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Research article

Subsoil Amendment With Poultry Manure as Topsoil Substitute for Promoting Successful Reclamation of Degraded Mine Sites in Ghana

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Abstract

Background: Despite the key role topsoil plays in reclamation, there are situations where topsoil is in deficit or unavailable, especially at degraded and abandoned mine sites in Ghana. The sites pose serious ecological and safety risks, underscoring the urgent need to finding alternative substrate for restoration. This study investigated the feasibility of using amended-subsoil as topsoil substitute for reclamation. The hypothesis was that amendment of stockpiled-subsoil with poultry manure positively influences tree growth and ground vegetation cover (GVC), which promote better soil stabilization at degraded mine sites. A graded waste-rock dump was covered with a 70 cm layer of the stockpiled subsoil at Newmont Ghana Gold Limited. Two experimental plots (24 × 15 m) were established with the treatments poultry manure (PLM 23 t ha⁻¹) and control (no PLM), followed by seeding of Cowpea (*Vigna unguiculata*) and planting of potted-seedlings of five forest tree species. The Laser-point-quadrat method was used to estimate GVC, whereas erosion was visually observed. Diameter and height data of planted trees and surviving numbers were collected.

Results: There was significant increase in tree growth and in GVC for the poultry manure treatment compared to the control. The manure provided sufficient nitrogen to overcome nitrogen deficiency and facilitated quicker and stronger vegetation growth that yielded superior soil stabilization.

Conclusions: The findings demonstrate the potential of manure application in promoting successful restoration of the many degraded and abandoned mine sites in Ghana to productive uses.

1. Introduction

Topsoil is universally recognized as very essential in the revegetation of disturbed mine sites and in ecosystem health. This is because topsoil is known to contain important resources for plant growth such as native seeds and other plant propagules, soil biota, organic matter (OM) and nutrients (Nsiah & Schaaf, 2018; Reuter, 1997; Sweeting & Clark, 2000; Wright, 2002; Zipper et al., 2011). Best reclamation management practices (BRMPs) therefore require that topsoil is salvaged and stockpiled prior to mining and reapplied as substrate for vegetation growth to promote site restoration (Norman, Wampler, Throop, Schnitzer, & Roloff, 1997; Nova Scotia Environment, 2009; Skousen, Zipper, Burger, Barton, & Angel, 2011).

Several studies have identified challenges regarding topsoil acquisition and storage such as unavailability at the site being mined, especially at quarry sites (Department of Environmental Conservation, 2005; Norman et al., 1997; Nsiah, 2012; Sweeting & Clark, 2000; Zipper et al., 2011). Also, where topsoil is available, there could be other potential challenges like contamination with plant pathogens and weed seeds (invasive species) that could defeat the restoration goal (Department of Environmental Conservation, 2005; Wright, 2002) or there could be topsoil deficit. For instance, whilst Newmont Ghana Gold Limited (NGGL) stockpiles all topsoil and subsoil separately to reconstruct the original layering of soil horizons for future restoration, this study perceived a potential topsoil deficit at the mine site. According to NGGL (2015), topsoil depth salvaged at the beginning of mining operation ranged from 8 to 20 cm, whereas subsoil depth was 120 to 150 cm. The company's standard practice for establishing vegetation on waste-rock dump is to replace 70 cm depth of the subsoil followed by 30 cm topsoil. This is perceived to generate potential topsoil deficit at the site, whilst subsoil will be in excess. Previous studies revealed the existence of many degraded and abandoned mine sites in Ghana where the topsoils were not salvaged and stockpiled prior to the mine operations (Nsiah, 2008, 2012). The sites pose serious ecological and safety risks and also serve as continuous sources of erosion and sedimentation to rivers and streams. These degraded sites should be restored to eliminate these risks and to make the land available for productive use. Even though topsoil could be imported from elsewhere to restore the degraded sites, such practice has been shown to be associated with other challenges such as high transportation costs and the topsoil exporting area is degraded to fix a problem elsewhere (Darmody, Daniels, Marlin, & Cremeens, 2009; Larney & Angers, 2012). Therefore, creation of alternative growth media for vegetation establishment in guaranteeing and promoting successful restoration of those degraded mine sites is warranted.

Some studies propose that where little or no topsoil for revegetation exists, it may be necessary to amend, manufacture or import soils depending on the final land use and site conditions (Darmody et al., 2009; Nova Scotia Environment, 2009). Others studies demonstrate that alternative materials such as subsoil, overburden, waste-rock, etc., can be applied as topsoil substitutes for revegetation during reclamation (Darmody et al., 2009; Department of Environmental Conservation, 2005; Nsiah, 2012; Zipper et al., 2011). In the United States, for instance, although Federal and State regulations require

that natural soil existing at sites prior to mining (topsoil) be salvaged and stockpiled for revegetation, the rule is waived for those working in areas where it is difficult to save the topsoil and where operators can show that topsoil substitutes are as good or better for the post-mining land use as the original soil (Skousen et al., 2011). Sweeting and Clark (2000) report an instance where invasive species had dominated a stockpiled topsoil at the Ranger Uranium Mine in northern Australia, rendering it unsuitable for site revegetation. Instead, waste-rock was found suitable for revegetation, and it was used in place of the original topsoil. Gerwin et al. (2010) and Hüttl, Gerwin, Schaaf, Zaplata, and Hinz (2014) demonstrated successful restoration of an open-cast mine in the Lusatian lignite-mining district in eastern Germany without the application of topsoil, after extensive application of amendments like lime and mineral fertilizer.

The chemical and physical properties, such as pH, nutrients, organic matter, effective cation exchange capacity (ECEC), bulk density, texture as well as heavy metal concentrations of topsoil substitutes are often adversely affected by the mining operations and pose constraints for vegetation establishment (Department of Environmental Conservation, 2005; Hutchings, Sinnet, & Doick, 2014; Vega et al., 2005).

The topsoil substitutes may also require techniques or amendments to increase their organic matter and nutrient contents as well as to improve the physical properties for successful revegetation (Larney & Angers, 2012; Wright, 2002). Even though it could take 250 to 350 years for mine spoils to reach organic matter levels similar to adjacent undisturbed soils in Saskatchewan (Anderson, 1977), studies have demonstrated that organic amendments can speed up the recovery process by injecting large amounts of organic matter to initiate nutrient cycling and overcome soil physical limitations (Salazar, Bosch-Serra, Estudillos, & Poch, 2009; Shipitalo & Bonta, 2008). While the application of topsoil is key in successful revegetation, amendment of mine spoil with manure and other organic materials has been demonstrated to improve soil physical, chemical and biological properties together with improved plant growth on degraded lands (Edwards & Daniel, 1992; Larney & Angers, 2012; Rollett, Taylor, Chambers, & Litterick, 2015). Poultry manure serves as an abundant source of OM and nutrients needed for sustained plant growth (Edwards & Daniel, 1992). Poultry manure is produced in abundance by the poultry industry in Ghana and is considered as a waste product, which can be obtained at a no cost.

The aim of this study is to characterize a seven-year old stockpiled-subsoil (STS) and subsequent amendment with poultry manure as a topsoil substitute in reclaiming degraded mine sites in Ghana. The practice is perceived as an appropriate and economic means of disposing of poultry manure as a by-product, whilst promoting successful restoration of degraded and abandoned mine-lands in Ghana for productive uses. The hypothesis was that amendment of STS with poultry manure positively influences growth of trees and ground vegetation cover, which promotes improved soil stabilization at degraded mine sites. The specific objectives were: (a) to characterize the STS and evaluate its potential as topsoil substitute in terms of pH, OM, nutrients, electrical conductivity (EC), ECEC, base

saturation (BS), texture, bulk density and heavy metal concentrations; and (b) to assess the effects of amendment of STS with poultry manure on tree growth and on the establishment of ground vegetation cover in stabilizing the site against soil erosion.

2. Data and Methods

2.1 Description of Study Location

The study was carried out on a waste-rock dump (WRD) generated from the Amoma Pit at NGGL Ahafo-south gold project, situated between latitudes 6°40', 7°15', North and longitudes 2°15', and 2°45' West, Kenya, in the Brong-Ahafo Region, Ghana (Figure 1). The NGGL Ahafo-south project involves the development of four pits, operated by the surface mining method, to produce and process

approximately 7.5 Mt of ore annually. The site has a bi-modal rainfall pattern with the major rain falling from mid-March to early July, and the minor rain falls from September to November, with average annual rainfall of 1,232 mm (Nsiah & Schaaf, 2018). March is typically the hottest month with an average temperature of 27.8 °C and August is typically the coldest month with a mean temperature of 24.6 °C. The soils have developed over weathered products of lower birimian phyllite and alluvial sediments within river and stream valleys and the floodplains of the Tano River. The soils are classified according to the FAO World Reference Base as Ultisols (Acrisols and Nitisols) in the highlands and Fluvents (Fluvisols) and Inceptisols (Cambisols) in the lowlands (NGGL, 2015). Hall & Swaine (1981) classified the area under the moist semi-deciduous ecological zone, northwest sub-type, which is characterized by a three-storey structure with emergent tall trees often exceeding 50 m in height.

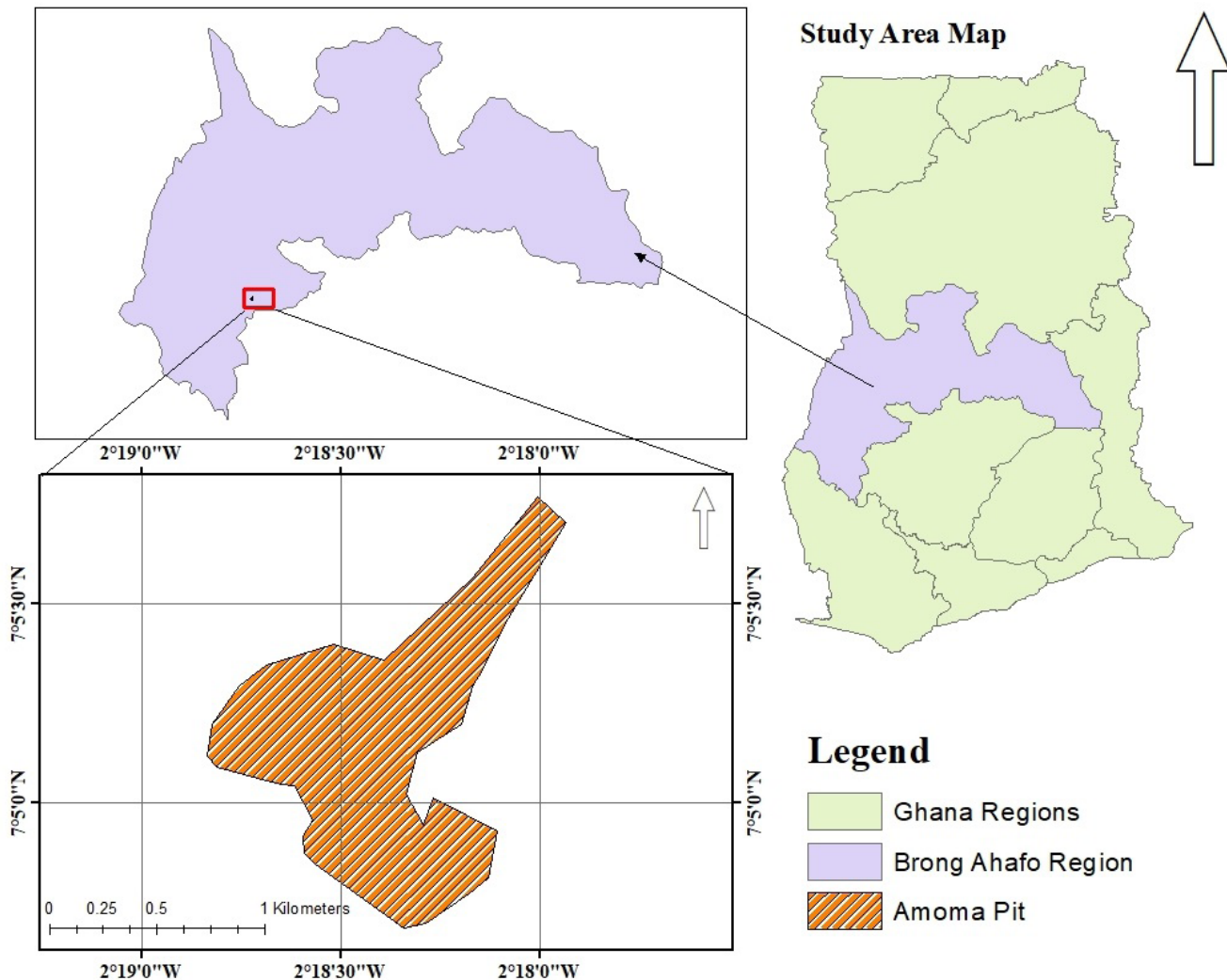


Figure 1: The study location, Amoma Pit at NGGL, Ahafo-South project, Kenya.

2.2 Methods

2.2.1 Design of Experiment

A trial plot measuring 15 m by 48 m was graded to form a 33% slope followed by placement of a 70 cm layer of a seven-year old STS, without topsoil (Figure 2). The STS was loosely placed on the waste-rock dump to avoid compaction and destruction to soil structure. Prior to the application of manure and tree planting, the STS was tested to determine its initial soil composition and potential heavy metal contamination, because heavy metal contamination has been associated with mining activities (Hazelton & Murphy, 2016). Six soil cores were randomly sampled to a depth of 30 cm with the help of soil auger, immediately after STS replacement in May, 2016. All six samples were mixed in a plastic bucket to make a composite sample. The content was transferred to a clean plastic tray for further divisions and approximately 1 kg of the composite sample was placed in a brown paper bag as described by Motsara and Roy (2008). Separate samples were taken with 100 cm³ metal ring cores to a depth of four centimeters to determine bulk density. All samples were taken with three replications following the same protocol and sent to the laboratory for analyses of physical and chemical soil properties, including heavy metal concentrations.

With the exception of samples used to determine soil bulk density, all other samples were air-dried and sieved through a 2 mm mesh. Soil pH and EC were measured with the aid of a multi-parameter PC 300 series electrode in 1:5 soil to water suspension (Motsara & Roy, 2008). The volumetric sodium tetraphenylboron method was used to determine exchangeable sodium (Na) and potassium (K), after dry ashing digestion of the soil sample and analysis with a Jenway flame photometer model PFP7. Magnesium (Mg) and calcium (Ca) were estimated by means of a Spectrophotometer (BSS 280 G), after extraction by ammonium acetate (Motsara & Roy 2008). Exchangeable acidity due to hydrogen (H) and aluminum (Al) was extracted using 0.1 N KCl solution. For the determination of hydrogen acidity, 5 drops of phenolphthalein indicator were added to the leachate and the leachate titrated with 0.05 N NaOH to colorless end point. In the case of aluminum acidity, the titrated extract from the hydrogen acidity test was treated with 3N NaF reagent and the mixture further titrated with 0.05 N HCl to pink end point. Total phosphorus (P) was estimated by the blue complex molybdate and thiophosphate (Bray P1) method in acid solution and analyzed using Buck Scientific Spectrophotometer (BSS) Model 280 G. Total nitrogen was determined by the Kjeldahl method (Motsara & Roy, 2008).

The ECEC was calculated by the summation of exchangeable bases and acidity, whereas BS was estimated as the percentage of the base cations (Na, K, Mg and Ca) of ECEC (Hazelton & Murphy, 2016). Organic matter from both manure and STS samples was determined by the loss of weight on ignition method as described by Motsara and Roy (2008), with the help of a muffle furnace model L9/S, at 550 °C for four hours. Total heavy metal concentrations in terms of As, Pb, Cu, Ni, Cr, Zn, Mn and Cd was extracted by means of acid digestion using a mixture of 9:4 nitric: perchloric acid and filtered through Whatman 1 acid-washed filter paper. Heavy metal analysis

was carried out by Atomic Absorption Spectrophotometric model AA 220 (Motsara & Roy, 2008). Particle size analysis was carried out through the hydrometer method (Bouyoucos, 1927) and textural class was determined using the textural triangle diagram according to the United States Department of Agriculture soil texture classification system. Bulk density was determined using undisturbed soil cores collected in a 100 cm³ metal ring core and weight was determined after oven-drying (Brady & Weil, 2008).

Having characterized the site, the experimental plot was split into two equal areas of 24 m × 15 m, followed by application of the treatments, poultry layer manure (PLM) and no amendment (control) on their respective plots. Even though application rates of organic amendments (OAs) of up to 100 t per hectare have been recommended (SNIFFER, 2010), the rates are site-specific based on the properties of the amendment materials (AMs), such as C:N ratio, purpose of application and quality of in-situ material, especially, pH, OM and nutrients, as well as the intended land use (Rollett et al., 2015). Due to the lack of N which produced a high C:N ratio following the STS characterization, a high rate of 23 t (dry weight) PLM per hectare was applied at one time. The manure was evenly spread over the soil surface manually and incorporated within the top 10 cm of soil with the aid of a shovel. The one-time application was selected because single large application of organic amendment has been proven to accelerate initial revegetation success and lead to self-sustaining net primary productivity (Larney & Angers, 2012). Manure application was followed by implementation of other BRMPs such as seeding of cowpea (*Vigna unguiculata*) as a cover crop and installation of "York" mat biological geotextiles on both treatment plots for erosion and sediment control (Nsiah & Schaaf, 2018). The cowpea was seeded at 30 cm intervals in irregular lines with 3-bean seed per hole. Analyses of the PLM (Table 1) showed it contained high nutrient contents, particularly total N and OM contents, with low C:N ratios.

In June 2016, 11 potted-seedlings of each of the indigenous tree species *Terminalia superba*, *Terminalia ivorensis* and *Khaya anthotica* and same number of the exotic species *Cedrela odorata* and *Senna siamea*, were planted with 3 m by 3 m spacing, through complete randomization, in each treatment plot. The individual trees for each species were thus, the replicates ($n = 11$). The indigenous species were selected because they are native to the region whilst *C. odorata* and *S. siamea*, despite being exotic species, were chosen because of their adaptability to the ecological site as well as their relatively fast growth rate. In addition, the selected tree species are rated as having high trade values in both the domestic and international timber markets. Their seedlings were either readily available at no cost from the NGGL nursery stock or bought at a relatively low cost from the University of Energy and Natural Resources nursery department in Sunyani.

2.2.2 Data Collection

The Laser-point-quadrat method (Bureau of Land Management's National Applied Resource Sciences Center, 1996) was used to determine the ground vegetation cover (GVC) by demarcating 1 m



Figure 2: The graded waste-rock dump (left); replacement of the STS on the graded rocks (right).

Table 1: Chemical composition of the applied poultry manure, numbers are means with standard deviations in bracket, $n = 3$

Parameter	pH	N (%)	P (%)	K (mg ^{-kg})	S (%)	Ca (mg ^{-kg})	Mg (mg ^{-kg})	OM (%)	OC (%)	C/N ratio
Mean	6.63	4.44	0.45	2.06	0.28	25.50	0.20	73.45	42.60	9.65
S.D.	(0.12)	(0.01)	(0.01)	(0.03)	(0.02)	(0.71)	(0.00)	(1.49)	(0.86)	(0.25)

by 2 m (2 m²) grid quadrats, yielding a total of 216 monitoring quadrat points per treatment plot. Four weeks after amendment application, tree planting and seeding of the cover crop, observations were made on “hits” and “misses” along a walking transect with the aid of a measuring tape (Figure 3). A “hit” was recorded if the laser beam made a strike on any vegetation, and a “miss” was recorded when the beam hit bare soil. Thus, only one hit or one miss was recorded in each of the 216 quadrats of each treatment plot. The percentage GVC for each treatment plot was calculated by dividing the number of hits in that plot by the total number of monitoring quadrat points and multiplying by 100. The combined effect of manure application and GVC on soil stabilization against erosion was visually observed.

Six months after the trees were planted (December, 2016), the

diameter and height data of the trees were measured and the number of surviving trees were counted. A tape measure was used to estimate tree height, which was measured from the soil surface to the tip of the tree canopy, whereas basal stem diameter was measured at 10 cm above the soil surface using a vernier calliper. Percentage survival of the individual tree species was calculated by dividing the number of trees surviving by the total number of that species initially planted, and multiplying the result by 100.

2.2.3 Data Analysis

All data were analyzed using IBM SPSS Statistics Version 25.0. Descriptive statistics (mean and standard deviation) were performed to determine the initial soil properties of the STS. The study hypothesis



Figure 3: Observations of hits and misses using Laser-point-quadrat; left = PLM; right = control; four weeks after the start of the experiment.

was tested using one-way ANOVA ($\alpha = 0.05$) to verify whether treatment significantly affected individual tree growth, with PLM as factor and height and diameter as the dependent variables. Data on tree growth and GVC were presented in bar graphs, with the aid of the legacy dialogs, for visual comparisons.

bulk density according to Brady and Weil (2008) with a near neutral pH. Nutrient contents with respect to exchangeable K and total N concentrations were very low whilst that of P was moderate. The OM/organic carbon (OC) content was moderate, which combined with the very low N content to yield a high C:N ratio. Whereas total Na was low, the other exchangeable bases, Mg and Ca, were moderate. Exchangeable acidity was very low, which promoted a high base saturation. The concentrations of heavy metals such as arsenic, lead, copper, nickel, chromium, zinc, manganese, and cadmium in the STS and that of the PLM (Table 3) were all within acceptable limits, when compared with USEPA (1994) and EU standards (Alloway et al., 2000).

3. Results

Results on the characterization of the STS used for the experiment, as depicted in Table 2, revealed the soil was sandy loam with a moderate

Table 2: Chemical and physical properties of the stockpiled-subsoil (STS), numbers are means with standard deviations in brackets; $n = 3$

Parameter	Value
pH	6.60 (0.10)
EC ($\mu\text{S cm}^{-1}$)	159.92 (1.21)
N (%)	0.04 (0.002)
P (%)	0.29 (0.006)
K (Cmol c kg^{-1})	0.05 (0.01)
Na (Cmol c kg^{-1})	0.77 (0.07)
Mg (Cmol c kg^{-1})	4.10 (0.26)
Ca (Cmol c kg^{-1})	7.03 (0.20)
H (Cmol c kg^{-1})	0.40 (0.08)
Al (Cmol c kg^{-1})	0.36 (0.04)
ECEC (Cmol c kg^{-1})	12.71 (0.43)
Base saturation (%)	94.02 (0.23)
OM (%)	3.83 (0.01)
OC (%)	2.22 (0.01)
C/N ratio	62.63 (3.20)
Bulk density (g cm^{-3})	1.30 (0.01)
Sand (%)	66.58 (0.88)
Silt (%)	22.33 (1.11)
Clay (%)	11.09 (0.40)
Texture	Sandy loam

Table 3: Heavy metal concentrations of the STS and the PLM against USEPA and EU standards. $n = 3$; Numbers are means with standard deviations in brackets; n.a. = not available

Heavy metal	STS	PLM	USEPA (Non-residential soil)	EU (Agric. Soil)
As (mg kg ⁻¹)	1.95 (0.21)	1.45 (0.07)	20	40
Pb (mg kg ⁻¹)	2.10 (0.42)	2.70 (0.57)	600	200
Cu (mg kg ⁻¹)	45.15 (1.49)	36.35 (0.21)	600	140
Ni (mg kg ⁻¹)	298.00 (60.81)	213.00 (1.41)	2400	n.a
Cr (mg kg ⁻¹)	0.40 (0.00)	0.40 (0.00)	100	150
Zn (mg kg ⁻¹)	101.75 (0.92)	7.75 (0.21)	1500	300
Mn (mg kg ⁻¹)	602.0 (140.01)	18.50 (0.71)	n.a	3000
Cd (mg kg ⁻¹)	4.85 (1.06)	1.50 (0.14)	100	n.a

Four weeks after planting and manure application, there was a positive response of GVC to poultry manure amendment, which was almost four times higher (79.8%) at the PLM, compared to the control (23.3%) (Figure 4 and Figure 5). Visual observations on the site revealed the presence of sheet and rill erosion on the control plot, whereas the manure-treatment plot showed superior soil stabilization (Figure 6).

Amendment of the STS with the PLM resulted in significantly greater ($p < 0.05$) diameter (Figure 7) and height (Figure 8) growth for the three species *K. anthotica*, *T. superba* and *C. odorata* as well as height

growth of *T. ivorensis* after six months of planting and amendment application. However, there was no amendment effect on both diameter and height growth of *S. siamea* and diameter of *T. ivorensis*. There was no clear difference regarding survival of the planted trees among treatment plots (Figure 9). *Cedrela odorata* recorded the highest survival of 100% in PLM, but moderate survival of 72.7% in control, whilst *T. superba* recorded 90.9% in both treatments. *Khaya anthotica* and *S. siamea* yielded the same survival value of 81.8% in PLM with survival in the control of 63.6% and 72.7%, respectively. *Terminalia ivorensis* recorded the lowest survival in both treatment plots (72.7% in PLM and 54.5% in control).



Figure 4: Effect of poultry manure on ground vegetation cover, four weeks after the start of the experiment; left = control (slow and poor vegetation growth with lower ground cover); right = manure treatment (fast and strong vegetation growth with greater ground cover).

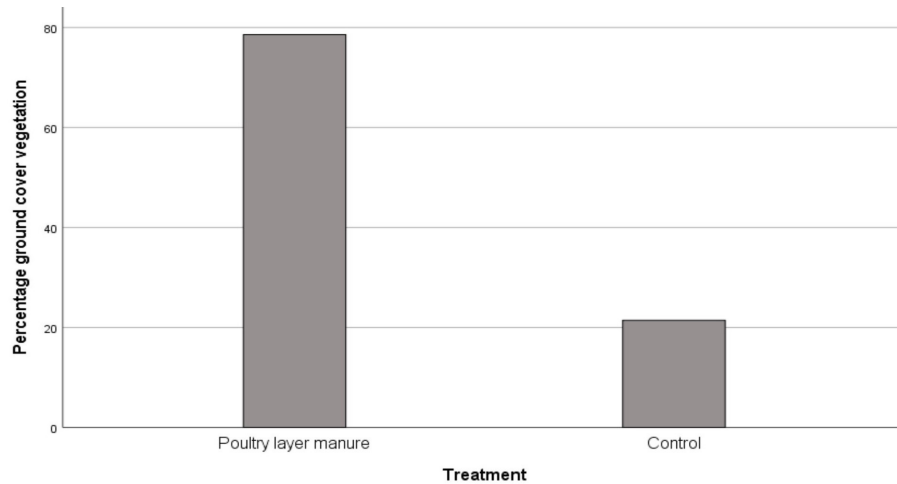


Figure 5: Effect of poultry manure on ground vegetation cover during restoration at NGGL.



Figure 6: Effect of poultry manure on soil erosion; left = manure treatment (no observable signs of erosion, superior soil stabilization,) right = control (presence of sheet and rill erosion, poor soil stabilization).

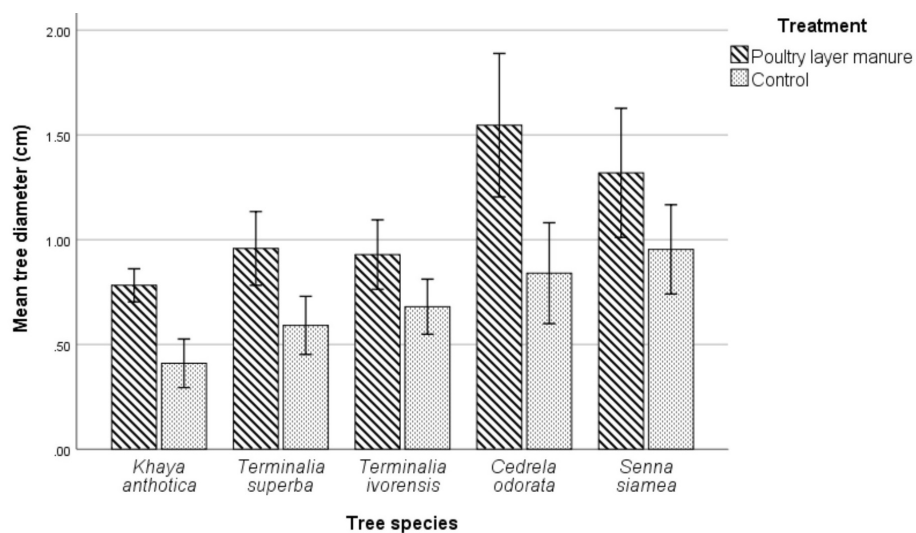


Figure 7: Effect of manure on diameter growth of five forest-tree species six months after planting on a waste-rock dump at NGGL. $n = 11$; Error bars represent 95% confidence interval.

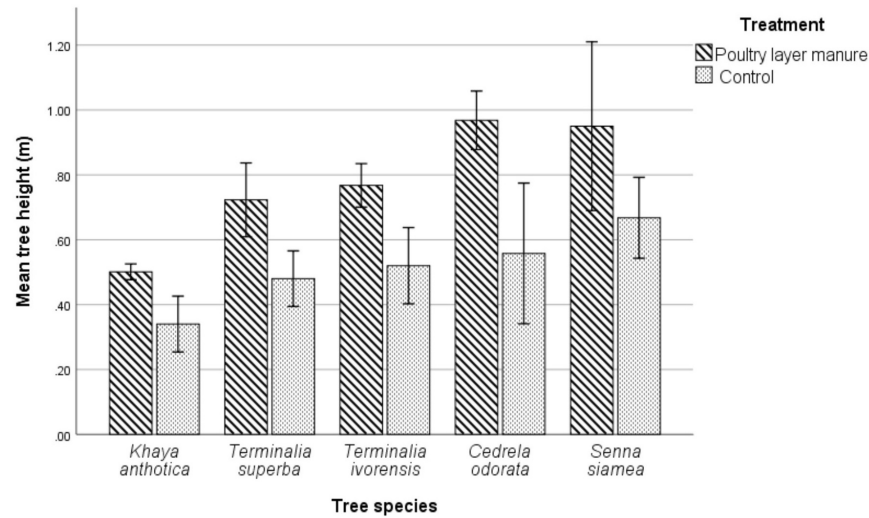


Figure 8: Effect of manure on height growth of five forest-tree species six months after planting on a waste-rock dump at NGGL. $n = 11$; Error bars represent 95% confidence interval.

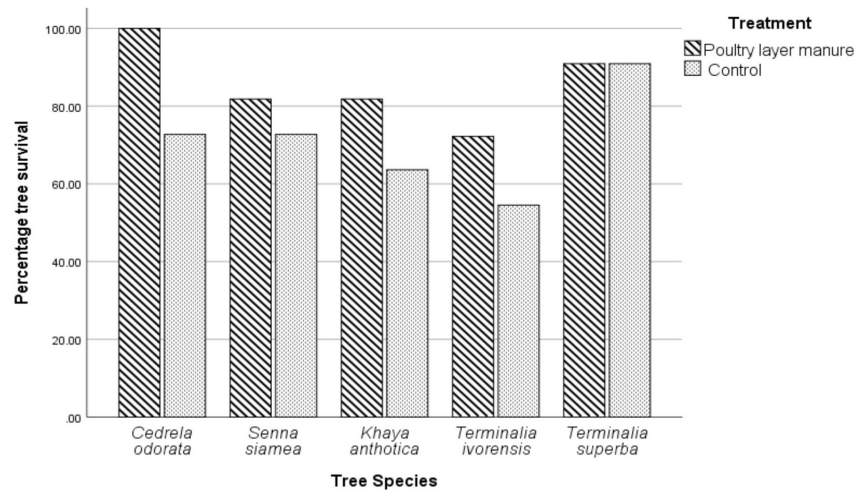


Figure 9: Effect of poultry manure on survival (%) of five forest-tree species six months after planting on a waste-rock dump at NGGL. $n = 11$.

4. Discussion

Relying on natural processes alone in building the biotic and abiotic resources required to restore disturbed mine sites could take several decades, if not centuries (Anderson, 1977). A major challenge during the initial phases of restoring degraded mine sites in Ghana is how to stabilize the soil against the highly erosive tropical rains and runoff, especially on graded-slopes, which are characteristic of surface mining (Norman et al., 1997; Nsiah, 2012; Nsiah & Schaaf, 2018; Wright, 2002). Therefore, beginning from ground zero, the application of the manure-amended subsoil material in this study aimed to reduce such long restoration periods by serving as substrate for establishing vegetation that would hasten the development of an initial stable ecosystem (Bradshaw & Hüttil, 2001). Both the topsoil

and the subsoil were separately stockpiled during the initial stages of mining activities at the Amoma Pit in 2009 to reconstruct the original layering of soil horizons during future restoration of the site. Unlike our previous study (Nsiah & Schaaf, 2019), which conformed to this goal of reconstructing the original soil layering at the site by replacing the stockpiled topsoil (STP) on top of the subsoil as substrate for vegetation establishment, this study replaced only the subsoil on the WRD in order to help overcome the potential topsoil deficit at the site. Again, the applied subsoil is similar in characteristics to those found at the degraded and abandoned mine sites in Ghana where the topsoils were destroyed during the mining activities, suggesting that the findings from this study could be transferred to those sites.

The results of the analyses of the STS revealed a near neutral soil pH

and conductivity, which were considered optimal for vegetation establishment on disturbed mine sites (Forest Research, 2014; Larney & Angers, 2012; Skousen et al., 2011) as well as on arable lands (Brady & Weil, 2008; Rollett et al., 2015). The content of OM was considered moderate compared to our previous study (Nsiah & Schaaf, 2019), where OM contents of a seven-year old STP and of fresh topsoil sampled from a nearby unmined site as reference, were both high. Thus, high soil organic matter (SOM) content is seen as an intrinsic characteristic of the site, which is a typical humid-tropical ecosystem with high temperatures and precipitation that facilitates fast accumulation of biomass into OM (Brady & Weil, 2008). Ca and Mg were moderate, with very low exchangeable acidity and high base saturation, which suggested that the soil had great potential for adsorbing and releasing the cations for plant growth (Brady & Weil, 2008). Total N content was very low and resulted in a high C:N ratio, indicating lack of N, which was considered as the main chemical limitation as far the ability of the STS for vegetation growth was concerned.

A major source of heavy metals in the environment has been attributed to the release and spread of metals as a result of human activity such as mining (Hazleton & Murphy, 2016). Organic amendments are often negatively viewed as waste products with undesirable features, particularly heavy metals, which can potentially be transported to surface and groundwater or can bio-accumulate in plants (Larney & Angers, 2012; Nicholson, Chambers, Williams, & Unwin, 1999). Subsequently, both the STS and the PLM were assessed for heavy metal concentrations, in order to evaluate any risk of potential contamination at the reclaimed site (SNIFFER, 2010). The results showed the concentrations of all measured heavy metals were within the acceptable limits, when compared with USEPA (1994) and EU standards (Alloway et al., 2000). This suggests that both the PLM and the mining activity had no adverse impacts on metal contamination and posed no ecological and human health risks to the site.

In terms of the physical properties, The STS contained high sand and low clay content, thereby yielding a sandy-loam texture with a lower bulk density than the STP used in our previous study (Nsiah & Schaaf, 2019), which had a higher bulk density and a texture of sandy-clay-loam. The low bulk density of the STS in this study was chiefly attributed to the fact that the subsoil material was loosely placed on the WRD, which lessened the effect on compaction. The relatively low bulk density and sandy-loam texture implied that the STS had a higher soil erodibility and therefore needed more extensive soil stabilization measures against erosion to allow the vegetation to establish and grow, compared the STP used in the previous study (Nsiah & Schaaf, 2019). Soil organic matter content, nutrient supply and pH have been described as the most important determinants for the suitability of a site for restoration (Bending et al., 1999; Gregorich, Carter, Angers, Monreal, & Ellert, 1994) following disturbances such as mining. Although the pH of the STS was optimum with moderate OM content, the nutrient, especially total N content, was very low and implied N deficiency. Nonetheless, results of the analyzed manure showed high total N and OC contents, generating a low C:N ratio, which was seen to be ideal for the release of N for plant growth (Brady & Weil, 2008).

The very low level of N in the STS called for a higher application rate of 23 t PLM per hectare in this study. This was contrary to that of our previous study (Nsiah & Schaaf, 2019), where a low application rate of PLM (1.1 t per hectare) was applied to the planted trees, due to the good quality of the STP.

The results revealed a significant influence of the PLM on both diameter and height growth of the planted trees as well as on GVC that promoted better soil stabilization on the manure treatment plot compared to the control, thereby confirming the study hypothesis. This was attributed to the manure-amendment with the STS that supplied sufficient N and additionally increased SOM, thereby promoting microbial activity and mineralization (Larney & Angers, 2012) that overcame the N deficiency. Thus, the conversion of the organic N in the manure to plant available form and additional increase in SOC were responsible for the significant increase in tree growth and increased GVC that ensured better site stabilization in developing an initial stable ecosystem.

The findings from this study support the results obtained by Seaker and Sopper (1988), which state that the restoration of disturbed mine sites depends on the reestablishment of vegetation that can thrive and sustain itself, provided that appropriate levels of organic C and N contents are available. The results further confirm those of previous studies, where the use of OAs were demonstrated to speed up the reclamation process by introducing large amounts of organic matter to initiate nutrient cycling and to overcome soil physical constraints (Salazar et al., 2009; Shipitalo & Bonta, 2008). Moreover, outcome of the study supports a statement by Rollett et al. (2015) that organic materials, along with other mineral soil-forming materials, such as subsoil, can be valuable additions in creating soil forming materials to improve and restore habitats. The advantage of using organic amendments over mineral fertilizers has been attributed to the fact that organic amendments add both nutrients and organic matter, resulting in more improvement of physical, chemical and biological soil properties (Larney & Angers, 2012). This further supports results obtained by Gardner, Naeth, Broersma, Chanasyk, and Jobson, (2012), which indicated that addition of biosolids was more effective at enhancing properties related to soil quality and fertility on reclaimed copper mine tailings sites in British Columbia than the traditional use of inorganic fertilizer.

Our previous study (Nsiah & Schaaf, 2019) discussed certain limitations concerning the use of Bermuda grass (*Cynodon dactylon*) as cover crop, which was NGGL's standard reclamation practice. The slow rate of establishment after transplanting the grass seedlings from the nursery stock promoted sporadic regeneration of herbaceous pioneer weed species that competed with the planted tree species, thereby hindering their survival and subsequent growth. To overcome these limitations, the Cowpea was selected in this study instead of the Bermuda grass, due to the capacity of the former in fixing atmospheric nitrogen as well as its relatively fast growth, long taproot and dense canopy cover for erosion control and weed suppression (Brady & Weil, 2008, Clark, 2007). Although the results of the present study confirmed such characteristics as fast growth rate and dense canopy cover of Cowpea that aided in better erosion and

sediment control, these effects could only be realized on the manure treatment plot. There was stunted growth and less GVC on the control plot, resulting in sheet and rill erosion. This was mainly ascribed to the lack of plant available N for the establishment of greater GVC essential for soil stabilization against erosion at degraded mine sites (Larney & Angers, 2012; Nsiah & Schaaf, 2018).

Manure contributions to decreasing soil erosion as observed in this study are in line with other studies that demonstrated application of compost decreased erosion by 86% compared to bare soils, and allowed quicker establishment of GVC (Demars & Long, 1998; Risse & Faucette, 2015). The combined positive effect of the PLM and the York mat biological geotextiles (BGTs) on erosion control (Nsiah & Schaaf, 2018), as witnessed in this study, also confirms the conclusions of a study by Bhattarai, Kalita, Yatsu, Howard, and Svendsen (2011), who maintain that a 50–50 mixture of compost and mulch provided the best erosion control measures compared to using either the compost or the mulch blanket alone in field experiments. The achievement of better soil stabilization on the erosion-susceptible subsoil against the highly erosive forces of tropical rains and run-off, as revealed in this research, is contrary to a study by Hüttl et al. (2014), which reported massive sheet and gully erosion during the first years of developing initial ecosystem at a Lusatian lignite mine North-eastern Germany, due mainly to a lack of vegetation cover. Thus, beginning from ground zero, the manure-amended subsoil promoted the establishment of quicker and stronger vegetation that offered superior soil stabilization, which was crucial in developing an initial stable ecosystem at the WRD, within a relatively short time period.

5. Conclusions

The study has demonstrated the potential of amending subsoil with poultry manure as topsoil substitute for reclamation of degraded mine sites in Ghana, as well as other humid tropical climates with similar characteristics. Implementation of BRMPs such as seeding of fast-growing cover crops and installation of BGTs on the manure-amended subsoil yielded superior soil stabilization against erosion, which further promoted the development of an initial-stable ecosystem, within a relatively short-time period. The findings highlight the potential of using poultry manure as organic amendment in safeguarding successful reclamation of the many degraded and abandoned mine sites in Ghana. This can go a long way in promoting public acceptability of mining as a developmental land use activity, rather than as a curse. We recommend further studies about the long-term effects of one-time manure application in building biotic and abiotic resources in continuing the successional processes that would lead to a self-sustaining ecosystem at degraded mine sites.

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