

MEASUREMENT OF PHYSICOCHEMICAL PROPERTIES, ELECTRICAL AND THERMAL CONDUCTIVITY OF WOOD ASH FOR EFFECTIVE SOIL AMENDMENT

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ABSTRACT

The ability of the soil to regulate heat energy is important for plant growth, soil texture and strength. Many agricultural soils are acidic in nature which tends to limit plant growth and microbial activity. Aside from agricultural lime, wood ash is used to amend physical and physicochemical properties of the soil. To maintain the soil hydraulic and physicochemical properties and to increase plant yield, it is important to know the physicochemical and physical properties of the ash used. The physicochemical and physical properties vary across various plant species. Ash samples from seven different plants were used for this study. The Horiba metre was used to measure the electrical conductivity, pH, Total Dissolved Solid (TDS) and salinity of the samples, while the Lees Disc apparatus was used to measure the thermal conductivity of the samples. The study revealed that *moringa oliefera* ash has the highest salinity, TDS and Electrical conductivity, while *azadichta indica* and *tiobroma cacao* have least pH. Also, *Kyah seleelygalisis* and *azadichta indica* had the highest and lowest thermal conductivity respectively.

Keywords : wood ash, electrical conductivity, salinity, total dissolved solid, soil amendment.

INTRODUCTION

Burning is a chemical reaction which occurs when heat energy reacts with sufficient oxygen leading to a chemical change. When a material undergoes a chemical change, its physical, structural and chemical properties change. Wood ash is a by-product of combustion of wood material. It is a chemical product or powdered residue from the destructive combustion or burning of wood. In many rural communities where biomass is their major source of energy, wood ash is perceived as a waste product. As a result of large quantities of wood combusted annually in Hungary, wood ash is seen as a waste rather than a by-product which is used for refilling mine-shafts ^[1]. Wood ashes have different constituents and nutrients, depending on the species of the plant that is burnt, the quality of the wood burnt and the parts of the plant used. Mineral content in plant's roots and branches than in the logs, hence the part of the plant burnt has impact on the quality of ash produced ^[1]. Ash contains all constituents of wood in concentrated form, aside carbon, nitrogen and hydrogen, which are expelled during burning. Aside from hydrogen and nitrogen expelled during combustion, all constituents of wood in their concentrated forms are found in the ash. Kopecky et al. (1995) ^[2] observed that, many of the Northern Wisconsin's soils are naturally acidic and low in potassium content; hence wood ash

currently being put in landfills has properties that made it suitable for much commercial lime and fertilizer. According to Saarsalmi et al. (2001) ^[3], wood ash was confirmed to be a good source of K, P, Mg, Ca and micronutrients. Ashes from sesbenia wood incorporated into the soil has been found to increase grain yield in maize plant and application of the ash to young maize plants had significantly increased its yield ^[4]. Wood ash also influenced soil's chemical properties such as increasing its effective cation exchange ability and alkaline saturation, and lowers the concentration of aluminum ^[5].

Studies by Sharland (1997) ^[6] indicated that wood ash has the same liming effect as commercial lime. When compared with traditional limestone, results confirmed that wood ash gives better responses to plant growth because of the additional nutrients it contains ^[7]. The alkalinity may vary from ash of one plant material to another, depending on the chemical makeup of the wood from which the ash is obtained. Hence, it is significant to determine the pH of wood ash obtained from various plant materials to ascertain the level of alkalinity before being used as soil additive. In dried state, clay soils are generally stiff but lose their stiffness when saturated with water. They have low bearing capacity and can easily compress. Clay soils have low shear strength and low bearing capacity can lead to tearing which causes serious damage to buildings and foundations. This thread is usually overcome by excavating the unsuitable soil and replacing with stronger material ^[8]. This process of soil stabilization by excavation is usually cumbersome and financially implicating, hence the need for other methods of soil stabilization. Sakr et al. (2008) ^[9], opines that lime decreases plasticity index, increases workability, increases California Bearing Ratio and soil strength, improves permeability of the soil and discourages shrinkage of soft soil for engineering usage. Ghobadi et al. (2014) ^[8], while performing several laboratory tests on untreated clay soils with lime mixed with pore fluid with different pH values of 3, 5, 7 and 9. The result show that shear strength parameters for the untreated clay increased if the pore fluid had pH of 9. They also found out that lime treated soil with a pH value of 9 has maximum cohesion and friction angle values. Therefore, alkaline media like wood ash are good treatment materials and stabilizers for loose and weak soils for engineering activities.

Electrical conductivity of liquid is affected by the amount of Total Dissolved Solid (TDS) present in it. The term TDS describes all solids (usually mineral salts) that are dissolved in water. All mineral salts dissolved in water are described by TDS. High solubility of salt in water entails higher electric conductivity ^[10]. As electric conductivity measures the extent of water to conduct electric current, it relates the amount of salt in solution and TDS. Salt dissociates into cation and anion to conduct electricity. From the above literature, and for effective soil management, it is important to measure the electrical conductivity and salinity of the soil during amendment with wood ash. The TDS and electrical conductivity of the wood ash should also be known during application to obtain an amended soil with required salinity and EC, since the concentration of minerals varies among different plant species.

The ability of the soil to regulate heat energy is very important to its stability, microbial activities and plant yield. This can be adequately understood with the study of soil thermal properties: thermal conductivity, volumetric heat capacity and soil thermal diffusivity. Aside from its physical properties, thermal properties of the soil predict its temperature effect on seed emergence and heat transport. Soil's temperature enhances both chemical and biological processes involved in plant growth. Soil temperature is not constant, seasonal and daily fluctuation in radiant energy enhanced energy changes in the soil surface ^[11]. Low soil temperature discourages nutrient uptake by plant due to high soil

viscosity. To encourage nutrient uptake, it is necessary to increase soil temperature, thereby reducing its viscosity ^[11]. Different soils have variable soil water retention and transmission for plant intake. This is as a result of their variable thermal and emissivity. That is to say, soil temperature is a function of heat flux into the soil as well as heat exchange between the soil and its environment ^[12].

The increase in soil temperature can cause damage to organic matter in the soil, since high temperatures discourage organic activities. According to Onwuka & Mang (2018) ^[11], decrease in organic matter and reduction in clay size reduces cation exchange capacity of the soil. Ylivainio & Peltovuori (2012) ^[13] as cited in (Onwuka & Mang, 2018) ^[11], observed that water-soluble phosphorus increased with soil temperature from 5 °C – 25 °C. Soil with very low temperature has low availability of phosphorus since organic matter that produces phosphorus is hindered by low temperature. Soil in very hot regions of the world suffers dehydration which leads to heat induced cracks in the sand-sized particles ^[14]. The knowledge of the level of thermal conductivity of ash from different plant materials would then serve as a guide to soil scientists and agriculturists on the plant whose ash can be added to a given soil for amendment without causing harm to the soil physical, chemical and biological properties, as well as to the plants grown on it. This necessitated the present study.

MATERIALS AND METHODS

The materials used for this study are ashes gotten from the following plants grown in West Africa; Guava tree (*kyah senelygalysis*), Neem tree (*azadichta indica*), Mango tree (*mangnifera indica*), Cocoa tree (*tribroma cacao*), Pea tree (*persea Americana*), Cola nut tree (*cola acuminata*) and Moringa (*moringa olieffera*). For easy analysis, these were coded A-G respectively. Leaves and branches from these plants were obtained and dried at room temperature. They were then burnt in an incinerator to prevent volatile ionic compounds that might likely affect the thermal conductivity of the samples from escaping to the atmosphere than burning in an open space. After burning, the samples were sieved with sieve of 20 micrometers, put in labeled plastic containers and taken to the laboratory for the measurement of physiochemical properties, electrical and thermal conductivity measurement. The Horiba (an automated instrument) was used as a standard instrument to measure the salinity, electrical conductivity and Total Dissolved Solid (TDS) of the sampled solution simultaneously.

Measurement of Thermal Conductivity

The Lee's Disc Apparatus shown in the figure 1 was used for the measurement of the thermal conductivity of the samples. 10g of each sample was measured and sealed in a disc formed paper bag whose thermal conductivity and thickness are known. The thickness of the bag and its content were measured with the aid of a micrometer screw gauge. The disc-like bag was then inserted in the space between disc A and B as shown in figure 1. The sample was heated with 12-volt DC supply till a steady temperature is reached as indicated by the three thermometers. The current source was then switched off and the rate of fall of temperature was taken at an interval of one minute. The same procedure was repeated for other samples for the evaluation of the thermal conductivity of each sample.

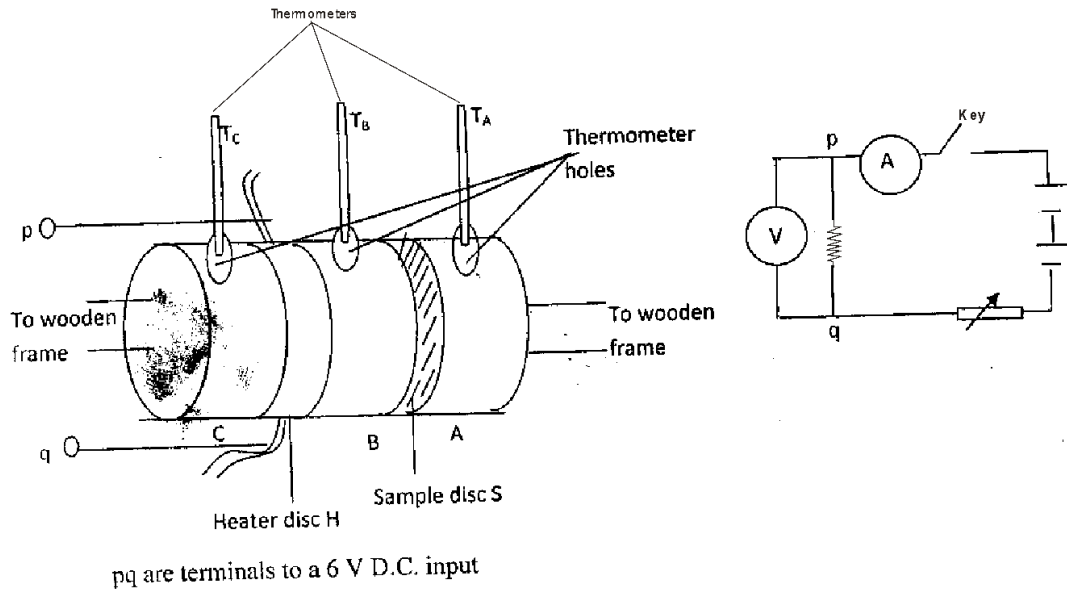


Figure 1. Less disc Apparatus for thermal conductivity of solid material

Theory

Let θ_A , θ_B and θ_C represent the temperatures in excess of room temperature of discs A, B and C respectively. When steady state has been reached, $\frac{de}{dt}$ represent the rate of emission of heat from the exposed surfaces measured in $\text{Jm}^{-2}\text{S}^{-1}\text{C}^{-1}$ excess temperatures. Assuming that the temperature of the specimen S is the mean of the temperatures of A and B, the total heat emitted per second is given, by

$$\frac{Q}{t} = \frac{de}{dt} a_A \theta_A + \frac{de}{dt} a_S \left(\frac{\theta_A + \theta_B}{2} \right) + \frac{de}{dt} a_B \theta_B + \frac{de}{dt} a_C \theta_C \tag{1}$$

Where a_A , a_B , a_C and a_S are the exposed surface areas of A, B, C and S respectively. Now the heat emitted per second is all supplied by the heating element. This is given by

$$\frac{Q}{t} = IV \text{ (JS}^{-1}\text{)} \tag{2}$$

Where I, is the current measured in amperes and V is the potential drop in volts across the heating element. From equation 1, we have

$$IV = \frac{de}{dt} a_A \theta_A + \frac{de}{dt} a_S \left(\frac{\theta_A + \theta_B}{2} \right) + \frac{de}{dt} a_B \theta_B + \frac{de}{dt} a_C \theta_C \tag{3}$$

Hence,

$$\frac{de}{dt} = \frac{IV}{a_A \theta_A + a_S \left(\frac{\theta_A + \theta_B}{2} \right) + a_B \theta_B + a_C \theta_C} \tag{4}$$

The heat conducted through S per second is given by

$$q = kA \frac{\theta_B - \theta_A}{d} \quad (5)$$

Where A, is the cross-sectional area of S, d the thickness and K, the thermal conductivity of S. Now the heat entering S from B does not pass into A since some of it is emitted from the curved surface of S. the heat flowing through S is therefore taken as the mean of the heat entering S from B and that leaving S for A. The heat entering S from B is that which is emitted by S and A together. It is given by

$$\frac{de_{AS}}{dt} = \frac{de}{dt} a_A \theta_A + \frac{de}{dt} a_S \left(\frac{\theta_A + \theta_B}{2} \right) \quad (6)$$

The heat leaving S for A is that which is emitted by A alone. It is given by, $e a_A \theta_A$. The mean of this is given by

$$\frac{1}{2} \left[e a_A \theta_A + e a_S \left(\frac{\theta_A + \theta_B}{2} \right) \right] = e a_A \theta_A + \frac{1}{4} e a_S (\theta_A + \theta_B) \quad (7)$$

At steady state, (2) and (3) are equal, hence

$$kA \frac{\theta_A + \theta_B}{d} = \frac{de}{dt} a_A \theta_A + \frac{1}{4} \frac{de}{dt} a_S (\theta_A + \theta_B) \quad (8)$$

Therefore

$$k = \frac{de}{a(\theta_A + \theta_B)} \frac{de}{dt} a_A \theta_A + \frac{1}{4} \frac{de}{dt} a_S (\theta_A + \theta_B) \quad (9)$$

Measurement of Cooling Rates of the Ash Samples

From cooling rates, the sample was heated to steady temperatures of 60-80°C. The power source was then switched off and the sample allowed to cool. The falling temperature of the ash sample was recorded after every two minutes interval as it drops after 34 minutes. The same procedure was repeated for other ash samples. Theoretically, the time rate of decrease of temperature is proportional to the difference in initial temperature before cooling and the surrounding as shown below.

$$\frac{d\theta_s}{dt} \propto (\theta_s - \theta_R) \quad (10)$$

Hence,

$$\frac{d\theta_s}{dt} = -k(\theta_s - \theta_R) \quad (11)$$

Where k , is a positive constant known as cooling constant, and the negative sign indicates that the temperature is decreasing. Using method of separation of variables and integrating we obtained

$$\theta_s = \theta_o e^{-kt} \quad (12)$$

Where,

$$\theta_o = \theta_s - \theta_R \quad (13)$$

Where θ_R , represents the ambient temperature of the disc and θ_s , falling temperature of the samples. A graph of temperature θ_s against time t , gives an exponential decay curve with gradient, which is the rate of cooling k , and is a determining factor of the time it takes an ash sample to adjust between their high and lower temperature ranges.

RESULTS AND DISCUSSION

Electrical Conductivity and Physiochemical Properties

The electrical conductivity and physicochemical properties of the wood ash samples coded A-G are presented in table 1 below. The temperature drops of the samples are presented in the table 2, while the rate of the fall of temperature for each sample is showing in figures 2 - 8 for the determination of the thermal conductivity of the samples.

Table 1. Electrical conductivity, pH, salinity and TDS of the samples

Ash sample	Electrical conductivity (Ω /millivolt)	pH	Salinity (PPT)	TDS (mg/Litre)
A: Guava tree (<i>kyah senelygalysis</i>)	40.00	10.78	3.00	389.00
B: Neem tree (<i>azadichta indica</i>)	49.00	11.52	1.60	485.00
C: Mango tree (<i>mangnifera indica</i>)	35.00	10.79	1.75	209.00
D: Cocoa tree (<i>tribroma cocoa</i>)	31.50	11.06	1.60	197.50
E: Pea tree (<i>persea americana</i>)	24.00	10.55	1.05	132.50
F: Cola nut tree (<i>cola acuminata</i>)	39.00	10.67	0.74	382.00
G: Moringa tree (<i>moringa olieferra</i>)	52.00	8.88	5.15	579.00

From Table 1, it is indicated that salinity of the samples does not follow the same variation as electrical conductivity and TDS. Although, *moringa olieferra* ash has the highest values of salinity, TDS and electrical conductivity, *cola acuminata* has least salinity but its electrical conductivity is greater than that of *persea americana*. Excess salt in the soil increases its osmotic pressure, which is not suitable for agricultural activities. Although, plant nutrients are readily available in the form of cations such as Na^+ , K^+ , Ca^{2+} and Mg^{2+} , along with anions such as Cl^- , SO_4^{2-} , NO_3^- and CO_3^{2-} , excessive accumulation of these ions when come in contact with acid rain leads to high soil salinity. From table 1, all the samples fall within the threshold of normal salinity required for agricultural practices ^[15]. Hence, soil amendment with wood ash will not influence the salinity content of the soil.

Samples with higher electrical conductivity like *moringa olieferra*, *azadichta indica*, and *kyah senelygalysis* is an indication of presence of excessive Na^+ . Soil amendment with these samples should be in moderate quantity to prevent poor tilt and low permeability that resist plant growth. From the values of TDS and electrical conductivity above, liming a

piece of land that is sandy in nature, *moringa oliefera* ash will be suitable. This is because sandy soil has low electrical conductivity due to its low cation content. In the absence of *moringa oliefera* ash, ashes from *azadichta indica*, *kyah senelygalysis* and *cola acuminata* can also be used to amend the electrical conductive properties of sandy soil. To increase the basicity of clay soil (which is characterized by high electrical conductivity), ashes from *tiobroma cacao*, *mangnifera indica* and *persea americana* can be used and the soil would still remain within the threshold of its electrical conductivity [16] *azadichta indica* and *tribroma cacao* have the highest pH values, while *moringa oliefera* has the lowest. *kyah senelygalysis*, *mangnifera indica*, *persea americana* and *cola acuminata* have pH values that are within the same range. This indicates that small quantity of *azadichta indica* and *tribroma cacao* will be required to neutralize an acidic soil while much of *moringa oliefera* will be needed for liming. Moderate amount of *kyah senelygalysis*, *mangnifera indica*, *persea americana* and *cola acuminata* are required for liming.

Thermal conductivity of the wood ash samples

The results of the cooling rate experiment used for the determination of the thermal conductivities of the five wood ash samples are presented in Table 2.

Table 1. Results for fall of temperature of the ash samples

Falling Temperature of Ash Samples (°C)							
Time (min)	A	B	C	D	E	F	G
0	70	70	68	67	74	78	66
2	67	69	66	65	72	76	64
4	64	68	64	63	70	74	62
6	61	67	62	61	68	72	60
8	58	66	60	59	66	70	58
10	55	65	58	57	64	68	56
12	54	64	56	55	62	66	54
14	50	63	54	53	60	65	52
16	47	62	53	51	59	64	50
18	44	61	51	49	57	62	48
20	41	60	49	47	56	61	46
22	40	60	47	45	54	60	44
24	37	60	45	43	52	60	42
26	34	59	43	41	50	58	40
28	28	58	41	39	49	56	38
30	26	57	39	37	47	51	36
32	22	56	37	35	45	49	34
34	19	55	35	33	43	47	32

For the sample A, the temperature initially is falling at a rate of 1.5°C per minute before increasing to 2°C per minute as the time approaches half an hour. At the 34th minute, the temperature of sample A dropped to 19°C. The ease at which the sample lost heat energy is an indication of having relative high thermal conductivity among the studied samples. As observed in table 2, the temperature of the sample B falls at one degree Celsius per minute. The slow rate at which the sample lost energy is an indication of its low thermal conductivity. The temperature of the sample only drops by 15°C after 34 minutes. This is about 36°C difference when compared to the temperature fall of sample A after 34 minutes. It is also observed that there is no change in the temperature of sample B at time intervals between 20, 22 and 24 minutes. Hence, the sample B can be attributed to having

very low ionic concentration, making it conduct least. Samples C, D and E are observed to be losing heat at the rate of 1°C per minute. As the time of cooling increases, the rate of fall of temperature of the samples decreases by a little fraction. Only G maintained a steady fall of temperature while F tends to behave like B since there is no change in temperature of the sample after the interval between 20 and 21 minutes.

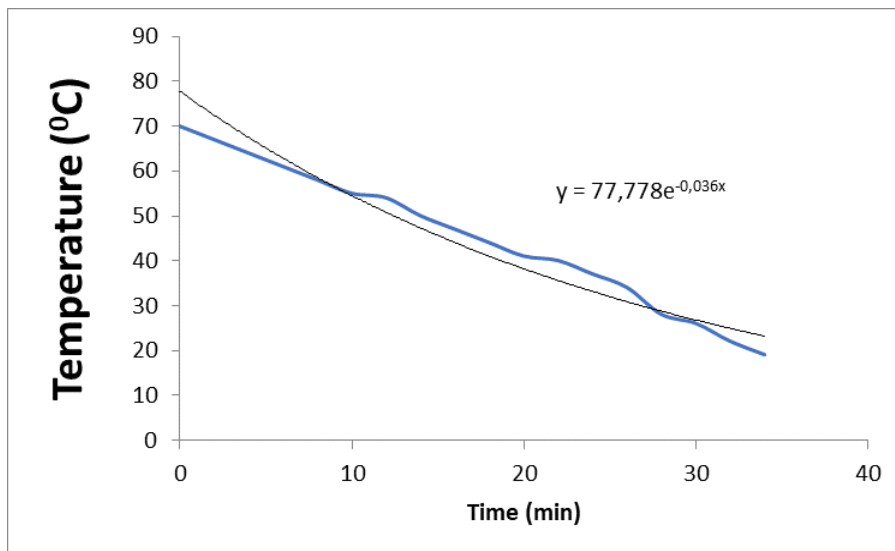


Figure 1. Rate of fall of temperature for *kyah senelygalysis* ash

Figure 1 presents the rate at which the sample A cools. The slope of the curve denotes the thermal conductivity of the sample, while the intercept on the temperature axis gives the highest temperature which the sample reached before it starts cooling. From the plot, the

value of k , is obtained to be 0.036°C per minute. The value of k is slightly higher compared with that of other samples, hence the sample A can be used to amend a typical sandy soil that is characterized by poor thermal conductivity owing to its poor water retention capacity due to its large diameter.

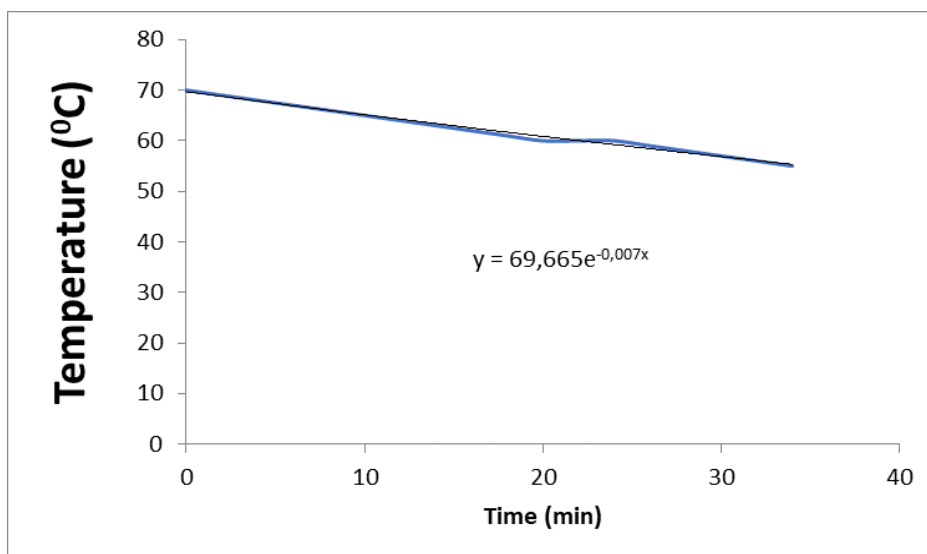


Figure 2. Rate of fall of temperature for *azadichta indica* ash

The rate of fall of temperature with time for sample B is displayed in Figure 2. Due to the slow rate of cooling of the sample, the plot of temperature against time is taking a linear

form. From the plot, the value of k for the *azadichta indica* ash is obtained as 0.007°C per minute. This value of k , for the sample suggests that its content is less in ionic concentration, which is indicated by slow thermal conductivity. Sample B is not advisable to be used for soil amendment for irrigation and hot weather conditions. This is because its poor thermal properties will restraint it from conducting radiant energy received from the sun leading to wildering of crop plants.

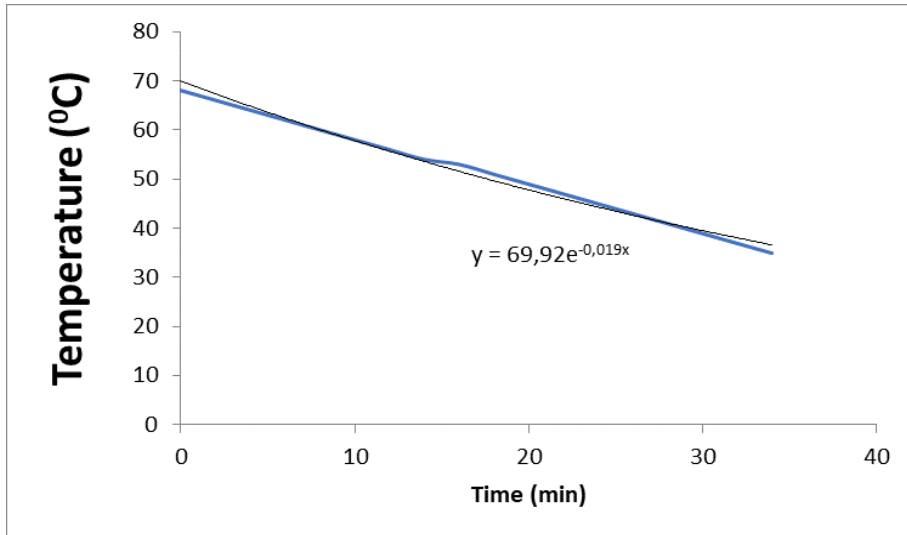


Figure 3. Rate of fall of temperature for *mangnifera indica* ash

Figure 3 gives the rate of cooling of sample C. The conductivity of the sample is 0.019°C per minute, which is moderate for soil microbial activities. Sample C can be used to amend soil with higher thermal conductivity and the soil will still maintain its osmotic and hydraulic pressure.

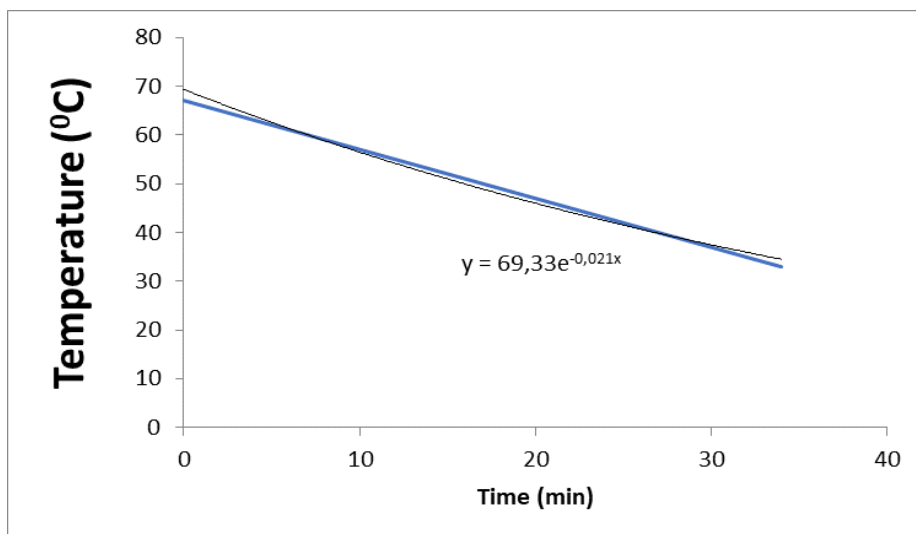


Figure 4. Rate of fall of temperature for *tiobroma cacao* ash

Figure 4 presents the rate of cooling of sample D. The thermal conductivity of the sample is given by the slope of the cooling curve. As obtained from the graph, the value of k for

the sample is 0.0210C/min. As obtained from table 1, the rate of cooling of the sample followed a regular pattern, hence there is no alternating of its cooling curve.

From the plot of the rate of cooling of sample E (Figure 5), the thermal conductivity of the sample E, is obtained as $k = 0.015^{\circ}\text{C}/\text{min}$. Samples such as E would serve as good materials for the amendment of clay soil, which have high thermal conductivity so that the high rate at which heat energy is conducted away from the soil is moderated. When much heat is conducted away from the soil especially during the wet season, the soil becomes damped, this discourages emergence of seeds.

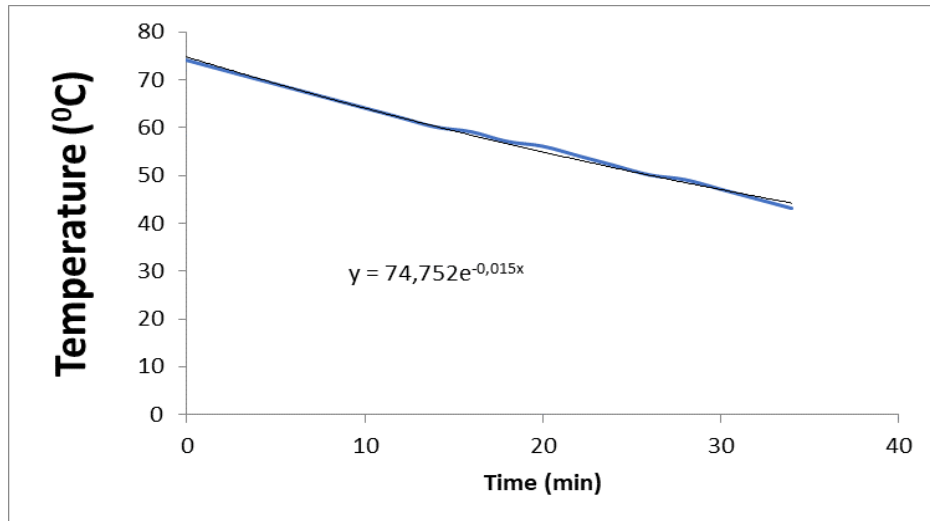


Figure 5. Rate of fall of temperature for *persea americana* ash

Figure 6 represents the rate of fall of temperature of sample F, the rate of cooling of the sample as denoted by the slope of the cooling curve is 0.015°C/min. The thermal conductivity of the sample is the same as that of E, but there is a slight variation in the cooling curves of the two samples arising from the fluctuation of the time of cooling of sample F towards the end of the observation.

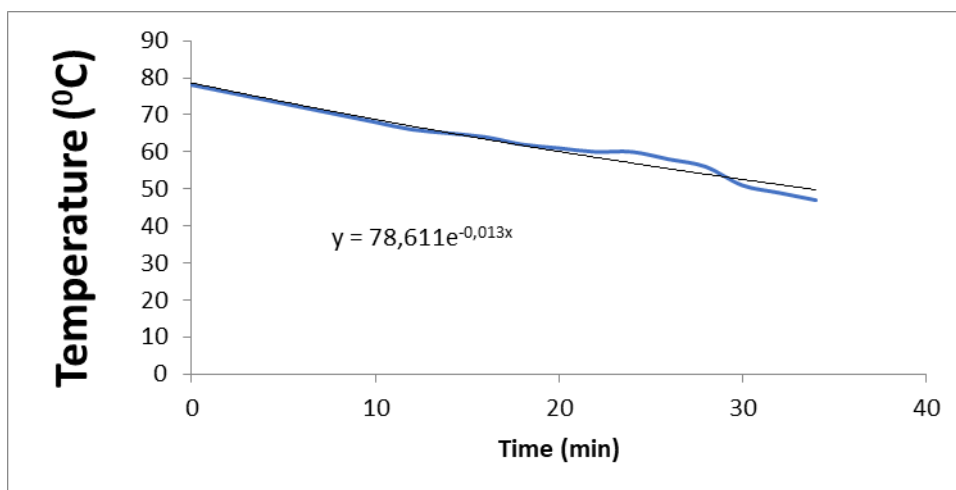


Figure 6. Rate of fall of temperature for *cola acuminata* ash

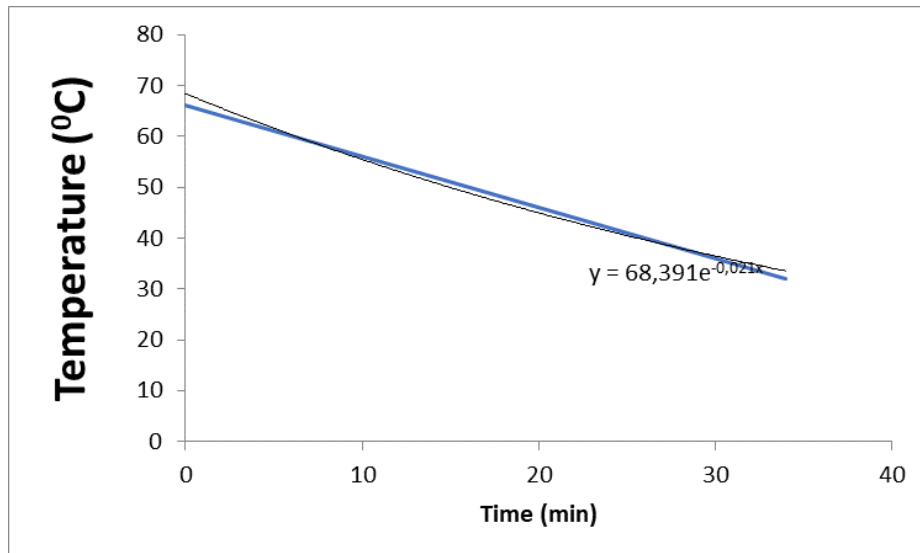


Figure 7. Rate of fall of temperature for *moringa oliefera* ash

Figure 7 show the rate of cooling of sample G. As obtained from fig. 4, the rate of loss of heat energy of sample G takes the same form as sample D. This makes both curves similar

and has equal value for k . The sample will conduct low heat energy and can be used for soil amendment in cold weather conditions. This is because the amended soil in extreme low temperature will conduct less heat less heat energy and conserve more to be used by soil organisms and plant roots.

CONCLUSION

Wood ash plays a pivotal role in soil stability and enhances its physical and chemical characteristics. The study of physiochemical properties of wood ashes from some plants indicated that *moringa oliefera* had the highest value of salinity. The study also showed that salinity does not follow the same variation as electrical conductivity and TDS but there exists a direct variation between TDS and electrical conductivity of the samples. It is seen that TDS increases with electrical conductivity.

The thermal conductivity of soil varies seasonally due to the size and moisture content of the soil. Soil can be stabilized or amended by using wood ash to achieve desired physical characteristics. Hence it is important to know the thermal conductivity of the ash to be used for the stabilization of a particular soil. The study for the determination of the thermal conductivity of ashes obtained from *kyah senelygalysis* (A), *azadichta indica* (B), *mangnifera indica* (C), *persea americana* (D), *persea americana* (E), *cola acuminata* (F) and *moringa oliefera* (G) sample was executed by Lee's Disc method of determining thermal conductivities of materials. The analysis reveals that *kyah senelygalysis* (A) ash has high value of the thermal conductivity of $0.036^{\circ}\text{C}/\text{min}$ among the studied samples, followed by *mangnifera indica* (C) ash. It was infered that these samples will be good amending material of soil that is predominantly sand in nature since sandy soil has low thermal conductivity. The sample *azadichta indica* (B), has the least value of

$k=0.007^{\circ}\text{C}/\text{min}$, which is suggested to be suitable for the stabilization of clay soil that has high thermal conductivity. In doing so, the desired soil hydraulic conductivity is maintained. The samples *mangnifera indica* (C), *persea americana* (D), *persea americana* (E), *cola acuminata* (F) and *moringa oliefera* (G) have similar and moderate thermal

conductivity. Hence, they are suitable for stabilization of different soils with different thermal properties.

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