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Method Article

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Analysis of physical and chemical properties of alternative substrate material for sustainable green roofs

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Abstract

Green roof is the roof of a building that is partially or completely enfolded with vegetation and its associated components. It promotes the sustainability of buildings and provides comfort for urban ecosystem. We have investigated the viability of using organic waste as a growing medium. This study determines the most suitable growing substrate by investigating organic wastes of Sawdust, Wood bark, Bio char, Coir, Compost and Base medium under the parameters of density, moisture content, drought resistance and thermal resistance, contribution for vegetation growth, pH, electric conductivity and nutrient constituents. Investigation of chemical parameters is a unique aspect of this study. New methodologies using mathematical concepts were used to find thermal conductivity and EC of specimens in our research. Preliminary study results shows that the most substrate composition will comprise 60% growing medium and 40% base medium (fertilizer + potting mix).

During the experimental studies, we have compared the test results of each organic waste specimens under the mentioned physical and chemical parameters. Base medium (90:10) has highest bearing capacity to withstand external loads including vegetation and other imposed loads. Sawdust (60:40) exhibited optimum attributes for lightweight substrate by having least saturated unit weight, dry unit weight and the highest moisture content. In terms of drought resistance and vegetation growth, Bio char (60:40) was exceptional. Wood bark (60:40) exhibited the most convincing thermal resistance. The best characteristics in terms of pH, EC and nutrient content were exhibited by Sawdust (60:40), Coir (60:40) and Compost (60:40) correspondingly. Based on final ratings by considering all the experimental results, Coir (60:40) have emerged as the optimum growing medium in terms of physical and chemical properties. The authors emphasize to utilize this experimental study results into large-scale construction industries to promote the urban ecosystems through sustainable green roof constructions.

Keywords: Growing medium, Sustainability, Organic wastes, Physical parameters, Chemical parameters, Urban ecosystems, Substrate composition

1. Introduction

Green roof is the roof of a building that is partially or completely enfolded with vegetation, growing medium and waterproofing membrane. Studies have described that Green roof vegetation would also be a strong solution for Urban Heat Island (UHI) effect due to the facilitation of indoor thermal comfort (Vijayaraghavan., 2016; Parizzo et al., 2011; Pianella, 2017). Furthermore, they promote storm water management with high rate of evapotranspiration (Andresen et al., 2005). There are also much communal benefits by Green roofs due to increased coverage of vegetation that could result the arrival of various birds and arboreal species (Jaffal et al., 2012). There are two types of Green roofs such as Intensive and extensive. Intensive Green roof requires high maintenance. It allows the designer and architect to create an interface akin to park with ample aesthetic view. Extensive green roof system consists lower substrate depth. It is a good platform for shallow root system plants with high drought resisting capacity (Culligan et al., 2014). Extensive green roof systems are much cheaper, hence making it more suitable for wide array of urban buildings.

Growing medium (substrate) plays an integral part at the efficiency, stability and sustainability of Green roof (Ampim et al., 2010). Apart from the storm water retention capacity and vegetation type, the overall success of Green roof is largely affected by the chemical and physical properties of substrates. There are two types of growing mediums in terms of economy such as commercial and non-commercial (Ampim et al., 2010). Commercial type of substrate is purchased in large scale at current industry because they are made of compositions with industrially accepted standards with paternal rights. Non-commercial substrates are prepared based on the customized vegetation aspects (Ampim et al., 2010). In terms of material classifications, the Green roof substrates are classified into Organic matter and mineral soils (Noya et al., 2017). Natural minerals such as gravel, clay, pumice, topsoil and sand can be used as growing mediums. These minerals exhibit high moisture content and electric conductivity. But growing mediums based on natural minerals cause heavyweight at top of the building structure, ultimately resulting on critical conditions for structural stability. Furthermore, they consist poor amount of nutrients, which draws the users to make additional investments for artificial fertilizers to facilitate the plant growth. The authors have selected organic growing mediums as candidate specimens since they are eco-friendly, contain less Sulphur (Ampim et al., 2010) and consists higher water retention characteristics.

Advanced research studies have also formulated the utilization of construction waste materials in growing medium (Ampim et al., 2010) such as rubble bricks, crushed concrete, crushed bricks, subsoil, formaldehyde resins and crushed bricks. The idea of composite substrates has also been tested in various researches using Michigan peat, USGA grade sand, Dolomite, Compost yard, Heat expanded slate and Turkey litter (Ampim et al., 2010). In another study the Grape marc compost, waste zeolite, pumice and Attapulgite clay were tested (Soulis et al., 2017). The common problem observed at using the construction waste materials like recycled aggregates was their heavyweight. Managing the wastes from cooked food remains is becoming a serious environmental issue in developing countries at recent times. Domestic Compost contains high concentration of starch more than 70% on dry matter and proteins up to 14% on dry matter (Melikoglu et al. 2013). The treatment using *amylases*, *amyloglucosidases* and *proteases* easily lead to the release of compounds available for the microbial growth (Simpson et al. 2012). These results based on past studies have made the authors to evaluate the viability of using the Composts made by wastes from consumed food remains as a growing medium in green roofs.

Correct selection of substrate would facilitate the survival of plants and their longevity. The lightweight substrates with low organic contents require the supplementary nutrients and water to maintain major plant growth functions (Getter et al., 2006). Stakeholders in construction industry focus more towards the economic benefits on increasing the user accommodations while little concerns provided towards sustainability of buildings. Therefore, the authors of this research study has drafted the required physical and chemical parameters for an optimum green roof substrate using the appropriate past studies and industrial experiences. Most of the past studies about green roofs have focused more on UHI mitigation (Dunnet., 2010), benefits of green roofs (Vijayaraghavan., 2016) and the hydrological properties of green roofs (Stovin., 2009). This research emphasize more on characterizing the required properties for growing mediums to be in green roofs and to find the most suitable mix proportion of traditional Base medium with selected substrate specimens to reap the maximum plant growth in green roof vegetation. Base medium comprises both commercially available fertilizer and potting mix at empirical proportions.

The objective of this study is to find the suitable substrate medium for green roofs using the selected waste materials based on predefined properties. Similar attempts were prominent in studies like using waste silica as a substrate for extensive green roofs (Krawczyk et al., 2017) and the viability to use recycled aggregates as green roof substrates (Mickovski et al., 2013). Based on the mentioned considerations it has been decided to progress the research study with organic matters since they edge out natural minerals, construction wastes and the composite substrates in many positive perspectives. The following domestically recruit able organic matters like Coir, Bio char, Sawdust, wood bark and Compost were selected along with base medium as controlled specimen.

The unique features of our research study are the consideration of parameters such as Thermal Conductivity of soil mixed aggregates, Nitrate content, Phosphate content and Total Dissolved Solid (TDS) contents for the experimental studies to determine the viability of selected specimens as a growing medium for green roof vegetation. Furthermore, new methodologies were used to resolve the experimental problems associated with traditional measurements of Thermal conductivity and Electric conductivity of selected substrate specimens, which are bad conductors of heat and ions. The proposed solutions for the encountered problems have offered a sustainable framework for future laboratory experiments based on the relevant parameters. Since there were limited researches have been done at past in the context of green roof substrates, this study would be a benchmark for developing future researches based on sustainable urban constructions.

2. Materials and Methodology

2.1 Preliminary study for the selection of growing medium

To determine the best mix proportions, a field test was conducted using buffalo grass and planting pots. Base medium was prepared with 90:10 commercial fertilizer and topsoil. The preliminary study was conducted for the rest of the five medium, with substrate specimens: Base medium mix proportions of 90:10, 80:20, 75:25 and 60:40 with 3 pots of buffalo grass under each ratio.

Four buffalo grass stems with lengths from 3.5-5.6 cm were planted in each pot. All stems would be from buffalo grass mat in order to ensure that health conditions and ages of the stems are approximately equal (Dareeju and Halwatura, 2010). The study was conducted for 28 days under manual watering, once per week. The results were quantified through measuring the bottom to apex height (Nagase et al.,

2012) based on previous studies. The most convincing mix proportion was selected to proceed with the successive physical and chemical experiments.

2.2 Particle size distribution of green roof substrates

Sieve Analysis has been conducted under ASTM C136-01 standards. All six specimens were weighed using electronic balance and undergone for extensive sieve analysis test using 50.0mm, 37.5mm, 20.0mm, 10.0mm, 5.0mm, 2.36mm, 1.18mm, 0.6mm and 0.3mm. Retained weight and the passing percentages were determined using spreadsheet software. Compressive strength is directly proportional to the percentage of fine aggregates (i.e. aggregate sizes less than 2.36mm). Passing percentage of fine aggregates were separately calculated for all six substrates and finally the compressibility rankings were given based on the magnitude of the percentage passing at sieves less than 2.36mm.

2.3 Density and moisture content of green roof substrates

Based on ASTM 1762-84 standards 25cm x 25cm trays were used in this experiment (Soane., 1994). The unit weight of each substrate was measured while having substrate depth of 2cm. The systems were poured with water until each trays were observed with a water discharge. Since the prepared growing medium specimens are categorized as undisturbed soils, the indirect method has been used (Al –Shammary et al., 2018) to find the density parameters. Therefore, net weight of substrates were found. Saturated density of each substrate were calculated using equation (1).

$$\gamma_{sat} = \left(\frac{Wsat}{V}\right) \times 9.81 \times 10^{-3} \qquad \text{Equation (1)}$$

W_{sat} = Saturated weight of substrates after subtracting the tray weight

V = Volume of system

γ_{sat} = Saturated unit weight of substrate

Each tray was dried using electrical oven at 120°C for 24 hours for dehydration.

$\gamma_{dry} = (\frac{Wdry-W}{V})$ x 9.81 x 10^{-3} Equation (2)

W_{dry} = Weight of substrates dried in oven, after subtracting the tray weight

γ_{dry} = Dry unit weight of substrate

$\gamma_{dry} = \frac{\gamma sat}{1+w}$ Equation (3)

$w = \frac{\gamma sat}{\gamma dry} - 1$ Equation (4)

2.4 Drought resistance of Green roof substrates

The main objective of this experiment is to determine the ability of substrate to sophisticate the survival of its vegetation during the scarcity for water. Drought resistance is proportional with the survival area of buffalo grass. Therefore, total area of vegetation is calculated first and then the survival area is calculated after the desired period. Finally, the percentage of survival areas were calculated for each substrate compared and then concluded with the results. Wooden frames, each equipped with 2m wide 450 gauge (114.5 Micron) transparent polythene were constructed to avoid the interaction of water under natural circumstances. Area of dead grass was calculated using visual inspection and measurements. It was measured using 10cm x 10cm wooden frames at every Wednesdays of the week for a span of 28 days. Then the dead vegetation area was determined in each specimen types. Ultimately, the survival area was found using the following mathematical computation:

$$\lambda_{\%} = \left(\frac{\text{Platform area} - \text{Dead grass area}}{\text{Platform area}}\right) \times 100 \qquad \text{Equation (5)}$$

$\lambda_{\%}$ = Survival percentage

2.5 Contribution of Green roof substrates for Vegetation cover

The main objective of this experiment is to determine the substrate that would sophisticate its vegetation with highest growth results. Substrates were laid on six 25cm x 25cm wooden boxes (Mickovski et al., 2013) using 10cm x 10cm wooden frames. *Tradescantia fluminensis* was selected to be planted because of its ability for quick growth. Same type and same aged *Tradescantia fluminensis* were recruited and planted at each of the substrate specimens to obtain rational results. The planted substrate frames were watered once per day for 28 days. The vegetation cover was measured using 10cm x 10cm wooden frames at every week for a span of 28 days. Ultimately, the vegetation cover was found using the following mathematical computation:

$$\delta_{v\%} = \left(\frac{\text{Platform area} - \text{Dead grass area}}{\text{Platform area}}\right) \times 100 \qquad \text{Equation (6)}$$

$\delta_{v\%}$ = Extent of vegetation

2.6 Thermal conductivity of Green roof substrates

Lee's disc method is a good solution to find thermal conductivity of bad conductors. Since it is not feasible to mold the specimens like wood bark and bio char into uniform disc shape, Lee's disc specimen method cannot be applied here. Therefore, several discrepancies would have occurred in the results if the research was relied upon the Lee's apparatus. Even if it made possible to mold, the non-uniformity of aggregate distribution observed in the nature of six selected specimens are not a compatible specimen condition to conduct Lee's disc method (Mahesh and Joshi, 2015). Because, only the uniform specimens can be smoothly molded into disc shapes. Therefore, it is more rationale to identify the thermal conductivity results in experimental conditions based on proper specimen preparation and relevant theoretical calculations. The study is designed to find the thermal conductivity of six different substrate mediums and to ultimately study their thermal resistance behaviors for comparative analysis.

An mathematical approach was conducted by using the TD – 8561 Thermal conductivity apparatus. The selected specimens were converted into heterogeneous solution to initiate the tests. The equation for the heat conducted through the material can be given as follows:

$$\Delta Q = \frac{kA\Delta T\Delta t}{h}$$

ΔQ = Total heat conducted

k = Thermal conductivity of given material

A = Area in which the conduction occurs

ΔT = Temperature difference

Δt = time duration of the conduction

h = Thickness of material

The equation to find the thermal conductivity k has derived as:

k (cal cm-1sec-1°C-1) = ΔQh/(AΔTΔt)   Equation (7)

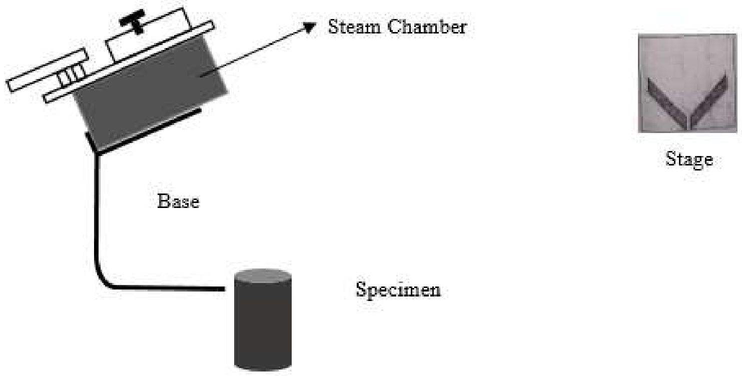

Figure 1: Experimental setup for thermal conductivity studies

Since the most convincing parameter of a Green roof substrate is Thermal resistance, it affects the microclimate and thermal comfort of the building. It has been determined by the following equation:

$R\Theta = \frac{\Delta x}{A \ x \ k}$ Equation (8)

The author has assumed that the energy transformation by conduction and convection are negligible (Jury et al., 1991). The entire experiment was conducted at open conditions in room temperature. As the first step, specimens were mounted on stage in a way that it is free to move. Temperature of the steam chamber was measured prior to testing each specimen since it cannot be assured that it is at 100°C, due to the fact that the tested laboratory located at 12.0m above MSL. The time duration was started to get recorded soon after observing the first sight of melted specimen. The flow of melted specimen allowed to get collected in the beaker for the duration of 20 minutes and the heat transfer was stopped afterwards. Mass and the temperature of the collected sample in beaker was measured and then substituted in the equation along with the temperature measured earlier at the gas chamber. Average thermal conductivity values were reported and then further proceeded for determination of thermal resistance. The best convincing substrate specimen in terms of thermal resistance has been ultimately identified.

2.7 pH of growing mediums

The experiment was conducted at 25°C laboratory temperature in Department of Bio Systems Technology laboratory at the South Eastern University of Sri Lanka. Standard specimen solution was prepared under (w/w) ratio of 1:2 with Deionized water according to ASTM E70. Then each substrate solutions were sophisticated with 2 replicates to obtain average magnitudes. Climatic condition was kept constant since room temperature was uniform and the substrate solutions were extracted using filter paper to avoid the discrepancy at pH readings due to texture of substrate aggregates.

Standard solution was prepared in 1:2 (V/V) ratio under ASTM E70 standards in beaker and transferred to conical flasks. Conical flasks were shaken thoroughly under rotary flask shaker at 200rpm for 1.5hrs until a clear colored solution was visually observed. Specimen solutions in conical flasks were transferred into 100ml beakers using ϴ125mm filter papers until no further solution fluid is observed inside conical flasks. Filter papers were made into floral shapes to boost the efficiency by increasing the contact area.

The extracted solutions in beakers were tested using pH meter. pH sensor was flushed thoroughly using distilled water. Sensor was wiped away with clean tissue paper. Then pH electrode was immersed vertically into the specimen in beaker. pH meter was extensively observed. When it displays a value with "READY" the corresponding value was noted since it is the stabilized pH value. A comparative analysis was made by the end of pH test for all the substrate specimens.

2.8 EC of growing mediums

The specimen solutions prepared for pH test was undergone to Electric Conductivity test using multimeter under open environment. The Electric Conductivity magnitudes were measured at corresponding temperatures and they were projected to absolute temperature of 25°C. During the observations at multimeter, sensor was flushed thoroughly using distilled water and was wiped away with clean tissue paper. Then Electric Conductivity electrode was immersed vertically into the specimen in beaker. Multimeter was extensively observed until it has displayed an unchanged value after pressing REC. Measurements were recorded along with the corresponding temperature. Then the sensor was flushed with distilled water, wiped with clean tissue and previous procedures were repeated for successive specimens. Finally, a comparative analysis was made by the end of pH test for all the substrate specimens.

2.9 Mineral contents of Green roof substrates

The total dissolved solid (TDS) content of each specimens and their replicates was measured using the multimeter by following the same procedures followed during EC test. Substrate solutions were prepared in accordance to ASTM E70 using 1:2 (v/v) ratio. Nitrate and Phosphate content were determined using DR 5000 Spectrophotometer. For the determination of Nitrates, $10cm^3$ each of the six sample solutions were pipetted in $50cm^3$ volumetric flask. Then 13N H_2SO_4 of $10cm^3$ volume was added to each specimen solutions and mixed uniformly with shakers and the system was allowed for thermal equilibrium at cold water bath with temperature from 0 to 10°C Brucine-Sulfanilic acid ($C_{29}H_{33}N_3O_7S$). The acidic solution was diluted with distilled water and placed in hot water bath for 25 minutes. After the observation of colour development, the system was allowed to cool into room temperature. The absorbance data were read at the wavelength of 410nm including blank of spectrophotometer. The procedure was repeated for other five sample solutions and the readings were analyzed.

50cm^3 of each specimen solution was pipetted with 500cm^3 volumetric flask, 5cm^3 Ammonium molybdate [$(NH_4)_2MoO_4$] and 3cm^3 Ascorbic acid ($C_6H_8O_6$) were appended and mixed thoroughly with solution shaker. Then the mixture was diluted using distilled water and allowed rest for 30 minutes in order to achieve maximum color formation. The absorbance data was obtained at the wavelength of 660nm including blank. The same procedure was repeated for the rest of the five specimen solutions. Finally, results from all the three parameters TDS, Nitrates and Phosphates were tabulated with mean values and the highly nutritious growing medium was identified among the substrate specimen solutions.

3. Results

3.1 Preliminary study results

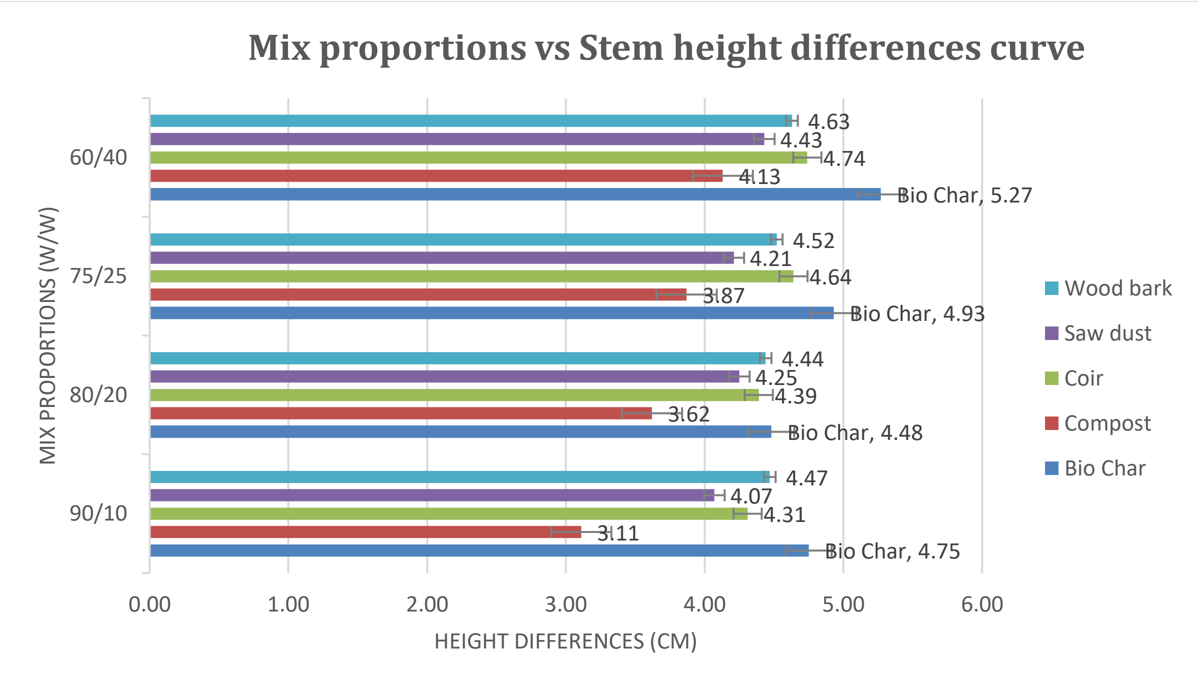

Figure 2: Mix proportions vs Stem height differences curve

The height differences at the end of 4 weeks-experimental study has been described by Figure 2. Maximum height differences at 60:40, 75:25, 80:20 and 90:10 mix proportions were observed at Bio char. The most convenient mix proportion was decided based on the average height differences in each type of ratios. Maximum average height difference was prevailed at 60:40 mix proportion (5.27 cm), while the minimum height difference was exhibited by 90:10 mix proportion (3.11cm).

3.2 Particle size distribution of growing mediums

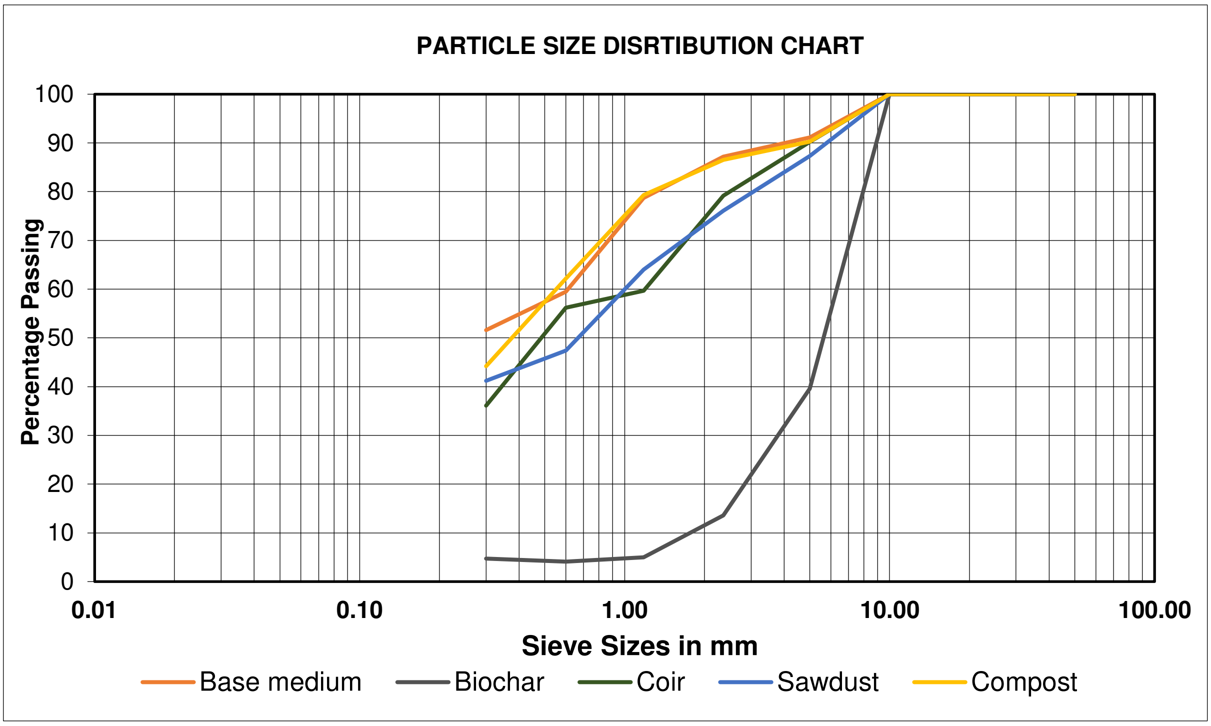

Figure 3: Particle size distribution curve

PSD curve of Figure 3 illustrates the deviations of passing percentages corresponding to sieve sizes. It has been observed that there were no retaining particles at 50-5.0 mm sieve sizes. Bio char (60:40) has an unusual trend of particle distribution compared to other candidates, due to its high amount of dust constituents. Table 1 shows the percentage of fine aggregates to deduce the compressive strength of substrate specimens. Highest percentage of fine particles are required to resist external compressions. Therefore, highest compressive specimen was given 6 points and the lowest type was rated with 1 point.

Table 1: Classification of substrates based on the compressive strength

Substrate	**Percentage of particles less than 2.36mm**	**Compressibility ranking**	**Points**
Bio char (60:40)	13.6	6	1
Sawdust (60:40)	76.1	5	2
Coir (60:40)	79.2	4	3
Wood bark (60:40)	83.5	3	4
Base medium (90:10)	87.2	1	6
Compost (60:40)	86.3	2	5

3.3 Density and moisture content of substrate specimens

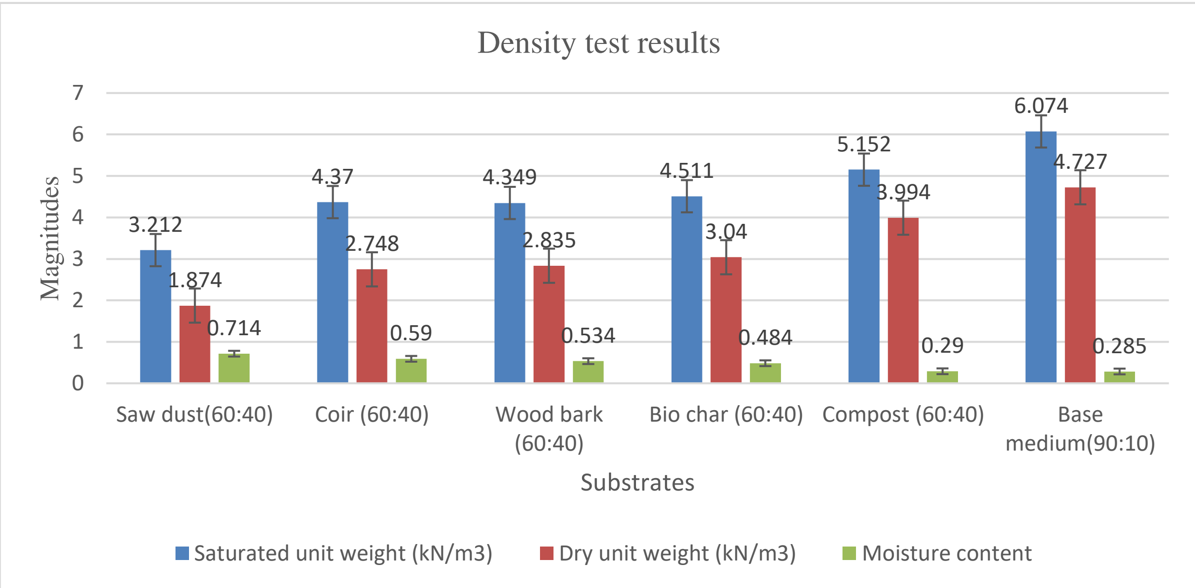

Figure 4: Unit weights and moisture content of substrates

Saturated unit weight and the dry unit weights were calculated for each specimens using Equation 1 and Equation 2, and Figure 4 represented the results. Base medium (90:10) has exhibited the maximum magnitudes for both dry unit weight and the saturated unit weight while Sawdust (60:40) exhibits minimum values for both parameters. Compost (60:40) exhibits the minimal differences among dry and saturated unit weights [1.158

kN/m^3]. Furthermore, moisture content of specimens were calculated based on ASTM 1762-84 guidelines using Equation 4 and the corresponding results were mentioned by Figure 4. The calculated moisture content values ranges from 0.285 – 0.714 . The maximum and minimum moisture contents exhibited by Sawdust (60:40) and Base medium (90:10) respectively. Table 2 shows the ratings based on calculated parameters. Highest dense medium has received the 1 points and lowest denser medium has received 6 points in Table 2, since low unit weight is favorable. Here, Sawdust (60:40) is has scored maximum due to its lightweight property and good moisture content.

Table 2: Ratings of substrates based on unit weight and moisture content

Specimen	**Rank (unit weight)**	**Points**	**Rank (Moisture content)**	**Points**	**Final rating**
Sawdust (60:40)	6	6	1	6	12
Coir (60:40)	5	5	2	5	10
Wood bark (60:40)	4	4	3	4	8
Bio char (60:40)	3	3	4	3	6
Compost (60:40)	2	2	5	2	4
Base medium (90:10)	1	1	6	1	2

3.4 Drought resistance of substrate specimens

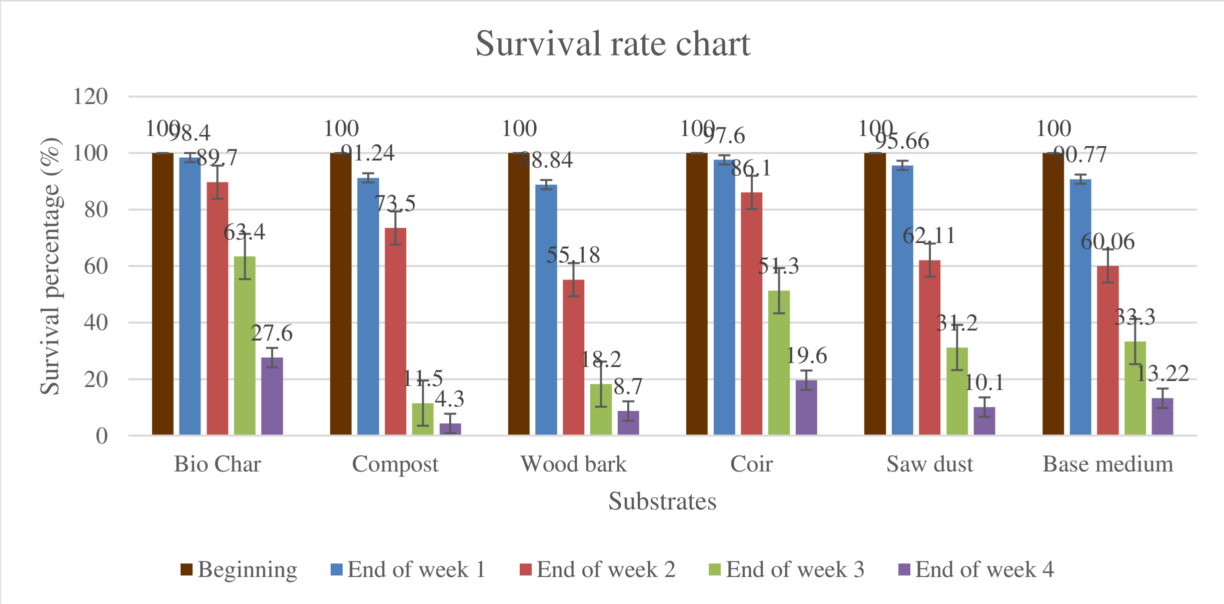

Figure 5: Survival rate chart

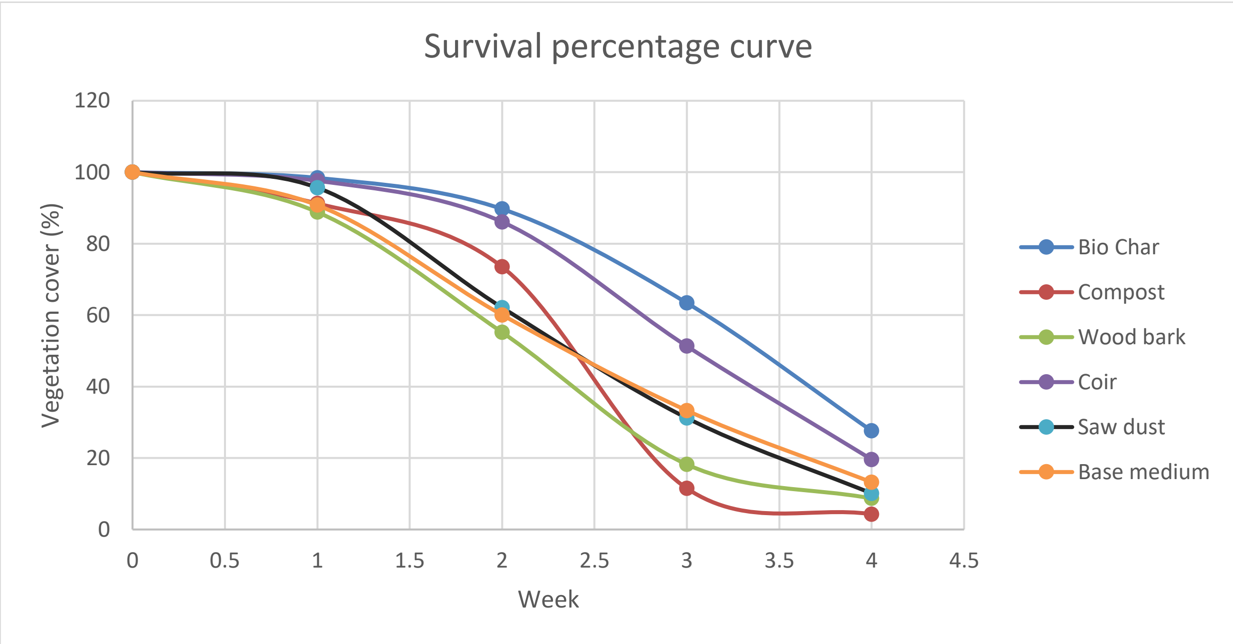

Figure 6: Survival percentage curve

Table 3: Ratings based on terminal survival percentage area

Substrate	Terminal survival percentage	Rank	Points
Bio char (60:40)	27.6	1	6
Compost (60:40)	4.3	6	1
Wood bark (60:40)	8.7	5	2
Coir (60:40)	19.6	2	5

Sawdust (60:40)	10.1	4	3
Base medium (90:10)	13.22	3	4

The observation based on Figure 5, Figure 6 and Table 3 shows that the Bio char (60:40) has indicated the highest survival percentage by the end of week 1 to week 4. Terminal survival percentage of Bio char (60:40) is determined to be 27.6%. In the other end, worst resistance against drought was observed at Compost (60:40) with 4.3% of terminal survival percentage. The reasons for these observed trends has been extensively elaborated under discussions. The second highest survival percentage is observed at Coir (60:40) with 19.6% of survival by the end of experiment.

3.5 Growth rate of substrate specimens

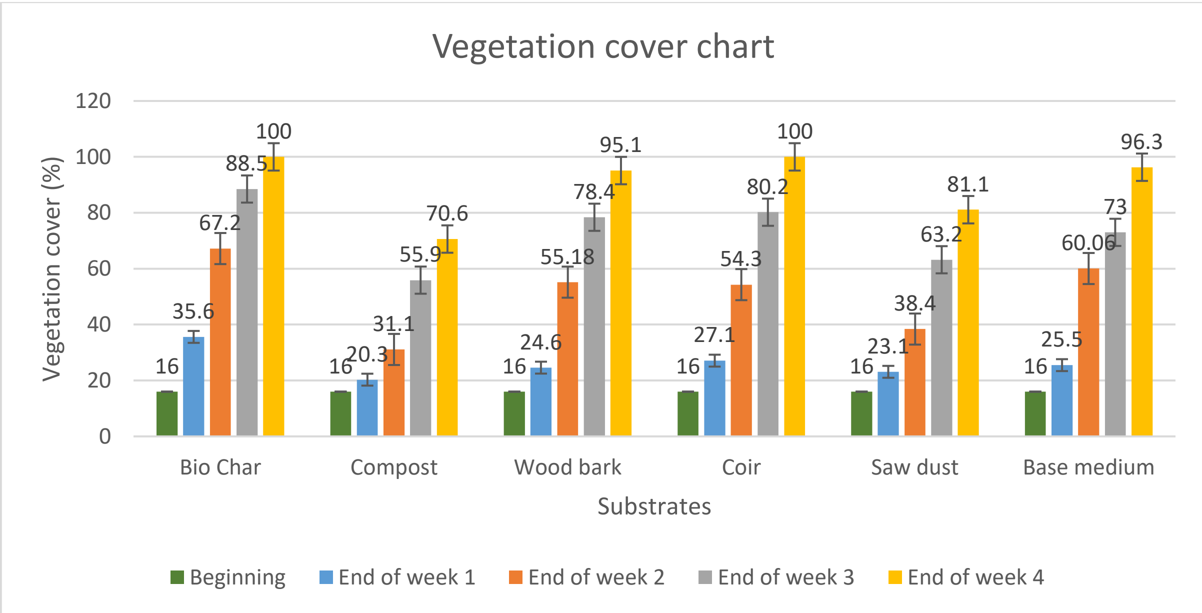

Figure 7: Vegetation cover chart

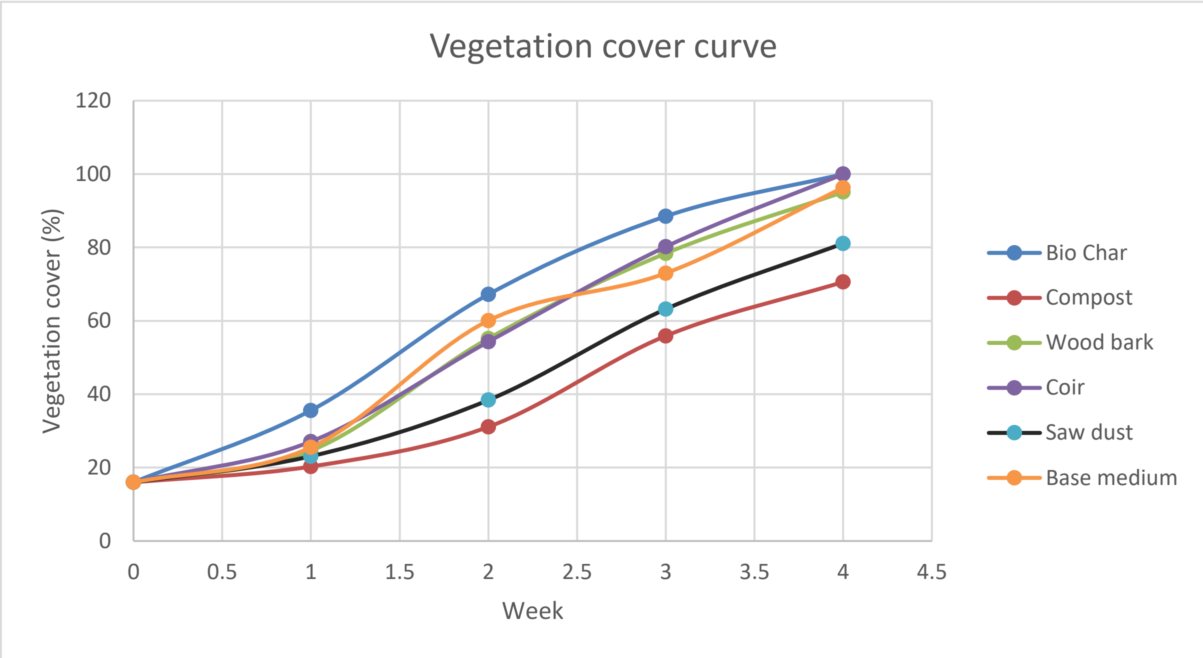

Figure 8: Vegetation cover curve

Table 4: Ratings based on the final vegetation cover percentages

Substrate	Final vegetation cover (%)	Rank	Points
Bio char (60:40)	100	1	6
Compost (60:40)	70.6	6	1
Wood bark (60:40)	95.1	4	3
Coir (60:40)	100	2	5
Sawdust (60:40)	81.1	5	2
Base medium (90:10)	96.3	3	4

The growth test results shows that the Bio char (60:40) has indicated the highest percentage growth rate at entire study period, from week 1 to week 4. Bio Char has been given full points of 6 because it shows exceptional growth coverage from the beginning of the experimental studies as mentioned by Figure 8. By the end of week 4, both Bio char (60:40) and Coir (60:40) have shown no empty area which means the vegetation cover has attained 100%. Minimum rate of growth was observed at Compost (60:40) with just 70.6% of whole area was distributed with vegetation. Further details on arrived decisions were extensively elaborated at chapter 4.5 of this manuscript.

3.6 Thermal Conductivity of Green roof substrates

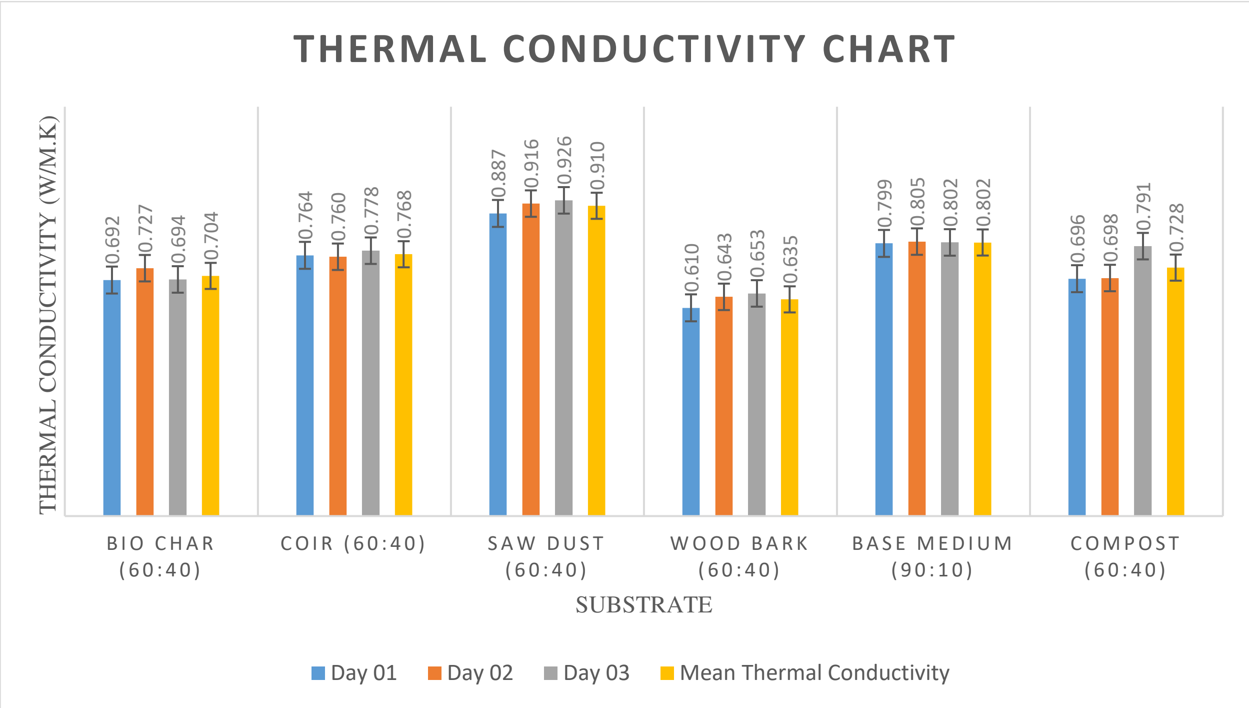

Figure 9: Thermal Conductivity results

Table 5: Thermal resistance of selected growing mediums

Substrate	**Δx (cm)**	**A (cm²)**	**k (W/m.K)**	**Thermal resistance Rθ (K/W)**	**Rank**	**Points**
Bio char (60:40)	2.09	31.673	0.704	9.356	2	5
Coir (60:40)	2.17	31.673	0.768	8.912	4	3
Sawdust (60:40)	2.17	33.494	0.910	7.122	6	1
Wood bark (60:40)	2.08	33.494	0.635	9.790	1	6
Base medium (90:10)	2.18	31.673	0.802	8.594	5	2
Compost (60:40)	2.09	31.673	0.728	9.059	3	4

The experimental readings were recorded at three days to get the most rationalized magnitudes to mitigate the influence of various discrepancies occurred at the experiment scenarios. Figure 9 represents the calculated results. Since the results show some extent of the influences from external factors like change of room temperature, change of atmospheric pressure and the probability of human errors. Therefore, mean values were considered for thermal conductivity, and the values were progressed to find the thermal resistance mentioned by Table 5. Maximum thermal resistance was observed at Wood bark (60:40) and the minimum thermal resistance is at Sawdust (60:40). Since high thermal resistance is preferable for the sustainability of green roof vegetation, Wood bark (60:40) has scored the highest points.

3.7 pH of Growing mediums

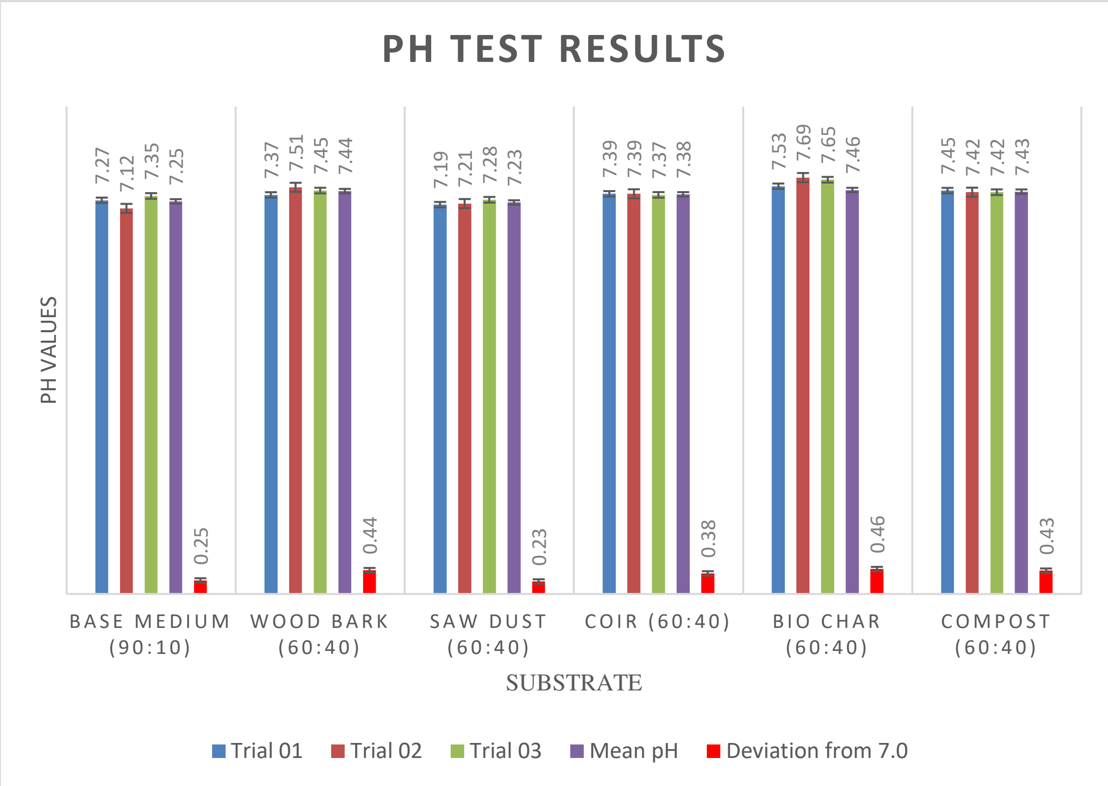

Figure 10: Determination of pH for specimen solutions

Table 6: pH test results and ratings

The test results show that the pH range varies from 7.247 to 7.623 while the minimum

Substrate	**Trial 01**	**Trial 02**	**Trial 03**	**Mean**	**Deviation from 7.0**	**Rank**	**Points**
Base medium (90:10)	7.27	7.12	7.35	7.25	0.25	2	5
Wood bark (60:40)	7.37	7.51	7.45	7.44	0.44	5	2
Sawdust (60:40)	7.19	7.21	7.28	7.23	0.23	1	6
Coir (60:40)	7.39	7.39	7.37	7.38	0.38	3	4
Bio char (60:40)	7.53	7.69	7.65	7.46	0.46	6	1
Compost (60:40)	7.45	7.42	7.42	7.43	0.43	4	3

pH magnitude exhibited by the Base medium (60:40) solution and the maximum pH observed in Bio char (60:40) solution. Since there were different magnitudes displayed for each replicas, the mean value has been taken into consideration to arrive for a conclusion based on the deviation from optimum pH value 7.0, which is highly anticipated for effective plant growth. The corresponding computations were described by Table 6. Accordingly, the specimen with minimal deviations from optimum value of 7.0 was provided with maximum points. It has also concluded that all the substrate solutions exhibits alkaline property as the distribution of pH range among all the substrates are greater than 7.

3.8 EC of Growing mediums

Table 7: Unprocessed EC results

Substrate	Electric Conductivity (µS/cm)	Temperature	Rank
Base medium (90:10)	1462	29.6°C	5
Wood bark (60:40)	1633	29.5°C	2
Sawdust (60:40)	1398	29.4°C	6
Coir (60:40)	1744	30.1°C	1
Bio char (60:40)	1468	29.5°C	4
Compost (60:40)	1473	29.5°C	3

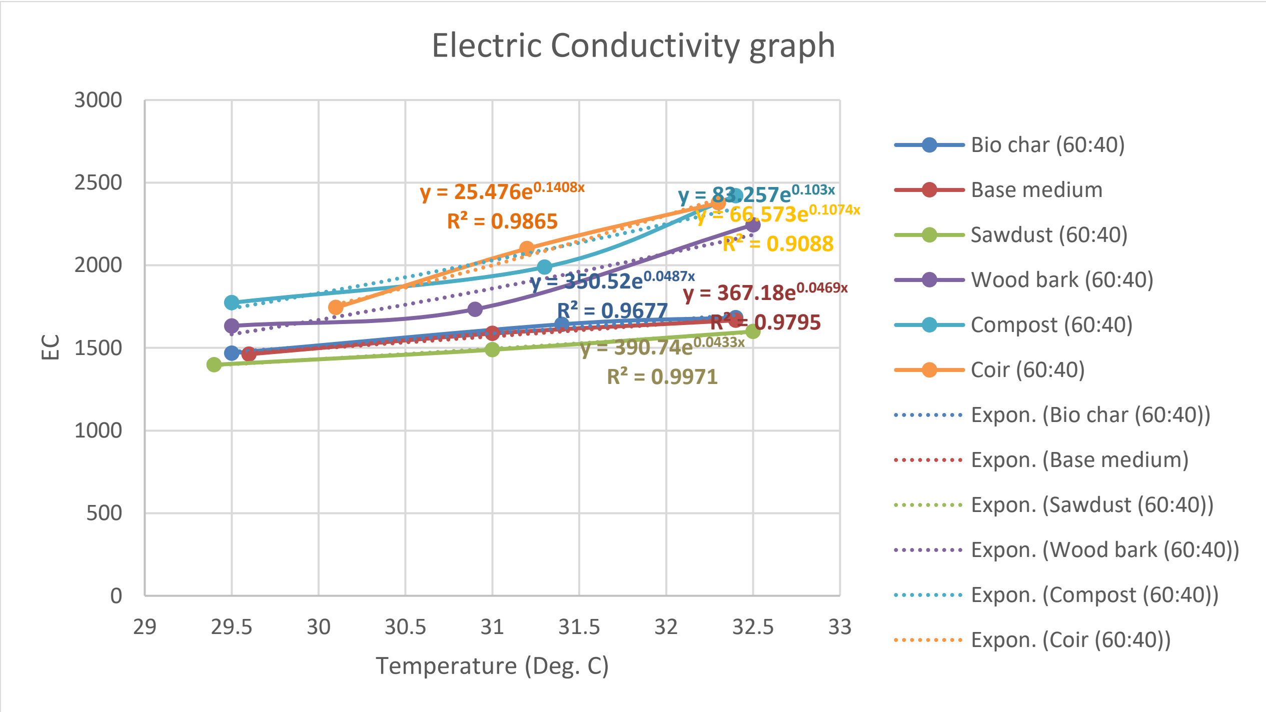

Figure 11: Electric Conductivity vs Temperature curve

The initial observations has been raised out questions whether the obtained values would be rational or not as the temperature varies with readings. Therefore, the EC values were obtained for each growing medium and its replicates mentioned in Table 7, were projected to absolute room temperature 25°C as in Figure 11 through constructing an Electric Conductivity vs Temperature curve. Since minimum salinity is best for plant growth, the highest points were given for the growing medium with EC according to Figure 11 has been rated as the best recommended specimen, in terms of EC.

Table 8: Rationalized EC test results and corresponding ratings

Substrate	**EC (µS/cm)**	**Temperature °C**	**EC (µS/cm)**	**Temperature °C**	**EC (µS/cm)**	**Temperature °C**	**Projected EC at 25°C**	**Rank**	**Points**
Base medium (90:10)	1462	29.6	1587	31	1667	32.4	1186.01	1	1
Wood bark (60:40)	1633	29.5	1734	30.9	2245	32.5	975.484	5	5
Sawdust (60:40)	1398	29.4	1489	31	1599	32.5	1153.48	3	3
Coir (60:40)	1744	30.1	2101	31.2	2377	32.3	860.962	6	6
Bio char (60:40)	1468	29.5	1643	31.4	1683	32.4	1184.31	2	2
Compost (60:40)	1773	29.5	1989	31.3	2420	32.4	1093.27	4	4

The projected EC values of each specimens were deduced by substituting *x* in corresponding equations of curve in Figure 11 with 25°C. EC ratings were given through comparing the projected magnitudes as in Table 8. It has been observed that the maximum EC and minimum EC were shown by Base medium (90:10) [1186.01μS/cm] and Coir (60:40) [860.92 μS/cm] respectively. Therefore, Coir (60:40) has been declared as the optimum candidate based on EC, by considering the aspect of salinity and its effect on plant growth, which has briefly described in chapter 4.8 within discussions.

3.9 Mineral contents of substrate specimens

Each substrate was measured along with its own three replicas to get more logistic values using the multimeter and the observed results were processed and ranked as in Figure 12. *y* axis (substrates) = 5 shows the mean values of measured TDS values. From the results, it has been evident that the highest amount of organic and inorganic substances found to be in Compost (90:10) [1087 ppm] and the second most exhibiting growing medium is Coir (60:40). Sawdust (60:40) consists the lowest dissolved compositions with 343 ppm.

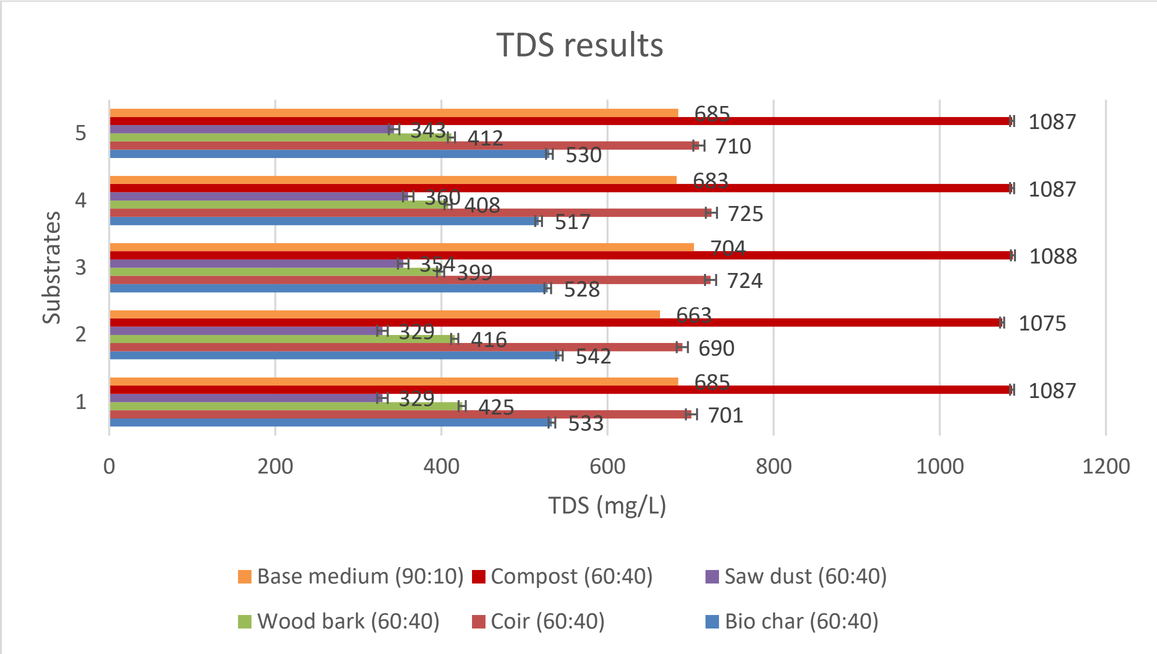

Figure 12: TDS computation on test specimens

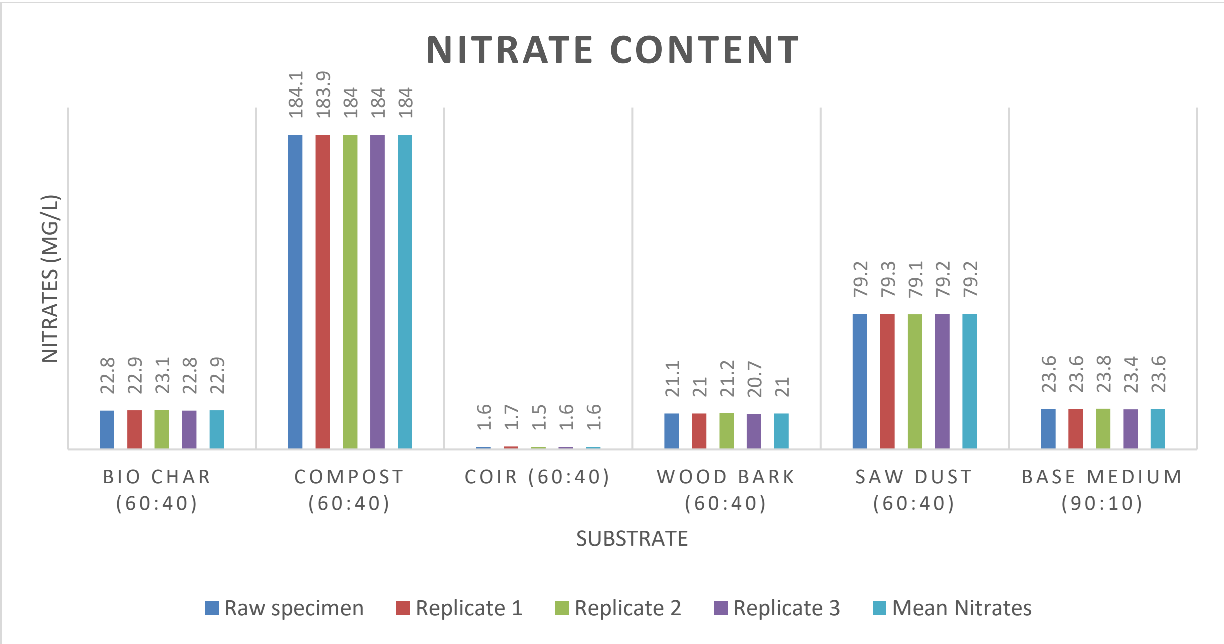

Figure 13: Nitrate content of Growing mediums

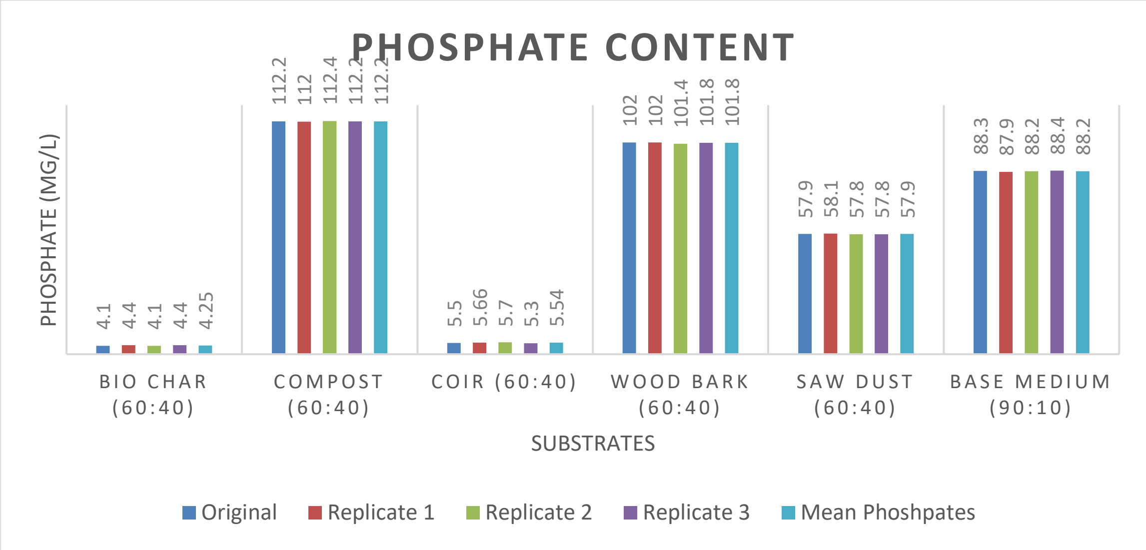

Figure 14: Phosphate content of Growing mediums

Table 9: Overall ratings based on total mineral content

Substrate	**Points$_{Nitrates}$**	**Points$_{Phosphates}$**	**Points$_{TDS}$**	**TOTAL POINTS**
Bio char (60:40)	3	1	3	7
Compost(60:40)	6	6	6	18
Coir (60:40)	1	2	5	8
Wood bark (60:40)	2	5	2	9
Sawdust (60:40)	5	3	1	9
Base medium (90:10)	4	4	4	12

According to the results based on Figure 13, the most Nitrogen-rich specimen among the selected candidates is Compost (60:40) [184 ppm] followed by Sawdust (60:40) [79.2 ppm]. Hence, Coir (60:40) consists the least. Reasons for this observation were reviewed under discussion. Furthermore, Sawdust (60:40), Wood bark (60:40) and Base medium (90:10) are almost inseparable in terms of Nitrate contents since all substrates possess 21-25 ppm nitrates. Phosphate test results of Figure 14 shows that Compost (60:40) [112.8 ppm] slightly greater than Wood bark (60:40) [101.8 ppm]. Bio Char (60:40) consists the least. The reasons behind the test results have been extensively elaborated at chapter 4.9 within discussions.

3.10 Selection of most compatible growing medium for green roof vegetation in terms of overall results

Table 10: Mean results of selected parameters

Substrate	Sawdust (60:40)	Coir (60:40)	Wood bark	Bio char (60:40)	Compost (60:40)	Base medium
Sieve analysis	76.1	79.2	83.5	13.6	86.3	87.2
γ_{sat} (kN/m^3)	3.212	4.37	4.349	4.511	5.152	6.074
γ_{dry} (kN/m3)	1.874	2.748	2.835	3.04	3.994	4.727
Moisture content	0.714	0.59	0.534	0.484	0.29	0.285
Drought resistance	10.1	19.6	8.7	27.6	4.3	13.22
Growth rate	81.1	100	95.1	100	70.6	96.3
Thermal resistance	7.122	8.912	9.79	9.356	9.059	8.594
pH	7.23	7.38	7.44	7.46	7.43	7.25
EC	1153.48	860.962	975.484	1184.31	1093.27	1186.01
TDS	343	710	412	530	1087	685
Nitrate	79.2	1.6	21	22.9	184	23.6
Phosphate	57.9	5.54	101.8	4.25	112.2	88.2

Table 11: Overall rating based on the experimental performance of the selected Green roof substrate candidates

Substrate	**Sieve analysis**	**Unit weight**	**Moisture content**	**Drought resistance**	**Growth rate**	**Thermal resistance**	**pH**	**EC**	**TDS**	**Nitrate**	**Phosphate**	***Total points***
Sawdust (60:40)	2	6	6	3	2	1	6	3	1	5	3	38
Coir (60:40)	3	5	5	5	5	3	4	6	5	1	2	44
Wood bark (60:40)	4	4	4	2	3	6	2	5	2	2	5	39
Bio char (60:40)	1	3	3	6	6	5	1	2	3	3	1	34
Compost (60:40)	5	2	2	1	1	4	3	4	6	6	6	40
Base medium (90:10)	6	1	1	4	4	2	5	1	4	4	4	36

According to ratings rubric in Table 11, Coir (60:40) has scored 44 out of possible 66 points by summarizing all the relevant test outcomes. The runner up among the candidates is Compost (60:40) and the least favourable medium to be used as Green roof substrate would be Bio char (60:40), solely based on the acquired points at test results.

4 Discussion

4.1 Preliminary study results

It has been observed that there were no any diseases identified in any of the buffalo grass stems in substrate specimens throughout the study period. Hence all the stems were remained alive by the end. It shows that all five waste materials selected (Bio char, coir, wood bark, Sawdust and compost) are qualified as a growing medium. However, the task assigned here was to find the most effective mix proportion among each type of growing medium.

Based on the results from Figure 2, the distinguished growth of stems was observed under 60:40 mix proportion at each of the five growing mediums. Specifically, Bio char exhibits highest growth and secondly by the coir. Least growth rate among 60:40 mix proportion is observed at Compost (60:40) whereas the second least is Sawdust (60:40). Furthermore, Bio char has exhibited the highest vertical growth in all types of mix proportions. Based on these results, it has been concluded that the study would be progressed further with 60:40 mix proportion of each of the five proposed growing mediums along with the base medium. Hence, it was assumed that Bio char (60:40) would exhibit same type of sophisticated results even for the vegetation cover area, which would be later tested under the rate of vegetation cover propagation.

4.2 Particle size distribution of Growing mediums

The ultimate objective of conducting a PSD test is to deduce the substrate specimen with highest compressive strength. Sieve analysis curve constructed based on AASHTO guidelines has been illustrated in Figure 3. It shows that the aggregate size of all particles from the six prepared substrate mixtures are less than 10mm. Furthermore, it has been observed during the experiment that the evolving of dust was comparatively higher in Bio char substrate mixture due to the incinerated remains. Therefore, the percentage of retaining particles at sieves less than or equal 5mm were drastically reduced. This type of dust formation would also drastically affect the industrial applications of Bio char substrate types in green roof because lot of volume more than required amount need to be used to attain the desired growing medium ratio.

The durability of a growing medium is characterized by its compressive strength which is proportional to its constituents of fine particles (Das and Sobhan, 2014). The computation of finer particles and the corresponding ratings are shown in Table 1. Based on the Particle size distribution (PSD) results, Base medium (90:10) has the highest bearing capacity to withstand external loads including vegetation and other imposed loads, if it has been selected as the Green roof substrate layer due to its exceptional compressive strength. Bio char (60:40) is the least favourable option for external loads during the practical application due to its low resistance against external compression.

4.3 Density and moisture content of substrate specimens

Saturated density of each samples were first calculated and then the specimens were dried at electric oven for 24 hours at 120°C. Moisture contents were calculated using Equation 4 and the results are mentioned in the Figure 4. Base medium consists of the highest saturated unit weight and dry unit weight. Least saturated unit weight and the dry unit weight were both exhibited by the Sawdust. The reasons for the low density of sawdust would be its higher amount of air voids (Prasad., 1979) and its particle size due to which most of the times the particles were stained on tray (Ni Chualain et al., 2004). Since excess density would result heavyweight in green roof system, the rating system was introduced to meet the objectives.

In terms of moisture content, dry density and saturated density, the results show that Sawdust (60:40) would exhibit the optimum attribute for a lightweight growing medium by having least saturated unit weight, dry unit weight and highest moisture content among the selected candidates while Base medium (90:10) remained the heaviest and the least hydrogenous growing medium among the selected specimens. Our studies states that Sawdust (60:40) is the most competent growing medium in terms of high moisture content, and it was observed that past studies (Harmayani and Anwar, 2012) and (Johansson et al., 2017) have also concluded that Sawdust (60:40) is a standout performer in terms of moisture content.

4.4 Drought resistance of substrate specimens

The ability to support the survival of its overlaying vegetation during the scarcity for water was measured. The most convincing substrate medium was determined based on highest survival area. Based on both graphical representations in Figure 5 and Figure 6, the maximum survival percentage was observed at Bio char (60:40), followed by the Coir (60:40). Minimum survival area was prevailed among Compost (60:40). Although the survival percentage in Compost (60:40) was higher than the Wood bark (60:40) by the end of week 2, the percentage of survival was drastically reduced in Compost (60:40) from 73.5% to 11.5% which was even less than Wood bark (60:40) that has 18.2%. These results have shown that there would have pathogenic microbial activities occurred due to the rich organic content of Compost (60:40). It would have affected the root system of buffalo grass.

Survival percentage of Sawdust (60:40) and Base medium (60:40) substrates were within same ranges from second to fourth week. Although more survival percentage was observed in Sawdust (60:40) by the end of week 2, Base medium (60:40) overtook Sawdust (60:40) at followed weeks. It would have occurred due to the stimulus rate of substrates due to environmental factors such as temperature and pressure.

The rankings and ratings for drought resistance of growing mediums were given by Table 3. Bio char has shown the leading survival percentage for entire study period. Since the rate of evapotranspiration is same for a particular vegetation, the main deciding factor of this experiment was the rate of evaporation from the growing mediums. Furthermore, Bio char (60:40) is more resistive against both air-borne and soil-borne pathogenic microorganisms (Ippolito et al., 2015). Therefore, the effect of pathogens would be immensely controlled in Bio char (60:40) than the other 5 specimens. The presence of Bio char at Bio char (60:40) would have reinforced the soil fertility and the transportation of nutrients in fibrous root system of buffalo grass (Xie et al., 2013). It would have helped the buffalo grass in Bio char (60:40) to reimburse the loss of nutrient during the absence of sunlight caused by polythene overlaying. Due to these features, the extinction of vegetation in Bio char would have been effectively controlled throughout the study period. Therefore, Bio char (60:40) is the most optimum substrate based on drought resistance, closely followed by Coir (60:40) due to its ability to withstand pathogen attacks (Jacoby et al., 2017). It is also noteworthy to mention that previous study on *Tritisivum aestivum* (wheat) have also stated that Bio char is a strong resistor against drought conditions (Haider et al., 2020) which supports the result of this experimental study. Furthermore, Coir (60:40) is also identified in this study as a decent growing medium against drought based on the experiment conducted by the author. Based on the experimental results at Drought resistance, it can be understandable that the pathogen resistivity is an important factor for the longevity of Green roof vegetation.

4.5 Growth rate of substrate specimens

Tradescantia fluminensis was planted in the six 25cm x 25cm wooden boxes, each contains substrate mixtures. At the beginning of experiment, vegetation was planted within 10cm x 10cm area using the 10cm x 10cm wooden frame. Then the frame was lifted from the stage and allowed the weed growth. Each of the vegetated wooden frames watered using 200ml measuring cylinder once per day. The propagation extent of each creeper were identified using Equation 6. The plotted graphs for each substrate are shown in Figure 7 and the comparisons of results are illustrated by the Figure 8. The overall ratings were given by Table 4, based on the observations from the graphical representations.

Bio char (60:40) has exhibited the highest rate of vegetation cover spread from the beginning of this experiment until the end of week 4. It has been shown that the Ammonia absorbed by the Bio char due to environmental processes were released back to the soil (Taghizadeh-Toosi et al., 2011) and this would result the betterment of plant growth (Saarnio et al., 2013). Because the release of NH_4^+ compounds by Bio char to the substrate mixture have induced more "back titrations" and increase the fertility of soil through accelerating the Nitrate content. Since all the substrate soil types are loams, the water retention of base medium soil is further improvised with the addition of Bio char (Busscher et al., 2010). These factors would have facilitated an unhindered supply of water and plant nutrients for the vegetation, thus resulting more glucose production at photosynthesis. Therefore, the overall results obtained for Bio char is acceptable in context of past studies.

The second successful substrate in sophisticating vegetation cover is Coir (60:40). It has produced more efficient results than the Base medium (60:40). Because when compared to Base medium (60:40), Coir (60:40) possess high effective air-water equilibrium (Barrett et al., 2016) and high rewetting capacity (Blok and Wever, 2008). The least vegetation cover was found at Compost (60:40) specimen. It has been observed that the substrate became more clayey in nature while interacted with water. Therefore, often the segregation was observed in wooden frame corners. Sawdust is the second least plant growth promoter according to this experiment, while base medium and wood bark remains decent contributors.

The poor performance of Sawdust (60:40) could be explained as follows: Sawdust is woody material, thus it requires Nitrogen for decomposition. The probability of decomposition is accelerated by the exposure for water during the manual water supply at experimental activities. When the sawdust biodegrades, it would draw out the nitrogen from the prepared substrate specimen compounds away from the root system of vegetation (*Tradescantia fluminensis*). It would have made the plant growth process weaker.

4.6 Thermal Conductivity of Green roof substrates

The experimental readings were recorded at three days to get the most rationalized magnitudes for thermal conductivity since the proceedings were based on mean values and to mitigate the influence of various discrepancies occurred at the experiment scenarios. Figure 9 represents the calculated results. Since the results show some extent of the influences from external factors like change of room temperature, change of atmospheric pressure and the probability of human errors. Therefore, a most comprehensive way has been formulated through determining the mean values to represent the thermal conductivity from logical perspective.

The results expressed by Figure 9 have shown that the thermal conductivity values of selected specimens range from 0.635 to 0.910 W/m.K. It is clearly known that the selected specimens belong to "sandy loam" soil category. Furthermore, the studies conducted by (Abu-Hamdeh and Reeder, 2000) have described that the thermal conductivity of sandy loam type soil should range between 0.19 to 1.12 W/m.K which shows that the values found in this experiment are within the acceptable range. Hence it shows that the research approach has been conducted in correct path. The maximum thermal conductivity is shown by the sawdust (60:40) and the minimum magnitude is expressed by the Wood bark (60:40). These results have motivated the author to check the influence of moisture content at this experimental outcome as described by (Yadav *et al.,* 1973). The computation results of moisture content of the selected substrate specimens were already elaborated at chapter 3.5. Therefore, it can be stated that the moisture content is indirectly proportional to thermal conductivity of soil substrate. Hence the assumption is verified correct. Thermal conductivity values for pure 100% Bio Char is 1.5 W/m.K (Yang et al., 2017). In this research, thermal conductivity of Bio Char (60:40) substrate is found to be 0.704 W/m.K, which is less than the maximum limit specified by (Yang et al., 2017).

The key requirement of finding thermal conductivity was to find the most appropriate Green roof substrate that would resist the heat and facilitate thermal comfort for the residents of the building. In this experiment, the determined values of thermal conductivity were used to deduce the thermal resistance of corresponding substrates by using the following theoretical consideration:

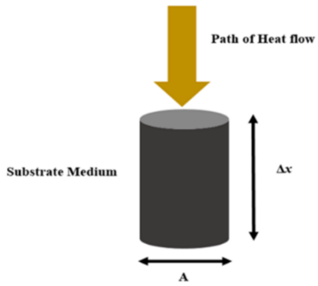

Figure 15: Heat flow across the substrate specimens

By considering the heat flow and the Equation 8 for computation, thermal resistance of all six Green roof substrates were determined as in Table 5. The average specimen thicknesses were considered to eliminate the observational errors encountered during Vernier calliper usage. Highest thermal resistance is exhibited by the Wood bark (60:40) and the lowest thermal resistance is observed at Sawdust (60:40). Furthermore, these results have shown that thermal conductivity magnitudes could be externally controlled by altering the moisture content of growing substrates. Past studies such as (Yadav *et al.,* 1973; Parikh *et al.,* 1979; Riha *et al.,* 1980) have also stated that thermal conductivity could be manipulated by changing the moisture content. Therefore, it has been undisputedly concluded that the thermal conductivity experiment in this research study using a novel methodology has produced successful outcomes since all the results have coincided with previously published past research studies. The calculated values were not compared with other studies because there were no any thermal conductivity researches conducted previously substrate mixtures containing both the selected growing mediums and soil compositions (i.e. fertilizer and topsoil). There were thermal conductivity test results calculated only for pure raw materials like Bio char without mixing with soil aggregates. Therefore, the author was unable to compare the results related with the exact specimens used in this study with any preceding studies since the materials used here are mixtures with soil. Because finding the thermal conductivity of pure 100% Bio char or Coir and the other selected substrate contenders would not contribute for the scope of this research. Several reasons could be cited for lack of research in this aspect such as due to the complexity in the natural state of soil, constant organic matter content of each specimens due to the climatic equilibrium and the unpredictability of biological processes in soil.

4.7 pH of Growing mediums

pH test was conducted for the substrate specimens based on ASTM standards and the results determined for three set of trials on specimens and their replicates. Finally, the mean value of pH was found. The pH values were compared with magnitudes from past studies for all the substrates excluding Compost (60:40), since there were no past studies made in terms of pH for Composts especially made from wastes extracted from cooked food remains. As the pH ranges from the past studies (Eksi et al., 2019) are supporting the test results mentioned in Figure 10 and Table 6, pH test results have been verified correct.

Based on the results, it has been identified that all substrate solutions exhibit slightly alkaline properties since the pH is greater than 7. The presence of C, N, P compounds have greatly influenced the variation of pH in substrate solutions. The interaction of each raw substrate material with its corresponding base medium proportion have formed Carbonyl, Nitrile and Phosphoryl compounds those exhibit less electronegative properties. Due to the decreased electronegativity, low concentrated electrons form. Therefore the amount of free hydrogens is increased, since reactive hydrogens are reduced due to less electronegativity. The presence of free hydrogens would increase the pH. These relationships could be mathematically described as follows:

$$pH \propto free\ hydrogens;$$

$$Reactive\ hydrogen\ ions \propto \frac{1}{electronegativity\ of\ the\ reactive\ groups}$$

Optimum pH range for Horticultural plant growth is 6.0-8.5 based on FLL guidelines (Eksi et al., 2019). The test results have satisfied the optimum pH requirement stated by previous research on extensive green roofs (Eksi et al., 2019) that has focused on the effect of substrate type and corresponding substrate depths. But for rational judgement, 7.0 has been considered the most appropriate substrate specimen for plant growth in terms of pH and the ratings were given at Table 6 based on the results of Figure 10. Accordingly, the most suitable substrate in context of pH was Sawdust (60:40) and the least convincing substrate is Bio char (60:40).

4.8 EC of Growing mediums

The EC test results based on the experiment were recorded and tabulated as mentioned by Table 7. It has been noticed that the results based on the raw readings were not rationally appropriate to arrive into a conclusion because each salinity values are based on different temperatures at Table 7. There has been a study conducted in past to identify the EC of coir substrate (Gougoulias et al., 2013) at temperature 27-32°C and the values were mentioned to be in range of 1.8-2.37 dS/m (i.e.1800-2370 μS/cm). In this experiment, the initial readings of EC values for Coir (60:40) based on Table 8, ranges from 1744-2377 μS/cm which gives similar readings as mentioned by (Gougoulias et al., 2013). It shows that the solution preparation and the method of taking the readings were verified correct at this test. However, in the perspective of author, since there are two independent variables, finding the mean EC values at each substrates are not acceptable option without arriving to a constant or an unchanged temperature for the considered readings. There were practical difficulties experienced in recording the EC values at a constant temperature. Therefore, to overcome these practical difficulties it has been devised to propose graphical method based on Cartesian coordinates. The EC magnitudes were determined through projecting the substrate test results for absolute room temperature 25°C as in Figure 11. Afterwards, the Electric conductivity values were rationalized for 25°C. The projected magnitudes were ranked and rated as in Table 8.

Total Salt concentration of all substrates ranges from 860.962 to 1186.01 µS/cm. The minimum salinity was observed at Coir (60:40). Therefore, it is the best contender among the selected six specimens to get better soil-water equilibrium. Highest EC value is observed at Base medium (90:10) therefore it is the worst specimen in terms of soil-water equilibrium. Furthermore, higher EC also means the amount of nutrients discharge by substrate is high to the surrounding environment, thus reducing the soil fertility (Ding et al., 2018). By these test results and the literature citations, the study concludes that the base medium substrate would consist maximum salinity, slightly greater than Bio char (1184.31 (µS/cm)) and least discharge would be at Coir (860.962 (µS/cm)). Therefore, in terms of salinity, the most convincing substrate specimen would be Coir (60:40).

4.9 Mineral content of substrate specimens

TDS content was identified in order to find the total mineral content of each substrate specimen solutions. Each substrate was measured along with its own three replicas to get more logistic values using the multimeter and the observed results were processed and ranked as in Figure 12. TDS is a measure of total nutrients in the substrates. If the substrate is optimum in pH and high in TDS, the root system would gradually start to utilize the rich breeding of dissolved minerals. However, if both the pH and TDS are high, the root system of vegetation would end up having trouble in absorbing the available nutrients. Therefore, it is not a logical decision to arrive for a conclusion to select the most suitable growing medium solely based on high TDS.

During the Nitrate test, specimens were undergone for hot water bath to get maximum color formation, which is capable to mitigate experimental errors. Figure 13 and Figure 14 mentioned the obtained DR-5000 Spectrophotometer test results for Nitrate and Phosphate contents correspondingly. The overall ratings in Table 9 have shown that, Compost (60:40) consists high amount of soil nutrients and the least amount of soil nutrients prevail in Bio char (60:40). There is a cost effectiveness in having a high nutritious substrate for Green roof vegetation. Industrial implementation of Compost (60:40) would require fertilizers less frequently due to the rich nourishment present in the existing substrate. Since the life rate of worms is drastically low in Bio char (60:40) due to high ash fraction, the rate of nitrification and phosphorification were low. In the perspective of plant growth, this high nutrient content should accompany with the optimum rate of salinity, soil pH and pathogen resistance to reap the optimum condition for plant growth.

Nitrates implant nitrogen to soil. Plants can intake both nitrate (NO_3^-) and ammonium (NH_4^+) ions and use for amino acid production to synthesize protein. Therefore, the existence of Nitrates accelerates plant growth through stimulating the increase of chlorophyll content (Sen et al., 2016). If the results in Figure 13 analysed based on the outcomes of (Sen et al., 2016), Compost (60:40) is the best source for plant growth to have better rate of photosynthesis due to its rich nitrate content. However, there were few more parameters need to be concerned to arrive for a comprehensive decision.

Among all the other substances, Phosphorous is an important macronutrient, which facilitates the formation of good root systems, flowers and fruits in plants. Orthophosphates are the majority of phosphate compounds generally in soil substrates (Rauscher, 2020). They are formed due to the existing organic minerals in soil or by those added during the fertilization. pH is highly influential with the phosphorous intake of vegetation. Similar to TDS, high pH rated substrate would drastically disrupt the phosphoric intake of plant roots. If a substrate medium consists low pH, then the phosphorous compounds react with Aluminium and Iron compounds to form Aluminium phosphate ($AlPO_4$) and Ferric phosphate ($Fe PO_4$). Maximum availability of phosphorus is largely observed in soil substrates at pH range 6.5-7.0. Generally, if the pH of a substrate is in between 6.0 - 7.5 and it contains rich nitrogen and phosphorus content along with other dissolved solids, the particular substrate would contribute high for the plant growth. Based on the pH test results , the mean pH of Compost (60:40) is 7.43 ($6.0 < 7.43 < 7.5$) and it contains the highest TDS, Nitrates and Phosphates according to the multimeter and spectrophotometer tests. Therefore, Compost (60:40) is the most deserving candidate in terms of Mineral contents.

5 Conclusion

This experimental research study has been systematically conducted with a preliminary study to select the most appropriate mix proportion, and further the study was proceeded with selected physical and chemical parameter tests based on literature review and brainstorming. Based on the conclusion of preliminary study, it was observed that the most appropriate mix proportion is 60:40 for all five selected specimens. Except the

Drought resistance test and the Growth rate test, all the other experiments were conducted in laboratory. With the provision of concise outputs from the experimental results, the main conclusions of this paper are as follows:

- Substrate mix consisting 60% substrates with 40% of conventional base medium (fertilizer + potting mix mixture) is the most optimum proportion for plant growth.
- Bio char (60:40) is the most drought resistive and the most growth inductive growth medium. Therefore, future studies can be made on producing Bio char containing substrates enforced with high nutrient containing compounds to reap maximum agricultural benefits
- Compost (60:40) made from the remains of consumed food has the maximum nutrients due to high content of amino acid. Although Compost (60:40) has high nutrient potential (in terms of Nitrates, Phosphates and TDS), the high rate of evaporation and its lack of pathogen resistance has made not suitable for green roof substrate.
- A comprehensive method was formulated to find thermal conductivity of growing mediums since there were bad conductors of heat. This method of finding thermal conductivity at heterogeneous solution state has eliminated thermal conductivity reading discrepancies encountered in Lee's disc method. This method has been verified correct since the calculated values were same as the thermal conductivity values mentioned for same type of specimens in past research studies.
- Unlike most of the past studies those have considered analysing only the physical parameters, our study has analysed the importance of chemical parameters as well

to make a more logistic and rationalized choice to select the most suitable growing medium for extensive green roofs.

- All the selected substrates exhibited slightly alkaline property (pH > 7.0).
- Since there were temperature variations prominent at each EC readings, a mathematical modelling was established through extrapolating the EC magnitudes of all six substrate specimens to 25°C. The results have shown that Coir (60:40) would be the most sustainable substrate layer based on salinity.
- Overall ratings and comparisons based on all the experiments conducted were summarised using Table 10 and Table 11. Based on these results, Coir (60:40) has been declared as the most suitable growing medium for green roofs among the selected organic wastes.
- Using the organic wastes as green roof substrates would reduce the construction cost. Therefore, more stakeholders would invest at green roofs and contribute to the sustainable built environment. Furthermore, this research study has shown a way to recycle the organic wastes, which would help to mitigate the environmental pollution in future.

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References

Abu-Hamdeh, N. and Reeder, R., 2000. Soil Thermal Conductivity Effects of Density, Moisture, Salt Concentration, and Organic Matter. *Soil Science Society of America Journal*, 64(4), pp.1285-1290.

AL-SHAMMARY, A., KOUZANI, A., KAYNAK, A., KHOO, S., NORTON, M. and GATES, W., 2018. Soil Bulk Density Estimation Methods: A Review. *Pedosphere*, 28(4), pp.581-596.

Ampim, P., Sloan, J., Cabrera, R., Harp, D. and Jaber, F., 2010. Green Roof Growing Substrates: Types, Ingredients, Composition and Properties. *Journal of Environmental Horticulture*, 28(4), pp.244-252.

Andresen, J., VanWoert, N., Rugh, C., Fernandez, R., Xiao, L. and Rowe, D., 2005. Green Roof Stormwater Retention. *Journal of Environmental Quality*, 34(3), pp.1036-1044.

Barrett, G., Alexander, P., Robinson, J. and Bragg, N., 2016. Achieving environmentally sustainable growing media for soilless plant cultivation systems – A review. *Scientia Horticulturae*, 212, pp.220-234.

Blok, C. and Wever, G., 2008. EXPERIENCE WITH SELECTED PHYSICAL METHODS TO CHARACTERIZE THE SUITABILITY OF GROWING MEDIA FOR PLANT GROWTH. Acta Horticulturae, (779), pp.239-250.

Busscher, W., Novak, J., Evans, D., Watts, D., Niandou, M. and Ahmedna, M., 2010. Influence of Pecan Biochar on Physical Properties of a Norfolk Loamy Sand. Soil Science, 175(1), pp.10-14.

Culligan, P., Marasco, D., Hunter, B., Gaffin, S. and McGillis, W., 2014. Quantifying Evapotranspiration from Urban Green Roofs: A Comparison of Chamber Measurements with Commonly Used Predictive Methods. *Environmental Science & Technology*, 48(17), pp.10273-10281

Dareeju, B. and Halwatura, R., 2010. Influence of Grass Cover on Flat Reinforced ConcreteSlabs in a Tropical Climate. Conference on Sustainable Built Environment,.

Das, B. and Sobhan, K., 2014. *Principles of geotechnical engineering*. Stamford: Cengage Learning.

Dunnett, N., 2010. PEOPLE AND NATURE: INTEGRATING AESTHETICS AND ECOLOGY ON ACCESSIBLE GREEN ROOFS. *Acta Horticulturae*, (881), pp.641-652.

Eksi, M. and Rowe, D., 2019. EFFECT OF SUBSTRATE DEPTH AND TYPE ON PLANT GROWTH FOR EXTENSIVE GREEN ROOFS IN A MEDITERRANEAN CLIMATE. *Journal of Green Building*, 14(2), pp.29-44.

G.,, B., Ippolito, F. and Scala, F., 2015. "A “black” future for plant pathology? Biochar as a new soil amendment for controlling plant diseases." Journal of plant pathology, 97(02), pp.223-234.

Getter, K. and Rowe, D., 2006. The Role of Extensive Green Roofs in Sustainable Development. *HortScience*, 41(5), pp.1276-1285.

Gougoulias, N., Papachatzis, A., Kalfountzos, D., Kostoulis, V. and Chouliara, A., 2013. VARIABILITY OF ELECTRICAL CONDUCTIVITY AND pH VALUES, OF THE NUTRIENT SOLUTION, IN GREENHOUSE TOMATO CULTIVATION, WITH COIR AS SUBSTRATE. *Annals of the University of Craiova Series: Biology, Horticulturae*, 18(2), pp.187-192.

Haider, I., Raza, M., Iqbal, R., Aslam, M., Habib-ur-Rahman, M., Raja, S., Khan, M., Aslam, M., Waqas, M. and Ahmad, S., 2020. Potential effects of biochar application on mitigating the drought stress implications on wheat (Triticum aestivum L.) under various growth stages. *Journal of Saudi Chemical Society*, 24(12), pp.974-981.

Harmayani, K. and Anwar, A., 2012. Adsorption of Nutrients from Stormwater Using Sawdust. *International Journal of Environmental Science and Development*, pp.114-117.

Jacoby, R., Peukert, M., Succurro, A., Koprivova, A. and Kopriva, S., 2017. The Role of Soil Microorganisms in Plant Mineral Nutrition—Current Knowledge and Future Directions. *Frontiers in Plant Science*, 8.

Jaffal, I., Ouldboukhitine, S. and Belarbi, R., 2012. A comprehensive study of the impact of green roofs on building energy performance. *Renewable Energy*, 43, pp.157-164.

Johansson, P., Ekstrand-Tobin, A., Svensson, T. and Bok, G., 2021. *Laboratory study to determine the critical moisture level for mould growth on building materials*.

Krawczyk, A., Domagała-Świątkiewicz, I., Lis-Krzyścin, A. and Daraż, M., 2017. Waste Silica as a Valuable Componentof Extensive Green-Roof Substrates. *Polish Journal of Environmental Studies*, 26(2), pp.643-653.

Melikoglu, M., Lin, C. and Webb, C., 2013. Stepwise optimisation of enzyme production in solid state fermentation of waste bread pieces. *Food and Bioproducts Processing*, 91(4), pp.638-646.

Mickovski, S., Buss, K., McKenzie, B. and Sökmener, B., 2013. Laboratory study on the potential use of recycled inert construction waste material in the substrate mix for extensive green roofs. *Ecological Engineering*, 61, pp.706-714.

Noya, M., Cuquel, F., Schafer, G. and Armindo, R., 2017. Substrates for cultivating herbaceous perennial plants in extensive green roofs. *Ecological Engineering*, 102, pp.662-669.

Parizotto, S. and Lamberts, R., 2011. Investigation of green roof thermal performance in temperate climate: A case study of an experimental building in Florianópolis city, Southern Brazil. *Energy and Buildings*, 43(7), pp.1712-1722.

Pianella, A., Aye, L., Chen, Z. and Williams, N., 2017. Substrate Depth, Vegetation and Irrigation Affect Green Roof Thermal Performance in a Mediterranean Type Climate. *Sustainability*, 9(8), p.1451.

Prasad, M., 1979. Physical properties of media for container-grown crops. I. New Zealand peats and wood wastes. *Scientia Horticulturae*, 10(4), pp.317-323.

Saarnio, S., Heimonen, K. and Kettunen, R., 2013. Biochar addition indirectly affects N2O emissions via soil moisture and plant N uptake. Soil Biology and Biochemistry, 58, pp.99-106.

Simpson, J. K., Nollet, L. M., Toldrá, F., Benjakul, F., Paliyath, G., and Hui, Y. H. (2012). *Food Biochemistry and Food Processing*, 2nd Edn. Oxford: Wiley-Blackwell Publishing.

Soane, B.D. and Van Ouwerkerk, C., Eds. (1994) Soil Compaction in Crop Production. Developments in Agricultural Engineering Series, Volume 11. Elsevier Science, Amsterdam, 662.

Soulis, K., Ntoulas, N., Nektarios, P. and Kargas, G., 2017. Green roof runoff reduction under different substrate depths and vegetation covers: the effect of initial substrate moisture conditions and total rainfall depth. *Acta Horticulturae*, (1189), pp.541-544.

Stovin, V., 2009. The potential of green roofs to manage Urban Stormwater. *Water and Environment Journal*, 24(3), pp.192-199.

Taghizadeh-Toosi, A., Clough, T., Sherlock, R. and Condron, L., 2011. Biochar adsorbed ammonia is bioavailable. Plant and Soil, 350(1-2), pp.57-69.

Vijayaraghavan, K., 2016. Green roofs: A critical review on the role of components, benefits, limitations and trends. Renewable and Sustainable Energy Reviews, 57, pp.740- 752.

Xie, Z., Xu, Y., Liu, G., Liu, Q., Zhu, J., Tu, C., Amonette, J., Cadisch, G., Yong, J. and Hu, S., 2013. Impact of biochar application on nitrogen nutrition of rice, greenhouse-gas emissions and soil organic carbon dynamics in two paddy soils of China. Plant and Soil, 370(1-2), pp.527-540.

Yadav, M. and Saxena, G., 1973. Effect of Compaction and Moisture Content on Specific Heat and Thermal Capacity of Soils. *Effect of Compaction and Moisture Content on Specific Heat and Thermal Capacity of Soils*, 21(2), pp.129-132.

Yang, X., Wang, H., Strong, P., Xu, S., Liu, S., Lu, K., Sheng, K., Guo, J., Che, L., He, L., Ok, Y., Yuan, G., Shen, Y. and Chen, X., 2017. *Thermal Properties of Biochars Derived from Waste Biomass Generated by Agricultural and Forestry Sectors*.