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Evaluation of the Thermal Conductivity of Soils in Edo State, Nigeria

[1]W.A. Molindo and [2]O.M. Alile
[1]Department of Agriculture (Soil Science Option) Faculty of Basic and Applied Sciences, Benson Idahosa University, Benin City Edo State, Nigeria
[2]Department of Basic Sciences (Physics Option) Faculty of Basic and Applied Sciences, Benson Idahosa University, Benin City, Edo State, Nigeria

Abstract: Investigations were conducted to evaluate the thermal conductivity of soils of Sedimentary rock origin in two locations namely; Obaretin in Ikpoba/Okha and Idumabi-Irrua in Esan Central Local Government Areas respectively in Edo State, Nigeria. The study was aimed at validating the effects of the thermal regimes of these soils and their relation to soil productivity. The investigation showed that soil conductivity is related to temperature factors such as soil resistance and resistivity that controls the processes involved in the production and plant growth. The investigation showed that soil thermal conductivity is related to temperature and solar radiation factors such as soil resistance and resistivity, that control the processes involved in plant growth and productivity with accompanied macro and micro fauna in soils. Functional activities of plant roots such as absorption of water and nutrients are encouraged at low or high soil thermal conductivity levels. In this study, there were significant (p = 0.05) differences in thermal conductivity in the soils of both locations. Similarly soil resistance and resistivity were significantly different (p = 0.05) in the two locations (Obaretin and Idumabi Irrua) in Ikpoba-Okha and Esan Central Local Government Area, Edo State, Nigeria. This study indicates attributes of temperature changes in soil regimes, reflecting the difference in vegetation obtained in the two locations. Therefore soil productivity and plant growth is influenced by soil thermal conductivity and it's related factors such as soil resistance and resistivity.

Key words: Evaluation, thermal conductivity, soil, resistivity

INTRODUCTION

Radiation energy from the sun is the power source that determines the thermal regime of the soil and the growth of plants. Agriculture is the exploitation of solar energy in the presence of an adequate water supply and sufficient plant nutrient to maintain plant growth (Monteith, 1958). Incoming radiation during the dry and rainy season vary because the direct beam penetration of the earth surface is affected by cloud cover. The global radiation is partition into reflected radiation and absorbed energy which is utilized in heating the soil and air above the soil (Ghosh, 1971; Zohdy *et al*., 1974).

The soil is a granular medium consisting of solid, liquid and gaseous phases (Etu-Efeotor *et al*., 1989). Its thermal conductivity depends upon the volumetric proportions of these components, the size and arrangement of the solid particles and the interface relationship between the solid and liquid phases. Baver *et al*. (1976) reported that the thermal conductivity of soil factions such as quartz is 26.3×10^{-3} cal/cm (sec) °C when measured parallel to the axis of the crystal and 16.0×10^{-3} when determined perpendicular to this axis. For water and air 1.4 and 0.06×10^{-3}, was recorded. This gives a ratio of thermal conductivity of 333:23:1 for quartz, water and air. It is obvious that the thermal conductivity of a granular soil will depend upon the intimacy of the contact of the solid particles and the extent to which air is displaced by water in the pore spaces between the particles (Okwueze, 1996). However, diffusivity denotes the temperature change that takes places in any portion of the soil as the heat flows into it from an adjacent layer. It is the change in temperature (°C) in one second, when the temperature gradient changes 1°C/cm$^{3.}$

Thermal conductivity in soil may be explained as the quantity of heat flow through an area of soil per unit time and temperature gradient. The thermal conductivity of some soils follow the order of sand > clay > peat. These conductivity differences are related to the degree of packing and porosity of the soil system. Thermal conductivity diminishes with decreasing particles size due to reduced surface contact between the particles through

Corresponding Author: O.M. Alile, Department of Basic Sciences (Physics Option), Faculty of Basic and Applied Sciences, Benson Idahosa University, Benin City, Edo State, Nigeria

which solar heat will readily flow. Increasing the bulk density of soil lowers the porosity and improves the thermal contact between the solid particles (Ujuanbi, 2000). This study investigated the resistance R and resistivity ρ, in soils in field locations at Obaretin Village in Ikpoba Okha LGA and Idumabi Irrua in Esan central LGA, both in southern and central regions of Edo state, Nigeria, respectively. With the aim to evaluate the thermal conductivity of the soils in these locations so as to verify the soils thermal regimes, through the application of theoretical soil physics, basic physics and geophysics principles of potential differences, resistance and resistivity using the soil as a medium and relating this to soil productivity and growth.

MATERIALS AND METHODS

The soils in this study are of sedimentary origin (Soil Survey Staff, 1975). Their physical properties were determined, using the Veihmeyer and Hendrickson (1949) method. The soils field moisture capacity was determined using the Boyoucous (1962) method. However, the theoretical principle of physics and geophysics were also applied to evaluate the aims of the study. In this case the conductivity (σ) of a material(soil) is simply the reciprocal of its resistivity, i.e., $\sigma = 1/\rho$. The unit of σ being expressed as $(\Omega m)^{-1}$ which is ohm per meter. When the resistivity of the soil is known, we can deduce the thermal conductivity of the soils in the locations. That is knowing the resistance of soils, the resistivity is also deduced.

$$K = \frac{\pi}{2}\left\{\frac{(AB/2)^2 - (MN/2)^2}{MN/2}\right\}$$

$$\rho = RA/L,\ \rho_a = KV/i, \qquad K = \pi CD\left\{\left(\frac{L}{CD}\right)^2 - 0.25\right\}$$

$$L = 2(AB/2)$$

Where CD = Potential Electrode spacing, L = Current electrode spacing, A = Area, K = Geometric factors. The macroscopic quantities V, R, I are of greatest interest when we are making electrical measurements on specific conductors. The resistance between two points in the soil was done by applying a potential difference (V) between points and measuring the current (i). The resistance (R) was taken as R= V/i, R is in ohms (Ω) = volt per ampere. The resistance of the soil depends on the potential difference applied. The potential difference (V) across the points in the soil measured and the electric field (E) at the point was taken into consideration. Instead of looking at the current density at the points determined, i.e., the resistance is replaced as resistivity (ρ) of the material, in this study.

The instrument used in this study were the Electrical Resistivity Survey Equipments. The major components of the equipments are electrodes, cables, generators, transmitters and receivers. The current electrode were made with ordinary steel. However, stainless steels are best for potential electrode because they polarizes better than other metals. Salt water was used around the electrodes where contact was poor. Single core, multi-strand copper wires insulated with PVC were used for the measurements. The mechanical strength required dictated the thickness of the cable because ground resistance is usually very much higher than the resistance of the cable (Osemikhan and Asokhia, 1994). The receivers in electrical resistivity consist of voltage measuring components. The instrument displayed the readings in digital form. The same method was used for measurement in both locations. The potential electrodes were connected to the terminals of the equipment (ABEM Terrameter) at a given space of distance (MN) called potential electrode spacing. Then the cables of the current electrode were spread across both ends over a range of measured distances having a current electrode spacing (AB). Asokhia (1992), used similar procedures in different studies. At every space of distance taken, the digital instrument displaced a resistance reading on the screen which was recorded. The theoretical principles of conversion from potential difference (V), resistance (R) and resistivity (ρ) and conductivity (σ), were applied to obtain the results and mathematical calculations deductions. These were subjected to statistical analysis.

AB/2 → current electrode spacing = measured distance on the surface of the earth
MN/2 → potential electrode spacing
R → resistance i.e., raw value from field work.
K → constant i.e., geometric factor
ρ → resistivity = 1/ σ
σ → conductivity = 1/ρ

RESULTS

Results of some physical properties and field moisture capacity of the soils is shown in Table 1, with appropriate temperatures.

Table 2, shows the results of measurements deduced from geophysical explorations, Physics and mathematical calculations obtained from the soils in first field location in Obaretin, Ikpoba Okha in south Edo State, Nigeria. The weather condition were relatively hot with temperature measuring a mean of about 38°C from the results (Table 1) it was observed that increased current electrode spacing ($^{AB}/_2$) and the potential electrode spacing ($^{MN}/_2$) was followed by a decrease in resistance (R) with an increased resistivity (ρ) and a decrease conductivity. The geometric factor may have influenced this results. The resistance (R) of the soil contributes to temperature differences between various soil horizons within the profile, therefore micro-organisms and other living organism that contributes to decomposition and formation of organic matter are reduced.

The result (Table 3) of the second study location (Idumabi, Irrua) in Esan Central local government of Edo state, Nigeria, shows that as the resistance (R) decreased from 28.50 to 0.10 ohms there was an increment in both the current electrode spacing, that is measured distance along the soil surface and the potential electrode spacing. Whereas there was an increase in resistivity (ρ) and a decreased in conductivity. (σ) The soils in both locations exhibited a similar trend in respect to the parameters measured. However, estimated values for the resistance, resistivity and conductivity differ (Table 2 and 3).

Table 1: Physical properties of soils in locations, Obaretin and Idumabi Irrua at (0-15 cm) depth

Physical properties	Obaretin	Idumabi irrua
PH (KCl)	5.0	5.8
Sand (%)	82.0	85.0
Silt (%)	10.0	9.5
Clay (%)	8.0	5.5
Field moisture capacity (FMC) (%)	15.3	14.0
Temperature (°C)	38.0	39.2

Table 2: Location, Obaretin L.G.A.: Ikpoba Okha State, Edo

S. No.	$\frac{AB}{2}$ (m)	$\frac{MN}{2}$ (m)	$R = \Delta V/I$ (ohm)	K	ρ (ohm-m)	$\sigma = 1/\rho \times 10^{-4}$ $(\Omega m)^{-1}$
1	1.00	0.15	144.40	10.24	1484.83	6.76
2	1.47	0.15	67.70	22.39	1514.21	6.60
3	2.15	0.15	30.40	48.17	1543.91	6.83
4	3.16	0.15	14.15	104.33	1556.87	6.77
5	4.64	0.15	6.81	225.22	1528.04	6.52
6	6.81	0.50	8.98	144.91	1424.22	7.69
7	10.00	0.50	4.07	313.37	1238.76	7.84
8	14.70	0.50	1.50	678.08	1034.42	9.83
9	21.50	0.50	0.63	1451.42	905.79	10.94
10	31.60	0.50	0.61	3136.28	893.00	5.23
11	46.40	1.00	0.75	3380.29	962.00	3.94
12	68.10	1.00	0.38	7283.17	1071.00	3.61
13	100.00	1.00	0.08	15706.39	1249.30	7.96
14	147.00	1.00	0.34	33941.77	1402.00	0.87
15	215.00	1.00	0.22	72608.49	15973.87	0.63
Mean	44.90	0.55	18.74	9270.30	3197.58	6.14

R = Resistance, K = Geometric factor, (ρ) = Resistivity, σ = Conductivity

Table 3: L.G.A., Esan Central Location: Idumabi-irrua, State: Edo

S. No.	$\frac{AB}{2}$ (m)	$\frac{MN}{2}$ (m)	$R = \Delta V/I$ (ohm)	K	ρ (ohm-m)	$\sigma = 1/\rho \times 10^{-4}$ $(\Omega m)^{-1}$
1	1.00	0.15	28.50	10.24	291.8400	34.27
2	1.47	0.15	15.60	22.39	349.2040	28.63
3	2.15	0.15	8.38	48.17	403.6646	24.77
4	3.16	0.15	4.48	104.33	467.3984	21.40
5	4.64	0.15	2.83	225.22	637.3726	15.69
6	6.81	0.50	4.04	144.91	585.4364	17.08
7	10.00	0.50	2.27	313.37	711.3499	14.06
8	14.70	0.50	1.01	678.08	684.8608	14.06
9	21.50	0.50	0.64	1451.42	928.9088	10.77
10	31.60	0.50	0.52	3136.28	1630.8656	6.13
11	46.40	1.00	1.18	3380.29	3988.7422	2.51
12	68.10	1.00	0.41	7283.17	2986.0997	3.35
13	100.00	1.00	1.30	15706.39	4711.9170	2.12
14	147.00	1.00	0.15	33941.77	5091.2655	1.96
15	215.00	1.00	0.10	72608.41	7260.8490	1.38
Mean	44.90	0.55	0.31	9270.30	2048.6600	13.25

R = Resistance, K = Geometric factor, (ρ) = Resistivity, σ = Conductivity

DISCUSSION

The mean value (44.90 m) for the current electrode spacing i.e measured distance along the surface of the soils was not influenced by locations (Obaretin and Idumabi Irrua both in Ikpoba Okha Esan Central local government area). This is because the thermal conductivity of humid tropical soils is subject to redistribution of water under the influence of temperature gradient. And for these locations the soil moisture content and temperature were 14.5% and 38°C, respectively. This indirectly encourages both micro and macro fauna in soils conditioning. Temperature and moisture are agents that assists in the survival of soil living organisms. The mean potential (0.55 m) electrode spacing was equal in both locations, indicating that the soils thermal conductivity was not influenced by this factor (potential electrode spacing). The soils resistance, 18.74 and 0.31 ohm for both locations (Obaretin in Ikpoba, Okha and Idumabi in Esan central), respectively was different, indicating that the encouragement of the soils to plant growth would vary. The higher resistance obtained in Obaretin soils indicate that the soil is likely to have a solid structure than that of Idumabi. The resistivity of the soils in both locations followed the same pattern as their resistance. The means (6.14×10^{-4} and $13.25\times10^{-4}\,\Omega$m) conductivities for Obaretin in Ikpoba Okha and Idumabi in Esan central respectively differed. This showed that both locations had different soil physical characteristics. Also, since they are in the southern and central regions of Edo state, Nigeria within the humid tropics, their ecological distribution differ. Therefore these physico-thermal factors investigated in this study do support soil conditions in relation to plant growth. For the activities of various soil micro/macro living organisms are most likely to be influenced by the soils thermal conductivity. Since thermal regimes of the soil can be modified either by regulating the incoming and outgoing radiation or by changing the thermal properties of the soils. This study has established that variations in the investigated parameters (soil thermal conductivity, resistance and resistivity) were regulated by the natural ecology of the studied locations. The basic impacts of a vegetation canopy on the thermal regime was not the same, with Idumabi Irrua having a less vegetation. The compaction on the soil surface increased its density and the thermal conductivity. Whereas the tillage condition in the soil at Obaretin on the other hand created a surface mulch which reduces the heat flux from the surface to the subsurface layer encouraging lower soil thermal conductivity. Consequently, temperature and radiation in fields contributes either positively or negatively to soil conditions and plant growth.

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