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Potential of Biochar for Minesoil Amendment and Floristic Diversity Enhancement at the Yongwa Quarry Site in the Eastern Region of Ghana

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ABSTRACT

Background: Reclamation of degraded and mined lands has become paramount due to exploitation of our resources. The study sought to explore the potential of biochar for amending degraded mined soil and stockpiled topsoil and its ability to enhance plant diversity at the Yongwa quarry site in the eastern region of Ghana.

Method: Two separate experiments were conducted using a randomized complete block design (RCBD). Four treatments were allotted randomly within each block for stockpiled topsoil and amended degraded mined soil experiments and replicated three times. Biochar and poultry manure were applied at 0.002 tons per every 2 m x 2 m plot. However, when applied in combination (biochar and poultry manure), they were applied at 0.001 tons of biochar and 0.001 tons of poultry manure per every 2 m x 2 m plot.

Result: The results of the study revealed a generally higher nutrient status and species diversity on the plots with amended soils compared to the control. The highest Shannon index (2.04) was recorded on the combined biochar and poultry manure-amended plots while the lowest was recorded on the control plot (1.08). A similar trend was observed on the degraded mined soil amended plots with the combined biochar and poultry manure-amended soil recording the highest Shannon index (2.32) and effective number of species values (10.15) compared to the other amendment plots.

Key words: Biochar, Degraded soil, Plant diversity, Stockpile soil.

INTRODUCTION

In mined land rehabilitation, the topsoil plays a very important role not only as a growth medium but also as a bank for numerous indigenous plant seeds (Ballard *et al.,* 1996). However, due to its long storage during mineral exploitation, the physical, chemical and biological properties are compromised by the time of rehabilitation. This results in soil nutrient depletion, soil degradation, lack of topsoil and reduced natural regeneration. It is therefore important to amend disturbed mine soils to provide alternative topsoil substitutes as well as improve the health of stockpiled topsoils for successful mine rehabilitation.

Most studies have explored different soil amendments such as cow dung, poultry manure, *etc*. which have proven to have some potential in soil nutrient restoration. However, their impacts are short-term, usually (1-5 years) (Bendfeldt *et al.,* 2001). Since mine rehabilitation is a long term project, it is important to adopt the use of amendments that have a lasting impact on the soil.

According to Glaser *et al*. (2002), the persistence of organic matter in tropical soils for centuries can be attributed to biochar application either consciously or unconsciously. Studies conducted by Lehmann *et al*. (2008), has dated naturally occurring biochar in Australian soils to 1,300 - 2,600 years. Similarly, controlled decomposition experiments have revealed that biochar can reside in the soil for between 1,300 to 4,000 years (Liang *et al*., 2008; Kuzyakov *et al*., 2009). The long term impacts of biochar on the soil are due to its aromatic structure which makes it physically, chemically and biologically stable and resistant to degradation (Novak *et al*., 2010). It may, therefore, be more suitable for amending degraded mined soils for long term projects such as mine rehabilitation compared to other amendments.

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MATERIALS AND METHODS

Description of the study area

The study was conducted at the Ghacem limestone quarry at Yongwa located at Klo-Begoro in the Yilo Krobo District of the eastern region of Ghana between January 2018 to August 2018 (Fig 1). The quarry covers an area of about 81.45 ha with about 46 ha of the area currently being mined. It is located at N6°33′00″ - W0°04′40″ (Fig 1).

Experimental design

Two experiments were laid separately at 5 m apart for stockpiled topsoil and degraded mined soil. The first experiment assessed the effect of biochar and poultry manure rates on stockpiled topsoil whilst the second

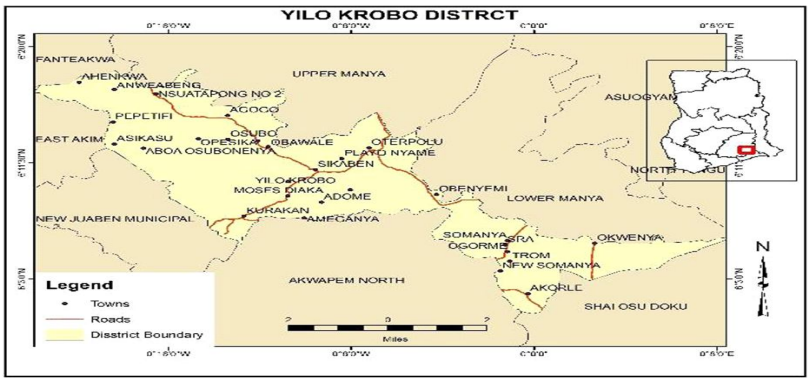


Fig 1: Map od study area.

experiment was on degraded mined soil. The experiments were laid in a randomized complete block design with three replications and the treatments allocated within the blocks. The amendments were applied and mixed thoroughly with the soils within the 0-15 cm layer of each 2 m x 2 m experimental unit. Where amendments were applied individually (biochar only or poultry manure only), they were applied at 0.002 tons per every 2 m x 2 m plot. However, when applied in combination (biochar and poultry manure), they were applied at 0.001 tons of biochar and 0.001 tons of poultry manure per every 2 m x 2 m plot. Degraded soils in this experiment are the waste soils (quarry dust) which are produced as by-products of limestone extraction while stockpiled soil represents topsoil that has been stockpiled for 13 years (2004-2017). The treatments used in the experiments for Stockpiled topsoil amendment were: Stockpiled topsoil only (Control, TS only), Stockpiled topsoil + Biochar (TS+B), Stockpiled topsoil + Poultry Manure (TS+PM) and Stockpiled topsoil + Biochar + Poultry Manure (TS + B+ PM). Treatments for the degraded mined soils were Degraded Mined soil (Control, MS), Degraded mined soil + Biochar (MS +B), Degraded mined soil + poultry manure (MS + PM) and Degraded mined soil + Biochar + Poultry manure (MS+B+PM).

Field data collection and analysis

All naturally regenerating plants on each 2m x 2m plot were identified and enumerated by observation from a botanist with Forest Research Institute of Ghana (FORIG). Soil samples were also collected from each plot at a depth of 0-15 cm in August, 2018 and analyzed for pH, N, P, K and OC. The pH was determined using a potentiometer in soils suspended in water and 0.01Molar (M) calcium chloride solution (SERAS, 2002). Nitrogen was determined by the Kjeldahl method (Bremner, 1960), Phosphorus by the spectrophotometric method (Bender and Wood, 2000), Potassium by the flame photometry method (Stanford and English, 1949) and organic carbon (Walkley-Black) (De *et al.,* 2007). The mean values of the soil analysis data were subjected to one-way analysis of variance and Tukey HSD All-Pairwise Comparisons Test using SPSS (Version 20). Shannon and Simpson's indices were used to estimate plant species diversity (Magurran, 2004).

$$\text{Shannon index (H)} = -\sum_{i=1}^{N} Pi \, Ln \, Pi$$

Where,

Pi = is the ratio of individual species in each plot (n) to the total number of species in the plot (N). *i.e*. Pi = (n/N),

Ln = natural log and Σ = sum of all figures.

$$\text{Simpson index (D)} = \Sigma \, Pi$$

RESULTS AND DISCUSSION

Naturally regenerated plant species on the stockpiled topsoil amended plots

A total count of 388 naturally regenerated species distributed over 19 species and 12 families were identified on the stockpiled topsoil amended plots (Table 1). The highest number of species (16) were recorded on the plots with combined biochar and poultry manure (TS + B + PM) and the lowest (5) recorded on the control plot. The study also observed 7 native, 8 non-native and 4 Invasive alien species on the experimental plots. However, the most dominant species on the plots was *Megathyrsus maximus* (native). The Fabaceae family recorded the highest number of species (4) followed by the Poaceae family (3). The Asteraceae and Solanaceae families recorded two species each while the Compositae, Malvaceae, Rubiaceae and the other families recorded one species each (Table 1).

Naturally regenerated plant species on the degraded mined soil amended plots

A total count of 295 naturally regenerated species distributed over 8 species and 6 families were identified on amended degraded mined soil. The plots amended with biochar recorded the highest number of species (8) while plots amended with poultry manure recorded four species each with the control plot. The study also observed 5 native, 1 non-native and 2 Invasive alien species on the experimental plots with the most dominant species being *Megathyrsus maximus* (native species) (Table 2).

Diversity of naturally regenerated plant species on the stockpiled topsoil and degraded mined soil

Stockpiled topsoil amended with biochar and poultry manure

Table 1: Naturally regenerated plant species on amended stockpiled topsoil.

Species	Species frequency from the treatment				Status	Family
	TS + B + PM	TS + B	TS + PM	TS only		
Tridax procumbens	15	7	11	3	Non-native	Asteraceae
Chromolaena odorata	4	4	9	5	Invasive Alien	Asteraceae
Aspilia africana	2	4	4	-	Native	Compositae
Mimosa pudica	2	2	6	-	Invasive Alien	Fabaceae
Solanum torvum	3	-	2	-	Non-native	Solanaceae
Sida acuta	3	3	-	-	Non-native	Malvaceae
Richardia brasiliensis	3	-	-	-	Invasive Alien	Rubiaceae
Cassia occidentalis	6	-	-	-	Invasive Alien	Fabaceae
Ricinus communis	21	-	5	3	Native	Euphorbiaceae
Cola gigantea	8	7	6	-	Native	Sterculiaceae
Centrosema pubescens	2	-	-	-	Non-native	Fabaceae
Oryza longistaminata	2	-	3	-	Native	Poaceae
Megathyrsus maximus	53	33	46	82	Native	Poaceae
Pennisetum purpureum	3	-	-	2	Native	Poaceae
Acacia auriculiformis	2	-	-	-	Non-native	Mimosaceae
Azadirachta indica	1	-	-	-	Non-native	Meliaceae
Physalis angulata	-	2	4	-	Non-native	Solanaceae
Senna occidentalis	-	-	3	-	Non-native	Fabaceae
Aneilema beniniense	-	-	2	-	Native	Commelinaceae
Total	130	62	101	95		

Table 2: Naturally regenerated plant species on amended degraded mined soil.

Species	Species frequency from the treatments				Status	Families
	MS + B + PM	MS + PM	MS +B	MS only		
Tridax procumbens	14	15	7	15	Non-native	Asteraceae
Aspilia africana	7	-	-	-	Native	Compositae
Ricinus communis	3	-	10	-	Native	Euphorbiaceae
Megathyrsus maximus	39	35	31	62	Native	Poaceae
Mimosa pudica	3	6	8	1	Invasive Alien	Fabaceae
Chromolaena odorata	-	12	9	8	Invasive Alien	Asteraceae
Oryza longistaminata	-	-	1	-	Native	Poaceae
Aneilema beniniense	-	-	9	-	Native	Commelinaceae
Total	66	68	75	86		

had the highest Shannon index (2.04) and the lowest (1.08) was recorded on the control plot. Simpson index values of 0.78, 0.76 and 0.68 were recorded for the combined amended (TS+BP+M), poultry manure and biochar amended plots respectively. The lowest Simpson index value (0.25) was recorded on the control plot (Table 3). Also, the combined amended plots (TS+B+PM) recorded the highest effective number of species (7.66) compared to the other amendments with the control plot recording the lowest (2.95).

A similar trend was observed on amended degraded mined soil (Table 4). This suggests that the addition of biochar to the soil had a positive effect on natural regeneration. Despite the positive effect of biochar on the natural regeneration of plant species, the synergistic effect of biochar and poultry manure had a more positive effect on plant regeneration with the dominance of *Megathyrsus maximus* on all established plots. These results may be due to biochar addition which released soluble nutrients contained in the fresh char and increased soil water retention (Atkinson *et al*., 2010; Thomas *et al*., 2013). The dark colour of biochar alters thermal dynamics and facilitates the rapid germination of seedlings (Genesio *et al*., 2012). Biederman and Harpole (2013) in a review paper also reported a positive response of belowground annual plants to biochar amendments in a meta-analysis. They, however, noted that perennial species had no response to biochar addition. Gundale *et al.* (2016) however observed that the biochar amendment alone was ineffective at enhancing the growth of the ground layer vegetation or the regeneration of forest trees and may, therefore, need the addition of other amendments to facilitate this process. The higher diversity as a result of the synergistic effect of biochar and poultry

manure is because in biochar production most volatile soil nutrients like nitrogen are lost through the combustion process. These nutrients are however replaced through the synergy between these amendments which provides the seeds with the nutrients needed in the readily available form which enhances natural regeneration of the plants. The enhancement of N mineralization associated with biochar and soil moisture retention due to biochar addition creates the required soil conditions for soil microbial activities. These activities of the soil microbes expose dominant plant seeds to the required conditions for natural regeneration (Keech *et al*., 2005).

Table 3: Diversity of naturally regenerated plant species on amended stockpiled topsoil.

Treatments	Shannon Index (H)	Simpson Index (1-D)	Effective number of species
TS+B+PM	2.04^{a}	0.78^{a}	7.66^{a}
TS+B	1.55^{b}	0.68^{a}	4.71^{c}
TS+PM	1.92^{a}	0.76^{a}	6.82^{b}
TS Only	1.08^{c}	0.25^{b}	2.95^{d}
P-Value	0.00	0.00	0.00

Means of same superscript letters are not significantly different at 5% level.

Table 4: Diversity of naturally regenerated plant species on amended degraded mined soil.

Treatments	Shannon Index (H)	Simpson Index (1-D)	Effective number of species
MS+B+PM	2.32^{a}	0.59^{ab}	10.15^{a}
MS+PM	1.20^{b}	0.65^{a}	3.31^{c}
MS+B	1.66^{ab}	0.76^{a}	5.26^{b}
MS Only	1.06^{b}	0.44^{b}	2.90^{c}
P-Value	0.002	0.003	0.00

Means of same superscript letters are not significantly different at 5% level.

Nutrient status of stockpiled topsoil and degraded mined soil amended soils

In the stockpiled topsoil amended plots, significantly higher soil pH was recorded for the control (8.2 ± 0.02) and biochar amended soil (8.3 ± 0.01) compared to the other treatments (Table 5). Soil organic carbon levels were significantly higher (1.23 ±0.20) in the combined amended soil (TS+B+PM). Though no significant difference (P > 0.05) was observed in nitrogen concentration, there was a marginally higher (0.09±0.018) nitrogen content in the combined amended soil compared to the others. A significantly higher phosphorus level (24.33±3.38) was observed in the combined amended soil (TS+B+PM) and Potassium level, on the other hand, was highest (1.00±0.26) in the poultry manure-amended soil and lowest (0.23±0.02) in the combined amended soil (TS+B+PM) (Table 5).

In degraded mined soil, higher pH was recorded in the combined amended (8.19±0.01), poultry manure (8.22±0.08) and control (8.16±0.01) soils (Table 6). Generally, organic carbon, nitrogen, phosphorus and potassium were higher in amended soils (Table 6). This implies that the addition of biochar had a positive effect on soil nutrient status. Comparing biochar to other organic amendments in a highly degraded ecosystem Kimetu *et al*. (2008) observed an increase in soil organic carbon concentrations. Despite the low nutrient content of biochar, its ability to mobilize and retain the nutrients in the soil solution increases the nutrient status of the soil. Furthermore, the study showed that, despite the increases in soil nutrient concentration with the addition of biochar, the synergistic effect of biochar and poultry manure was more positive compared to the plots amended with biochar only. These results may be due to the fact that biochar releases the nutrients within the plant biomass into the soil and also enhances the activities of soil microbes which make nutrients readily available to the plants (DeLuca *et al*., 2006). While biochar itself is low in nitrogen due to nitrogen volatilization in the production

Table 5: Nutrient status of stockpiled topsoils.

Treatments	Soil pH	% O.C	% N	Available P ppm	K me/100g
TS	8.2 ± 0.02^{a}	0.51 ±0.04^{b}	0.04 ±0.003^{a}	0.09±0.01^{b}	0.39±0.07^{ab}
TS+B	8.3 ± 0.01^{a}	0.64±0.04^{ab}	0.07±0.006^{a}	2.04±0.86^{b}	0.85±0.01^{ab}
TS+B+PM	7.2 ± 0.07^{c}	1.23 ±0.20^{a}	0.09±0.018^{a}	24.33±3.38^{a}	0.23±0.02^{b}
TS+PM	7.8 ± 0.02^{b}	0.61 ±0.15^{b}	0.06±0.018^{a}	1.11±0.04^{b}	1.00±0.26^{a}
P value	0.00	0.02	0.20	0.00	0.01

Means of same superscript letters are not significantly different at 5% level.

Table 6: Nutrient status of degraded mined soils.

Treatments	Soil pH	% O.C	% N	Available P ppm	K me/100g
MS	8.16±0.01^{a}	0.33±0.02^{b}	0.03±0.003^{b}	1.29±0.49^{b}	0.46±0.01^{b}
MS+B	7.83±0.09^{b}	0.35±0.07^{b}	0.04±0.008^{b}	1.910±0.07^{b}	0.44±0.05^{b}
MS+PM+B	8.19±0.01^{a}	1.35±0.03^{a}	0.12±0.014^{a}	37.51±11.24^{a}	1.33±0.07^{a}
MS+PM	8.22±0.08^{a}	0.78±0.43^{ab}	0.08±0.032^{ab}	5.74±2.03^{b}	1.29±0.36^{a}
P value	0.01	0.03	0.03	0.01	0.01

Means of same superscript letters are not significantly different at 5% level.

process, its ability to immobilize nitrogen (Kimetu *et al*. 2008) and enhance nitrogen mineralization (Ameloot *et al*., 2015) increases soil microbial activity and cation exchange capacity which makes nutrients readily available in the soil for plant use (Lehmann *et al*., 2011; Brewer *et al*., 2011). Therefore, the high nutrient status could be due to the addition of poultry manure. According to Biederman and Harpole (2013), the composting of biochar and organic materials enhanced nutrient use efficiency, biological activation of biochar, better material flow management and a higher and long-term C sequestration potential compared to individual compost and biochar applications.

CONCLUSION

The study proved that biochar can improve the nutrient status of both stockpiled topsoil and degraded mined soil. Its use also enhanced plant diversity and therefore ideal for the improvement of stockpiled and degraded soils. We recommend that mined and degraded sites could employ the use of biochar for reclamation and rehabilitation.

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Conflict of interest statement

The authors declare that there is no conflict of interest arising from this publication

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