Assessment of Thermal Conductivity of Soil Samples Obtained in Jalingo Metropolis, Taraba State, Nigeria.

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Abstract- The component of soil physics that has found important uses in engineering, climatology, and agriculture are properties of thermal conductivities of soil. In order to assess this, the thermal conductivities of Ten (10) different locations in the Jalingo metropolis were obtained and analyzed. Variations have been observed in the thermal conductivity. The highest (0.3234Wm-1k-1) and the lowest (0.2357Wm-1k-1) thermal conductivity of soil were obtained at Kona and Abuja phase2 seen at respective temperatures of 34oC and 41oC. The sample areas are mostly sandy soil and are more prone to high bulk density. The soil samples obtained have the same or similar engineering and agricultural behavior, because the growth and development of a crop may be determined to a large extent by soil thermal capacity.
Keywords: Thermal conductivity, temperatures, soil samples, thermal capacity.

I. INTRODUCTION

Thermal conductivity is themeasure of the ability of a material to allow the flow of heat from its warmer surface through the material to its colder surface, determined as the heat energy transferred per unit of time and per unit of surface area divided by the temperature gradient, which is the temperature difference divided by the distance between the two surfaces (the thickness of the material),expressed in watts per Kelvin per meter [1, 2].

Thermal conductivity of a soil is the ability of a soil to conduct heat [30]. It is required in manyareas of engineering, agronomy, and soil scienceto conduct analysis and modeling associated withnumerous agricultural, hydrological and industrial applications [4].In agronomic practice, seed germination, seedling emergence, and establishment are affected by their microclimate, which is influenced by soil thermal properties [5,6]. The study of temperature distribution in soil profiles requires a solution to the heat transfer equation. This solution depends on the formulation of the boundary condition as well as the soil thermal properties, which are represented by the thermal conductivity and thermal diffusivity coefficients [7].The engineering aspects include the design of underground telecommunication and power transmission cables [8] and underground thermal energy storage, as well as ground source heat pump systems [9].

Simulation of heat transmission through soil requires an accurate measurement of soil thermal conductivity. Soil thermal conductivity measurement will have a wide variety of applications. This measurement will be valuable in the calculation of heat loss through basements, slabs and crawl spaces and will thereby improve the accuracy of homely building energy analysis [10]. Soil is the most important mineral or resource on which both human and animals depend upon for their survival in the areas of agriculture, economic and shelter. Therefore there is a need to study the thermal properties of soil with a view to strengthening our dependence on agriculture, mineral resources and water resources and so on with an attempt to discourage our complete dependence on fossil fuels.

The aim of this study is to evaluate the thermal conductivity of soil samples obtainable in the Jalingometropolis using the Lee Disc Method.The results from this study could be used for future land map building and farming plans by the government, entrepreneurs, and NGO's within the town of Jalingo. Accurate determination of soil thermal conductivities is important in almost every scientific field. The values obtained in this study will facilitate in areas of engineering, agronomy and soil science.

II. THEORY OF OPERATION

Heat conduction is stated as, H:

$$H = \frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{x} \qquad 1$$

Where $\frac{\Delta Q}{\Delta t}$ is the rate of heat flow, k is the thermal conductivity, A is the total cross-sectional area of conducting surface, ΔT is temperature difference, and x is the thickness of conducting surface separating the two temperatures.

$$k = \frac{\Delta Q}{\Delta t}\frac{1}{A}\frac{x}{\Delta t} \qquad 2$$

Thermal conductivity is the quantity of heat, ΔQ, transmitted during time Δt through a thickness x, in a direction normal to a surface of area A, per unit area of A, due to a temperature difference ΔT, under steady state conditions and when the heat transfer is dependent only on the temperature gradient[11]. Alternatively, it can be thought of as a flux of heat (energy per unit area per unit time) divided by a temperature gradient (temperature difference per unit length).

Therefore;

$$k = \frac{ms\left(\frac{dT}{dt}\right)x}{A(T_2 - T_1)} \qquad 3$$

where m and c are respectively the mass and specific heat capacity of the lower disc.

Equation 3 will be used to evaluate the thermal conductivity of the different soil samples at different locations.

The moist content percentage value is calculated using the equation[12];

$$w = \frac{m_w}{m_s} x\ 100\ \% \qquad 4$$

Where; w is moisture content, mw mass of water and ms mass of solid soil particles

III. MATERIALS AND METHODS

3.1 Sample Collection

The sample collection was done at ten (10) different locations in Jalingo town. The various locations selected randomly were: Mile 6, FGGC Road, ATC, SabonGari, UgwanKasa, Mayo Dasa, Kona, Abuja Phase2, TADP, and Gullom. A shovel was used to clear the top layer of the soil and also in order to properly drill the soil, auger or digger was usedas the case may be. The soil auger was marked at every 0.5m, 1.0m, 1.5m, 2.0m and drill into the soil. The length of the soil auger is 2m long, which is detachable and can be screwed at every 1m point length. The points marked on the soil auger of the soil samples were collected into a container of known mass. The combined mass of samples and containers were weighed using electronic balance and are recorded. More samples were collected and put into polyethylene bags in other to preserve their water contents.

3.2 Determination of the soil moisture content

Some amount of the moist soil sample from Mile 6 at 0.5m depth was collected in a small container of know mass and weighed using the portable digital balance and was also recorded. More samples from Mile 6 at different depths such as 0.5, 1.0m, 1.5m, and 2.0m were collected and recorded. The process was repeated for; FGGC Road, ATC, SabonGari, UgwanKasa, Mayo Dasa, Kona, Abuja Phase2, TADP and Gullom. Further analysis of the moist soil samples and the containers were put in the oven at a temperature of about 1050C and left for 24hours. The samples and the containers were removed from the oven and put into desiccators and allowed to cool. When dried, the samples in the containers were weighed again in order to get the mass of the dried soil samples.

3.3 Determination of Thermal Conductivity of each soil sample collected.

A disc form mould was used with diameter and thickness to prepare the specimen. Each of the specimens was molded with compression in order to ensure the conductivity of the particles of the samples and to remove any trapped air. The samples were one after the other molded and carefully removed from the lubricated mould and then dried under the sun. Lee Disc Method was used to test the samples. Radius and diameter of the mould were taken to the obtained accurate measurement of the area using the constant of pi. Two thermometers T1 and T2 at steady temperatures were recorded. The two thermometers T1 and T2 were switched in position and their steady temperature reading was taken. The cylinder A is now removed and a Bunsen flame was allowed to play at the bottom surface of slab B until T2 records temperature above 100 more than the steady temperature. The specific heat capacity (c) used in evaluating the thermal conductivity of the soil samples was obtained from the measured data from the work [13]. The diameter of the soil sample and its thickness were measured using a micrometer screw gauge. Lastly, the mass of the sample was determined. Equation 3 was used to calculate the values for thermal conductivity.

IV. RESULTS AND DISCUSSIONS

Table 1 shows the temperature recorded at an interval of 60 seconds for the samples. It is observed that the temperature decreases with time increases. Figure 1 to 10 show graphs of the cooling temperature of each soil sample collected at the stated locations. The graph of each sample shows a line decreasing from left to right and slightly increased towards the end for some location producing a negative slope which signifies that maximum air temperature drop and heat transfer in the soil is achieved with higher thermal conductivity. It also explains further that soil with higher thermal diffusivity has higher rate of heat transfer and can transfer more amount of heat through the nearby soil to the outer subsoil faster for samples that slightly increased towards the end of the line of the graph. In metals, thermal conductivity approximately tracks electrical conductivity according to the Wiedemann Franz law, as freely moving valence electrons transfer not only electrical current but also heat energy. However, the general correlation between electrical and thermal conductance does not hold for other materials, due to the increased importance of phonon carriers for heat in non-metals.

The moisture contents at various locations are displayed in Table 2.The average results of thermal conductivity against samples obtained from all the locations are shown in Figure 11. Variations have been observed in the thermal conductivity. This conductivity is related to the degree of packing and porosity of the soil system. The results show that thermal conductivity decreases with the increase in moisture content. As the voids between the soil particles become completely filled with moisture, the soil thermal conductivity no longer increases with increasing moisture content, which gave a parallel line to the moisture of the content on the axis. The Figure shows steady state temperature or common temperature or ambient temperature for the soil type under study which explained that the soil samples have the same or similar engineering and agricultural behavior, because the growth and development of a crop may be determined to a large extent by soil thermal capacity.

From the results obtained, the soil at FGGC Road, UgwanKasa, Gullom, TADP, Mayo Dasa and SabonGari ward is sandy soil. The soil at Abuja Phase2 and Mile 6 are Clay soil while those at Kona and ATC are loam soil.It was observed that due to the difference in their specific heat capacities and temperature variation with respect to their depths the thermal conductivity at Kona was observed to be much higher than those at Mile 6, which were also higher than the rest of the locations. Fall in temperature with time increase was observed for all the locations selected.

Table 1: Temperature and Time Recorded at the highest depth.

S/N	Time(s)	Temperature (oC)									
		Mile 6	FGGC ROAD	ATC	SABON GARI	UNGWAN KASA	MAYO-DASA	KONA	ABUJA-PHASE2	TADP	GULLOM
1	0	67	68	70	68	70	72	71	70	73	70
2	60	66	67	70	65	69	70	70	70	68	69
3	120	65	66	69	64	68	69	69	69	65	66
4	180	63	65	68	63	68	68	68	68	64	65
5	240	61	64	67	62	67	67	67	67	63	63
6	300	61	63	66	61	66	66	66	66	62	61
7	360	60	62	65	60	65	65	65	65	61	61
8	420	59	61	63	59	64	63	63	63	61	60
9	480	59	60	61	58	62	61	61	61	60	59
10	540	58	59	61	57	62	61	61	61	60	59
11	600	57	58	60	56	61	60	60	60	59	58
12	660	56	57	59	55	60	59	59	59	58	57
13	720	54	56	59	54	59	59	59	59	57	56
14	780	53	55	58	53	59	58	58	58	56	54
15	840	52	54	57	52	57	57	57	57	55	53
16	900	51	53	56	50	55	56	56	56	54	52
17	960	51	52	54	49	55	54	54	54	53	51
18	1020	50	50	53	48	53	53	53	53	52	51
19	1080	49	49	52	47	53	52	52	52	50	50

20	1140	49	48	51	46	51	51	51	51	49	49
21	1200	48	47	51	45	49	51	51	51	48	49
22	1260	47	46	50	44	48	50	50	50	47	48
23	1320	46	45	49	43	47	49	49	49	46	47
24	1380	45	44	49	42	46	49	48	49	45	46
25	1440	44	43	48	41	45	48	48	48	44	45
26	1500	43	42	47	41	44	47	47	47	43	44
27	1560	42	41	46	41	43	46	46	46	42	43
28	1620	41	41	45	41	42	45	44	45	41	42
29	1680	41	41	44	41	41	44	44	44	41	41
30	1740	40	40	43	40	41	43	43	44	41	41
31	1800	40	40	42	40	41	43	41	43	41	41
32	1860	40	40	41	40	40	42	40	42	40	40
33	1920	40	40	41	40	40	41	40	41	40	40
34	1980	40	40	41	40	40	40	40	40	40	40
35	2040	40	40	40	40	40	40	40	40	40	40

Table 2: Soil moisture recorded at various locations obtained at the highest depth.

S/N	Location	Weight of empty container (g)	Weight of moist soil (g)	Weight of Container + moist soil (g)	Weight of oven dry soil (g)	Weight of container + oven-dry soil (g)	Weight of water (g)	Soil moisture content (%)
1	Mile 6	23.0	48.5	71.5	45.8	68.8	2.7	5.9
2	FGGC ROAD	23.0	49.6	72.6	43.0	66.0	6.6	15.3
3	ATC	24.3	55.6	79.9	49.9	74.2	5.7	11.4
4	SABON-GARI	24.2	48.5	72.7	44.7	68.9	3.8	8.5
5	UNGWAN-KASA	23.1	65.6	88.7	56.7	79.8	8.9	15.7
6	Mayo-DASA	23.0	48.5	71.5	45.8	68.8	2.7	5.9
7	KONA	27.9	61.6	89.5	57.2	85.1	4.4	7.6
8	ABUJA PHASE2	26.4	66.6	93.0	61.6	88.0	5.0	11.1
9	TADP	23.0	48.5	71.5	45.8	68.8	2.7	5.9
10	GULLOM	23.8	51.7	75.5	44.2	68.0	7.5	16.9

Table 3Sample Parameter

Thickness of sample x	0.021
Specific heat capacity of sand c	930Jkg-1C-1
Area of sample A	0.0038m2
Specific heat capacity of loam c	990 Jkg-1C-1
Thickness of sample m	0.2010m
Specific heat capacity of clay c	870 Jkg-1C-1
Diameter of soil sample d	0.082m
Radius of sample r	0.041m

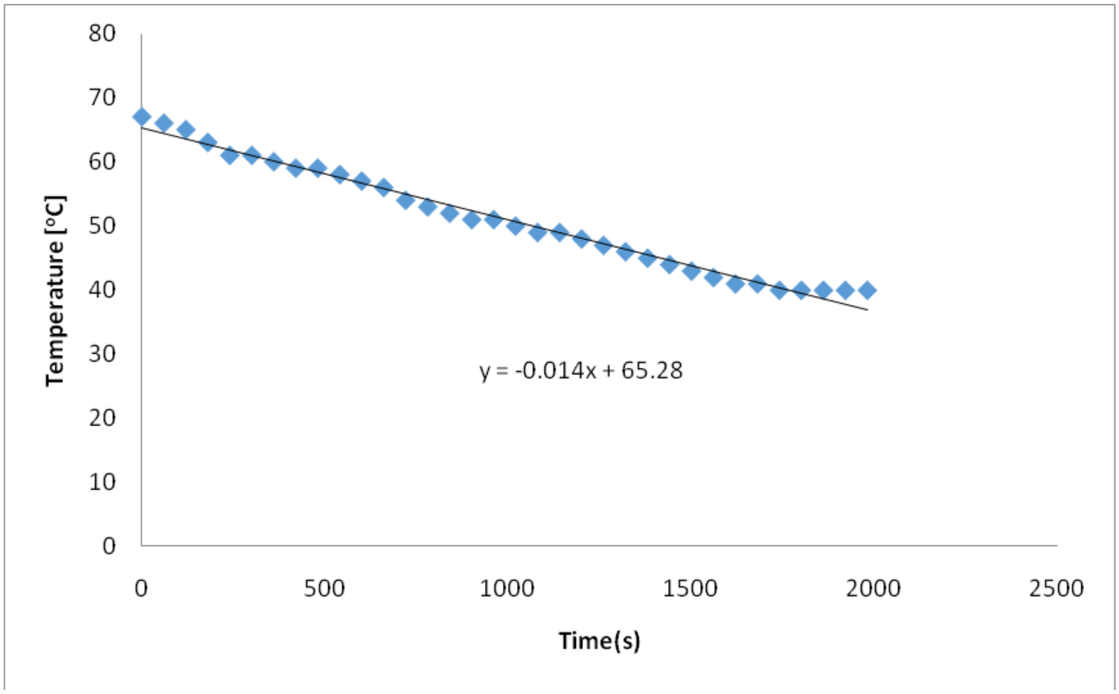

Figure 1: Graph of Temperature vs Time for Mile 6

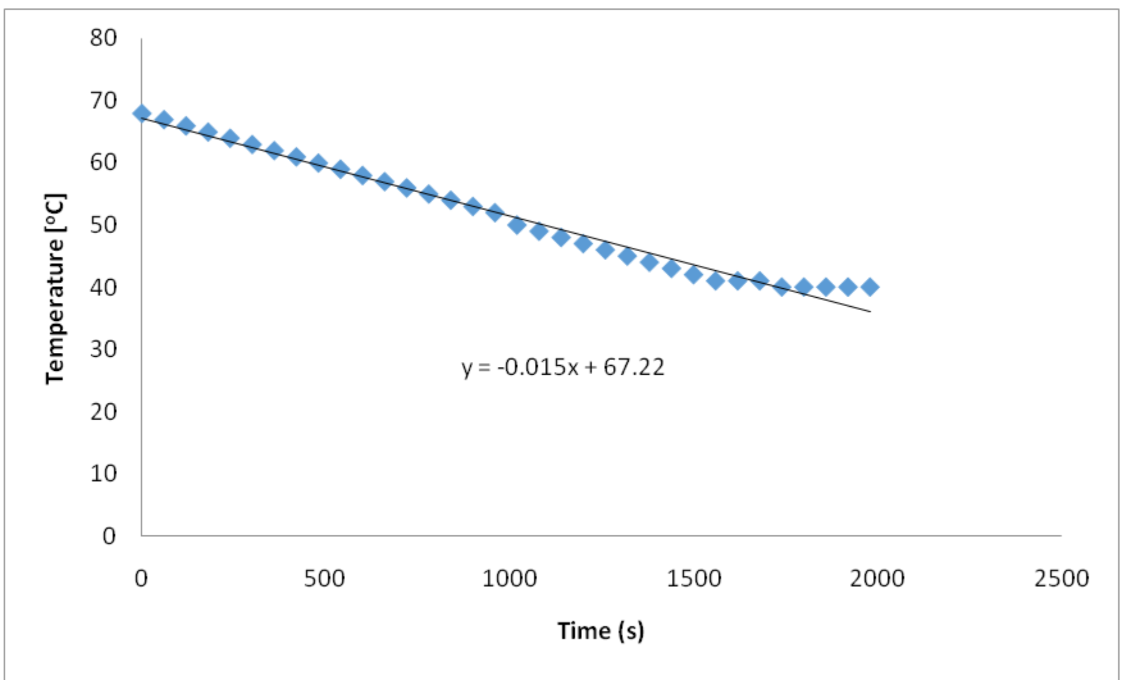

Figure 2: Graph of Temperature vs Time for FGGC ROAD

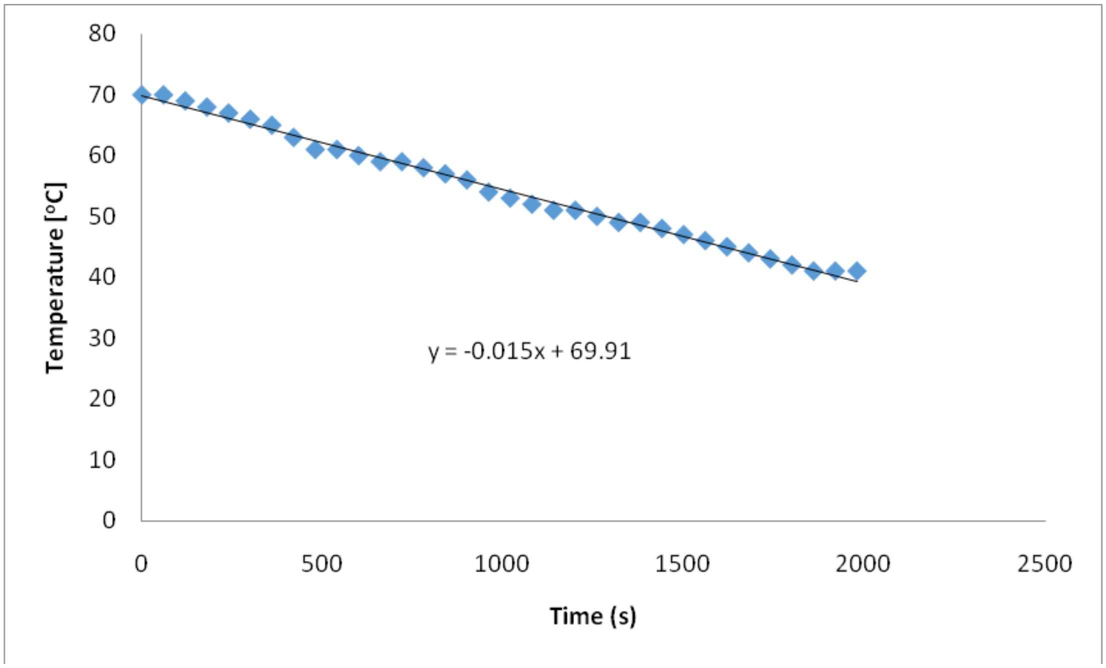

Figure 3:Graph of Temperature vs Time for ATC

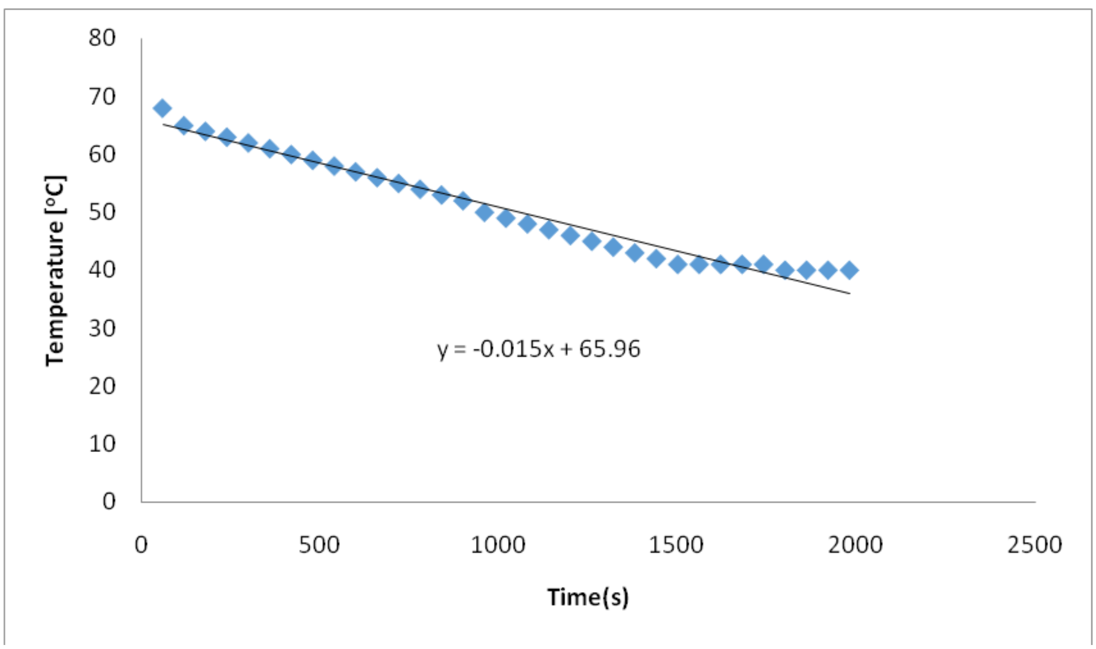

Figure 4: Graph of Temperature vs Time for Sabon-Gari

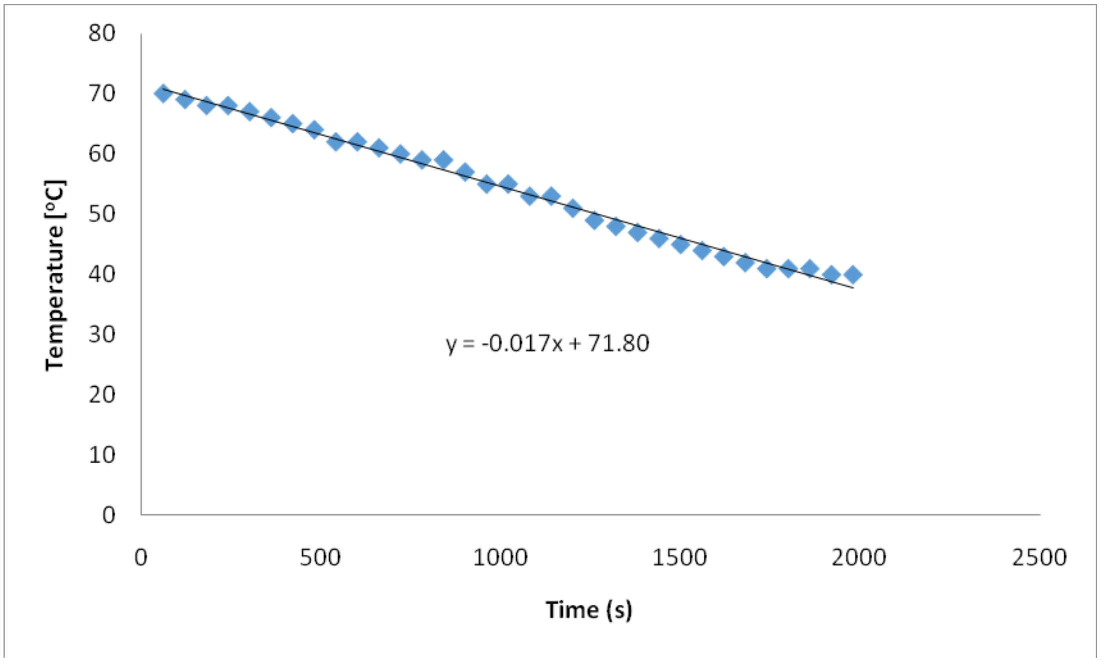

Figure 5: Graph of Temperature vs Time for Ungwan Kasa

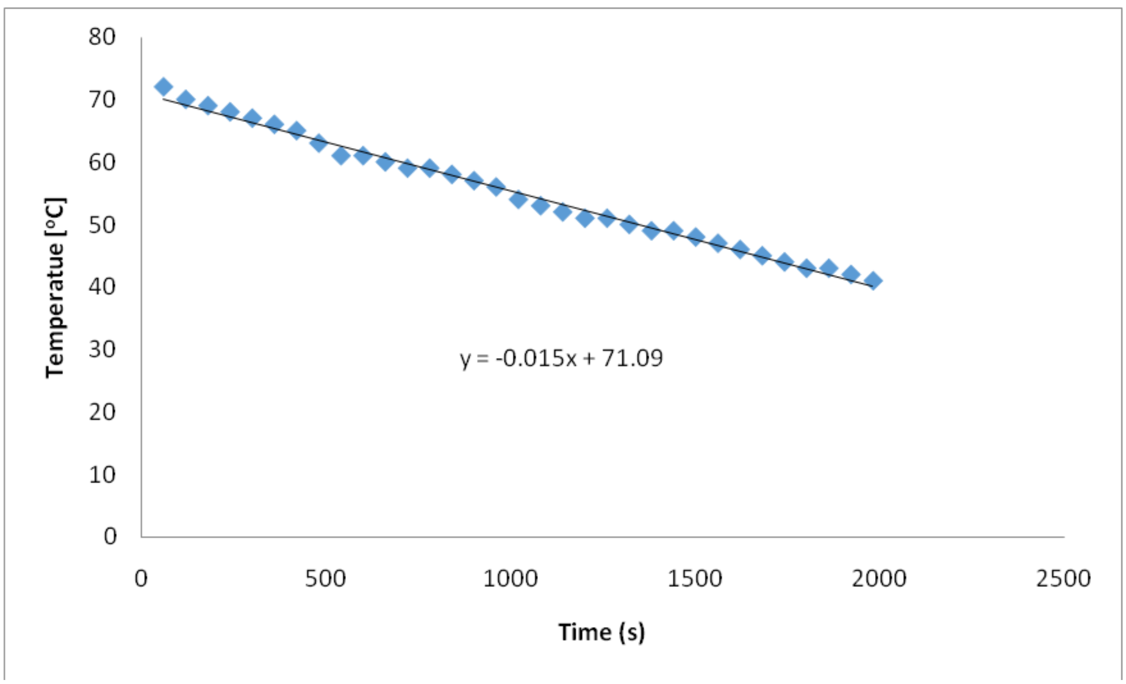

Figure 6: Graph of Temperature vs Time for Mayo-Dasa

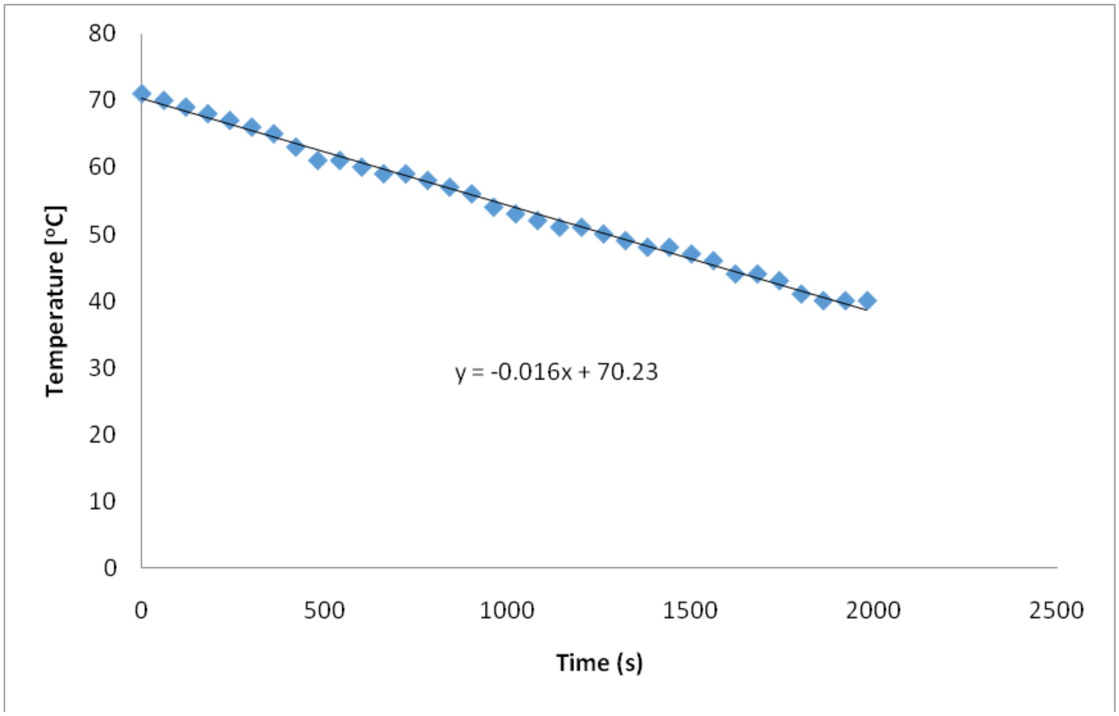

Figure 7: Graph of Temperature vs Time for Kona

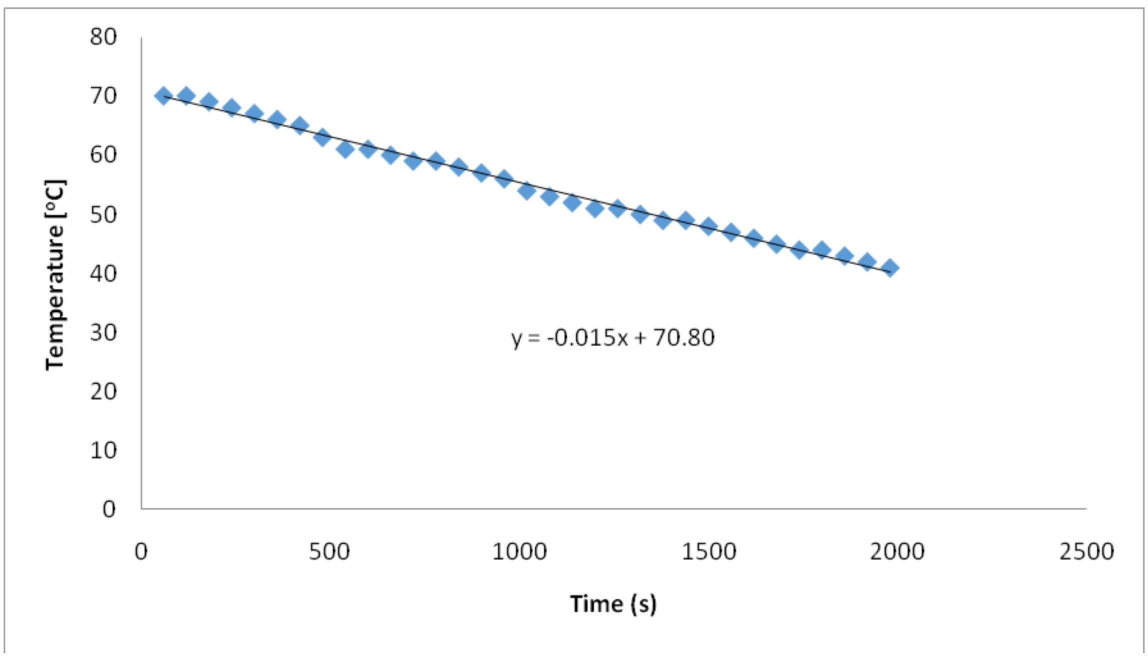

Figure 8: Graph of Temperature vs Time for Abuja Phase2

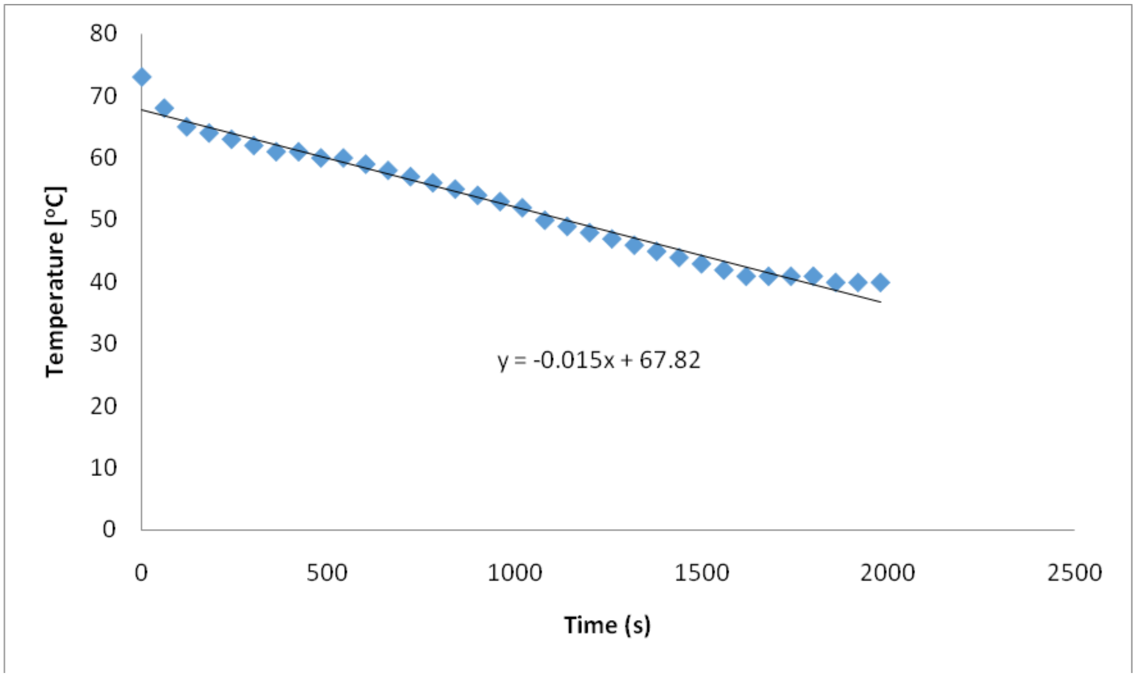

Figure 9: Graph of Temperature vs Time for TADP

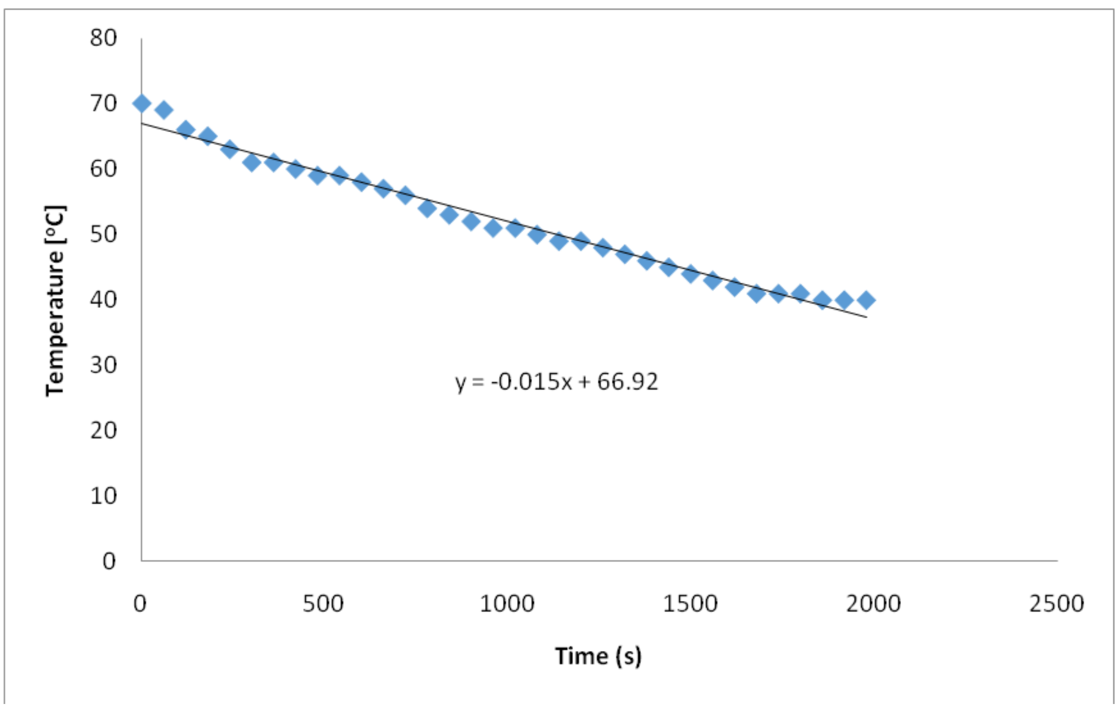

Figure 10: Graph of Temperature vs Time for GULLUM

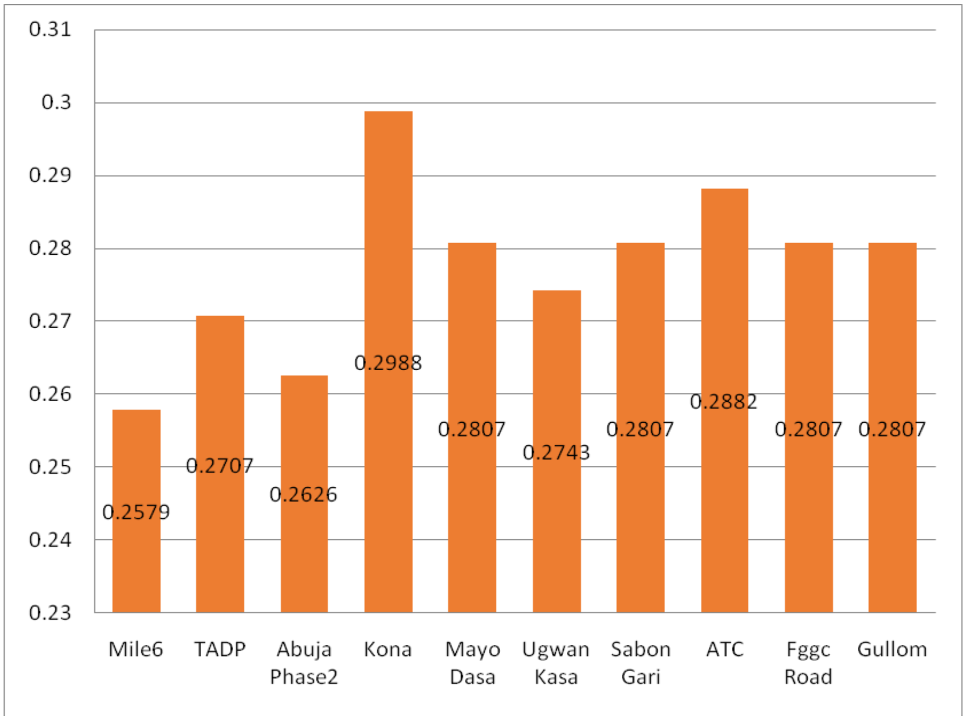

Figure 11:Results of thermal conductivity of the different locations

V. CONCLUSION

The thermal conductivity of the soil samples from the ten selected locations of Jalingo metropolis has been properly evaluated and analyzed using the Lee disc apparatus and the effects of moisture content of the soil samples were carefully analyzed using the compaction test method.The result obtained shows that the effect of moisture content on the thermal conductivity of the selected soil samples increases with increasing soil density.The soil sample obtained at FGGC Road, UgwanKasa, Gullom, TADP, Mayo Dasa and SabonGari ward is sandy soil. The soil at Abuja Phase2 and Mile 6 are Clay soil while those at Kona and ATC are loamy soil. It is observed that the soil samples obtained have the same or similar engineering and agricultural behavior, because the growth and development of a crop may be determined to a large extent by soil thermal capacity.

VI. REFERENCES

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