Effect of Biochar Produced From Paddy Husk and Coconut Frond on Soil Physical Properties and productivity of Ginger in a laterite soil

ABSTRACT:

The effect of biochar produced from paddy husk and coconut frond on soil physical properties and yield of ginger crop was studied in a laterite soil of Kerala, India. The treatments included paddy husk biochar (PHB) and coconut frond biochar (CFB) each @ 10, 20 and 30 t ha^{-1} + NPK as per KAU package of practices (KAU POP) recommendation, KAU POP alone (30 t FYM + 75: 50: 50 kg NPK ha^{-1}) and absolute control. The recovery of paddy husk biochar (PHB) was 50 % and that of coconut frond biochar (CFB) was 40%. Physical properties of the soil were significantly improved by the application of biochar compared to FYM as per KAU POP application. Specific surface area (68.74 and 2.56 m^2 g^{-1} respectively) and water holding capacity (276.33 and 256.51% respectively) were higher for PHB compared to CFB whereas bulk density was lower for PHB (0.27Mg m^{-3}) than CFB (0.35Mg m^{-3}). Biochar application reduced the bulk density, increased the water holding capacity and water stable aggregates of soil. Plant height, rhizome spread, and ginger yield were calculated towards interpreting the direct influence of biochar on growth of ginger. All these parameters were positively influenced by the incorporation of biochar at different rates. The highest ginger yield was obtained for PHB @ 30 t ha^{-1} (13964.2 kg ha^{-1}) which was on par with CFB @ 30 t ha^{-1} (13418.3 kg ha^{-1}). From the investigations, it can be concluded that application of PHB or CFB @ 30 or 20 t ha^{-1} along with NPK as per KAU POP produced significantly higher yield than FYM treatment as per KAU POP can be considered as the economically viable treatments in laterite soil.

Key words: biochar, FYM, soil physical properties, ginger and yield

1.INTRODUCTION:

Ginger is a tropical plant adapted for cultivation even in regions of subtropical climate including the high ranges and prefers a rich soil with high humus content. Ginger is one among the important spices of India and is being used as both fresh vegetable and dried spice. India is the largest dry ginger producing country, where ginger is cultivated in nearly all the states. The main ginger growing states are Kerala, West Bengal and North Eastern Region [1]. Improving the crop yield by maintaining a good soil health and reducing the cost of production has now become a task for researchers to guarantee a sustainable agriculture. Healthy soil, the vital element of healthy environment, is the basis of sustainable agriculture.

Decrease in organic matter content of soil under exhaustive farming systems is a major reason for reduction in soil health. Organic matter plays a critical role in soil ecosystem because it provides substrates for decomposing microbes (that in turn supply mineral nutrients to plants), improves soil structure and water holding capacity, increases natural resistance against soil-borne pathogens, and reduces heavy metal toxicity [2]. For managing soil health, organic amendments like animal manure, municipal biosolids, green manure, compost, biochar etc. can be added. Among these, the huge potential of biochar as a soil amendment in agriculture has recently been recognized.

Use of biochar in agricultural systems is one viable option that can enhance carbon sequestration in the soil, reduce farm waste and improve soil quality and crop productivity. Biochar is the carbonaceous material obtained by the thermo chemical decomposition of biomass on heating under oxygen limited conditions. Pyrolysis and gasification are the two different thermo chemical conversion processes used for the production of biochar. The interesting property of biochar is that it remains in the environment for much longer periods than the decomposable biomass [3].

Soil physical and chemical properties have a direct effect on soil productivity for crop production. Studies have shown that biochar application improved the soil physical, chemical, and biological properties and thereby crop yield. Biochar treated soils reported better crop stand and improved crop growth rate [4]. The use of chemical fertilizers also can be reduced by biochar application due to improved nutrient availability, soil microbes and carbon storage in soil [5]. Accounting for all the benefits of FYM, biochar and integrated nutrient management, the study compares the effects of biochar produced from paddy husk and coconut frond at different rates along with N, P and K and KAU POP treatment (FYM along with N, P, K) on physical properties of soil and ginger crop yield.

2.MATERIALS AND METHODS

2.1 Description of the study area: A field experiment was conducted during 2019 to compare the effect of biochar and FYM application using ginger as the test crop in a laterite soil at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The experimental site was situated at 8.50^0 North latitude and 76.90^0 East longitude at an altitude of 29 m above MSL.

2.2 Climate: The period of crop growth was from May to December 2019. Data on average rainfall, temperature, evaporation and relative humidity at monthly intervals were collected from Meteorological Observatory attached to the College of Agriculture, Vellayani Thiruvananthapuram, Kerala during the cropping period. The mean air temperature of the site ranged from 25.03 ^{0}C to 31.66 ^{0}C, relative humidity from 83.5 – 92.8 per cent and average rainfall from 3.0 to 13.1 mm during the crop growth period.

2.3 Biochar production: Biochar was produced by the method of slow pyrolysis from paddy husk and coconut frond using a double barrel micro biochar kiln. The technology developed for the conversion of tender coconut husk to biochar [6] at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani was adopted with necessary modifications, for the conversion of rice husk and coconut frond to biochar.

2.4 Biochar analysis: A composite sample each from paddy husk and coconut frond biochars were collected and allowed to pass through a 2 mm sieve. The specific surface area of biochar was measured using the N2-BET method (Micrometrics, Tristar 3020) and the surface morphology of biochar was investigated using scanning electron microscopy (SEM, JEOL JSM-7600F). The water holding capacity of biochar was calculated using Keen – Raczkowski Box method and the bulk density by cylinder method [7].

2.5 Field experiment: The field was cleared and beds of size 3m×1m at a height of 25 cm were prepared. Three blocks with eight plots each were laid out in randomized design. The treatments included paddy husk biochar (PHB) and coconut frond biochar (CFB) each @ 10, 20 and 30 t ha^{-1} + NPK as per KAU POP, KAU POP alone (30 t FYM + 75: 50: 50 kg NPK ha^{-1} [8]) and control. Single bud sprout transplanting technique was practiced for planting and the cultivar used was Karthika. For raising sprouts pro-trays were used with a growth medium and nursery medium of partially decomposed coir pith and vermicompost in the ratio of 3:1. Sprouted rhizomes were planted after one month at 20 cm x 20 cm spacing. Trichoderma was mass multiplied in FYM with a ratio of 1:9 and was applied during planting. Mulching of each bed was done with coconut leaves immediately after transplanting. Harvesting was done at eight months of transplanting when the leaves started to show partial yellowing.

Data on plant height, rhizome spread and ginger yield were recorded. Plant height was calculated from the base of the main stem to the base of the fully opened young leaf and expressed in centimeter. The horizontal spread of rhizome was also measured and expressed in centimetre. When the plants started partial yellowing the rhizomes were harvested. The harvested rhizomes were washed and dried at $70 \pm 5^{\circ}C$ in a hot air oven to a constant weight and expressed in kg ha^{-1}.

2.6 Soil analysis: Soil samples were collected from all the treatment plots before planting, 60 and 120 days of crop and also at harvest. Collected samples were air dried, sieved (2 mm sieve) and stored in labelled polythene bags. Soil without sieving was used to analyze the water stable aggregates. Bulk density of the soil was determined using the method of Piper [7]. Keen – Raczkowski Box method was used for determination of water holding capacity and Yoder's apparatus was used for the determination of water stable aggregates. Initial fertility parameters of soils of the study is given in Table 2.

2.7 Statistical analysis: Based on the procedure explained by Cochran and Cox [9] the data obtained from different observations were subjected to statistical analyses. Treatment significance was tested using F test in ANOVA and CD values were calculated for the treatments which were found significant.

3. RESULTS AND DISCUSSION

3.1 Biochar characteristics

Scanning electron microscopy (SEM) images of paddy husk and coconut frond biochar produced at various spatial resolutions and magnifications are depicted in Plate 1 and 2, respectively. The SEM micrographs displayed a highly disordered and complex morphology with longitudinal channels and pores. High content of volatile matter in feedstock lead to the formation of pores in biochar [10]. Rajkumar [11] also stated that, the pores generated during the process of pyrolysis were observable by SEM micrographs in different shapes and size and remained scattered over the surface of biochar.

Bulk density (BD) of biochar (Table 1) varied with the feedstock used; lower BD was recorded for PHB (0.27 Mg m^{-3}) compared to coconut frond biochar CFB (0.35 Mg m^{-3}). The lower values of BD of biochar compared to the BD of soil (1.34 Mg m^{-3}) explain its capability in decreasing soil bulk density and improving soil porosity thus imparting the potential to hold more water when applied to soil [11]. The specific surface area of biochar produced from paddy husk was higher (68.74 m^2 g^{-1}) than from coconut frond (2.56 m^2 g^{-1}). Residual biochar retains some pores present in the biological tissue. Furthermore, the dehydration of tissues and the release of structural H_2O, CO, CO_2 and H_2 from the biological tissue during pyrolysis generate additional internal porosity in biochar particles that improve the surface area of biochar [10]. Lower surface area of CFB compared to PHB can be due to blocking of the residual pores by inorganic material [12]. The volume and distribution of pore size of biochar is positively related to surface area. Volatile organic compounds released from the biomass during the process of pyrolysis leads to the formation of pores and cracks in biochar. The pore network of biochar includes micro, meso, and macropores [13]. Due to dehydroxylation of the biomass, micropores are formed more than meso and macro pores during pyrolysis. Microporosity improves the surface area of biochar that in turn improves the ability of biochars to adsorb minerals and water [14].

It was noticed that the feed stock used for biochar production had significant effects on water holding capacity. Paddy husk biochar had higher water holding capacity (276.33%) compared to coconut frond biochar (256.51%). Probably due to the lower density and higher surface area observed for PHB. This is in conformity with the results obtained by Purakayastha *et al*. [15], who reported that rice straw biochar had higher water holding capacity and lower bulk density compared to maize straw biochar.

Paddy husk and coconut frond biochar produced were alkaline in nature, with a pH of 7.8 and 8.3 respectively. Alkalinity of the biochars produced may be due to the production of ash during the process of pyrolysis or due to the presence of alkali and alkaline earth metal carbonates in biochar [11]. Wide variation in EC was observed as the values varied from 0.8 dS m^{-1} for PHB to 4.2 dS m^{-1} for CFB. Presence of phosphates, silica, heavy metals, sesquioxides, dominance of carbonates of alkali and alkaline earth metals and reduced amount of organic and inorganic nitrogen present in the biochar may be the reason for high electrical conductivity. The total N, P, K, Ca, Mg and S content of PHB and CFB were 0.84 and 0.44 %, 0.13 and 0.29 %, 0.20 and 0.54 %, 0.41 and 0.56%, 0.16 and 0.42% and 0.26 and 0.21% respectively (Table 1). The elemental concentration of biochar is mainly influenced by the type of feedstock. A feedstock rich in one element will produce biochar rich in that same element.

3.2 Response of Soil Physical Properties to Biochar Application

3.2.1 Soil bulk density

Soil bulk density is one of the most studied properties due to biochar application. From Table 2 it is clear that bulk density of soil significantly decreased with an increase in the amount of biochar applied and also with days after planting of the ginger crop (DAP). The bulk density of PHB and CFB was much less compared to both the soils used for the present study. Thus biochar application could reduce the density of the bulk soil through the mixing or dilution effect and by interacting with soil particles to improve aggregation and porosity [16]. The reduction in soil BD was higher for PHB compared to CFB after which can be attributed to the lower BD of PHB as compared to CFB. As crop stages advanced, The BD of soil showed a slight increase probably due to the compaction effect.

3.2.2 Water holding capacity (WHC)

Application of biochar increased the water holding capacity (Table 3) of the soil significantly compared to the control. This could be due to the abundant micropores in the biochar applied soils that helps to physically retain water or the improved aggregation that resulted in creating more pore spaces. Another reason for the differences in water content between biochar-treated plots and the control could be due to the differences in bulk density between the treatments. WHC of all PHB applied treatments was significantly higher than that of FYM application (KAU POP) at all stages of crop growth. Though at 60 DAP only the WHC of soil treated with 30 t ha^{-1} CFB was significantly higher, as period advanced lower application rates also resulted in higher WHC compared to KAU POP. The WHC of all PHB treatments were also significantly higher than the corresponding CFB treatments at all stages of crop growth. The bulk density of the control plots (Table 2) was higher, thus reducing the spaces where water could be retained compared to the biochar-treated plots. Chan *et al.* [5] also reported that the water retention ability of biochar could be as a result of increase in overall net soil surface area after biochar application.

3.2.3 Water stable aggregates (WSA)

WSA was significantly higher for PHB 30 t ha^{-1} compared to all the treatments (Table 4) except CFB @ 30 t ha^{-1} and PHB @ 20 t ha^{-1} at all stages of crop growth, which were on par with each other. All the biochar treatments except PHB and CFB at 10 t ha^{-1} registerd significantly higher values than KAU POP. The WSA aggregates for PHB and CFB were on par for the respective doses of application and at all stages of sampling. An improvement in WSA by 17.5 per cent (at 60 DAP), 21.12 per cent (at 120 DAP) and 19.68 per cent (at harvest) respectively was observed in laterite soil due to the application of PHB @ 30 t ha^{-1} compared to KAU POP (Table 3). Increased concentration of Ca and Mg after biochar incorporation leading to increased flocculation of soil particles might be reason for increased WSA [17]. The increasing mean weight diameter of the soil particles of the biochar applied soils probably due to the increased amount of oxidized functional groups after the degradation of biochar, flocculation of both soil particles and the biochar also might have improved the WSA [3]. Binding of organic amendments with soil particles by electrostatic attraction, leading to the formation of micro-aggregates [18] also improves the WSA.

3.3 Response of ginger to biochar application

Plant height, rhizome spread, and ginger yield were calculated towards interpreting the direct influence of biochar on ginger. All these parameters were positively influenced by the incorporation of biochar at different rates. The improved soil physical properties for the biochar applied treatments leading to reduced bulk density and increased porosity would have enhanced root penetration for nutrient absorption and also better plant and rhizome growth compared to control. The better performance of PHB treatments compared to CFB in the present study might be due to the better characteristics of PHB like low bulk density, high surface area and water holding capacity compared to CFB and FYM.

3.3.1 Plant height

The plant height of ginger was significantly increased by the application of biochar compared to control (Fig. 1). The treatment receiving PHB @ 30 t ha^{-1} recorded the highest mean value for plant height which was on par with the treatment receiving PHB @ 20 t ha^{-1} and significantly higher than PHB @ 10 t ha^{-1} at all stages of crop growth. Even though PHB @ 30 t ha^{-1} was on par with CFB @ 30 t ha^{-1} and significantly higher than CFB @ 20 t ha^{-1} at 60 DAP, these treatments were on par with each other at 120 DAP and at harvest. Plant height for KAU POP was significantly lower than PHB @ 30 t ha^{-1} and on par with all other biochar treatments at 60 DAP whereas at 120 DAP which was significantly lower than PHB and CFB @ 30 t ha^{-1} and on par with PHB and CFB @ 20 t ha^{-1} and PHB @ 10 t ha^{-1} and at harvest which was significantly lower than PHB and CFB @ 30 t ha^{-1} and PHB @ 20 t ha^{-1} and on par with and CFB @ 20 t ha^{-1} and PHB @ 10 t ha^{-1}.

Biochar application promoted the growth of the ginger crop at every stage of crop growth and the increase in growth observed with increasing rate of biochar application compared to FYM application could be due to the ability of biochar to decrease leaching loss of nutrients, improve retention of water and nutrients and to increase aeration and microbial activity in the soil. This is in conformity with the results of Dainy [16], who had reported that plant growth characters and yield were improved in the treatment receiving biochar. This was noticed in the present study also. This might be due to the supply of nutrients present in biochar as well as improving the nutrient use efficiency of applied nutrients, plus ensuring better metabolic partitioning.

3.3.2 Rhizome spread

Yield attributes like rhizome spread and weight analysed in the present study show that all these parameters were significantly influenced by the treatments. The observations showed that all the treatments significantly influenced rhizome spread of ginger at harvest (Fig 2). With increasing rate of applied biochar, rhizome spread also increased. The highest value for rhizome spread was for the treatment PHB @ 30 t ha^{-1} (30.3 cm) and which was on par with CFB @ 30 t ha^{-1} (28.3 cm) and KAU POP (26.9 cm). The rhizome spread for PHB and CFB were on par at respective stages of application and significantly lowest value was in control.

3.3.4 Rhizome yield

A significant effect on ginger yield was evident for the different treatments as given in Table 3. The highest ginger yield was obtained for PHB @ 30 t ha^{-1} (13964.2 kg ha^{-1}) which was on par with CFB @ 30 t ha^{-1} (13418.3 kg ha^{-1}). The treatment receiving KAU POP showed significantly lower value compared to the treatments PHB and CFB each at 20 and 30 t ha^{-1}. The absolute control treatment which received no manures or fertilizers had given in significantly reduced yield, which might be the direct effect of decreased supply of nutrients to the growing plants besides poor soil physical and biological conditions. Porous nature of biochar imparts a high surface area and hence can improve moisture holding capacity and nutrient dynamics in soil, which further influence the soil microbial activity, which might be the reason for improvement in crop yield as reported by Liang *et al*. [19].

4. CONCLUSION

Field experimental results showed that biochar made from paddy husk and coconut frond can be used to improve the yield of ginger and soil physical (bulk density, water holding capacity and water stable aggregates. From the investigations, it can be concluded that application of PHB or CFB @ 30 t ha-1 along with NPK as per POP can be considered as the economically viable and the best treatments. Therefore, biochar could be used as an organic amendment in sustainable agriculture.

Table 1. Physical, electro-chemical and chemical properties of paddy husk biochar (PHB) and coconut frond biochar (CFB)

Sl. No.	Properties	PHB	CFB
	A. Physical properties		
1	Bulk density (Mg m^{-3})	0.27	0.35
2	Specific surface area (m^2 g^{-1})	68.74	2.56
3	Water holding capacity (%)	276.33	256.51
	B. Electro-chemical properties		
1	pH	7.80	8.30
2	EC (ds m^{-1})	0.80	4.20
	C. Chemical properties		
1	Total N (%)	0.84	0.44
2	Total P (%)	0.13	0.29
3	Total K (%)	0.20	0.54
4	Total Ca (%)	0.41	0.56
5	Total Mg (%)	0.16	0.42
6	Total S (%)	0.26	0.21

Table 2. Initial fertility parameters of soils of the experimental site

Fertility parameters	
Physical properties	
Sand (%)	63.52
Silt (%)	10.25
Clay (%)	25.65
Textural class	Sandy clay loam
Bulk density (Mg m^{-3})	1.34
WHC (%)	28.57
WSA (%)	47.12
Electro chemical properties	
pH	4.86
EC (dS m^{-1})	0.22

Chemical properties	
TC (%)	1.57
Available N (kg ha^{-1})	205.11
Available P (kg ha^{-1})	51.23
Available K (kg ha^{-1})	160.43

Table 3. BD of laterite soil as influenced by treatments at different periods of field study, Mg m^{-3}

Treatments	60 DAP	120 DAP	At harvest
T_1-Absolute control (soil alone)	1.34	1.37	1.38
T_2-PHB @ 10t ha^{-1} + NPK as per POP	1.25	1.27	1.31
T_3-PHB @ 20t ha^{-1} + NPK as per POP	1.22	1.25	1.28
T_4-PHB @ 30t ha^{-1} + NPK as per POP	1.18	1.21	1.24
T_5-CFB @ 10t ha^{-1} + NPK as per POP	1.32	1.33	1.35
T_6-CFB @ 20t ha^{-1} + NPK as per POP	1.28	1.30	1.34
T_7-CFB @ 30t ha^{-1} + NPK as per POP	1.24	1.26	1.29
T_8-KAU POP (30 t FYM + 75: 50: 50 kg NPK ha^{-1})	1.33	1.34	1.36
SEm (±)	0.016	0.019	0.020
CD (0.05)	0.048	0.059	0.060

Table 4. WHC of laterite soil as influenced by treatments at different periods of field study, %

Treatments	60 DAP	120 DAP	At harvest
T_1-Absolute control (soil alone)	29.09	27.15	23.06
T_2-PHB @ 10t ha^{-1} + NPK as per POP	46.65	45.87	41.87
T_3-PHB @ 20t ha^{-1} + NPK as per POP	53.65	50.84	47.51
T_4-PHB @ 30t ha^{-1} + NPK as per POP	58.61	56.05	52.55
T_5-CFB @ 10t ha^{-1} + NPK as per POP	38.54	36.20	32.96
T_6-CFB @ 20t ha^{-1} + NPK as per POP	42.09	38.83	35.25
T_7-CFB @ 30t ha^{-1} + NPK as per POP	48.02	44.91	41.60
T_8-KAU POP (30 t FYM + 75: 50: 50 kg NPK ha^{-1})	33.84	29.09	24.97
SEm (±)	3.049	2.698	2.560
CD (0.05)	9.146	8.093	7.68

Table 5. Effect of treatments on WSA in laterite soil at different periods of field experiment, %

Treatments	60 DAP	120 DAP	At harvest
T_1-Absolute control (soil alone)	47.67	45.43	43.64
T_2-PHB @ 10t ha^{-1} + NPK as per POP	53.30	51.79	49.11
T_3-PHB @ 20t ha^{-1} + NPK as per POP	55.86	54.47	52.66

T_4-PHB @ 30t ha^{-1} + NPK as per POP	57.39	56.02	53.26
T_5-CFB @ 10t ha^{-1} + NPK as per POP	51.22	48.90	46.96
T_6-CFB @ 20t ha^{-1} + NPK as per POP	53.59	51.48	49.71
T_7-CFB @ 30t ha^{-1} + NPK as per POP	55.90	53.79	51.47
T_8-KAU POP (30 t FYM + 75: 50: 50 kg NPK ha^{-1})	48.84	46.25	44.50
SEm (±)	1.186	1261	1.109
CD (0.05)	3.557	3.784	3.328

Table 6. Effect of treatments on ginger yield in laterite soil, kg ha^{-1}

Treatments	Dry ginger yield
T_1-Absolute control (soil alone)	7240.0
T_2-PHB @ 10t ha^{-1} + NPK as per POP	10816.7
T_3-PHB @ 20t ha^{-1} + NPK as per POP	12793.3
T_4-PHB @ 30t ha^{-1} + NPK as per POP	13964.2
T_5-CFB @ 10t ha^{-1} + NPK as per POP	9431.7
T_6-CFB @ 20t ha^{-1} + NPK as per POP	12451.7
T_7-CFB @ 30t ha^{-1} + NPK as per POP	13418.3
T_8-KAU POP (30 t FYM + 75: 50: 50 kg NPK ha^{-1})	11502.5
SEm (±)	299.53
CD (0.05)	898.59

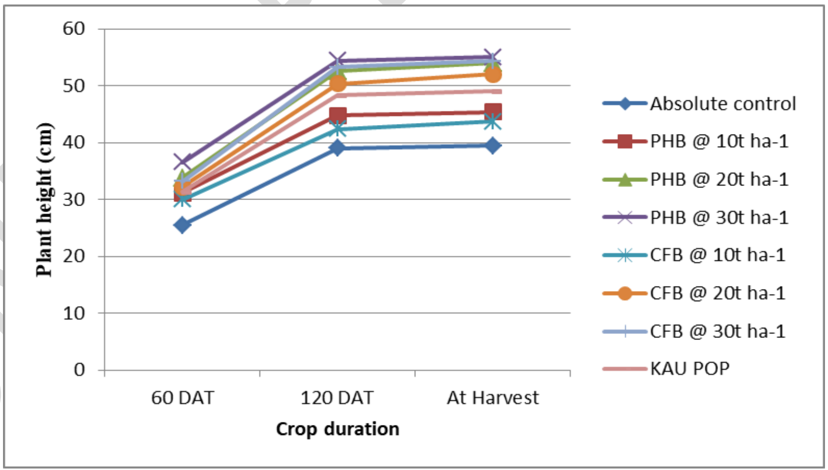

Fig. 1 Effect of treatments on plant height of ginger, cm

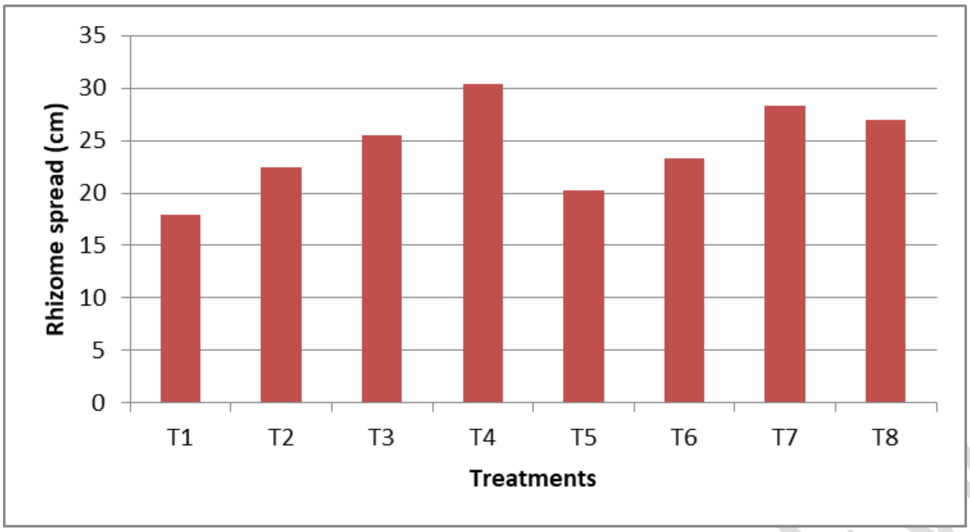

Fig. 2 Effect of treatments on rhizome spread of ginger

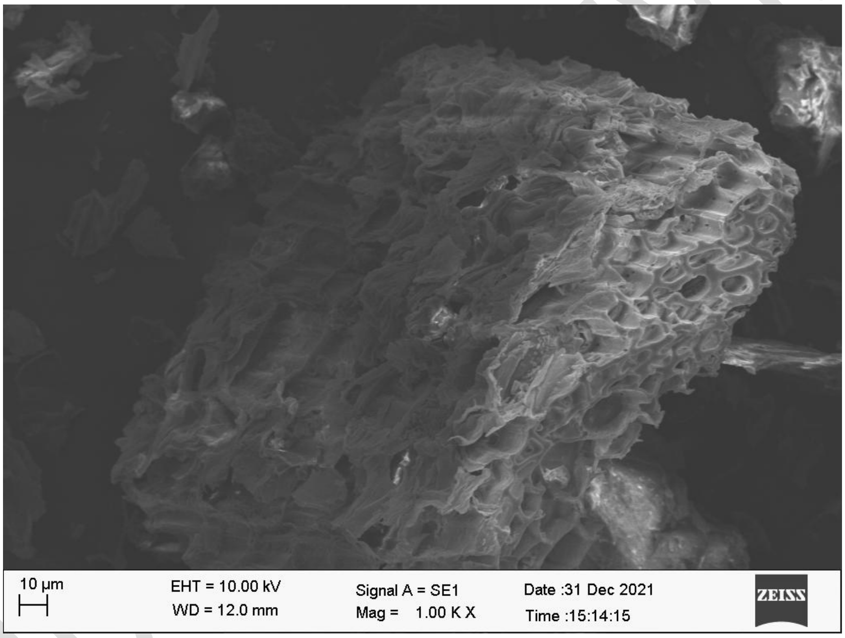

Plate 1. SEM micrographs of paddy husk biochar

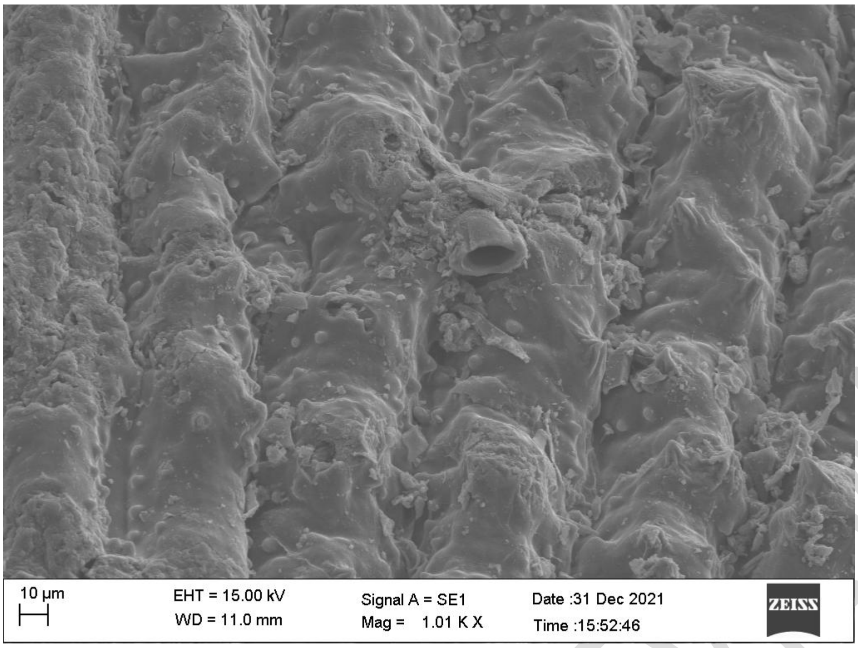

Plate 2. SEM micrographs of coconut frond biochar

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