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A NOVEL TREATMENT FOR DETERMINING THERMAL CONDUCTIVITY OF THE SOIL SUBSTRATES FOR SELECTING SUSTAINABLE GROWING MEDIUMS IN TERMS OF THERMAL RESISTANCE

SUMMARY

The Thermal conductivity of the soil is important to determine the horticultural performance of growing medium. Microclimatic features influence the viability of soil mixtures for vegetation. The goal of this study is to assess the heat conductivity of soil mixture samples comprising Coir, Biochar, Sawdust, Wood bark, and Compost in order to discover the best growth medium in terms of thermal resistance. Specimens were prepared by mixing 60% of raw materials with 40% topsoil and moulded into cylinders. Each sample were converted into semi solids and undergone for thermal conductivity apparatus measurements. Thermal conductivity of each specimen was determined using mathematical analysis based on experimental readings. The calculated results were used to deduce thermal resistance. Thermal conductivity values of all specimens were observed in the range from 0.64 W/mK to 0.91 W/mK. The maximum and minimum thermal conductivity magnitudes were exhibited by Sawdust (60:40) and Wood bark (60:40) respectively. In terms of suitability as a growing medium, Wood bark (60:40) contains highest thermal resistance while the lease thermal resistance was determined in Sawdust (60:40) due to its high thermal conduction. This research concludes that Wood bark (60:40) is the most convincing substrate in terms of thermal sustainability.

Keywords: Growing medium, Thermal resistivity, Thermal Conductivity Apparatus, Microclimatic features, urban ecosystem

INTRODUCTION

Soil is one of the most important and most complex natural resources, but current developments (climate change, soil erosion, and urbanization) increasingly threaten this valuable resource (Spalevic *et al.*, 2020). According to the United States Department of Agriculture soil is defined as a natural body

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comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment (Spalevic, 2011; Santana *et al.*, 2021; Spalevic *et al.*, 2020; Rodrigues Neto *et al.*, 2022). Plant substrate is defined as a substance on or in which plants grow. Thus, even soil can be viewed as a substrate. The main functions of the substrate are generally: providing plant anchorage, and delivering water, nutrients and oxygen to the roots.

Thermal property of aggregates is a primitive requirement in many fields like engineering, materials science and agriculture. Recent studies have shown that there is an increasing trend of research activities to find thermal properties. According to (Ghuman and Lal., 1985) the microclimatic features are influenced by thermal properties of soil, most particularly the stand establishment, germination of crops and the emergence. Thermal conductivities of the soil substrates are determined by elements that may be classified into two categories: inherent characteristics and externally manageable ones. Soil texture and the mineral content can be categorized into inherent properties (Wierenga *et al.*, 1969) while soil management and moisture content can be included into the externally manageable factors. Among the manageable factors, moisture content is the most difficult parameter to manage (Yadav and Saxena, 1973). In the early studies (Riha *et al.*, 1980), special consideration was given to studying the effect of water content on the thermal conductivity of soil aggregates, and it was discovered that the maximum state of soil conductivity is observed during the moist state of soil because the flow of mineral ions facilitates more thermal conduction than the dry state of soil. Studies conducted by Parikh *et al.*, (1979) and Noborio & McInnes (1983) have revealed a decrease in thermal conductivity along with the increased concentration of mineral salts such as $CaCl_2$, $MgCl_2$, NaCl and Na_2SO_4 especially in 0.1 mol/kg of heterogeneous soil solution. Thermal conductivity of water moistened Quartz sand was comparatively higher than the thermal conductivity of same type of Quartz sand moistened with 0.25 mol/kg KOH (Globus & Rozenshtok, 1989). Therefore, the study has been conducted with moistened substrate specimens to study the thermal conductivity behaviour without discrepancy.

The trial approach to measure the thermal conductivity of soil by using temperature rise or fall was first developed in the studies based on soil analysis (Jackson & Taylor, 1965) and the method was further developed with volumetric heat capacity of soil from volumetric proportions in accordance to shape of the soil aggregates (De Vries, 1963). One of the milestones in thermal conductivity studies was the discovery of Dual probe technique (Bristow *et al.*, 1993; Kluitenberg *et al.*, 1993). In this method, two needle probes in parallel are placed; one contains a heater and the other a temperature sensor. Dual probe technique was used in the studies conducted by Sailor *et al.* (2008) under ASTM D5334 guidelines to measure the thermal conductivity of soil mixtures. However, the needle probe method is a relatively expensive way and it requires certain expertise in using the microcontrollers and sensors. Therefore, it is not always a feasible option in the developing countries, where the artificial intelligence programming technology is still not in use widely. Hence, the entire information about the corresponding soil specimen needs to be completely known to use it as an input data. Furthermore, this method is entirely based on the programming of sensors, thus resulting in an unpredictability of errors in measurements if a lack of skills in programming were to prevail.

Lee's apparatus is effective in finding the thermal conductivity of weak conductors, it is not appropriate in this circumstance since it is difficult to mould wood bark and Biochar specimens into a uniform disc shape. Although if moulding were possible, the non-uniformity in aggregate distribution of the five selected specimens would not be a suitable specimen state for performing Lee's disc technique according to the outcomes of past research on gelatine-silica aerogel, the heterogeneous mixtures cannot be moulded as discs. Therefore, study is designed to find the thermal conductivity of five different substrate mediums and to ultimately study their thermal resistance behaviours for comparative analysis using the customized thermal conductivity apparatus. The objective is to assess the heat conductivity of soil mixture samples comprising Coir, Biochar, Sawdust, Wood bark, and Compost in order to discover the best growth medium in terms of thermal resistance.

MATERIAL AND METHODS

Theory. Heat can be transferred by three different methods like conduction, convection and radiation. Each method can be analyzed by in its corresponding mathematical principles. Total heat transfer through a material in terms of the material's thermal conductivity (k) Surface area of conduction (A); temperature gradient (T); material thickness (H); heat transfer (q); and time of conduction (t) is:

$$\Delta q = \frac{\Delta T k A \Delta t}{H}$$

Therefore, thermal conductivity $k = \frac{H \Delta Q}{\Delta t A \Delta T}$ in (in cal/cm.sec.℃)

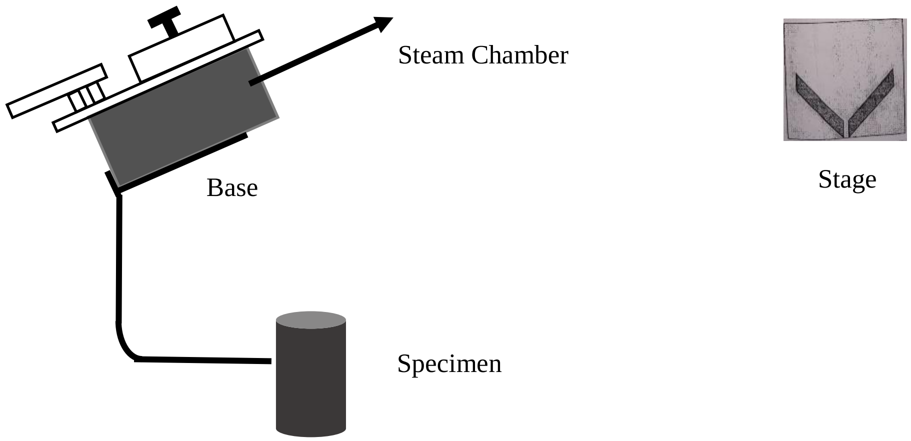

Figure 1. Thermal conductivity

Thermal resistance (R) could be derived as $R = \frac{\Delta x}{kA}$

Sampling and Analysis. The specimens were prepared at the Faculty of Applied Science, South Eastern University of Sri Lanka (SEUSL) in May 2021 by using the five growing mediums namely Biochar, Coir, Sawdust, Wood bark and Compost. 60% of each specimen was mixed with 40% of topsoil. The prepared samples were compacted with 35 blows under ASTM standards and moulded cylindrical shapes. Afterwards, each moulds were converted into semi solid mixtures through mixing with water under 1:2 (w/w) according to ASTM D70 guidelines. The experiment was carried out in open air at room temperature. Specimens were put on stage so that they could move freely. Prior to evaluating each specimen, the temperature of the steam chamber was monitored. Because the testing laboratory was not located at the Mean Sea Level, it cannot be assured that the equipment is at 100°C. Following that, heat is allowed to circulate through the sample. The total time were measured immediately when the first sight of the melting from specimen was observed. Melting of specimen was allowed to gather in the beaker for twenty minutes and afterwards heat transmission stopped. The mass and temperature of the specimens in the beaker were measured and afterwards entered into the equations. The experiment was conducted for three days. Each specimen was undergone with experimental activities three times under same steps and the corresponding thermal conductivity values were measured. Ultimately, the averaged results were reported, and the thermal resistances of specimens were measured. The determined values were translated into SI units. Table 1: Characteristics of the diary manure based on batch hydrolysis

RESULTS AND DISCUSSION

Thermal conductivity of five chosen substrate specimens are as follows: Biochar, Coir, Sawdust, Wood bark, and Compost amended with soil. Table 1, Table 2, and Table 3 show the computed findings. The results are influenced by external factors such as changes in room temperature, changes in air pressure, and the possibility of human error. As a result, the mean values were computed.

Table 1: Thermal Conductivity results for day 01

Day 01 **Substrate**	**Weight of collected substrate + Beaker (g)**	**Weight of Beaker (g)**	**Weight of substrate**	**Collection time (s)**	**H (cm)**	**T2 - T1**	**Inner diameter (cm)**	**A(cm^2)**	**Thermal Conductivity (W/m.K)**
Biochar (60:40)	57.61	43.28	14.33	1200	2.1	38.3	6.35	31.67	0.69
Coir (60:40)	57.72	42.48	15.24	1200	2.17	38.1	6.35	31.67	0.76
Sawdust (60:40)	60.88	42.45	18.43	1200	2.22	38.4	6.53	33.49	0.89
Wood bark (60:40)	56.16	42.45	13.71	1200	2.08	38.9	6.53	33.49	0.61
Compos t (60:40)	57.58	43.28	14.3	1200	2.1	37.6	6.35	31.67	0.70

Table 2: Thermal Conductivity results for day 02

Day 02 Substrate	Weight of collected substrate + Beaker (g)	Weight of Beaker (g)	Weight of substrate	Collection time (s)	H (cm)	T2 - T1 (℃)	Inner diameter (cm)	A(cm^2)	Thermal Conductivity (W/m.K)
Biochar (60:40)	58.33	43.28	15.05	1200	2.1	38.3	6.35	31.67	0.73
Coir (60:40)	57.47	42.48	14.99	1200	2.2	38.2	6.35	31.67	0.76
Sawdust (60:40)	61.89	42.45	19.44	1200	2.19	38.7	6.53	33.49	0.92
Wood bark	56.4	42.45	13.95	1200	2.13	38.5	6.53	33.49	0.64
Compost (60:40)	58.01	43.28	14.73	1200	2.05	38.1	6.35	31.67	0.7

Table 3: Thermal Conductivity results for day 03

Day 03 Substrate	Weight of collected substrate + Beaker (g)	Weight of Beaker (g)	Weight of substrate	Collection time (s)	H (cm)	T2 - T1 (℃)	Inner diameter (cm)	A(cm^2)	Thermal Conductivity (W/m.K)
Biochar (60:40)	58.04	43.28	14.76	1200	2.06	38.6	6.35	31.67	0.69
Coir (60:40)	58.2	42.48	15.72	1200	2.13	37.9	6.35	31.67	0.78
Sawdust (60:40)	62.88	42.45	20.43	1200	2.1	38.6	6.53	33.49	0.93
Wood bark (60:40)	57.32	42.45	14.87	1200	2.04	38.7	6.53	33.49	0.65
Compost (60:40)	59.26	43.28	15.98	1200	2.12	37.7	6.35	31.67	0.79

Table 4: Mean Thermal conductivity values for test specimens

Substrate	Mean Thermal conductivity	Rank
Biochar (60:40)	0.70	4
Coir (60:40)	0.77	2
Sawdust (60:40)	0.91	1
Wood bark (60:40)	0.64	5
Compost (60:40)	0.73	3

Table 5: Moisture content of substrate specimens

Substrate medium	$W_{sample,sat}$**(kg)**	γ **(kN/m^3)**	$W_{sample,dry}$**(kg)**	γ_{dry}**(kN/m^3)**	**w**	**Rank**
Saw dust	0.409	3.212	0.239	1.874	0.71	1
Coir	0.557	4.370	0.350	2.748	0.59	2
Wood bark	0.554	4.349	0.361	2.835	0.53	3
Bio char	0.579	4.511	0.387	3.040	0.48	4
Food waste	0.657	5.152	0.509	3.994	0.29	5

Table 6: Computation for the average substrate thickness

	Substrate thickness (cm)			
Substrate	**h_1 (Day 01)**	**h_2 (Day 02)**	**h_3 (Day 03)**	**Δx *(cm)***
Biochar(60:40)	2.1	2.1	2.06	2.09
Coir(60:40)	2.17	2.2	2.13	2.17
Sawdust(60:40)	2.22	2.19	2.1	2.17
Wood bark(60:40)	2.08	2.13	2.04	2.08
Compost (60:40)	2.1	2.05	2.12	2.09

Table 7: Experimental outcomes of Thermal resistance

Substrate (60:40)	**A (cm^2)**	**Δx *(cm)***	**k (W/m.K)**	**Thermal resistance R_Θ (K/W)**	**Rank**
Coir	31.67	2.17	0.77	8.91	**4**
Compost	31.67	2.09	0.73	9.06	**3**
Biochar	31.67	2.09	0.70	9.36	**2**
Wood bark	33.49	2.08	0.64	9.79	**1**
Sawdust	33.49	2.17	0.91	7.12	**5**

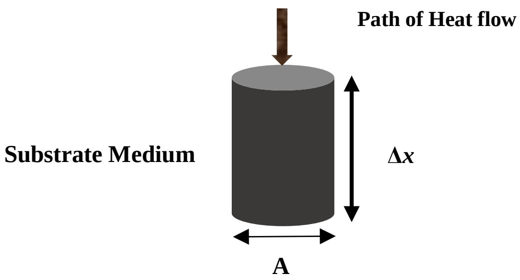

Figure 2: Heat flow across test specimen

Thermal conductivity results in Table 4 has shown that all the specimens exhibits thermal conductivity magnitudes corresponding to "sandy loam" (i.e. 0.64 $Wm^{-1}K^{-1}$ to 0.91 $Wm^{-1}K^{-1}$) soil group. According to a previous study soil thermal conductivity effects, sandy loam possess thermal conductivity from 0.19 $Wm^{-1}K^{-1}$ to 1.12 $Wm^{-1}K^{-1}$ (Abu-Hamdeh and Reeder, 2000; Abu-Hamdeh, 2003).) thus verifying the accuracy of the current experiment executed in this study. The largest thermal conductivity was found in sawdust (60:40), while the lowest magnitude was found in wood bark (60:40). The following part of the analytical investigation looked into the influence of water content reported by (Yadav and Saxena, 1973) on their experimental outcomes. Table 5 shows the calculations to study the effects of moisture content at thermal conductivity of our selected substrates. According to the findings of Table 4 and Table 5, the thermal conductivity of substrate is proportional to its water retaining ability and our study validates the outcomes of Yadav and Saxena (1973).

The primary goal for determining thermal conductivity was to identify the best substrate for heat resistance and thermal comfort for the sustainable agriculture. The heat flow scenario across substrate specimens can be effectively described by Figure 2. The thermal resistances of all five substrates were determined using the heat flow and the equation for computation, as shown in Table 7 where Wood bark (60:40) emerged as the best fitting substrate in terms of thermal resistance. To avoid the observational mistakes experienced while manipulating the Vernier, the average specimen thicknesses were evaluated. Furthermore, the results of Tables 4 and 5 indicated that thermal performance magnitudes of soil substrates could get externally manipulated via altering the moisture content of growing mediums. This finding supports the conclusions reached by Parikh *et al.* (1979); Yadav and Saxena (1973); Riha *et al.* (1980).

Since there were no prior thermal conductivity experiments for the stated substrate materials had been undertaken, the scientists were unable to compare the results to any earlier investigations. The complexity of the default mode of soil, the consistent organic content of each substrate specimen because of climate stability, as well as the volatility of bioactivity within soil are all reasons for the paucity of study in this topic.

CONCLUSION

The findings of this study reveal that heat conductivity varies according to organic content, soil texture and water content. Thermal conductivity increases as moisture content increases.

Furthermore, the study's findings are backed by the conclusion remarks of Abu-Hamdeh and Reeder (2000), which affirm that all types of soil correspond to the sandy loam category, which is excellent for horticulture and planting. It demonstrates that the test was done without mistakes because the selected growth media specimens were previously known before to the experiment that they belonged to the sandy loam type.

Finally, this experimental study on substrates made from organic wastes amended with soils concludes that, in terms of thermal resistance after studying the thermal conductivity behaviour of substrates, the most convincing growing medium would be Wood bark (60:40) and the least suitable would be Sawdust (60:40).

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