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Full Length Research Paper

Biochar from oil palm waste as an amendment for the remediation of soil disturbed by open-cast coal mining

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The use of biochar as a soil amendment in agricultural systems and greenhouse experiments has yielded promising results. However, little is known about spoil soil remediation using biochar. Therefore, the effect of the application of biochar from oil palm residues on the remediation of mine waste from open-cast coal mines was examined. Experimental seed germination and root growth of buffelgrass (*Cenchrusciliaris L*) and Brachiaria (*Brachiaria decumbens*) on mine waste were examined. Incubation experiments in Petri dishes and pot bioassays demonstrated that the biochar application rate influenced seedling growth and seed germination.

Keywords: Mine waste characterization, seed germination, remediation, seedling.

INTRODUCTION

Open-cast mining drastically disturbs the landscape and soil properties and negatively impacts the physical, chemical, and biological properties of farmland (Shrestha and Lal, 2011). During surface mining operations, vegetation is removed to allow topsoil to be pushed aside in stockpiles until post-mining reclamation. Huge amounts of waste materials from coal mining operations alter the pH and metal leaching and cause an increase in electrical conductivity due to excess salinity and loss of nutrients (Li, 2006; Beesley et al., 2010; Arranz-González, 2011;). Under acidic conditions, the high availability of Al, Mn, Zn, Fe and Cu is the principal deterrent to plant growth (Diaz-Muegue e al., 2013), and metals in mine tailings inhibit plant growth characteristics (Chun-xi et al., 2007; Shi et al., 2011).

The objective of any remedial action is to decrease risks to human health, the environment and property to acceptable levels by removing or reducing the source of contamination or by blocking exposure pathways (Gavrilescu et al., 2009). Extensive research has been conducted on the remediation of soils with clay minerals, zeolites, organic amendments and compost to immobilize metals through cation exchange, sorption, complexation and precipitation (László, 2000; Geebelen e al., 2002; Roman et al., 2003; Tejada et al., 2006; van Herwijnen and Hutchings, 2007; Motsi et al., 2011).

Recently, soil recalcitrant organic carbon (also known as biochar), which is a black carbon material, has been studied as a soil amendment (Glaser et al., 2002; Lehmann and Joseph, 2009; Masulili and Utomo, 2010).

The application of biochar improves some physical and chemical soil properties (Chan et al., 2007). For example, in one study, biochar application increased soil aggregation, water holding capacity and cation exchange capacity (Atkinson et al., 2010). The type of biochar and its application rate influence wheat seed germination and seedling growth (Solaiman et al., 2011). However, some studies have reported that maize seed germination and early growth are not significantly affected by biochars (Free et al., 2010). The biochar remediation of Cu, Zn and Cd in soil samples has also been evaluated (Uchimiya et al., 2011a,b).

The objective of this study was to evaluate the use of biochar from palm oil waste as a mine soil amendment. The results highlight of the chemical composition of mine waste and biochar, as well as the effectiveness of biochar for seed germination and root seedling of buffelgrass (*Cenchrusciliaris L*) and Brachiaria (*Brachiaria decumbens*)

MATERIALS AND METHODS

Biochar samples were obtained from the "Centro Corporación de Investigación de la Palma de Aceite – Cenipalma". The biochar manufacturing process involves the pyrolysis of oil palm trunk (*Elaeis guineensis Jac*) using FAO technology and temperatures between 200 °C–400 °C.

The pH and electrical conductivity (EC) of biochar were measured in water at a ratio of 1:5 (w/v). The carbon (C), hydrogen (H), nitrogen (N) and sulfur (S) contents of the biochar were determined using a CHNS elemental analyzer. The oxygen content was estimated by mass difference (100% - C, H, N and ash %). Water holding capacity (WHC) and cation exchange capacity (CEC) were measured using the NTC 5167 standard method (ICONTEC, 2004). Infrared spectra were obtained in solid phase using an infrared spectrometer (Thermo Scientific-Nicolet 6700). All biochars were sieved using a 2-mm sieve before being placed in a Petri dish.

Mine spoil samples were collected from the Jagua Coal Reserve Area in northern Colombia. Three waste samples were collected for laboratory analysis and air-dried for 2 days at room temperature.

The coal mine waste samples were characterized using the Sobek method (Sobek, 1978). Color was measured by comparison with color chips based on the Munsell color system. Soil texture was analyzed utilizing a Bouyoucos hydrometer. The pH level of each sample was measured in a soil/water slurry at a 1:1 (w/v) ratio, and EC was measured at a ratio of 1:5 (w/v). Total nitrogen (Nt) was determined using the Kjeldahl method, and soil organic carbon (SOC) was calculated using the Walkley-Black method. Extractable P was measured and acid-base accounting was performed. The S content in the mine wastes was determined using a CHNS elemental analyzer.

The concentrations of total Al, Mn, Zn, Fe and Cu were determined by atomic absorption spectrometry (AAS) after acid digestion according to method 3050b (US-EPA, 1989) for mine wastes and biochar.

The germination rate and root growth experiments were performed according to Solaiman et al. (2011). Fifty seeds of buffelgrass (*Cenchrusciliaris L*) and fifty seeds of Brachiaria (*Brachiariadecumbens*) were cultured in Petri dishes (8.5 cm diameter) on a layer of filter paper moistened with deionized water. The five biochar types were added in the following quantities: 0, 0.5, 1.0, 2.5, and 5.0 g/Petri dish. All Petri dishes were covered with lids and incubated in the dark at 25 °C for 72 h. The germination percentage and root length were then assessed.

The root lengths of the fresh roots of seedlings were measured using a ruler, and the values for each Petri dish were summed. For the bioassays in pots, fifty buffelgrass and fifty Brachiaria seeds were mixed separately with each of the mine waste materials at application rates of 0 t/ha, 4 t/ha and 24 t/ha. Pots were submerged in water and allowed to drain for 24 h. The pot bioassays were performed at an average temperature of 22 °C and 60-65% relative humidity. Total rainfall was 306.96 mm during the 12 days of the experiment.

The seed germination data were statistically analyzed using ANOVA, and the means were separated by employing Duncan´s Multiple Range Test (DMRT). Each bioassay was performed in triplicate, and the leaching test was performed in duplicate.

RESULTS AND DISCUSSIONS

Figure 1 and Table 1 present the characteristics of the biochar and mine waste. The Fourier transform infrared (FT-IR) spectrum of the biochar sample contained a band at 3422.26 cm-1, which corresponds to stretching due to hydroxyl group vibrations. There were also bands at 1600 cm-1 and 1460 cm-1 resulting from carboxylic group vibrations and bands between 1000 cm-1 and 1300 cm-1 due to C–O bonds. The spectrum of these functional groups is similar to that reported by Cantrell et al. (2012).

The analytical results presented in Table 1 reveal that the biochar from oil palm trunks was slightly alkaline, with a pH of 8.9. The char had a dark gray color, a high percentage of carbon (70.1%), a high WHC and a C/N ratio of 81.51. The CEC showed similar amendment characteristics.

The pH values of the wastes ranged from acidic (MW2, sandy loam texture with carbolitic fragments) to neutral (MW3, loamy sand texture) and basic (MW1, sandy clay loam texture). The SOC percentages were highest in the MW2 waste, possibly due to interference by carbon

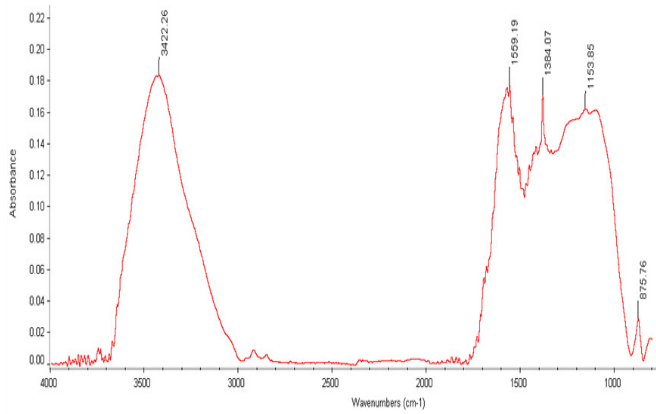

Figure 1. FT-IR Spectra of biochar from oil palm trunk (*Elaeis guineensis Jac*)

Table 1. Characteristics of mine waste and biochar from oil palm trunk (*Elaeis guineensis Jac*)

References	Units	Mine waste MW1	Mine waste MW2	Mine wasteMW3	Biochar
pH	-	8.38	3.44	7.06	8.92*
EC	uS/cm	353.8	1196.6	435	242**
Sand	%	50.66	79.83	85.53	-
Silt	%	28.33	9.17	6.66	-
Clay	%	21.01	11	7.81	-
WHC	%	40	35	35	241.6
Soiltexture	-	Sandy clayloam	Sandy loam	Loamysand	-
Munsell color (Wet)	-	10YR6/4	Gley 1 2.5/N	5YR6/4	Gley2.5/N
SOC	%	0.84	4.50	0.36	0.68
P	mg/kg	190.35	20.67	66.7	-
N Total K	%	0.07	0.68	0.07	-
CEC	(cmol.kg−1)	29.8	36.9	26.7	42.80
Total copper	mg/kg	29.55	10.64	22.43	3.20
Total zinc	mg/kg	153.43	49.97	146.48	35.13
Total iron	mg/kg	32528.18	14156.18	32903	211.36
Total aluminium	mg/kg	9226.45	3271.97	2333.96	284.82
Total manganese	mg/kg	497.34	1.59	444,72	47.44
S	%	0	0.77	0.2	0.15
C	%	-	-	-	70.10
H	%	-	-	-	2.81
N	%	-	-	-	0.86
O	%	-	-	-	25.16

* pH water 1:5; ** EC in water 1:5

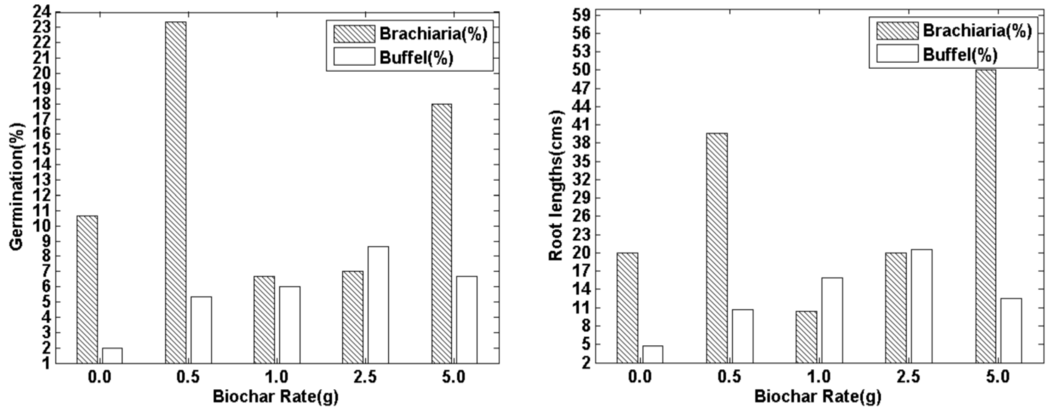

Figure 2. Effect of biochar on seed germination in soil-less Petri dish bioassay

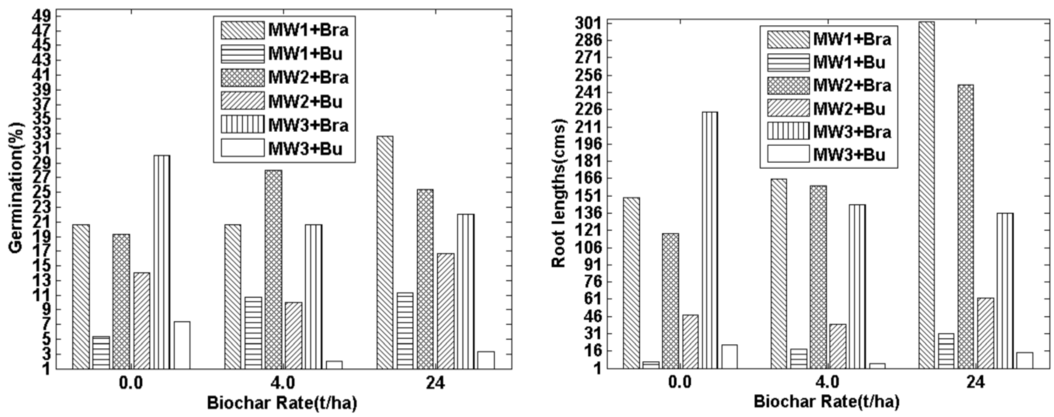

Figure 3. Effect of biochar on seed germination in pot bioassay

Table 2. Results of ANOVA factorial analysis of Petri dish without soil

		P-Value			
Factor	df	GerminationBrachiaria	RootlengthBrachiaria	GerminationBuffelgrass	Rootlength Buffelgrass
Biochar rate	4	0.1700	0.0395	0.8257	0.8257

fragments from coal or the presence of carbonaceous shales under wet oxidation (Arranz-González, 2011). High concentrations of heavy metals were observed in all samples. The sulfur in MW2 may be derived from the coal extraction process.

The MW1 waste had high contents of Fe (32528.18 mg/kg), Al (9226.45 mg/kg), Zn (153.45 mg/kg), Mn (497.34 mg/kg) and Cu (29.55 mg/kg). By contrast, biochar contained 284.82 mg/kg Al and 3.20 mg/kg Cu were present in biochar.

The germination and root length statistical analyses are summarized in Table 2. The response of Brachiaria grass was greater than that of buffelgrass in both the Petri dish assays and the pot assays (Figures 2 and 3). Average germination percentages ranged from 54% (Brachiaria+0.5 g of biochar in Petri dish) to 32.66% (MW1+Brachiaria+24 t/ha of biochar in pots). The lowest percentages were 2% (MW3+buffel+4 t/ha of biochar) and 19.33% (MW2+Brachiaria+0 t/ha). The highest cumulative root lengths were 150 cm (Brachiaria+5.0 g of biochar in Petri dishes) and 302.5 cm (MW1 + Brachiaria +24 t/ha of biochar in pots).

The ANOVA results for the Petri dish bioassay revealed an interaction between the biochar application rate and Brachiaria root length (Table 2). Germination was not significantly affected by the biochar application rate ($p>0.05$) for Brachiaria and buffelgrass. The results of the Duncan test of the soil-less Petri dish bioassay (Table 3) indicated that the presence of biochar favored greater seedling lengths of Brachiaria, had a low influence on

Table3. Mean values of germination rates and root lengths measured in Petri dish without soil.

Treatment	Germination (%)		Root length (cm)	
	Buffelgrass	*Brachiaria*	Buffelgrass	*Brachiaria*
B0	1 a	5.33 ab	4.7 a	27.8 cd
B0.5	2.67 a	7.00 ab	10.7 a	39.6 bc
B1	2 a	3.33 ab	10.8 a	10.4 a
B2.5	3.33 a	2.67 a	16.8 a	20.4 ab
B5	2.33 a	9.00 b	10.1 a	50 d

Note: * _ Means followed by the same letter (s) are not significantly different at $p<0.05$, according to Duncan's Multiple Range Test (DMRT).

Table 4. Results of ANOVA factorial analysis of the pot bioassay with open environmental conditions, biochar rate and mine waste type.

		P-Value			
Factor	df	Germination Brachiaria	Rootlength Brachiaria	Germination Buffelgrass	Rootlength Buffelgrass
Mine wastetype	2	0.9671	0.1764	0.0120	0.0171
Biochar rate	2	0.6060	0.0028	0.6905	0.0647

Table 5. The mean values of germination and growth parameters of Buffelgrass and Brachiaria seedlings under different biochar rates.

Treatment (t/ha)	Germination (%)		Rootlength (cm)	
	Wastetype	Buffelgrass	Buffelgrass	*Brachiaria*
0	MW 3	4.22a	1.6a	4.74a
4	MW 1	9.11ab	1.81ab	4.83a
24	MW 2	12.9b	2.74b	6.86b

Note: * _ Means followed by the same letter (s) are not significantly different at $p<0.05$, according to Duncan's Multiple Range Test (DMRT).

Brachiaria germination (B5), and did not influence buffelgrass germination and root length.

The ANOVA results for the pot bioassay revealed an interaction between the mine waste type and buffelgrass germination and root length and between the biochar application rate and Brachiaria root length (according to DMRT) (Table 4). This indicates that increasing the biochar application rate to 24 t/ha promotes root elongation ($p<0.05$). At 24 t/ha, increased growth was observed in the three residues compared to samples treated with the lower biochar application rate. Buffelgrass growth results (at 24 t/ha) were close to the significance value of the dose interaction ($p<0.05$). Furthermore, in the interactions with different types of residues, the growth results indicated that the most favorable response was to MW1, followed by MW2 and finally MW3.

The effect of biochar on these two grasses was opposite that reported by Solaiman et al. (2011), for wheat (*Triticumaestivum L.*) and mung bean (*Vigna radiate L*). Duncan's multiple range test was used to separate the means of the dependent variables, which were significant in both the Petri dish (Table 2) and pot (Table 4) bioassays. Significant differences in both seed germination and root length were observed for differing biochar application rates to Brachiaria in the Petri dish test (B 2.5-B5).

The data in Table 5 indicate that the presence of biochar favored root elongation for Brachiaria and buffelgrass. The type of residue seems to have influenced germination. MW3 impeded germination, possibly due to its low content of SOC, CEC and clay and its high sand content. Mine waste with a high content of Al, Zn and Mn appears to decrease the root length of buffelgrass and Brachiaria. However, this effect can be compensated for with the use of biochar from palm oil waste. The results demonstrate that lower amounts of SOC in the applied biochar (0 t/ha) lead to lower mean buffelgrass and Brachiaria germination percentages and root lengths.

The DMRT analysis of buffelgrass showed significant differences in biochar rates for different substrates (Table

5). These results are in line with studies by Solaiman et al (2011), who investigated the effect of biochar and soil properties on seed germination and seedling variation. Biochar application generally increased the root length of buffelgrass and Brachiaria. Root length gradually increased ($p<0.05$) with increasing biochar application rate. The soil-less Petri dish bioassay did not clearly reveal how buffelgrass root growth and germination varied with the biochar application rate, indicating that more research is needed. By contrast, trials in pots containing mine waste showed an increased interaction when the biochar application rate was increased. The limited evaluation of biochar application rates is a potential limitation of this study.

CONCLUSIONS

In summary, seed germination assays confirmed that biochar can be used as an amendment for the remediation of mine waste soil properties. The use of biochar from oil palm residues improves the physicochemical characteristics of the edaphic material. The effects of biochars on early growth of Brachiaria and buffelgrass depended on the biochar application rate. The application of this organic amendment helps reduce the toxicity of heavy metals. The application of biochar using biomass waste from oil palms is an environmentally friendly technology for use in mine soil restoration, and the implementation of biochar could be used for the ecological restoration of landscapes affected by open-cast coal mining.

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