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Evaluation Of Annual Soil Temperature Cycles At Different Pedology And Times Over A Period Of One Year In Ikot Ekpene Local Government Area, Akwa Ibom State, Nigeria

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ABSTRACT: A pedological evaluation is essential in understanding all aspect of soil science. Temperatures at different depths in the soil have great influence on seed germination and growth of crops and plants, which is very essential in agricultural and botanical fields. Hence, the objective of this paper was to evaluate the annual soil temperature cycles at different depths [0cm (top soil), 10cm, 30cm and 50cm] and times over a period of one year in parts of Ikot Ekpene Local Government Area, Akwa Ibom State, Nigeria using appropriate standard procedures. The daily soil temperature ranges from 29.7 ^oC – 42.9 ^oC for months covering dry season with a simple mean of 36.3 ^oC; 21.2 ^oC – 29 ^oC for months covering rainy season with a simple mean of 25.1. The mean temperature for all season is 30.7 ^oC, indicating that these locations are favourable for farming. The model, which encompasses transient heat flow principle, was used and certain assumptions were made. For example: the heat flow in soil was one-dimensional and thermal diffusivity was taken as constant. This can be successfully applied to find the temperature of the soil under the ground at any day of the year if the average climatic conditions do not vary drastically throughout the year. It was found that in dry season, the soil temperature increases with depth and in wet season, it first decreases up to certain depth and then starts to increase with depth. This is due to the effects of solar thermal energy and ground thermal energy.

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The shallow subsurface (soil) is a mixture of organic matter, minerals, gases, liquids, and organisms that together support life. The Earth's body of soil is the pedosphere, which has four important functions: it is a medium for plant growth; it is a mean of water storage, supply and purification; it is a modifier of Earth's atmosphere; it is a habitat for organisms; all of which, in turn, modify the soil. Soil interfaces with the lithosphere, the hydrosphere, the atmosphere, and the biosphere. The term pedolith, used commonly to refer to the soil, literally translates ground stone. Soil consists of a solid phase of minerals and organic matter (the soil matrix), as well as a porous phase that holds gases (the soil atmosphere) and water (the soil solution). Accordingly, soils are often treated as a three-state system of solids, liquids, and gases. Soil is a product of the influence of climate, relief (elevation, orientation, and slope of terrain), organisms, and its parent materials (original minerals) interacting over time. It continually

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undergoes development by way of numerous physical, chemical and biological processes, which include weathering with associated erosion.

Soil temperature profoundly influences many biological processes, including plant growth and development, and the behavior of soil-dwelling microorganisms, insects, and higher animals. Much of the works on soil temperature effects on plant growth is summarized in Eric *et al.* (2019). The warm weather plants, cotton and watermelon, are significantly more sensitive to low temperatures than are collards, which are grown as a winter crop in the southern United States. Plants are also sensitive to the extremes of temperature between day and night, winter and summer. In many species, it is this fluctuation of temperature rather than its absolute or average value which is the key ingredient seed germination.

Consequently, a complete understanding of the soil temperature dependence of plant growth and development requires knowledge of soil temperature as a function of time. Soil temperature variation with depth is another factor of importance affecting plant growth. The metabolic processes of soil-dwelling microorganisms are also temperature-dependent. They break down organic matter, produce nitrogen, and play a part in the aggregation of the soil itself (Richards *et al.,* 1952). In turn, these processes affect plant growth and maintenance of the nutrient cycle. Monteith (1973) points out, however, that it is difficult to observe the behavior of the flora and fauna in an undisturbed, natural soil.

Thus, relatively little is known concerning temperature effects on the processes affecting plant growth and maintenance of the nutrient cycle. Hence, the objective of this paper is to evaluate the annual soil temperature cycles at different depths and times over a period of one year in Ikot Ekpene Local Government Area, Akwa Ibom State, Nigeria.

MATERIALS AND METHODS

Location of the Study Area: Ikot Ekpene is in the south of Nigeria and is a Local Government Area of Akwa Ibom State, Nigeria (Fig. 2). Ikot Ekpene local government area has a total land mass of 240.7 sq.km and is bounded in the North by Obot Akara Local Government Area, in the west by Essien Udim Local government area and in the east by Ikono Local Government Area. Ikot Ekpene is located within the oil palm forest belt of Nigeria and the area promises high dividends for agro allied industries.

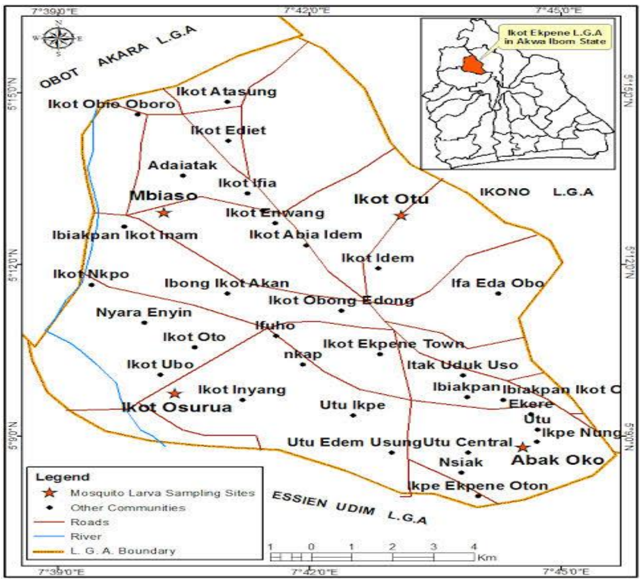

Fig. 2: Map of Ikot Ekpene Region.

It has a latitude of 5.17938 (Lat (DMS) 5°10'55" N) and longitude of 7.7148099 (Long (DMS) 7°42'53.3"E). Its elevation is 24 meters / 78.74 feet. The precise study location was Ikot Obong Edong, a town located in Ikot Ekpene, Nigeria. More so, geologically confirmed sources have indicated the presence of some solid minerals deposit such as, diamond and sand for glass manufacturing, clay for ceramic products.

Methodology: The method employed in this study is an empirical model. In this study, certain assumptions were made. Some of these assumptions were that soil was homogeneous, the thermal soil temperature from December 2023 - November 2024 (at depths 0cm, 10cm, 30cm and 50cm) were obtained from the field. The overall annual average temperature was estimated as T_a = 28.9^{o}C. Under these conditions the pertinent heat equation is shown in equation 1 (Hillel, 1980).

$$\frac{\partial T}{\partial t} = D_h \frac{\partial^2 T}{\partial z^2} \qquad (1)$$

Where; T is soil temperature, $D_h = \kappa/C$ is the thermal diffusivity, k is the thermal conductivity and C is the volumetric heat capacity, t is time, and z is soil depth. We apply the boundary conditions for z = 0 and $z \to \infty$. We assume that at infinite depth ($z \to \infty$) the temperature is constant and equal to T_a. The temperature at the surface and infinite depth can be expressed respectively as:

$$T(0,t) = T_a + A_0 \sin \omega t \qquad (2)$$

$$T(\infty,t) = T_a \qquad (3)$$

Using these boundary conditions the equation (1) yields equation 4 as:

$$T(z,t) = T_a + A_0 e^{-z/d} \sin\left(\omega t - \frac{z}{d}\right) \quad (4)$$

Where; T(z, t) is the soil temperature at time t (day number of year) and soil depth z (meter), T_a is the average soil temperature (℃), A_0 is the annual amplitude of the surface soil temperature (OC), d is the damping depth (meter) of daily fluctuation. The damping depth is defined as,

$$d = (2D_h/\omega)^{1/2} \quad (5)$$

Where; D_h is the thermal diffusivity and ω = 2π/365 day^{-1} is the radial frequency, in the case of annual variation the period is 365 days.

From equations (2) and (4) we have seen that the quantity A_0 is a constant regardless of depths.

Here, the equation (4) is the solution to the second order equation (1). The solution is not affected with the addition of constants. So let us take the equation 6:

$$T(z,t) = T_a + A_0 e^{-z/d} \sin[2\pi(t - t_0)/365 - \frac{z}{d} - \pi/2)] \quad (6)$$

This equation satisfies equation (1) so the equation (6) is also one of the solutions of equation (1).

The empirical values (i.e. t_o and π/2) used in this equation are used by Hillel. Choosing suitable value of thermal diffusivity the equation can be used for any type of soil. There are many models to calculate the soil temperature using different values of D_h and t_0 for various types of the soil. In this equation (6) the value of t_0 is the lowest temperature day number of the year. For example if the temperature of a year is minimum at July 29, then t_0 = 29.

The solution of second-degree equation can be used as a model to determine the temperature at given depth at given time of the year. There may be different methods to choose the constants D_h and t_0. Here we have chosen the value of thermal diffusivity (D_h) to be 288cm^2/day and it is assumed constant throughout the year. Transient heat flow principles were used and heat flow was considered one-dimensional. And the value of empirical constant t_0 is taken as the day number of the year such that the day has the lowest temperature. The graphs of temperature versus day number of the year were plotted for different depths.

where, the one-dimensional heat flow equation is:

$$T(z,t) = T_a + A_0 e^{-z/d} \sin[2\pi(t - t_0)/365 - \frac{z}{d} - \pi/2$$

Where; T_a = Annual average temperature (28.942^{o}c), A_o = Annual amplitude = $T_{max} - T_a$, T_{max} = Maximum temperature of the year, t_o = Day number for minimum temperature day of the year, D_h = Thermal diffusivity (here taken constant as 288 cm^2/day) ω = Angular frequency= 2π/T, T= time period =365 days, d = Damping depth = $(2D_h/\omega)^{1/2}$

Thus,

$$T(z,t) = 28.9 + 9.8e^{-z/d} \sin\left[\frac{2\pi(t-29)}{365} - \frac{z}{d} - \frac{\pi}{2}\right] \quad (7)$$

Equation (7) could be used to determine the soil temperature at various depths for any day of the year

.

RESULTS AND DISCUSSION

The measured soil temperatures at different depths for the annual cycle are shown in figure 3-6. The data points show the measured soil temperature at various points throughout the year. A polynomial regression model has been fitted to the data, with R^2 values indicating a reasonably good fit. This means the model explains approximately 87.7%, 89%, 82.89% and 90% of the variation in soil temperature in the four chosen depths. The curves show a general trend of soil temperature fluctuation throughout the year, likely reflecting seasonal changes in air temperature and solar radiation. The model suggests a non-linear relationship between the number of days and soil temperature, with temperature initially decreasing, and potentially decreasing again towards the end of the year. It can be seen from the figures that the average temperature varies with the months of the year and became more apparent during the dry and wets seasons. We have high temperature means between November to March (dry season) and low temperature mean between April and October (wet season). The soil temperature does not follow the same pattern in summer and winter seasons: in winter the temperature of soil increases with depths whereas in summer the temperate of soil first decreases up to certain depth then increases with depths. Soil temperature has an effect on the environment sensed by the plant, and may influence the rate of the development. Generally, crop yield rises with soil temperature increase to a point and decreases with further increase in soil temperature.

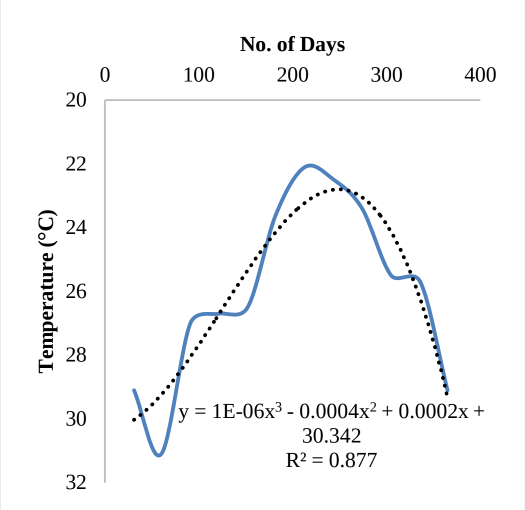

Fig. 3: Measured annual variation of soil temperature at 0cm

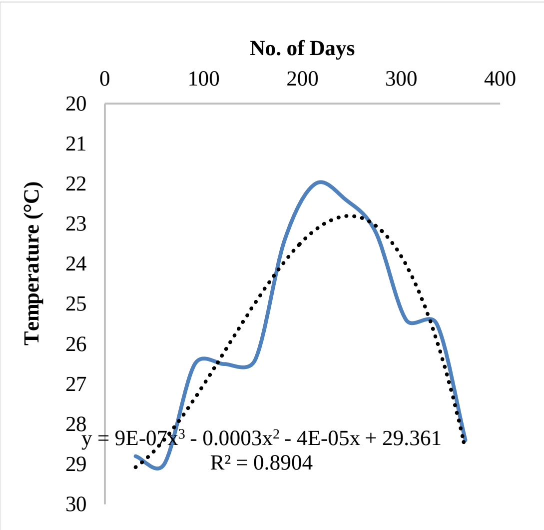

Fig. 4: Measured annual variation of soil temperature at 10cm

The rainy and dry season variation of soil temperature at different depths: 0 cm, 10 cm, 30 cm, and 50 cm were invested and data showed that the temperature increases with depth in dry season (e.g. December, January and February) and the temperature first decreases up to the depth about 10 cm and then increases with depth in case of rainy season (e.g. June, July). This can be explained on the basis of two energy sources as follows; solar thermal energy and ground thermal energy. In dry season, ground thermal energy is dominant at all depth and its value increases with depth. But, in rainy season, there is dominant role of solar thermal energy up to certain depth than ground thermal energy and temperature is higher in upper layer than lower layer up to certain depths and after crossing effective penetration depth of solar energy again temperature increases with depth as given by ground thermal energy.

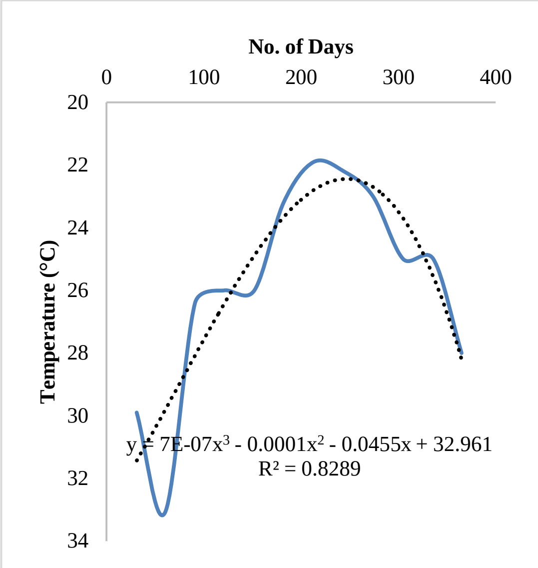

Fig. 5: Measured annual variation of soil temperature at 30cm

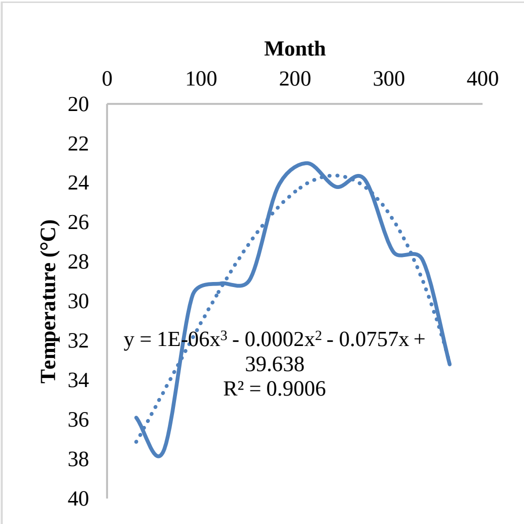

Fig. 6: Measured annual variation of soil temperature at 50cm.

Conclusions: As buttressed in this work, both soil and surface temperature are dynamic in nature, having yearly, seasonal and diurnal cyclic variations (Hasfurther *et al.*, 1972). The temperature of the soil depends on the ratio of the energy absorbed to that lost from the soil. From the analysis of this study, there is a strong positive correlation between these two variables as increase in one variable leads to a corresponding increase in the other. It is important for farmers to have enough knowledge of the temperature of the soil on which they plant. The Predictive equations obtained can be used to affirm the suitability of any crop whose performances at different temperature conditions are known, which could lead to increase crop yield. The model presented here gives highly satisfactory result for the under surface temperature of soil at predefined depths at any day of the year.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data Availability: Data are available upon request from the first author or corresponding author.

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