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Impact of the Combined Application of Biochar and Compost on Mine Soil Quality and Growth of Lady's Finger (*Abelmoschus esculentus*)

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Abstract

Amelioration of mine soil is challenging because of the lack of biologically active organic matter. The study was aimed to recycle yard waste into compost and biochar and to use them to reclaim mine soil. Biochar prepared at 350 °C showed the highest stable organic matter yield index and was used for the experiments. Lady's finger was grown on mine soil amended with biochar (1%–5%), compost (2%–10%), and biochar-compost mixtures (2%–10%). Mine soil pH increased in all treatments. Mine soil dehydrogenase activity (42%–224%), microbial biomass carbon (4%–257%), and hydrolase activity (3%–230%) increased by combined application of biochar and compost. Lady's finger plant height, biomass, and fruit yield were superior in biochar–compost mixtures compared to biochar and compost alone treatment. Thus the use of compost along with biochar could be recommended for reclamation of mine soil.

Keywords Biochar · Compost · Mine soil · *Abelmoschus esculentus* · Microbial biomass

Mine soil (MS) has hostile physiochemical properties for establishment of plant life. Higher stone and rock fragments, higher bulk density due to compaction, poor structure with low water retention capacity, low CEC and poor nutrient retention capcity, lower amount of biologically active organic C, low plant nutrients, and impoverished microbial activity of MS limits the establishment of vegetation (Ahirwal and Maiti 2018; Ahirwal and Pandey 2020; Mukhopadhyay et al. 2016a, b). Generation of organic wastes are increasing due to increase in food and fibre production. Yard waste is a common biomass available worldwide that consists of grass, leaves, tree litter, flowers, etc. obtained from the care and maintenance of lawn, road side pavements, garden, etc. Conversion of yard waste to biochar (BC) leads to conservation of significant amount of organic carbon (Ravindra et al. 2019; Singh 2018). BC have high surface area, porosity, surface charges, and high carbon content. These properties of BC could be used for reclamation of MS (Ghosh and Maiti 2020). But, BC carbon is recalcitrant that could not be utilized by soil microorganism, so addition of biologically active carbon along with BC is a better option. Thus, it is proposed that a portion of yard waste converted to BC and another to compost could be used together for reclamation of MS.

A beneficial combination of BC and organic manure or compost as a preferable alternative has been proven in recent studies (Abideen et al. 2020; Agegnehu et al. 2017; El-Naggar et al. 2019). Biomass yield increased with combined application of BC and compost (Adekiya et al. 2019; Schulz et al. 2013). In a tropical Ferralsol, maize yield increased by 10%–29% by applying BC, compost and mixtures of the two (Agegnehu et al. 2016). A pot study was conducted by Naeem et al. (2018) and found that the maize yield was higher for combined application of BC with compost and fertilizers. Application of BC improved the pH of the MS and the germination percentage and root length of Brachiaria grass seeds (Muegue et al. 2017). In an acidic MS, application of Miscanthus BC along with lime decreased the leaching of metals and improved β-glucosidase enzyme activity (Novak et al. 2018).

Beneficial effect of BC on ameliorating soil properties has been widely demonstrated in agricultural soils. The benefit of the co-application of biochar and compost has to be validated for MS. Maintaining and improving biologically active organic matter in MS is imperative for reclamation

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and vegetation. To assess the effect of combined application of yard waste biochar and compost on the changes in MS properties, a short term pot experiment was conducted. A popular vegetable crop grown by the local community, Lady's finger (*Abelmoschus esculentus* (L.) Moench) was used as the test crop. This study was aimed for optimization of the process for biochar preparation; for quick evaluation of the effect of biochar and compost on MS, and to find out the appropriate dose of biochar/ compost application.

Materials and Methods

Yard waste consisting of tree litter and grass was collected from the garden of Central Institute of Mining and Fuel Research, Dhanbad were sized to around 40 mm and air dried. A stainless steel box of 500 mL capacity was used for the preparation of BC. The yard waste sample was taken in the steel box and heated in a muffle furnace with restricted air supply. The samples were heated at 350, 450 and 550°C temperatures at varying dwell time of 0.5, 1.0, 1.5, and 2.0 h. After carbonization, the BC yield was recorded and all the samples were ground in a mill (RM200; Retsch, UK); and sieved through 40 mesh sieve. Yard waste compost was prepared as detailed in Cooperband (2000). BC-compost mixture was prepared by combining the prepared BC and compost in 1:4 ratios and incubated for 15 days.

Bulk quantity of MS was collected from coalmine overburden (OB) dumps of Vishwakarma opencast projects, Jharia Coalfield (JCF), India. MS sample was dried under shade and sieved through a 2 mm sieve. BC obtained from 350 °C with 0.5 h dwell time was selected for amending the MS. For the experiment, plastic pots were used with a total volume of $\approx$ 15000 cm^3 and a top cross-section area of 500 cm^2. There were 10 treatments with four replications ($n=4$) and in all the treatments a uniform amount of 10 kg MS was mixed with 0.5 kg of local garden soil. Characterisation of MS and garden soil used in pot experiment is as follows: pH (6.04, 6.46), EC (0.24, 0.22dS/m), organic carbon (1.81, 0.97%), available N (6.42, 63.4 mg/kg), available P (2.40, 11.6 mg/kg), exchangeable K (3.50, 9.65 mg/kg), respectively. The processed MS sample was treated with BC, compost and BC-compost mixture at different doses as per the details given in result Table 2.

Originally, 5 seeds of lady's finger (*Abelmoschus esculentus* (L.) Moench) were sown in each pot; after germination, plants were thinned to two plants per pot. Irrigation was done as and when required. The plants attained full growth and maturity at about 70 days and pod maturity around 95 days. Tender fruits were harvested on alternated days. After harvest, plant growth and yield data were recorded.

The labile fraction of C in BC (Calvelo Pereira et al. 2011; Walkley and Black 1934); labile organic matter; total organic matter content or loss-on-ignition (LOI) (Noyce et al. 2016); carbon lability index, stable organic matter (SOM), and SOM yield index were calculated as per the protocol cited in our previous study Kumar et al. (2013). Labile organic matter was calculated by using a factor (1.724) generally used for converting soil organic C into soil organic matter.

$$\text{Carbon lability index (CLI)} = \text{OC}/\text{LOI}$$

$$\text{Stable organic matter (SOM)} = \text{LOI} - (\text{OC} \times 1.724)$$

$$\text{Stable organic matter yield index(SOMYI)} = \frac{\text{Char yield}}{100} \times \text{SOM}$$

Yard waste, BC and compost were analysed for proximate composition in a thermogravimetric analyser (Eltra, TGA) as per ASTM method D1762-84. The ultimate composition was determined with a CHNS elemental analyser (ElementarVario Cube CHNS analyser, Germany). C/N and H/C ratios were calculated on ash free basis. Elemental composition of biochar, compost and biochar-compost mixture were determined by ICP-OES (iCAP 6300dUO, Thermo Fisher Scientific, UK) by following ASTM method D6349 - 13 (ASTM 2013). Water holding capacity, pH (BC:water suspension, 1:10 w/v) and EC (1:10 w/v) was determined by following the respective standard protocols.

The physico-chemical (soil texture, bulk density, water holding capacity, pH, EC, organic C, available nitrogen, available phosphorus, exchangeable K, cation exchange capacity) and biological properties [dehydrogenase activity (DHA), fluorescein diacetate hydrolase (FDA), and microbial biomass carbon (MBC)] of the soil samples were analyzed as per standard procedures (Mukhopadhyay et al. 2014; Mukhopadhyay et al. 2016a, b).

SYSTAT 12 software was used for analysis of variance (ANOVA) to evaluate the effect of different BC-compost treatments on soil and plant growth. Duncan multiple range test was employed for mean comparison at $p < 0.05$. Hierarchical dendrogram for different parameters was obtained by Ward's hierarchical clustering method.

Results and Discussion

Biochar preparation conditions were optimized to obtain maximum yield of char with reasonable amount of stable carbon. BC yield decreased with increase in temperature and retention time (Fig. 1) due to the breakdown of biomass at higher temperatures resulting in the release of easily degradable carbon compounds (Crombie et al. 2013). Excess loss of organic matter during pyrolysis is not desirable as MS requires more organic matter, however the organic matter

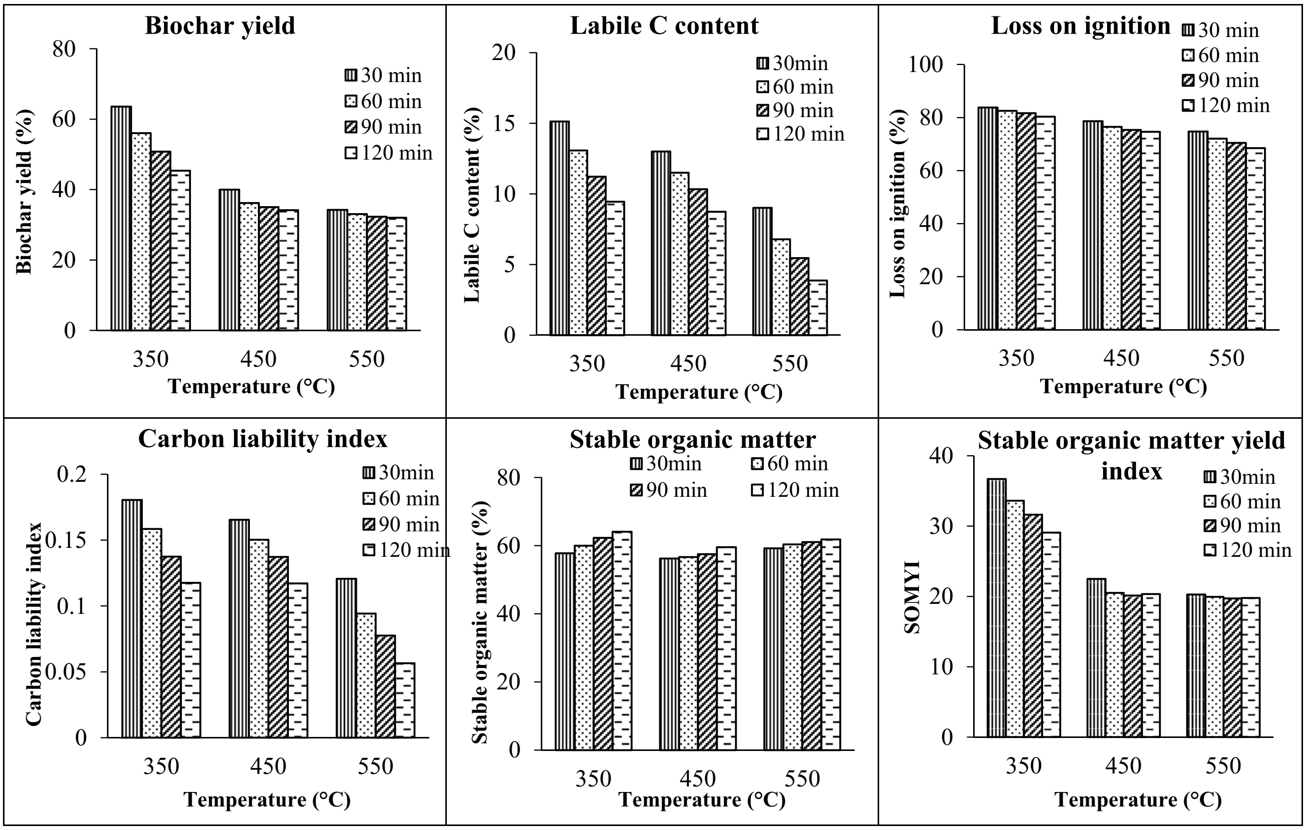

Fig. 1 Impact of pyrolysis temperature and residence time on char parameters

should be stable against mineralization. When temperature was increased from 350 to 450°C (30 min), BC yield decreased drastically by 37%. Labile C content in the BC decreased with increase in temperature which indicates the formation of stable C in BC at higher temperature (Fig. 1) (Calvelo Pereira et al. 2011; Masto et al. 2013). High ash and low LOI was found in BC prepared at higher temperature (Masto et al. 2013). The decrease in LOI content from 350–550 °C is due to the breakdown of ligno-cellulosic components (Tsai et al. 2012). Appropriate amount of LOI (organic matter) is needed in the biochar for successful reclamation of mine soil. Carbon lability index (OC/LOI) was decreased with increase in pyrolysis temperature. Stable organic matter (SOM) content of the BC was highest at 350 °C with 120 min residence time. The stable organic matter yield index was maximum for the BC prepared at 350 °C with 30 min residence time; we used this BC for the pot experiment. As the biochar is to be used for MS amendment, stable organic matter yield is more crucial than stable organic matter content (Mašek et al. 2013). The surface properties of the biochar and other quality parameters might be better in char prepared at high temperature. However, for soil application where bulk quantities of biochar are needed, low temperature char with maximum stable C yield is preferred (Masto et al., 2013). The properties of the yard waste, BC, compost and BC-compost mixture used in the experiment are summarized in Table 1. Decrease in H/C and O/C ratios (Table 1) for BC as compared to the initial parent biomass is due to dehydration and decarboxylation reactions resulting in removal of O and H. Yu et al. (2014) reported that biochar prepared at low temperature has more effect on dry matter yield of maize than the BC prepared at high temperature. The negative effect of high temperature BC is due to the increase in soil pH as the pH of the BC increases with pyrolysis temperature (Cao et al. 2018).

After harvest of the crop, the post-harvest soils were analysed for different soil properties (Table 2). MS pH increased from 6.02 in control to 7.36, 6.24 and 7.22 respectively for BC, compost and BC-compost mixture treated soil. pH was not affected by compost but BC increased pH significantly (Adekiya et al. 2019). BC increased the acidic pH of MS (6.02) to neutral range (7.22 with BC-C (10%); 7.36 with 5% BC) which has positive influences on nutrient availability and microbial activity. Alkaline earth elements (Ca, Mg, Na,) present in the BC played a major role in increasing the MS pH (Chintala et al. 2014). Presence of $CaCO_3$ and other alkaline oxides in BC increases the pH of the MS. Soil EC increased from 0.194 dS/m to 0.408, and 0.290 dS/m

Table 1 Characterisation of yard waste biomass, biochar, compost and biochar-compost mixture

	WHC	pH	EC	Proximate analysis			Ultimate analysis							Total elemental content										
				VM	FC	Ash	C	H	N	S	C/N	H/C	O/C	P	K	Ca	Mg	S	Fe	Cu	Mn	Ni	Zn
Unit	%	–	dS/m	%	%	%	%	%	%	%	–	–	–	%	%	%	%	%	%	mg/kg			
YWBM	–	–	–	75.8^{a}	12.5^{b}	11.7^{d}	41.7^{b}	5.95^{a}	1.95^{a}	0.31^{b}	24.9^{b}	1.69^{a}	0.69^{a}	–	–	–	–	–	–	–	–	–	–
BC	77.1^{c}	9.83^{a}	1.40^{c}	44.2^{b}	28.8^{a}	26.6^{c}	52.1^{a}	3.01^{b}	1.77^{b}	0.37^{a}	34.3^{a}	0.69^{c}	0.23^{d}	0.09^{c}	2.27^{a}	9.28^{a}	0.20^{c}	0.11^{a}	0.41^{c}	7.95^{c}	133^{b}	4.48^{b}	29.8^{c}
COM	168^{a}	7.18^{c}	1.63^{a}	25.2^{c}	4.84^{c}	69.9^{a}	15.9^{d}	2.26^{d}	1.38^{d}	$0.28b^{c}$	13.5^{d}	1.69^{a}	0.48^{b}	0.71^{a}	1.01^{c}	3.90^{c}	0.66^{a}	0.03^{c}	0.72^{a}	14.7^{a}	127	3.03^{c}	44.5^{a}
BC–COM	120^{b}	8.79^{b}	1.54^{b}	28.6^{c}	17.0^{b}	54.3^{b}	30.1^{c}	2.73^{c}	1.62^{c}	0.25^{c}	21.6^{c}	1.08^{b}	0.28^{c}	0.46^{b}	1.42^{b}	7.66^{b}	0.46^{b}	0.05^{b}	0.68^{b}	8.29^{b}	138^{a}	6.86^{a}	38.8^{b}

Mean, n = 4, standard deviation for all parameters is less than 10%; means with same alphabets are not significant at $P < 0.05$ by Duncan's multiple range test

YWBM Yard waste biomass, *BC* yard waste biochar, *COM* compost, *BC-COM* yard waste biochar and compost mixture, *WHC* water holding capacity, pH (1:10,w/v), *EC*(1:10,w/v) Electrical conductivity, *VM* volatile matter, *FC* fixed carbon

respectively for BC, and BC-compost mixture treated mine soil.

Organic carbon content of the MS (1.85%) was almost doubled by adding BC (3.96%) or BC-compost mixture (4.02%). Besides addition of C through BC and compost, the increase in root growth and root exudate also enhance the soil C content (Mukhopadhyay et al. 2016a, b). The high CEC of the BC-compost added soils increases the nutrient availability to the crop by holding the nutrients on the soil exchange sites. With the increasing dose of compost (2%–10%), plant nutrient content and biological activity increased significantly. CEC of the control soil was 11.2 cmol(+)/kg and it has increased to 15.2, 13.2, and 15.6 cmol(+)/kg in BC, compost and BC-compost treated soils, respectively. High CEC of the BC helps in retention of nutrients (Godlewska et al. 2017). CEC of the BC hold the plant nutrients and prevents leaching loss and increases the buffering capacity of the soil (Agegnehu et al. 2017; Novak et al. 2018). Improvement in soil, pH, EC, organic C, and CEC increased the plant availability of soil nutrients. Available P content increased by 2–6 times by BC; 2–3 times by compost; and 2–7 times by BC-compost mixture addition. Similarly, K content increased by 1.5 – 3.5 times due to BC-compost addition. BC has less effect on the N content of the MS, whereas compost or BC-compost application increased the N content by 2 times. Overall combined application of BC and compost has enhanced the plant nutrient contents of MS and no adverse effect was noticed even at the higher dose of 10% application of BC-compost mixture.

Soil dehydrogenase activity was higher for the BC-compost mixture (95.79–115.5 μgTPF/g/24 h) followed by compost (59.37–94.08 μgTPF/g/24 h) treated soils. Only BC addition (48.41–59.71 μgTPF/g/24 h) has marginally increased the dehydrogenase activity as compared to the control (34.02 μgTPF/g/24 h), however dehydrogenase activity decreased at high dose of BC (5%) application. Similarly, MBC was also marginally increased with BC treatment, but co-application of BC and compost increased the MBC by 2–3.5 times. Increase in dose of compost or BC-compost treatments increased the MBC significantly. FDA hydrolase activity increased from 8.59 mg fluorescein/kg/h in control to 8.88–13.44 mg fluorescein/kg/h in BC treated soils, and the corresponding increase was 14.33 -16.81 and 19.67–28.32 mg fluorescein/kg/h for compost and BC–compost added soils, respectively. The labile carbon in the compost supplies the required energy feedstock for the soil microorganism. Thus the co-application of BC and compost significantly helped in inhabitation of soil microorganisms in MS (Agegnehu et al. 2017).

Shoot length and root length was not affected by BC, but compost and BC-compost mixture significantly increased the stem and root length (Table 2). Particularly the root length was increased from 24.31 cm in control to 25.84

Table 2 Soil characteristics after harvesting of lady's finger plants andgrowth and yield data under different treatments

S. no	Treatments	pH	EC	OC	N	P	K	CEC	DHA	MBC	FDA	Stem height	Root length	Shoot dry wt	Root dry wt	Fruit fresh wt	Yield/pot	Yield increase (%)
1	Control (MS)	6.02^{e}	0.194^{d}	1.85^{g}	22.3^{g}	2.81^{h}	4.23^{h}	11.2^{e}	34.02^{h}	82.5^{h}	8.59^{h}	105.8^{e}	24.31^{c}	76.91^{d}	10.65^{e}	10.19^{i}	346.5^{i}	–
2	MS + BC (1%)	6.30^{d}	0.207^{c}	2.42^{f}	24.2^{f}	4.24^{g}	6.68^{g}	12.4^{d}	56.17^{f}	85.4^{gh}	8.88^{h}	106.2^{de}	24.41^{c}	83.12^{c}	12.68^{d}	11.12^{g}	402.6^{g}	16.19^{g}
3	MS + BC (2%)	6.95^{b}	0.288^{b}	3.11^{d}	23.9^{f}	7.32^{e}	9.85^{c}	13.2^{c}	59.71^{e}	87.2^{g}	11.96^{g}	107.7^{d}	24.43^{c}	83.36^{c}	12.61^{d}	10.45^{h}	390.6^{h}	12.73^{h}
4	MS + BC (5%)	7.36^{a}	0.408^{a}	3.96^{a}	24.3^{f}	18.59^{b}	16.13^{a}	15.2^{ab}	48.41^{g}	88.4^{g}	13.44^{f}	108.2^{d}	24.51^{c}	84.28^{c}	12.71^{d}	11.19^{g}	405.2^{g}	16.94^{g}
5	MS + C (2%)	6.11^{de}	0.116^{g}	2.81^{e}	28.2^{e}	4.12^{g}	6.46^{g}	12.3^{d}	59.37^{ef}	97.67^{f}	14.33^{ef}	110.8^{d}	25.32^{b}	89.79^{bc}	14.97^{c}	11.83^{f}	450.2^{f}	29.93^{f}
6	MS + C (5%)	6.19^{de}	0.128^{f}	3.71^{c}	36.2^{c}	6.03^{f}	7.82^{f}	12.8^{cd}	89.49^{d}	147.7^{d}	14.79^{e}	115.6^{c}	25.21^{b}	92.38^{c}	19.04^{bc}	12.04^{e}	498.3^{e}	43.81^{e}
7	MS + C (10%)	6.24^{d}	0.187^{d}	3.86^{b}	48.3^{a}	9.32^{d}	9.22^{d}	13.2^{c}	94.08^{c}	231.8^{b}	16.81^{d}	118.2^{b}	25.84^{b}	97.43^{b}	21.95^{b}	12.19^{c}	586.6^{c}	69.29^{c}
8	MS + BC-C (2%)	6.23^{d}	0.113^{g}	2.88^{e}	27.3^{e}	7.32^{e}	6.23^{g}	13.4^{c}	95.79^{c}	127.4^{e}	19.67^{c}	115.8^{c}	25.82^{b}	94.13^{ab}	19.96^{b}	12.14^{d}	528.4^{d}	52.50^{d}
9	MS + BC-C (5%)	6.56^{c}	0.159^{e}	3.86^{b}	32.6^{d}	11.46^{c}	8.54^{e}	14.7^{b}	110.18^{b}	218.2^{c}	21.01^{b}	128.4^{a}	26.12^{a}	103.52^{a}	26.98^{a}	12.75^{a}	657.5^{a}	89.75^{a}
10	MS + BC-C (10%)	7.22^{a}	0.290^{b}	4.02^{a}	39.7^{b}	20.84^{a}	14.23^{b}	15.6^{a}	115.54^{a}	294.4^{a}	28.32^{a}	126.2^{a}	26.14^{a}	104.64^{a}	27.98^{a}	12.58^{b}	630.3^{b}	81.90^{b}

Mean, n = 4, standard deviation for all parameters is less than 10%; means with same alphabets are not significant at $P < 0.05$ by Duncan's multiple range test

MS Mine soil, *BC* biochar, *C* compost, *BC-C* biochar-compost mixture, *EC* electrical conductivity (dS m^{-1}), *OC* Organic carbon (%), *N* Available N (mg/kg), *P* available P (mg/kg), *K* exchangeable K (mg/kg), *CEC* cation exchange capacity (cmol(+)/kg soil), *DHA* dehydrogenase activity (µg TPF/g/24 h), *MBC* microbial biomass carbon (mg/kg), *FDA* fluorescein diacetate hydrolase activity (mg fluorescein/kg/h), stem height (cm), root length (cm), shoot dry wt (g), root dry wt (g), fruit fresh wt (g), yield/pot (g), yield increase (%)

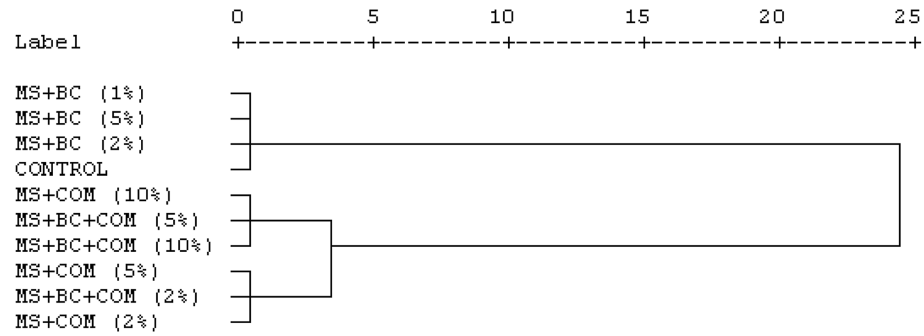

Fig. 2 Hierarchical dendrogram for different mine soil treatments based on mine soil quality and plant parameters obtained by Ward's hierarchical clustering method (*MS* mine soil, *BC* biochar, *COM* compost)

and 26.14 cm respectively for 10% addition of compost and BC-compost. The corresponding increase in stem length was 105.8 vs 110.8–118.2 cm for compost and 105.8 vs 115.8–126.2 cm for BC–compost added soils. Shoot weight was significantly increased with BC (83.1–84.3 g/pot) or compost (89.8–97.4 g/pot) or BC-compost (94.1–104.6 g/pot) treated soil than the control (76.9 g/pot). Similarly, the root weight increased with BC (12.7 g/pot) or compost (15–22 g/pot) or BC–compost (20–28 g/pot) treatment than the control (10.7 g/pot). Fruit yield increased by 12.7–16.9% for BC; 29.9–69.3% for compost; and 52.5–89.8% for BC–compost treatment. The maximum fruit yield (657.5 g/pot) was observed for 5% application of BC–compost. Similar result on the beneficial effect of biochar was reported by Abideen et al. (2020); Adekiya et al. (2019). The increase in crop yield due to BC-compost combined application is due to the amelioration of MS quality. The improvement in soil physical, chemical and biological conditions favours the plant root proliferation and foraging of plant nutrients (Agegnehu et al. 2017). Liu et al. (2012) reported increase in soil pH, organic carbon and plant nutrients by compost and BC addition. MS has high porosity; application of BC to MS can reduce nutrient leaching (Agegnehu et al. 2017; Major et al. 2012).

The cluster analysis (Fig. 2) showed that cluster-1 is associated with BC alone and control. In general, these treatments had poor effect on MS amelioration and plant growth, while treatments having maximum effect on soil improvement and plant growth were placed in cluster 2 and those having medium effect in cluster 3. Cluster analysis demonstrated the need for organic amendments along with BC for amelioration of MS. Increased plant growth and fruit yield in the BC–compost treatment is due to the improvement in the soil physical and chemical properties which in turn provided a habitable environment for the soil microorganisms.

Yard waste can be converted into biochar and compost for use in MS reclamation. Biochar prepared at low temperature (300 °C) with 30 min retention time is recommended for use in MS reclamation. Combined application of biochar and compost even up to 10% dose is favourable for improving the soil pH, CEC, nutrient availability and biological activity of the MS. Local organic waste could be sustainably converted into biochar and compost for reclamation of mine land. This practice could also be adopted by the local community for growing vegetable crops like lady's finger in their agricultural lands affected by coal mining.

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