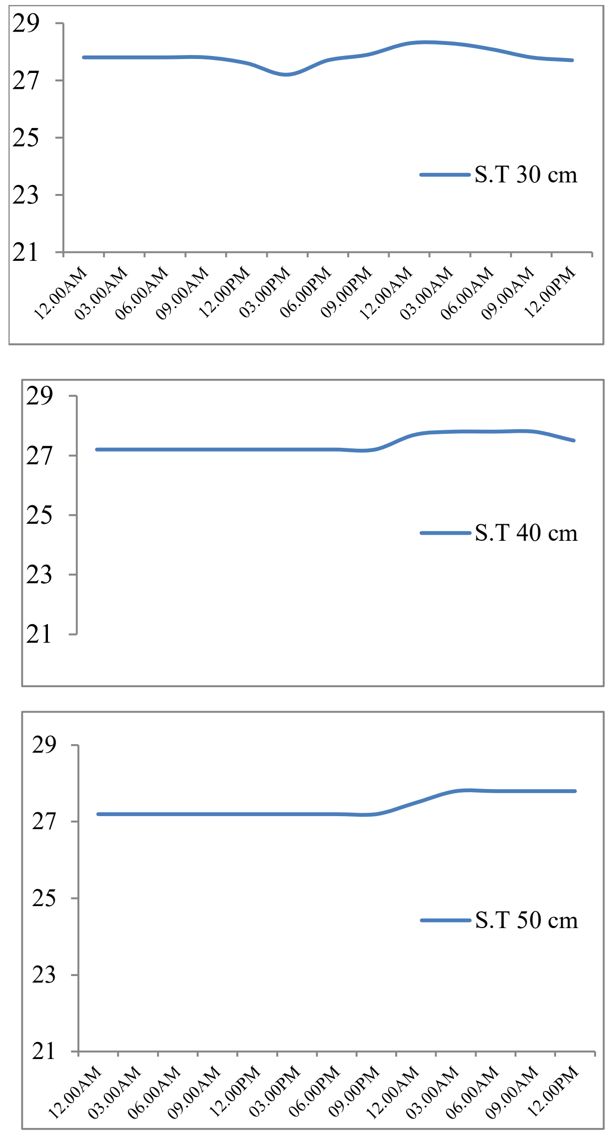

Fig. 3. Diurnal variation of soil temperature at Ayadi, Irele L. G. A. during the dry season.

$$D = \frac{\tau}{4\pi}\left[\frac{Z_2 - Z_1}{t_2 - t_1}\right] \quad (1)$$

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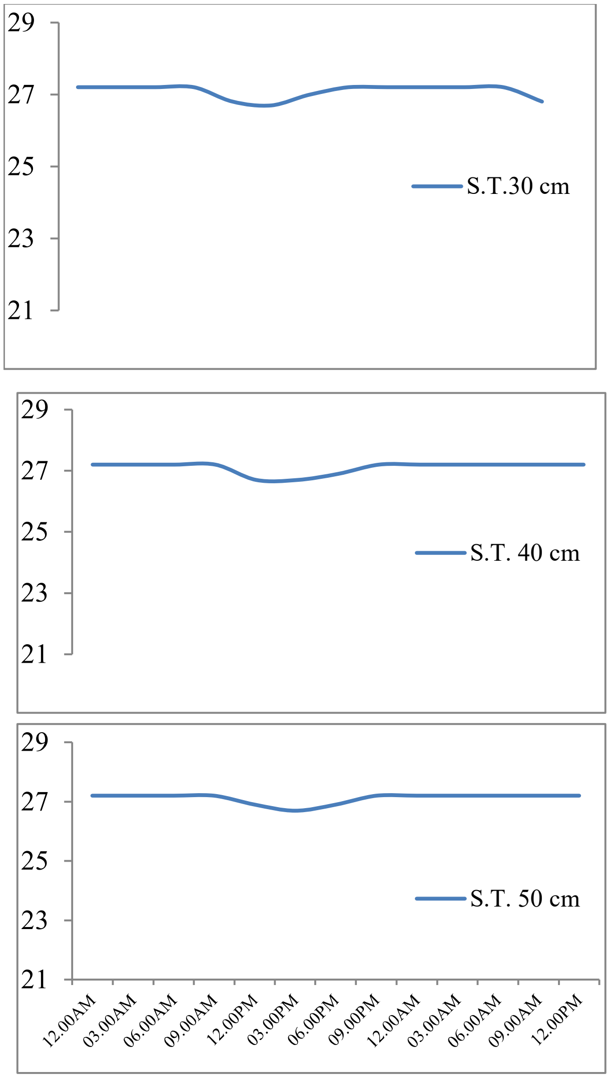

Fig. 4. Diurnal variation of soil temperature at Ayadi, Irele L. G. A. during the dry season.

where, τ is the period of fundamental cycle (24 hours), Z_2 and Z_1 are soil depths while t_2 and t_1 are the time taken for the amplitude of the temperature through Z_2 and Z_1 to get to its maximum or minimum values, t_1 (s) and t_2 (s) are the times (over a three hourly period) at which the temperature waves respectively reaches its maximum or minimum value at the two depths. The diurnal period of oscillation was 24 hours or 86400 s.

Soil Heat Flux

The soil heat flux was determined using the equation [11]

$$G = -K\left[\frac{T_2-T_1}{Z_2-Z_1}\right] \quad (2)$$

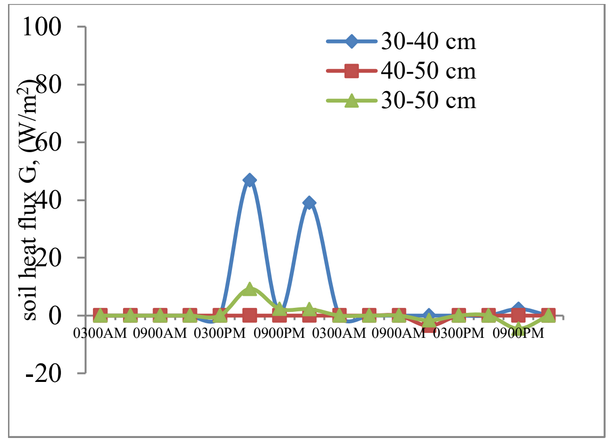

Fig. 5. Diurnal variation of soil heat flux at Ayadi, Irele L.G.A. during the dry season.

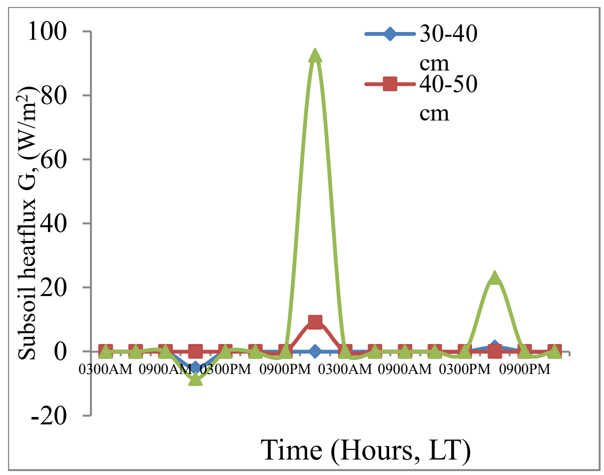

Fig. 6. Diurnal variation of soil heat flux at Ayadi, Irele L.G.A. during the wet season.

where, T_2 *and* T_1 are the maximum or minimum temperature at the two depths. K which is the thermal conductivity was obtained from the product of thermal diffusivity (D), soil bulk density ρ_b and specific heat of soil (C_P). Thus,

$$K = D\rho_b C_p \quad (3)$$

3. RESULTS AND DISCUSSION

Figures 1 and 2 show the diurnal variation of air temperature at the study area during dry and wet season respectively. The average air temperature for the dry season was 42°C while that for the wet season was 39°C. The air temperature attained the highest peak between 2 to 3 pm in the dry and wet seasons. Figures 3 and 4 show the diurnal variation of soil temperature at the 30, 40 and 50 cm depths

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for the dry and wet seasons respectively. The average moisture content for the soil of the study area at the 30, 40 and 50 cm depths were 9.33, 8.48 and 14.19% respectively. The bulk densities of the soils were 1.30, 1.34 and 1.40 g/cm^3 for the three depths while the porosities of the soils at different depths were 27.65, 28.09 and 30.80% respectively. The soil colour was dark brown in the 30 cm layer, indicating the presence of organic matter, reddish brown and dark red in the 40 and 50 cm layers respectively. The soil texture was sandy clay loam at the 30 cm layer, clay loam at the 40 cm layer and clay at the 50 cm layer.

The results obtained showed that the soil temperature decreased with depth. This can be attributed to the fact that temperature functions are greatest at the surface than at the subsoil. Also, clay soils have low porosity; they do not have much pores and holes in them which make it difficult for the transfer of heat between clayey layers. Soil temperature of the surface layer varies more or less according to air temperature. For clay soils, the heat received from the surface soil is held within the soil for a long time thereby increasing the temperature at the surface.

The diurnal variations of the subsoil heat flux for the dry and wet seasons are as shown in Figures 5 and 6 respectively, while Figures 7 and 8 show the diurnal variation of the thermal diffusivity of soil of the study area during the dry and wet seasons respectively. The subsoil heat flux values during the dry season ranged between 0.58 and 52.84 W/m^2, while that of the wet season ranged between -0.77 and 98.50 W/m^2 suggesting that more heat flowed downward during the rainy season. The average diurnal temperature at 40 cm depth was constant during the dry season thus leading to a constant thermal distribution throughout the period. This was also observed for the thermal diffusivity of the soils. The soil at 30 cm depth had a seemingly constant temperature distribution which led to reduced thermal diffusivity and soil heat flux at these depths. The subsoil heat flux were higher in the wet season than the dry season. This aligns with the results reported by other researchers [5,12]. Increasing moisture content in the soil increases the specific heat of the soil thus leading to an increase in the soil heat flux. Vegetation cover is also a factor that can affect soil heat flux. The intensity of temperature decreases due to the inhibition of the incident solar radiation received at the vegetated surface which results in a decrease in the intensity of the soil heat flux [13].

In determining the thermal diffusivity of the soil, the phase-lag method was used because it gives a better determination under uncontrolled conditions. The average thermal diffusivity values at the different depths had values between 0.74×10^{-7} and 238.7×10^{-7} m^2/s for the dry season, while the wet season had a range of 1.97×10^{-7} to 238.7×10^{-7} m^2/s. The thermal diffusivity of the soil varied more during the wet season compared to the dry season. The continuous variation of the thermal diffusivity as seen in the wet season was as a result of the temperature fluctuations

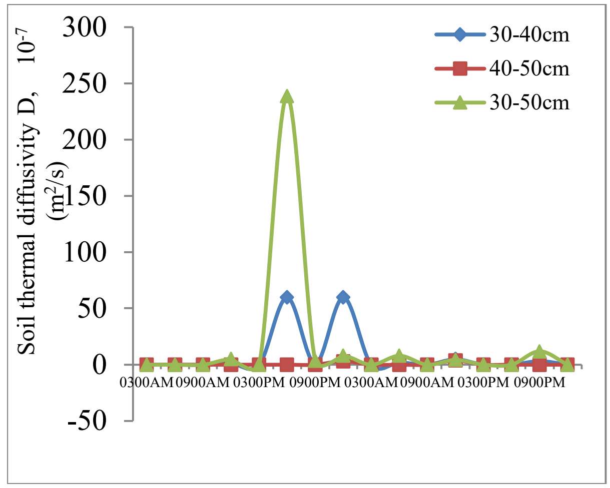

Fig. 7. Diurnal variation of thermal diffusivity of soils at Ayadi, Irele L.G.A. during the dry season.

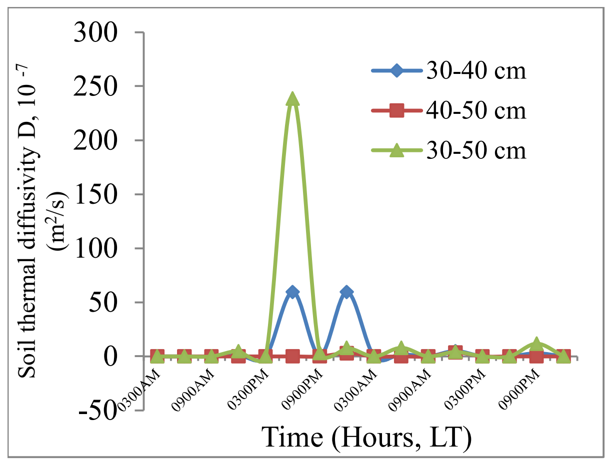

Fig. 8. Diurnal variation of thermal diffusivity of soils at Ayadi, Irele L.G.A. during the wet season.

during this period. Generally, the values obtained for the soil temperature, moisture content, soil heat flux and thermal diffusivity were within the acceptable limits suitable for the crops cultivated in these regions.

5. Conclusion

The effect of some physical properties of soil on the thermal diffusivity and soil heat flux over Ayadi, Irele Local Government Area of Ondo State have been determined. The result showed that to a large extent, the soil heat flux and thermal diffusivity are influenced by the moisture content of the soil, temperature of the soil as well as air temperature. The results showed high variability of the soil heat flux during the wet season compared to the dry season. The research work is recommended as a reference tool for understanding the possible changes that take place in the soil

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in relation to its temperature, thermal diffusivity and heat flux in the study area.

Generally, the results obtained for the physical and thermal properties of the soil of the study area show that the soils would support crop production, and will serve as a good medium for ground wave propagation.

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