CSIR COLLEGE OF SCIENCE AND TECHNOLOGY

IMPROVING FERTILITY STATUS OF MINE TAILINGS FOR LETTUCE PRODUCTION USING ORGANIC AND INORGANIC AMENDMENTS

PRINCE ADDAI

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BY

PRINCE ADDAI

Thesis submitted to the Department of Soil Resources Management of the CSIR
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the award of Master of Philosophy Degree in Soil Health and Environmental
Resources Management

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this College or elsewhere.

Candidate's Signature………………………………. Date ……………………

Name: Prince Addai

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the CSIR College of Science and Technology.

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ABSTRACT

Restoration of decommissioned Gold Mine Tailings (GMT) is an environmental challenge. In this study, an attempt was made to evaluate the combined application of organic and inorganic amendments' effects on the growth and yield of lettuce in GMT. A Completely Randomized Design (CRD) with three replications was used. For this, a greenhouse pot experiment with eight (8) treatments mixed with tailings collected from Obuasi decommissioned mine site was set up at the CSIR Soil Research Institute. Treatments used were; control, 5 t ha^{-1} Rice Husk Biochar (RHB), 60 kg N-80 kg P_2O_5-80 kg K_2O (100% NPK), 2.5 t ha^{-1} RHB + 30 kg N-40 kg P_2O_5-40 kg K_2O (50% NPK), 5 t ha^{-1} Poultry Litter Compost (PLC), 2.5 t ha^{-1} PLC + 30 kg N-40 kg P_2O_5-40 kg K_2O (50% NPK), 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC and 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 30 kg N-40 kg P_2O_5-40 kg K_2O (50% NPK). At the end of the study, the highest lettuce yield (433.9 kg ha^{-1}) was found in 2.5 t ha^{-1} RHB + 50% NPK followed by the 2.5 t ha^{-1} PLC+ 50% NPK (405.4 kg ha^{-1}). There was no significant difference between them. The lowest yield (144.9 kg ha^{-1}) was recorded in the Control. Again, application of amendments to the GMT showed a significant difference ($P<0.05$) in pH, organic carbon, total nitrogen content, phosphorus, cation exchange capacity (Ca, Mg, Na and K) of the tailings. The study revealed that the addition of amendments could improve lettuce growth and yield parameters of lettuce and also improve physical and chemical properties of GMT in the semi-deciduous forest zone of Ghana.

KEY WORDS

Biochar

Gold mine tailings

Heavy metals

Poultry litter compost

Reclamation

Soil amendments

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DEDICATION

To my family

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LIST OF ACRONYMS

FAO	-	Food and Agriculture Organization
UN	-	United Nations
GMT	-	Gold Mine Tailings
SOM	-	Soil Organic Matter
ISFM	-	Integrated Soil Fertility Management
ATP	-	Adenosine Triphosphate
CSIR	-	Council for Scientific and Industrial Research
SRI	-	Soil Research Institute
RHB	-	Rice Husk Biochar
EDTA	-	Ethylenediaminetetraacetic acid
SOC	-	Soil Organic Carbon
CEC	-	Cation Exchange Capacity
ECEC	-	Effective Cation Exchange Capacity
WHO	-	World Health Organization
EC	-	Electrical Conductivity
AAS	-	Atomic absorption spectroscopy
CRD	-	Complete Randomized Design
MCF	-	Moisture Correction Factor
AWC	-	Available Water Capacity
FC	-	Field Capacity
ANOVA	-	Analysis of Variance
ppmP	-	parts per million Phosphorus

PLC	-	Poultry litter compost
RHB	-	Rice husk biochar
BC	-	Black carbon
SOC	-	Soil organic carbon
AWC	-	Available water content
WRB	-	World reference base

CHAPTER ONE

INTRODUCTION

The expansion of the mining industry over the past decades has resulted in the erection of tailings dam facilities to contain mine effluents or tailings as an environmental safety measure. Gold Mine Tailings (GMT) are waste materials generated after grinding and processing of ores and other economically retrievable minerals. These tailings are generally perceived to have concentrations of heavy metals at toxic levels and low soil fertility and organic matter, making them potentially unsuitable for growing agricultural crops for human consumption.

According to Fellet, Marchiol, Delle Vedove and Peressotti (2011), it is not just the phytotoxic effects of the high heavy metal concentrations that are against the plant settlement but also the extreme pH values, very low fertility, minimum water-holding capacity and the unfavorable substrate structure impede crop colonization. Management of Gold mine tailings after mine closure is challenging due to the complex chemical composition of the material (Kiventerä, Piekkari, Isteri, Ohenoja, Tanskanen, & Illikainen, 2019). The major question is how to turn the mine tailings into a productive resource for agricultural purposes (e.g., crop production) without contaminating the produce with toxic levels of micronutrients for human consumptions (Osei, 2012).

Background to the Study

For decades, a lot of environmental studies have aimed at using phytoremediation approaches to reclaim mine sites, including mine tailings.

However, these methods take a long time to clean contaminated soils due to unfavourable conditions in tailings substrates, such as moderate or high levels of heavy metals, low levels of macronutrients and poor substrate structure. The attempt to reclaim these sites require additional soil amendments to achieve enhanced plant germination and reduce the risk of pollution from tailings surfaces (Bopp, Christl, Schulin, & Evangelou, 2016). Hence, amendments need to be considered to change the physical and chemical properties of the mine tailings substrate, rendering it suitable for plant colonization or crop production.

Soil amendments, including organic sources such as compost and biochar, are used as sinks to immobilize the elemental contaminant by breaking the cycling of the elements in the soil-plant-animal (humans) ecosystem (Osei, 2012). Biochar has been found to sorp metal ions, thereby reducing the bioavailability of such metals and the risk of toxicity (Siaw, Asamoah, & Aklamati, 2015). Literature supports that biochar is able to effectively sorb organic and inorganic pollutants (Beesley, Moreno-Jiménez, & Gomez-Eyles, 2010). Also, biochar as a soil amendment has the potential to preserve and enhance soil organic matter (SOM) and sequester C (Ding *et al*., 2016). Compost as soil amendments can improve soil physical properties to prevent dispersion and also improve the fertility of the soils (Scotti, Bonanomi, Scelza, Zoina, & Rao, 2015). This study, therefore, seeks to evaluate and improve the fertility status of old gold mine tailings for lettuce production using organic and inorganic amendments

Statement of the Problem

Unreclaimed gold mine tailings remain a source of soil contamination at Obuasi due to the presence of sulfides such as pyrite (acid generation) and the concentration of heavy metals. The conditions in gold mine tailings are characterized by high to moderate concentrations of heavy metals, making it difficult to crop or plant settlement. Heavy metals absorption into biological systems can cause various degrees of damage to the environment, plants, animals and humans, which can lead to loss of biodiversity (Hackman, 2014).

The physical, chemical and biological properties of old gold mine tailings have rarely been studied in Ghana after mine closure, thereby leaving tailings structure uncharacterized in the selected area. There are limited published data on converting gold mine tailings into productive agricultural resources to enhance food security for post-mining use in Ghana. Again, much is not known about the behaviour of gold mine tailings when left for a period of two decades, the risks of metal exposure and nutrient status. Also, little action has been taken over the years to turn old gold mine tailings into an agricultural resource for crop production in Ghana.

Finally, the relationship between the physicochemical properties and heavy metal concentrations of the tailings are not known and well understood when the mine site is abandoned. The toxic chemicals used to extract the valuable materials from the ore, such as the cyanide used in gold mining, remain in the tailings at the end of the process and may leach into ground water (Logsdon, Hagelstein, & Mudder, 1999).

Purpose of the Study

In a world of increasing population and growing economies, global issues including climate change, food insecurity and energy demand necessitate the identification of innovative techniques of sustainable management of soils. Agricultural productive land resources continue to decrease in size due to the massive expansion of industries and urbanization. Expectations for agricultural soils to maintain, or even improve quality, increasing crop yield, sequestering carbon (C) and producing biofuels are challenged. This is because of the heavy demands by the projected population increases while approximately 1 in 7 people are already food insecure (FAO, 2001).

With the aim of meeting the needs of the growing population in Sub-Saharan African, old gold mine tailings and contaminated mine sites must be monitored and assessed in order to turn old gold mine sites into an agricultural resource for crop production using Integrated Soil Fertility Management (ISFM). However, metal-contaminated soils are notoriously hard to remediate with conventional technologies (Marques, Rangel, & Castro, 2009) such as electrokinetics. The in-situ immobilization of metals using soil amendments processes has been given more and more importance and is seen as an attractive, low-cost remediation alternative (Kumpiene, Lagerkvist, & Maurice, 2008; Mench, Vangronsveld, Lepp, Ruttens, Geebelen, & Bleeker, 2007).

Phytoremediation technologies are the most preferred remediation techniques in heavy metal contaminated soils, but unfavourable conditions in tailings substrates such as moderate or high levels of heavy metals, low levels of macronutrients and poor substrate structure hinder plants growth. This often requires additional soil amendment to achieve enhanced plant germination and may prolong the length of time required to stabilize and reduce the risk of pollution from tailings surfaces (Robinson, Bañuelos, Conesa, Evangelou, & Schulin, 2009). The combined application of biochar and poultry manure compost to the soil is not a new concept. These applications were most likely a result of both habitation activities and deliberate soil application by native populations (Lehmann, Gaunt, & Rondon, 2006).

In recent years, more research work is directed towards finding new remediation technologies that are not only cost-effective but also easy to apply (Fellet et al., 2011). Literature gives evidence that biochar is able to effectively sorb organic and inorganic pollutants (Beesley *et al.*, 2010). Whereas biochar is considered as a soil amendment, the focus of most studies have dealt with the nutrient status of the amended soils, including CEC, nutrient content and the carbon sequestration potential of the amended soils.

Characterization of old gold mine tailings is very imperative because it informs management/or land users about possible amendments or alteration of physical, chemical and biological properties of mine tailings to support plants growth. Compost and biochar have the ability to immobilize harmful components of heavy metals in mine tailings and hence improve tailings structure for plant colonization. Again, knowledge on the characterization of gold mine tailings will help site managers to adopt potential remediation alternatives. This will serve as a guide to screen plants with phytoremediation potentials when reclaiming old gold mine tailings in Ghana. It will also help to achieve environmentally sound management of chemicals and all wastes.

Characterizing and knowing the levels of heavy metals of mine tailings at the Obuasi mine site is important because studies have shown that toxicological risks arise when soil arsenic (As) concentrations exceed 40 mg kg^{-1} (Pendergrass & Butcher, 2006). Again, studies have shown that prolonged exposure to Arsenic could lead to cancer, diabetes, thickening of the skin, nervous system disorders, liver disease and digestive system problems (Kapaj, Peterson, Liber, & Bhattacharya, 2006)

Research Objectives

The main objective of the present work was to study the effects of combined application of organic and inorganic amendments on old GMT for lettuce production. Specific objectives were to;

1. characterize the physicochemical properties and heavy metal content of gold mine tailings
2. evaluate the effect of soil amendments on the growth and yield of lettuce
3. evaluate the effect of soil amendments on the physicochemical properties and heavy metal content of gold mine tailings
4. evaluate the effect of different treatment on nutrient and metal uptake of lettuce

Research Questions

1. Will the selected organic and inorganic amendments improve the fertility status of mine tailings and hence increase the yield of lettuce production?
2. What is the effect of combined application of biochar or compost with NPK on tailings physicochemical properties?

Hypothesis

The study tested the following hypotheses;

1. Application of biochar, compost with NPK fertilizer will improve the fertility status of mine tailings and also increase the growth and yield components of lettuce.
2. Combined application of biochar, compost and NPK have an effect on pH total nitrogen, available phosphorus, organic carbon, cation exchange capacity, total exchangeable bases of gold mine tailings

Significance of the Study

The research is relevant and of value to policy makers, farmers and the scientific community. The results of the study revealed knowledge about twenty years of decommissioned mine tailings; in terms of nutrient availability, levels of heavy metals, available moisture content and how to improve the fertility status using the Integrated Soil Fertility Management approach. The data or results of the study can be used by mining industries or communities and Environmental

Protection Agency (EPA). The data generated for post-mining use in terms of reclamation, rehabilitation and restoration. Lastly, the research will serve as a basis for future research.

Delimitation

The Tailings sample for the research was twenty (20) year old gold mine tailings from abandoned or decommissioned mine site at Obuasi due to lack of access to a recently closed GMT. Again, it was conducted in a greenhouse and not at the decommissioned tailings site because of difficulty in getting access to the place.

Limitations

The research was limited due to the fact that trace elements or micronutrients needed for growth, such as copper, iron, manganese, zinc etc., were not included in the studies due to financial difficulty in micronutrients analysis. Again, soil microbial activities could not be determined due to lack of funds.

Organisation of the Study

This study is organized into five (5) chapters. The chapter one represents the introduction of the study, the statement of the problem investigated, the purpose of the study, the objectives of the study, research questions and hypothesis, significance of the study, delimitation and limitation of the study. The chapter two talks about relevant literature reviewed. The chapter three explains the materials and methods used for the study. It also talks about how data were collected and analyzed. Chapter four represents the results and discussions of the study. The chapter five represents the summary as wells as findings, conclusion and recommendation of the study.

CHAPTER TWO

LITERATURE REVIEW

Lettuce is one of the most important leafy vegetables in Ghana, as well as in the world. Researches on various aspects of its production technology have been carried out worldwide. Among these researches, knowledge of the fertility status of decommissioned gold mine tailings is limited, let alone converting it for lettuce production. Very few numbers of works were reported on organic and inorganic sources of nutrients like biochar, Poultry litter compost, NPK and their combination on lettuce was studied. Some researches and their findings related to the present study both in Ghana and abroad were reviewed in this chapter.

Lettuce as a Vegetable Crop

Lettuce (*Lactuca sativa* L.) constitutes one of the most important vegetable crops worldwide (Pizarro *et al.*, 2019). It is a leafy herbaceous self-pollinated annual plant of the Asteraceae family. It is cultivated worldwide and usually consumed as a green salad. Lettuce (and chicory) estimated global production was nearly 25 million tonnes in 2014 (Armas, Pogrebnyak, & Raskin, 2017), as was informed by the Food and Agriculture Organization of the United Nations.

Despite this huge amount of lettuce harvested, its production and the production of other vegetables must be constantly enlarged to keep up with the demand of a rapidly increasing world population. This enhanced production is usually achieved by applying nitrogen fertilizers because the scarcity of this element most commonly limits plant growth. Nevertheless, the use of large amounts of nitrogen is expensive and could also contaminate surface and ground water resources (Barrameda-Medina *et al.*, 2017). Poultry litter compost is being applied as an economically suitable alternative to chemical fertilizers. In terms of volume, litter represents the main solid leftover from the primary level in the different poultry industries (Voss-Rech *et al.*, 2017).

Lettuce Production in Ghana

In view of the soil's nature, farmers apply lots of inorganic fertilizers mainly, NPK (15-15-15), in order to produce adequate quantities of lettuce for the market. A study conducted by Owusu and Owusu (2010) on the market potential for lettuce in Kumasi, the second-largest city in Ghana, indicated that lettuce has high demand in urban areas. According to Owusu and Owusu (2013), consumers are willing to pay a premium for quality organic fruits and vegetables, which include lettuce. However, the quality of water for the cultivation of lettuce in urban areas in Ghana leaves much to be desired.

Lettuce thrives best on well-drained fertile soils which have high levels of organic matter (Drechsel & Keraita, 2014; Obuobie *et al.*, 2006;). Adequate nutrients and continuous water supply are essential to the vigorous growth of leafy vegetables (Bessin, Seebold, Saha, Wright, & Strang, 2013; Obuobie *et al.*). Some growth variables in agronomic studies that were considered include the morphological characteristics of plants such as plant height, leaf area and a number of leaves (Křístková, Doležalová, Lebeda, Vinter, & Novotná, 2008). A number of studies have been conducted in Ghana concerning the use of organic fertilizers in lettuce production. Organic fertilizers make nutrients available to plants, improve soil structure, aeration and drainage through soil micro and macro-organism activities (Masarirambi, Hlawe, Oseni, & Sibya, 2010; Islam, Ayesha, Shahin, Tusher, & Khanom, 2012).

Characterization and Heavy Metal Composition of Mine Tailings

Metal smelting to separate minerals has introduced many pollutants into the soil. Mining and smelting facilities release huge quantities of heavy metals and other toxic elements to the environment; these persist for long periods, long after the end of these activities (Ogundele, Owoade, Hopke, & Olise, 2017). Toxic mining wastes are stocked up in tailings, mainly formed by fine particles that can have different concentrations of heavy metals. These polluted particles can be dispersed by wind and water erosion, sometimes reaching agricultural soils. For example, Mileusnić *et al*. (2014) found high levels of lead and copper in agricultural fields located near a tailings dam in Namibia (Mileusnić *et al*., 2014). Toxic concentrations of chromium and nickel were also found in agricultural soils near an abandoned chromite-asbestos mine waste in India and in crops grown in those soils, resulting in a high risk to human and livestock health (Kumar, Maiti, Tripti, Prasad, & Singh, 2017).

Individual layers in a tailings deposit, whether fine or coarse, are made up of mixtures of tailings sands. According to Vermeulen (2007), tailings sands are shown to be almost pure silica quartz with approximately 10% illite. Tailings slimes, on the other hand, contain considerable amounts of clay minerals (20% muscovite, 15% illite and 20% pyrophyllite, kaolin and clinochlore) and traces of pyrite and other sulphides in addition to the quartz. Tailings, consequently, have a significant number of fine clays, which can be expected to have a major effect on the mechanical behaviour of the material. Tailings sands are highly angular to subrounded, bulky, but flattened particles, whereas the finer slimes are made up of thin and plate-like particles characteristic of clay minerals. Particle surface textures can range from smooth to rough on a micro-scale (Vermeulen, 2007).

The mining of mineral resources results in the production and accumulation of a large number of tailings, causing many problems with respect to mining, the environment, and the economy (Lyu, Chai, Xu, Qin, & Cao, 2019). In the mining process, tailings must be reasonably treated to prevent them from entering the water cycle through rivers. The storage of tailings under water can effectively hinder the chemical reactions that they undergo. Therefore, it is a critical practice to store these substances in ponds or impoundments behind dams. However, tailings dams frequently fail, resulting in the discharge of significant quantities of tailings into the natural environment, thereby causing grievous casualties and serious economic losses (Lyu *et al*.).

According to Fellet *et al*. (2011), mine tailings represent a source of toxic pollutants, mainly heavy metals, which may spread to the surrounding areas to harm humans. The metallic mining industry generates tailings, which are defined as the waste materials generated by the grinding and processing of ores and other materials containing economically retrievable minerals. The chemical composition of tailings depends on the minerals mined and the extraction technique. These processes add to the potential reclamation difficulties at these sites. Chemicals reaching tailings ponds may undergo further reaction over an extended period of time, changing their character (Hossner & Hons, 1992).

Metal mining and milling processes

Mining and milling of metal ores coupled with industries have bequeathed to many countries the legacy of a wide distribution of metal contaminants in soil. During mining, heavier and larger particles that settle at the bottom of the flotation cell are directly discharged into natural depressions, including onsite wetlands resulting in elevated concentrations (Okrah, Opoku, & Asante, 2010). Extensive Lead (Pb) and Zinc (Zn) ore mining and smelting have resulted in contamination of soil that poses a risk to human and ecological health. Many reclamation methods used for these sites are lengthy and expensive and may not restore soil productivity. Soil heavy metal environmental risk to humans is related to bioavailability. Assimilation pathways include the ingestion of plant material grown (food chain) or the direct ingestion (oral bioavailability) of contaminated soil (El-Amier, Alghanem, & Alzuaibr, 2017).

Other materials are generated by a variety of industries such as textile, tanning, petrochemicals from accidental oil spills, or utilization of petroleum-based products, pesticides, and pharmaceutical facilities and are highly variable in composition (Wuana & Okieimen, 2011). Although some are disposed of on land, few have benefits to agriculture or forestry. In addition, many are potentially hazardous because of their contents of heavy metals (Cr, Pb, and Zn) or toxic organic compounds and are seldom, if ever, applied to land. Others are very low in plant nutrients or have no soil conditioning properties (Sumner, 2000; Wuana & Okieimen, 2011).

Heavy Metal versus Environmental Safety

The rapid global industrial development has resulted in a significantly increased risk of environmental contamination with heavy metals (Pacyna-Kuchta, Wietrzyk-Pełka, Węgrzyn, Frankowski, & Polkowska, 2020; Zwolak, Sarzyńska, Szpyrka, & Stawarczyk, 2019). Some of these contaminants occur naturally, but anthropogenic sources, especially mining activities, have contributed significantly to their upsurge. Although mining provides huge social and economic benefits to peoples, the long-term adverse effects on the environmental resources cannot be ignored. Anthropogenic activities and natural mineralization of rocks and minerals are primarily responsible for the pollution of soils by the excessive release of heavy metals (Lahori *et al.*, 2017; Mahar *et al.*, 2016). Mining, smelting, vehicular emissions, industrial waste and other related activities are some of the major sources of heavy metals soil contamination (Akoto *et al.*, 2017). Abandoned mine sites pose serious environmental threats due to the contaminated nature of mine soil. These sites contain heavy metals and other pollutants and their spread may cause a lot of damage to natural ecosystems nearby. Due to their properties, such as toxicity, persistence, and nonbiodegradation, contamination with metals has become a serious and widespread environmental threat, particularly in urban areas (Zwolak *et al*., 2019).

Heavy metal contamination of soils and its management is a challenging issue worldwide primarily because heavy soil metals (HMs) do not rapidly mineralize into other forms, and their persistence in the environment causes numerous adverse effects on the soil ecosystem and agricultural productivity. It also pollutes underground water reserves, resulting in serious health problems for living organisms (Wuana & Okieimen, 2011). High concentrations of toxic metals in soil can reduce soil fertility and lead to accumulations in food and drinking water, with the potential to endanger human health through ingestion and/or inhalation (Bortey-Sam *et al.*, 2015). Tailings represent a source of metal pollution to the surrounding environment and pose a risk to human health as well as animal life (Siaw *et al.*, 2015).

In order to prevent and avoid the spread of heavy metals into the surrounding areas after mine abandonment, these sites must be monitored and remediate with appropriate technologies, including the application of biochar. Biochar is the carbon-rich end product of thermal degradation of organic biomass in the absence of oxygen (Klinar, 2016). Whereas biochar is considered as a soil amendment, the focus of most studies have dealt with the nutrient status of the amended soils, CEC, pH, nutrient content, vegetative growth and the carbon sequestration potential of the amended soils (Siaw *et al*., 2015).

The potential risk of heavy metals in soils

The most common heavy metals found at contaminated sites in order of abundance are Pb, Cr, As, Zn, Cd, Cu, and Hg (Wuana & Okieimen, 2011). These metals are important since they are capable of decreasing crop production due to the risk of bioaccumulation and biomagnification in the food chain (Wuana & Okieimen, 2011). There is also the risk of superficial and groundwater contamination.

Intake of cadmium (Cd)-contaminated food causes acute gastrointestinal effects, and kidney damage has been reported with chronic exposures (Godt *et al*., 2006; Johri, Jacquillet, & Unwin, 2010). Mercury, and especially the methylmercury compounds, accumulates mainly in the brain tissue, causing damage to the central nervous system, especially the developing fetal brain. In adults, it causes hearing, speech, and visual disorders, cardiovascular diseases, and limb muscle paralysis. Arsenic has carcinogenic, neurotoxic (hearing disorders) and genotoxic effects and causes cardiovascular diseases, peripheral vascular disorders, anaemia, and dysfunctions of the reproductive system (Abdul, Jayasinghe, Chandana, Jayasumana, & De Silva, 2015; Mandal, 2017).

Plant Nutrient

Plants generally acquire their mineral elements from the soil solution. Six essential mineral elements are known as macronutrients, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S), are required in large amounts; whilst micronutrients such as chlorine (Cl), boron

(B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), nickel (Ni) and molybdenum (Mo) are required in smaller amounts (White & Brown, 2010). In fact, a deficit in any one of these mineral elements reduces plant growth and crop yields (White & Brown, 2010).

Nitrogen

Nitrogen forms important structural, genetic and metabolic compounds in plant cells. It is a major element of the chlorophyll molecule and important for strong vegetative growth. It enhances phosphorus absorption. Excessive application of nitrogen leads to excessive vegetative growth. Nitrogen is best absorbed in the presence of an optimum amount of calcium (Razaq *et al.*, 2017).

Phosphorus

Phosphorus is a major constituent of energy-transfer compounds such as adenosine triphosphates (ATP). It is necessary for cellular metabolism and essential in fruit and seed production. It also stimulates root production. It aids in the efficient utilization of Nitrogen (Razaq *et al*., 2017).

Potassium

Potassium is important in the formation and transport of carbohydrates. It is also essential for cell division, protein formation, disease resistance and fruit quality (Wang *et al*., 2018).

Calcium and Magnesium

Calcium and Magnesium serve corrective purposes. They tend to correct soil toxicity and enhance the absorption of nutrients such as Nitrogen. Magnesium (Mg^{2+}), an essential ion for cells and biological systems, is involved in a variety of cellular processes, including the formation and breakdown of microtubules. It also forms part of mitochondria and aids in spindle fibre formation during cell division (Uz & Sarikaya, 2016).

Micronutrients

The trace elements or micronutrients needed for growth such as copper, iron, manganese and zinc have become important ingredients of plant nutrition in the recent past. A shortage of one or more of these trace elements usually, but not always, affects the appearance of plants leading to chlorotic, bronzed or mottled colour leaf and causing the death of growing tips (Soetan, Olaiya, & Oyewole, 2010)

Organic Amendments Available for Soil Reclamation

Organic amendments used in soil reclamation emanate from a variety of sources, including agriculture, forestry and urban areas. Of those generated by agriculture, livestock manure (fresh, composted, solid fractions from anaerobic digesters) from various species (cattle, hogs and poultry) is the most prevalent. Other amendments derived from agriculture include crop residues (straw, legumes, compost, etc. Forestry produces organic amendments such as deinking sludges, wood chips and shavings. In the past, large- scale recycling of wood ash to forests is considered a means of replenishing base cations, particularly Ca, taken up by the trees. Wood residuals from the forest and lumber industries were burnt to produce wood ash (Ohlsson, 2000).

Organic amendments from urban waste streams include biosolids such as sewage sludge, municipal and sludge could be used for soil reclamation. Again, biodegradable component of municipal solid wastes such as kitchen waste, market waste, office paper waste etc., can also be incorporated into soil for reclamation option. The food processing industry (vegetables, grains, meat, fish, etc.) creates organic by-products for land application (MacLeod, Kuo, Gallant, & Grimmett, 2006), but currently, these are rarely used in reclamation.

Amendment options

The choice of amendment for use in reclamation is governed by various factors. These range from the physical, chemical and biological suitability of the organic amendment material to those counterparts of the soil to be reclaimed (Larney & Angers, 2012).

Mine soils, because they are in such a degraded state, tend to be subjected to the highest application rates of organic amendments. In reviewing a large number of studies, Sopper (1992) presented rates of 7 to 997 t ha^{-1} of municipal sludge for mine soil reclamation. Kost, Boutelle, Larson, Smith and Vimmerstedt (1997) reported an extremely high paper mill sludge rate of 3450 t ha^{-1}, admittedly incorporated to 60 cm depth, but nevertheless 10 to 100 times higher than agricultural land application rates.

Mainly, the use of composted poultry manure allows the recycling of organic material and nutrients and also adds value to this waste product (Caceres, Magri, & Marfa, 2015). The main problem with this practice is the threat of spreading manure-borne pathogenic microorganisms, mostly when it is applied to vegetables, which will then be consumed as fresh products (Maiti & Ghose, 2005). This risk increases with the use of raw manure, in particular poultry litter, a usual practice in vegetable production (Pizarro *et al*., 2019). The use of composted manure can reduce microbiological contamination, particularly with enteropathogenic bacteria (Erickson, Liao, Jiang, & Doyle, 2014), since aerobic composting of animal manure is a beneficial treatment that inactivates these pathogens (Erickson *et al*., 2014).

Biochar and its Preparation

Biochar is a product of thermal decomposition of biomass produced by the process called pyrolysis or ‘a solid material obtained from the carbonisation of biomass. (Yadav & Jagadevan, 2019). Biochar is generally defined as charred organic matter produced with the intent to apply to soils to sequester carbon and improve soil properties (Lehmann & Joseph, 2012).

Biochar has been found to be biochemically recalcitrant as compared to un-charred organic matter and possesses considerable potential to enhance long-term soil carbon pool (Lehmann, Gaunt, & Rondon, 2006). Biochar has been shown to improve soil structure and water retention, enhance nutrient availability and retention, ameliorate soil acidity, and reduce Aluminum toxicity to plant roots and to soil microbiota (Glaser, Lehmann, & Zech, 2002).

Effects of biochar on soil chemical properties

Soils in the heavy rainfall zone of the tropics require the maintenance of crop productivity in the medium to long term. This phenomenon had mainly been attributed to intrinsic as well as anthropogenic factors. It has been reported that the addition of biochar to sandy and nutrient-impoverished soils led to the improvement and maintenance of soil productivity. The addition of biochar to soil causes changes in pH, electrical conductivity, CEC and nutrient levels (Amonette & Joseph, 2012; Gundale & DeLuca, 2007; Warnock, Lehmann, Kuyper, & Rilling, 2007).

Although not a new concept, Lehmann, Gaunt and Rondon (2006) proposed biochar (BC) application as a sustainable way to improve highly degraded lands. According to the authors, BC is a soil conditioner that enhances plant growth by supplying and retaining nutrients and by providing other services such as improving the physical, chemical and biological properties of the soil (Glaser, Lehmann, & Zech, 2002: Lehmann, Kern, German, Mccann, Martins, & Moreira, 2003).

Furthermore, BC influences the porosity and consistency of the soil through changing the bulk surface area, the pore size distribution, the particle size distribution and the density and packing (Liu, Dugan, Masiello, & Gonnermann, 2017). The capacity of BC in reducing nutrient losses arises from its charge and surface area properties. The functional groups of BC influence the sorption process depending on the nature of their surface charge so that both transition metals and non-transition metals can be sorbed onto the surface of BC particles (Amonette & Joseph, 2012).

Biochar and soil pH

The increases in soil pH induced by biochar additions are not surprising given the well-documented use of materials such as wood ash in modifying pH and nutrient availability, particularly P and K (Mahmood, Finlay, Fransson, & Wallander, 2003). Uzoma *et al*. (2011) reported significant increases in pH of sandy soil with biochar rates of 0, 10, 15 and 20 t ha^{-1}. These rates, respectively, recorded pH values of 6.4, 7.1, 7.3, and 8.4 of an initial soil pH of 6.4. The increases in pH with an increase in biochar rates translate to a significant positive linear relationship. A similar trend was also reported by Chan, Van Zwieten, Meszaros, Downie and Joseph (2008) when they investigated the agronomic value of green waste biochar as a soil amendment. They observed that biochar applications of 0, 10. 50 and 100 t ha^{-1} resulted in soil pH values of 4.58, 4.61, 4.75 and 5.19 as against an initial soil pH of 4.5.

Biochar and soil available P

The application of biochar to sandy soils has been observed to increase in available P. As observed by Uzoma *et al*. (2011), application of biochar rates of

10, 15 and 20 t ha^{-1} led to increases in the levels of available P. The above rates resulted in available P of 0.12, 0.15, 0.18 and 0.16 g kg^{-1} for the above biochar rates, respectively; to an initial soil available P of 0 t h^{-1}. They attributed the increases in P availability to high levels of P in the cow dung biochar as well as the increases in soil pH from 6.4 to 8.0, which also led to P availability. However, the reduction in P at the highest level of biochar application (20 t ha^{-1}) was attributed to P fixation with calcium as a result of pH increases towards alkalinity. The increasing availability of P with biochar applications was also observed by (Chan *et al*., 2008) in a study involving the use of poultry litter biochar as a soil amendment.

Biochar and soil total nitrogen

The incorporation of biochar to soils has been observed in literature to reduce ammonium leaching (Lehmann *et al*., 2003) and in some cases, reduce N_2O emission (Spokas, Koskinen, Baker, & Reicosky, 2009). These mechanisms that lead to a decrease in N losses should contribute to increasing N in soils after biochar applications. The above observations were confirmed by Chan *et al.* (2008) when they observed increasing total N content of an Alfisol with an increasing rate of biochar applications. It was revealed in their experiment that the soil with an initial N content of 0 t h^{-1} increased to 0.26, 0.28 and 0.33% with biochar rates of 10, 25 and 50 t ha^{-1}, respectively. Increasing N content of soils with biochar applications was further confirmed by Chan *et al.* They reported a significant increase in N content of an Alfisol when its initial N content which was 1.3 g kg^{-1}increased to 1.7, 1.5 and 1.6 g kg^{-1} for biochar rates of 0, 10, 25 and 100 t ha^{-1}, respectively.

Biochar and soil organic carbon

The recalcitrance of black carbon (BC) has been investigated by a lot of researchers (Glaser, Lehmann & Zech, 2002: Lehmann, Kern, German, McCann, Martins, & Moreira, 2003). Agusalim, Wani and Syechfani (2010) observed an increase in soil organic carbon (SOC) upon application of rice husk biochar to rice cropping system in an acid sulphate soil. In their experiment, they observed that soil with an initial SOC of 0.78% increased to 4.09% upon the application of 10 tons of rice husk biochar. This represents a percentage increase of 524% over the unamended soil. Chan, Van Zwieten, Meszaros, Downie and Joseph (2007) also observed a similar trend. They observed that soil with an initial SOC content of 18 g kg^{-1} was increased to 21.6, 27 and 43.4 g kg^{-1} with biochar rates of 0, 10, 50 and 100 t ha^{-1}, respectively.

CEC of biochar applied soils

The cation exchange capacity (CEC) of the soil is a measure for how well some nutrient (cations) are bound to the soil and, therefore, available for plant uptake and prevented from leaching to ground and surface waters *(*Verheijen *et al.*, 2010). Uzoma *et al.* (2011) reported increasing CEC of soil with increasing biochar rates. They observed this when cow manure biochar was applied to sandy soil with an initial CEC of 0.71 cmol$_c$ kg^{-1}. This was increased to 0.75, 0.92 and

1.14 with biochar rates of 0, 10, 15 and 20 t ha^{-1}. The increase in the CEC of the soil with increasing rates of biochar was attributed to the large surface area of the biochar and the corresponding negative charges. The increase in CEC with biochar additions was further confirmed by Chan *et al*. (2008). They observed this when green waste biochar was applied to an Alfisol with an initial CEC of 7.7 cmol$_c$ kg^{-1}. Biochar rates of 0, 10, 50 and 100 t ha^{-1} led to CEC increases of 8.42, 8.08 and 9.10 cmol$_c$ kg^{-1}. The phenomenon of increase in CEC with biochar incorporation into soils could be due to the high surface negative charge resulting from oxidation of carboxylic and phenolic groups of biochar (Liang *et al*., 2006).

Biochar Impacts on Agronomic Yields

Soil fertility is influenced by a number of soil properties and involves a complex balance of biotic and abiotic reactions that are spatially and temporally dynamic. Adding biochar to soils may produce immediate effects on properties such as soil nutrition, water retention, or microbial activity (Atkinson, Fitzgerald, & Hipps, 2010; Lehmann *et al*., 2011), although these effects vary depending on soil type (Spokas, Baker, & Reicosky, 2010, 2009; Van Zwieten *et al*., 2010). Nonetheless, because of its generally recalcitrant nature, biochar may also have long-term impacts on soil environments. For biochar to serve a beneficial role in revitalizing nutrient-impoverished soils, there should be a significant increase in the quantity of plant-available nutrients and its nutrition retention capacity (Spokas *et al*., 2012, Sohi, Krull, Lopez-Capel, & Bol, 2010). From a soil fertility perspective, this increased mineralization could provide nutrient resources to plants (Ding *et al*., 2016) and biochar with high volatile matter contents (Deenik, McClellan, Uehara, Antal, & Campbell, 2010) have also suppressed plant growth.

The application of biochar in combination with N and P fertilizers on two rice cultivars showed that grain yields increased with increasing biochar applications of 4 and 8 t ha^{-1} whilst biochar rates of 16 t ha^{-1} resulted in yields decline (Asai *et al*., 2009). These they attributed to increased N deficiencies resulting from the high C: N ratio of biochar.

Crop Yield

As the global population continues to increase, improving crop yield continues to be a major focus of soil research. The stabilization of Soil Oraganic Matter (SOM) is the major mechanism upon which physical, chemical, and biological mechanisms stabilize and therefore, sustain biomass productivity (Lal, 2010). Soil management techniques that focus on providing immediate nutrients for crop production have a little long-term impact on SOM, while those that provide recalcitrant amendments improve SOM (Palm, Gachengo, Delve, Cadisch, & Giller, 2001). Although SOM stability plays an important role in restoring crop yield, nutrient release through decomposition is the main mechanism for short-term improvements in crop yield (Kimetu *et al*., 2008). Biochar recalcitrance does not allow for nutrient release through decomposition to be the dominant factor causing changes in crop yield. Mechanisms attributed to biochar's impact on crop yield, especially in degraded soils of the tropics, are generally chemically and biologically related and include increased nutrient retention due to changes in CEC, increased soil pH from the release of carbonates, and improved habitat for soil biota (Glaser, Lehmann & Zech, 2002; Thies & Rillig, 2012). Nutrient retention by absorption increased available water capacity (WC) due to changes in porosity and reduced soil strength are the main physical mechanisms in which biochar improves crop yield. Additionally, the charcoal effect, discussed below, may also play an important role in improving crop yield (Graber *et al*., 2010). Biochar-induced immobilization of N is a major mechanism of observed crop yield declines. Asai *et al*. (2009) measured leaf chlorophyll concentration (SPAD-values) and grain yield of two rice cultivars under biochar application with both N and P fertilizers.

Grain yield increased with 4 and 8 t $ha^{-1}$of biochar application. At 16 t ha^{-1}, grain yield decreased, probably resulting from increased N deficiencies caused by biochar, which has a high C: N ratio. Yet, a lysimetric study indicated that bagasse biochar is effective in reducing NO_3-N concentrations in percolating water and increasing N absorption by sugarcane (Chen, Shinogi, & Taira, 2010). Improved plant growth, evident in tomato plant height and leaf area and pepper plant leaf nodes and leaf area, was attributed to one of two mechanisms related to the charcoal effect: (i) a shift to more beneficial microbial communities was caused by residual organic tars or (ii) low concentrations of chemicals in biochar stimulated a plant immune response inducing more aggressive growth.

Soil Moisture Retention

Soil moisture characteristics are among primary indicators of soil physical quality. Laboratory procedures to measure parameters, such as moisture retention, involve soil core samples either taken from field sites or packed using bulk soil. Packed cores are useful for biochar analysis of moisture retention because an exact ratio of amendment to soil can be measured (Liu *et al*., 2016). Core samples taken from the field are more representative of the pore size distribution, and therefore, reflect more realistic changes in moisture retention. Newly pyrolyzed biochar is initially hydrophobic, as observed by hydrophobic molecule sorption, caused by chemical reactions during the pyrolysis process (Keiblinger, Zehetner, Mentler & Zechmeister-Boltenstern, 2018; Bornemann, Kookana & Welp 2007). As biochar oxidizes, negatively charged functional groups bond to the surface of the biochar particle, which mitigates the hydrophobic behaviour (Liang *et al*., 2006).

Observed increases in water retention confirm this change. The impact of biochar on moisture retention in sandy soils suggests that dry climates with high sand content would benefit significantly from amendment (Alotaibi & Schoenau, 2019; Basso, Miguez, Laird, Horton, & Westgate, 2013). Biochar characteristics and amended medium properties influence moisture retention, evident by a range of increases in Available Water Content (AWC) from 18% to 370% and increases in FC up to 82% (Brockhoff, Christians, Killorn Horton, & Davis, 2010).

Biochar characteristics play an important role in AWC, evident by no significant change when loamy sand was amended with pecan biochar up to 44 t ha^{-1} (Busscher *et al*., 2010). Potential improvements in the water holding capacity likely depend on biochar feedstock, charring conditions and soil properties (Novak *et al*., 2009). Some studies suggest that the biochar pore size distribution may have a particularly important role in determining changes in plant AWC. As well as stabilizing nutrients and allowing their more economical transportation, composting is a means of eliminating many of the undesirable features of raw livestock manure including pathogens such as Escherichia coli (Larney & Blackshaw, 2003), parasites such as Giardia and Cryptosporidium (Van Herk *et al*., 2004), weed seeds (Larney & Blackshaw 2003), antibiotics (Cessna *et al*., 2011) and pesticide residues (Biiyuksonmez, Rynk, Hess & Bechinski, 2000).

In southeastern Spain, Zanuzzi, Arocena, Van Mourik and Cano (2009) added pig manure and sewage sludge in combination with a blanket application of marble wastes aimed at building soil organic matter and accumulating calcite in mine tailings. The acidity of the tailings combined with low rainfall in the study area precipitated secondary calcite as infillings within the 0 to 4 cm surface layer. The build-up of soil organic matter resulted from a stable organic matter calcite complex as dense incomplete infillings mixed with secondary calcite and cappings on calcite particles from marble waste addition. These cappings provided water and nutrients to support initial seedling establishment in mine tailings. Sydnor and Redente (2002) found that incorporation of organic matter significantly increased above-ground biomass, in the reclamation of a high elevation gold mine in Colorado, with mushroom compost being more effective than biosolids. Treatments with topsoil supported plant growth with significantly higher trace element tissue concentrations than those without topsoil.

Composted Poultry Litter

Composting is a technique that can be used to reduce the amount of organic waste through recycling and the production of soil fertilizers and conditioners (Khater, 2015). It is comparable to peat moss in its conditioning abilities. Areas, where composting can be beneficial are in the recycling of the organic fraction of the municipal waste. It reduces as much as 30% of the volume, in the form of organic matter, entering our already overcrowded landfill sites. Furthermore, the composting process, if performed correctly, transforms wet and odorous organic waste into an aesthetical dryer, decomposed and reusable product (Khater, 2015).

Crop residues, unused bedding materials, silage, manures, and similar on-farm materials can be used as co-compost cover materials, along with many off-farm residues and wastes. Since a mortality compost pile cannot be turned until the bio-decomposition of the carcass body has been largely completed, the type and thickness of the cover and base layer materials play a key role in influencing the biodegradation of carcasses and the development and retention of heat that is necessary for pathogen inactivation (Fonstad *et al*., 2003).

Effects of compost on crop production and soil quality

The beneficial effects on crop production and soil quality reported in (Atiyeh, Edwards, Subler, & Metzger, 2001) are directly related to the physical, chemical and biological properties of the composts (Ojo, 2018). The physical and chemical properties of organic wastes and the factors that affect their performance in composting require easily identifiable and reliable methods to control the process in situ in order to make proper decisions about its performance. Although the characteristics of yard waste will vary, depending upon the predominant vegetation in the area and the season of the year for its collection, composted green waste typically contains low levels of heavy metals, commonly present in sludge-based composts, which makes them more environmentally sound (Benito, Masaguer, Moliner, Arrigo, & Palma, 2003). To produce a sound and a good quality compost, the chemical and physical properties of the compost should be determined by the end of the processing period

Use of composted poultry litter as an amendment to tailings for cultivation

All types of animal manure (including humans) can be used as fertilizer, but some are easier to collect and store than others (Szogi, Vanotti, & Ro, 2015). Cow manure, poultry manure and pig manure were found to be effective in reducing Lead (Pb) availability to plants, leading to lower uptake of Pb. They are commonly used as amendments for tailings because the addition of organic matter can significantly improve their physical and nutrient characteristics (Page-Dumroese, Ott, Strawn, & Tirocke, 2018).

Efficient use of manure is possible by using appropriate collection, decomposition and storage, and application techniques. The right use of this valuable resource helps improve the fertility of the soil and requires little cash investment. Manure serves as a good source of nutrients when applied to agricultural fields at the right time. However, if not managed well, manures can be removed from agricultural fields through erosion on steep slopes and leaching to valley bottoms, etc. This could affect effective nutrient cycle of the farm (Szogi et al., 2015).

Effect of Soil Amendments on Water Holding Capacity of Gold Mine Tailing

Water holding capacity is often a limiting factor in mine tailings that can lead to poor revegetation success, especially if the growing season has a severe moisture deficit. The water holding capacity of soil materials is an important consideration for land reclamation. Suitable soil water content is essential for seed germination, seedling establishment and plant survival. The water holding capacity of materials varies with properties such as structure, pore size, particle size, the proportion of coarse material, and organic matter content (Sheoran, Sheoran, & Poonia, 2010).

CHAPTER THREE

MATERIALS AND METHODS

A pot experiment was carried out at the CSIR-Soil Research Institute, Kwadaso-Kumasi, during the period from March 2019 to August, 2020 to study improving fertility status of gold mine tailings for lettuce production using organic and inorganic amendments. The materials and methods, a statistical tool that was used for conducting the experiment, are presented in this chapter

Study Area

The experiment was conducted at the Soil Research Institute greenhouse with GPS location: 06° 40’ 29.7” N latitude, 001° 40’ 08.2” W longitude. The Vegetation of the area lies within the moist semi-deciduous forest zone of Ghana. The site has a bimodal rainfall distribution pattern with mean annual rainfall between 1250mm and 1750mm. The mean average annual temperature is 25.5°C. Relative Humidity is fairly moderate but high during the rainy season (i.e., 75%-80%). The vegetables grown in the area are mostly cabbage, lettuce and carrot.

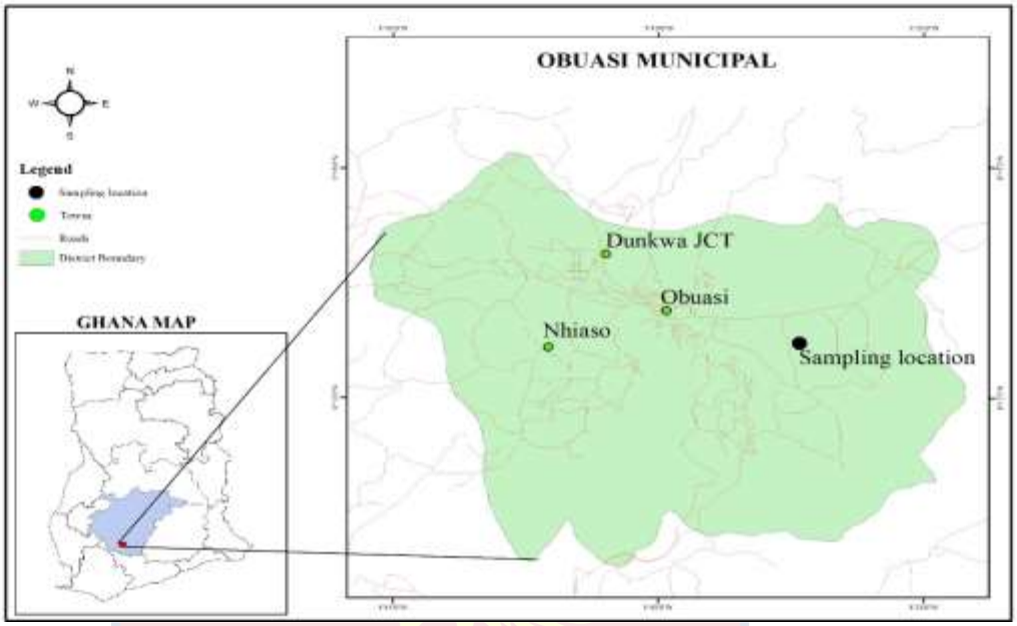

Figure 1- Location map of Obuasi indicating sampling location of GMT used for the experiment.

Source: Field data (2020)

Tailings Sampling, Sample Preparation and Characterization

Tailing sampling

The tailing samples used in this study were twenty (20) year old gold mine tailings collected from an old mining site at Obuasi Municipality in the Ashanti Region of Ghana. The tailing was a sandy loam with a pH of 7.3. It is a typical old gold mine tailing in the semi-deciduous forest zone of Ghana and the site has a long history of mining. A composite sample was collected from the 0-20 cm layer, brought to the laboratory at CSIR-SRI, air-dried, crushed and sieved through a 2 mm sieve. The composite tailings sample was analyzed for physico-chemical properties, using standard procedures. The samples were analyzed for soil nutrients, texture, moisture content, organic carbon, hydraulic conductivity, water holding capacity and dry bulk density at the Soil Research Institute laboratory. Soil samples were also analyzed for physico- chemical properties, using standard procedures after harvest.

Physical and Chemical Analysis of Gold Mine Tailings

The pH of the tailings

Tailing pH was measured in a 1:2.5 tailing-water ratio using a glass electrode (Bante Instrument 902) pH meter. Approximately 10 g of tailing was weighed into a 50 ml polythene beaker and 25 ml of distilled water was added to the tailing. The Tailing-water solution was stirred thoroughly and allowed to stand for 30 minutes. After calibrating the pH meter with buffers of pH 4.00 and 7.00, the pH was read by immersing the electrode into the supernatant and the pH value recorded.

Electrical conductivity (EC) of the tailings

EC analysis was performed using a Thermo scientific Electrical Conductivity (EC) electrode Orion 013605MD, connected to a Thermo Scientific Orion 4 Star pH-Conductivity Benchtop meter. Calibration was done using the following buffers: 147 us/cm and 1413 us/cm. The samples were presented in a 50 ml Falcon tube, in which the electrode was immersed, and the EC reading was taken**.** Electrical conductivity (EC) in 1:5 tailings-water suspension was measured by the electrical conductivity meter.

Tailings organic carbon

Tailings organic carbon was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). The procedure involves wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid. After the reaction, the excess dichromate is titrated against ferrous sulphate. Approximately 1.0 g of air-dried tailing was weighed into a clean and dry 250 ml Erlenmeyer flask. A reference sample and a blank were included. 10 ml of 0.1667*M* potassium dichromate ($K_2Cr_2O_7$) solution was accurately dispensed into the flask using the custom laboratory dispenser.

The flask was swirled gently so that the sample was made wet. Then using an automatic pipette, 20 ml of concentrated sulphuric acid (H_2SO_4) was dispensed rapidly into the tailings suspension and swirled vigorously for 1 minute and allowed to stand on a porcelain sheet for about 30 minutes, after which 100 ml of distilled water was added and mixed well. 10ml of ortho-phosphoric acid and 1ml of diphenylamine indicator was added and titrated by adding 1.0*M* ferrous sulphate from a burette until the solution turned dark green at the end-point from an initial purple colour. About 0.5 ml 0.1667*M* $K_2Cr_2O_7$ was added to restore excess $K_2Cr_2O_7$ and the titration was completed by adding $FeSO_4$ drop-wise to attain a stable end-point. The volume of $FeSO_4$ solution used was recorded and % C calculated.

Calculation:

The organic carbon content of tailing was calculated as:

$$\% \text{ O.C} = \frac{M \times 0.39 \times mcf \times (V1 - V2)}{s}$$

Where:

M = molarity of ferrous sulphate solution.

V_1 = ml of ferrous sulphate solution required for blank.

V_2 = ml of ferrous sulphate solution required for the sample.

s = weight of air-dry sample in grams.

$$mcf = \text{moisture correcting factor } \frac{(100 + \% \text{moisture})}{100}$$

0.39 = 3 x 0.001 x 100 % x 1.3 (3 = equivalent weight of carbon).

1.3 = a compensation factor for the incomplete combustion of organic carbon

Total nitrogen of the tailings

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory Staff (1984). Approximately 0.2 g of tailing was weighed into a Kjeldahl digestion flask and 5 ml distilled water added. After 30 minutes, a tablet of selenium and 5 ml of concentrated H_2SO_4 were added to the tailing and the flask placed on a Kjeldahl digestion apparatus and heated initially gently and later vigorously for at least 3 hours. The flask was removed after a clear mixture was obtained and then allowed to cool. About 40 ml of distilled water was added to the digested material and transferred into a 100ml distillation tube. 20 ml of 40 % NaOH was also added to the solution and then distilled using the Tecator Kjeltec distiller. The digested material was distilled for

4 minutes and the distillate was received into a flask containing 20 ml of 4 % boric acid (H_3BO_3) prepared with PT5 (bromocresol green) indicator producing approximately 75 ml of the distillate. The colour change was from pink to green after distillation, after which the content of the flask was titrated with 0.02*M* HCl from a burette. At the end-point, when the solution changed from weak green to pink, the volume of 0.02*M* HCl used was recorded and % N calculated. A blank distillation and titration were also carried out to take care of traces of nitrogen in the reagents as well as the water used.

Calculation:

The percentage nitrogen in the sample was expressed as:

$$\%N = \frac{(M \times (a-b) \times 1.4 \times mcf)}{s}$$

Where:

M = concentration of hydrochloric acid used in the titration.

a = volume of hydrochloric acid used in sample titration.

b = volume of hydrochloric acid used in the blank titration.

s = weight of air-dry sample in grams.

$$mcf = \text{moisture correcting factor}\ \frac{(100 + \%\text{moisture})}{100}$$

Available phosphorus- Bray 1 Phosphorus

The readily acid-soluble forms of phosphorus were extracted with a HCl: NH_4F mixture (Bray's no.1 extract) (Bray & Kurtz, 1945). Phosphorus in the extract was determined on a spectrophotometer by the blue ammonium molybdate method with ascorbic acid as a reducing agent. Approximately 5 g of soil was weighed into a 100 ml extraction bottle and 35 ml of extracting solution of Bray no. 1 (0.03*M* NH_4F in 0.025*M* HCl) was added. The bottle was placed in a reciprocal shaker and shaken for 10 minutes, after which the content was filtered through Whatman no.42 filter paper. The resulting clear solution was collected into a 100 ml volumetric flask.

An aliquot of about 5 ml of the clear supernatant solution was pipetted into a 25 ml test tube and 10 ml colouring reagent (ammonium paramolybdate) was added as well as a pinch of ascorbic acid and then mixed very well. The mixture was allowed to stand for 15 minutes to develop a blue colour to its maximum. The colour was measured photometrically using a Spectronic 21D spectrophotometer at 660 nm wavelength. Available phosphorus was extrapolated from the absorbance read.

A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6 mg P/l was prepared from a 12 mg/l stock solution by diluting 0, 10, 20, 30, 40 and 50 ml of 12 mg P/l in a 100 mL volumetric flask and made to volume with distilled water. Aliquots of 0, 1, 2, 4, 5 and 6 ml of the 100 mg P/l of the standard solution were put in 100 ml volumetric flasks and made to the 100 ml mark with distilled water.

Calculation:

$$P(\mathrm{mgkg^{-1}}) = \frac{(a-b) \times 35 \times 15 \times \mathrm{mcf})}{s}$$

Where:

a = mg/l P in sample extract.

b = mg/l P in blank.

s = weight of air- dry sample in gram.

mcf=moisture correcting factor $\frac{(100+\%\text{moisture})}{100}$

35 = volume of extracting solution.

15 = final volume of sample solution.

Exchangeable cations

Exchangeable bases (calcium, magnesium, potassium and sodium) in the tailings were determined in 1.0*N* ammonium acetate (NH_4OAc) extract.

Extraction of the exchangeable bases

A 5 g tailing sample was transferred into a 100 ml plastic bottle and 100 ml of buffered 1.0*N* ammonium acetate (NH_4OAc) extracting solution at pH 7 was added. The sample was agitated for 1 hour at 160 revolutions per minute and the extract was filtered into an Erlenmeyer flask.

Determination of calcium

A 25 ml portion of the extract was transferred to an Erlenmeyer flask. Hydroxylamine hydrochloride (1.0 ml), potassium cyanide (1.0 ml of 2 % solution) and potassium ferrocyanide (1.0 ml of 2 %) were added. After a few minutes, 4 ml of 8M potassium hydroxide and a spatula of murexide indicator were added. The solution obtained was titrated with 0.01*N* EDTA solution to a pure blue colour. The titre value was recorded.

Determination of calcium and magnesium

For the determination of the calcium plus magnesium, 25 ml of the extract was transferred into an Erlenmeyer flask. A 1.0 ml portion of hydroxylamine hydrochloride, 1.0 ml of 2.0 percent potassium cyanide buffer (from a burette), 1.0 mL of 2.0 percent potassium ferrocyanide, 10.0 ml ethanolamine buffer and 0.2 mL Eriochrome Black T solution were added. The solution was titrated with 0.01 *N* EDTA (ethylene diamine tetra acetic acid) to a pure turquoise blue colour. The titre value was recorded.

The titre value for calcium was subtracted from this value to get the titre value for magnesium.

Calculation:

Exchangeable Calcium (cmol of Ca (+)kg^{-1} soil =

$$\left[\frac{V1\text{-}V2}{V3}\times V4\times N\times\frac{100}{w}\right]\times mcf$$

Where:

V_1 = volume of EDTA required for sample aliquot titration, ml

V_2 = volume of EDTA required for blank titration, ml

V_3 = volume of aliquot taken, ml

V_4 = total volume of original NH_4OAc extracts, ml

N = normality of EDTA

w = weight of sample taken in g

mcf=moisture correcting factor $\frac{(100+\%\text{moisture})}{100}$

Exchangeable Calcium plus Magnesium (cmol of Ca+Mg kg^{-1} soil)

$$=\left[\frac{V5-V6}{V7}\times V4\times N\times\frac{100}{w}\right]\times mcf$$

Where:

V_5 = volume of EDTA required for sample aliquot, ml

V_6 = volume of EDTA required for blank aliquot, ml

V_7 = volume of aliquot taken, ml

V_4 = total volume of original NH_4OAc extracts, ml

N = normality of EDT

w = weight of sample taken in g

mcf=moisture correcting factor $\frac{(100+\%\text{moisture})}{100}$

1ml 0.01 N EDTA = 0.2004 mg Ca^{2+} = 0.1216 Mg^{2+}

Exchangeable potassium and sodium determination

Potassium and sodium in the extract were determined by an Atomic Absorption Spectrometer (AAS). A standard series of potassium and sodium were prepared by diluting both 1000ppm potassium and sodium solutions into 50ppm. This was done by taking a 5 mL portion of each into one 100 ml volumetric flask and made to volume with distilled water. Portions of 1.0, 2.0, 4.0 and 8.0 ml of the 50 ppm standard solution were put into 100 mL volumetric flasks respectively. 10 ml of lanthanum and caesium solution was added to each flask and made to volume with distilled water. The standard series obtained was 0.5, 1.0, 2.0 and 4.0 ppm for potassium and sodium. Potassium and sodium were measured in the extract by AAS after diluting the extract to 25 ml volume at wavelengths of 766.5 and 589.0 respectively.

Calculations:

$$\text{Exchangeable K (ppm)}=\frac{(a\text{-}b)\times 25\times 20}{10\times 39.1}$$

$$\text{Exchangeable Na (ppm)}=\frac{(a\text{-}b)\times 25\times 20}{10\times 23}$$

Where:

a = concentration from reading (AAS)

b = blank concentration from reading (AAS)

25 = dilution factor of the extract

20 = extraction ratio

Texture of the tailings

The tailings texture was determined by the hydrometer method. Approximately 25 g of tailing was weighed into a 250 ml plastic bottle and 5 ml of Calgon (Sodium Bicarbonate and Sodium Hexa-metaphosphate) and 100-150 ml of water was added. The suspension was mixed for a few minutes. The bottle was shaken for 3-4 hours using a mechanical shaker and the content was transferred to cylinders, then the volume was made up to 500 ml. Each cylinder was hand-agitated for 1 minute; hydrometer readings were read 15 minutes later. Each reading was increased by 0.5 to account for meniscus. A second reading was taken 18 hours later.

A blank reading was taken and was also prepared 5 ml of Calgon in a volume made up to 500 ml. At each hydrometer reading, the temperature was also taken. The first reading provides the sum of clay and silt (C + S) and the second reading clay alone. The various portions were expressed in percentage and using the textural triangle the texture was determined.

Calculation:

Clay % = (2nd reading. – B2) x 2

Silt % = [(1st reading – B1) – (2nd reading – B2)] x 2

Sand % = 100 – Clay% — Silt%

Where:

1st reading= First reading (Clay + Silt)

2nd reading = Second reading (Clay)

B1 = Blank 1

B2 = Blank 2

Determination of Water Holding Capacity of Tailings

Two separate laboratory tests were done to determine how much plant available water a tailing can hold. In determining the field capacity water content of the tailings, a dry pulverized tailing sample was placed on a ceramic plate. The sample was then saturated with water and left to equilibrate overnight. The next day, the porous ceramic plate was placed into a container that is pressured with -1/3 atmosphere of pressure (about 5 psi). The slight pressure in the container pushed excess water out of the tailing sample and through the ceramic plate. After 24 hours, the tailing samples were then weighed, placed in an oven at 105^{o}C for two hours and then weighed again.

In determining the tailing permanent wilting point, a dry pulverized tailing sample was placed on a ceramic plate and saturated with water overnight. The next day the ceramic plate is placed into a container that is pressurized with 15 atmospheres of pressure (about 225 psi). This pressure pushes most of the water out of the tailing sample and through the ceramic plate. The samples were left in the pressurized container for 48 hours. The samples were then weighed before they are placed in an oven at 105^{o}C for two hours to remove the remaining water. The amount of water that is left in the tailing is held too tightly for plants to extract (hygroscopic water). Once this step was completed, the amount of plant-available water in the tailing was calculated, as shown in an example below.

Available water =Field Capacity-Wilting Point

i.e., $AWC = \theta_{fc} - \theta_{wp}$

Biochar Preparation

The biochar used was a rice husk feedstock obtained from a rice processing factory. It was charred through a slow pyrolysis process at a temperature of 550°C for an hour in a muffle furnace (N11/HR/P300). Subsequent samples were charred at the same temperature to obtain a weight of 1.5kg for the whole study. This was done at CSIR-Soil Research Institute (SRI). Biochar was subjected to grinding and sieving through a 2mm sieve. Physicochemical properties of the biochar were then characterized at the SRI laboratory prior to the experiment.

Characterization of Rice Husk Biochar

pH determination

A 5 g of sieved biochar sample was weighed into a centrifuge tube and 25 ml of distilled water added to obtain a biochar-water suspension ratio of 1: 5. (Singh, Dolk, Shen, & Camps-Arbestain, 2017). These suspensions were shaken for 20 minutes using a mechanical shaker. The pH of each suspension was taken using a Jenway 3330 Research pH meter after it has been calibrated. Each biochar type pH was replicated three times and the values recorded.

Total carbon determination

The ashing method as described by Mclaughlin (2010) was followed. 5 g of each biochar sample was weighed in triplicates into a pre-weighed porcelain crucible. The crucibles were then placed into a pre-warmed furnace and temperature set at 550°C and ashing left to complete overnight. After cooling, the masses of each crucible plus ashes were weighed and recorded. This measurement for each sample was taken in triplicates. Total carbon determination was calculated as follows:

$$\% \text{ C}=\frac{W2-W3}{W1-W3}\times 100$$

Where:

W1= wet weight of biochar and porcelain crucible (grammes)

W2= dry weight of biochar and porcelain crucible (grammes)

W3= weight of porcelain (grammes)

Total nitrogen of biochar using the micro-Kjeldahl method

A sample of biochar weighing 0.2 g was digested with conc. H_2SO_4-H_2O_2 mixture in a Tecator Digestor 2012. A blank digest was also done. Twenty-five millilitres of the digest were distilled into a 100 ml conical flask containing 2% boric acid. The distillate was titrated against 0.0071 *M* from green to pink. The total N content was determined using the formula below:

$$\%\text{N}=(S-B)\times T\times 14\times 5\times 100/200$$

Where:

S= volume of 0.0071M HCl used for sample titration

B= volume of 0.0071M HCl used for blank titration

T= molarity of HCl

14= atomic weight of nitrogen

5= sample dilution factor

200= sample weight in mg

100= factor for %

Total phosphorus determination

The method used here was the ascorbic acid method. There were three replicates. The digest and its contents were washed into 100 ml conical flasks as described in the determination of total nitrogen. A 5µgP ml^{-1} (ppm) of working standard was prepared from a 100 ppm stock solution of P. A 0, 0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 ppm of P were prepared from 5µgP ml^{-1} (ppm) working standards by pipetting 0.5 ml, 1 ml, 2 ml, 3 ml, 4 ml, and 5ml into a 25 ml volumetric flask and 4 ml of reagent B was added and made to the mark with distilled water. The solution was allowed to stand for 15 minutes for blue colour development. To ensure homogeneity in treatment, 1 ml of an aliquot of the digest in the 100 ml conical flask were pipetted into the working standards. For the samples, 1 ml of aliquots were pipetted into various 25 ml volumetric flasks and 4 ml of reagent B (a solution containing ammonium molybdate and potassium antimony tartrate in ascorbic acid solution) was added to the sample aliquot and topped to the mark by addition of distilled water. The solutions were allowed to stand for 15 minutes for the development of the blue colour.

The readings of the concentrations of phosphorus in both the working standards and samples were done using a spectrophotometer. Before the reading, the spectrophotometer (Spectronic 20) was heated up for 20 minutes. It was then calibrated by using the 0 ppm blank standard. Then, the readings of the working standards were taken at 880nm wavelength. Readings were recorded and graphs of absorbance against working standards generated using micro soft office excel 2007. The absorbances of the various sample aliquots were immediately recorded. The concentrations of the samples were determined using the relations from the graph of absorbance against the concentrations of the working standards. The linear relationship is expressed as $y= mx+c$. From the standards P concentrations and following the determination of their respective absorbances, the following linear relationship was established: $y= 0.714x +0.006$, where y is the absorbance in %, x is the concentration of P in solution expressed as ppm or µg ml^{-1}, 0.714 is the gradient of the slope and the 0.006 is the y-intercept. The final concentration of P in the various samples was then calculated using the equation as follows:

$$\text{ppm of P in biochar} = \text{ppm of P in solution} \times \frac{\text{vol of extractant(ml)}}{\text{weight of biochar(g)}} \times \frac{\text{final vol.of aliquot}}{\text{initial vol.of aliquot pipetted}}$$

Total potassium determination

Potassium was determined from the H_2SO_4-H_2O_2 digest following a procedure as described by Stewart & Lee (1974). Before the flame photometer reading was done, the flame was made to equilibrate for 30 minutes and standards of potassium passed through the flame photometer for calibration. The concentration of K was determined by flame photometry. Readings were recorded in triplicates.100 ml contents were then passed through a flame photometer and readings done in triplicates. The final concentration of K in solution was determined using the formula below:

$$\%K = {}^{C}/_{100} \times wt$$

Where:

C= concentration of potassium from emission curve

Wt.= weight of soil in grammes

Characterization of Poultry Litter Compost

Poultry litter compost used was prepared in a specific experimental composting process, following Alfano *et al*. (2011). Briefly, compost was prepared by mixing humid poultry manure and maize stovers for a period of four months. The compost used was prepared by CSIR- SRI Microbiology Division. The compost was subjected to drying, grinding and sieving through a 2mm sieve and its physicochemical properties were then characterized prior to the experiment.

Nutritional composition of poultry litter compost and rice husk biochar

The percentage of nutrients levels in the Poultry Litter Compost and Rice Husk Biochar was determined at the Soil Research Institute laboratory (Amendola, Montagnoli & Terzaghi, 2017; Alfano, Lustrato, Lima, Vitullo & Ranalli, 2011).

Experimental Design and Pot Layout

The experimental design adopted for this study was Complete Randomized Design (CRD) with eight different treatments and three replications.

Tailings samples were randomly taken at different points at a depth of 0- 20 cm from the old gold tailings dump site at Obuasi. Two-weeks old lettuce (*Lactuca sativa*) seedlings were transplanted into plastic pots filled with seven different substrates and a control. The treatments were (i) Control (un-amended) (ii) 5 t ha^{-1} Biochar (iii) 60 kg N-80 kg P_2O_5-80 kg K_2O (iv) 2.5 t ha^{-1} Biochar + 30 kgN-40 kg P_2O_5-40 kg K_2O (v) 5 t ha^{-1} Compost (vi) 2.5 t ha^{-1} Compost + 30 kg N-40 kg P_2O_5-40 kg K_2O (vii) 2.5 t ha^{-1} Biochar + 2.5 t ha^{-1} Compost (viii) 2.5 t ha^{-1} Biochar + 2.5 t ha^{-1} Compost + 30 kg N-40 kg P_2O_5-40 kg K_2O. Plants were then grown until maturity (6 weeks) in a screened greenhouse at CSIR-Soil Research institute, Kumasi-Ghana, under controlled water regime. Temperature ranged between 24^{o}C and 36°C and natural day length corresponding to major season (May–July).

Lettuce Establishment and Management

Source of seed

The lettuce seeds for this research were obtained from Holland Greentech, Ghana. Bed preparation was done on 30th of May, 2020 and lettuce seeds were nursed on 2nd June 2020 at the nursery site of CSIR-Soil Research Institute

Germination test

A germination test was first performed to know the viability of the lettuce seeds used. The procedure is as follows: (i) Water-absorbent material was placed inside a waterproof tray; (ii) 150 seeds were counted out and placed on absorbent material inside the tray; (iii) The absorbent material was carefully saturated; (iv) Regular checks were done to see that the absorbent material remains moist and the number of germinated seeds was recorded after 7-10 days; (v) 121 seeds were counted and a germination test was computed after ten days.

Calculating the germination rate

Germination rate is the average number of seeds that germinated over the 7- 10-day periods and it was calculated using the formular below;

$$\text{Germination } (\%) = \frac{\text{Number of seeds that germinated}}{\text{Number of seeds on the tray}} \text{ x } 100\%$$

121 seeds germinated in a tray of 150 seeds after 10 days. The germination percentage was then calculated as

$$\text{Germination } (\%) = \frac{121}{150} \text{ x } 100\% = 81\%$$

Soil Amendments

Use of inorganic amendments

Urea, single super phosphate and muriate of potash were applied as single basal dose as per the treatment details in Table 1.

Table 1 - *Treatments Applied on Gold Mine Tailings*

Treatments	Abbreviation
Control (un-amended)	Control
5 t ha^{-1} Rice Husk Biochar	5 t ha^{-1} RHB
60 kg N-80 kg P_2O_5-80 kg K_2O	100% NPK
2.5 t ha^{-1} Rice Husk Biochar + 30 kg N-40 kg P_2O_5-40 kg K_2O	2.5 t ha^{-1} RHB + 50% NPK
5 t ha^{-1} Poultry Litter Compost	5 t ha^{-1} PLC
2.5 t ha^{-1} Poultry Litter Compost + 30 kg N-40 kg P_2O_5-40 kg K_2O	2.5 t ha^{-1} PLC+ 50% NPK
2.5 t ha^{-1} Rice Husk Biochar + 2. 5 t ha^{-1} Poultry Litter Compost	2.5 t ha^{-1} RHB+ 2.5 t ha^{-1} PLC
2.5 t ha^{-1} Biochar + 2.5 t ha^{-1} Compost + 30 kg N-40 kg P_2O_5-40 kg K_2O	2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK

Source: Field data (2020)

Use of organic amendments

The biochar was obtained from rice husk feedstock which was pyrolysed at 550^{o}C in a Micro furnace at Soil Research Institute, Kwadaso. The rice husk biochar is used as a soil conditioner containing high levels of natural organic matter, nutrients and trace elements. The Poultry Litter Compost was a mixture of poultry litter and maize stovers that had been composted for a period of three (3) months and packed for research purposes.

Soil amendment application

One week prior to sowing, pre-calculated quantities of organic fertilizers in the form (biochar, Poultry litter compost) at full and half recommended rates were applied to the experimental pots, as shown in (Table 1). Inorganic fertilizers in the form of urea, single super phosphate and muriate of potash were applied as single basal dose as per the treatment details and were incorporated well into the soil two weeks after transplanting.

Figure 2 - Gold Mine Tailings and organic amendments used for the study. GMT= Gold Mine Tailing, RHB= Rice Husk Biochar, PLC=Poultry Litter Compost

Filling of Gold Mine Tailing into Pots

The diameter of the pot was 15 cm and the height was 13 cm giving an area of 0.069 m^2. Each pot was filled with a 1.5 kg sample and this was calculated by filling the pot with water leaving about 5 cm above it. The volume obtained was 949.85 cm^3 and this was multiplied with the bulk density of soil (1.57 g cm^{-3}) to give 1489 g, which is approximately 1.5 kg. Lettuce seedlings were raised and transplanted after 2 weeks with 1 seedling per pot.

Sowing and transplanting

The seeds of the lettuce were nursed at the nursery site. After two weeks of nursing the seeds, the seedlings were transplanted into experimental pots filled with seven different substrates and control in a greenhouse planting one seedling per pot.

Growth and Yield Parameters

Plant analysis

Plant morphological analyses were performed at two weeks' interval by measuring the main leaf parameters: Leaf number (LN), Leaf length (LL) and Leaf width (LW) and perimeter (LP). A week to discard the experiment, leaf and root biomass allocation was determined before (fresh weight, FW) and after (dry weight, DW) two days of drying in an oven at 105°C. The measurements were performed on two plants.

Leaf area determination

Leaf length and width were measured in centimetres using a ruler during vegetative growth on 2nd, 4th and 6th weeks after sowing. One plant was selected and measured from each pot. The Leaf Area (LA) was computed by multiplying the Leaf Length (LL) by the Leaf Width (LW) and the product multiplied by the 0.578 correction factor;

$$LA = LL \times LW \times 0.578.$$

Numbers of leaves

The number of leaves emerging after the 2nd, 4th and 6th week was recorded. One plant was selected and measured from each pot.

Plant height

Plant heights and the number of leaves were measured. Lettuce height was recorded from the ground level to the highest point after the 2nd, 4th and 6th WAS.

Chlorophyll content

The chlorophyll content was recorded on the lower, middle and upper leaves using SPAD meter. The recordings were done on the 2nd, 4th and 6th week after transplanting. One plant was randomly picked and measured from each treatment and replication.

Fresh mass and dry mass determination

At the end of the growing period (6 weeks), the lettuce plants were harvested. Above-ground biomass was harvested from each plot. The harvested plants were weighed to determine the fresh weight, then oven-dried at 70 °C to constant weight to determine the total dry matter production

Chemical Analysis of some Plant Parameters (Plant analysis)

Plant sampling and preparation

Lettuce parts sampled at harvest at the end of the 6 weeks growing season were kept in paper envelopes and oven-dried at 60^0C for 48 hours, after which they were milled to pass through a 2 mm mesh sieve. The nitrogen, phosphorus, potassium, calcium and magnesium concentrations of the lettuce plant were determined.

Total nitrogen determination

Total nitrogen was determined by the Kjeldahl method, in which plant material was digested with concentrated sulphuric acid and hydrogen peroxide with selenium as a catalyst. The organic N present was converted into NH_4^+. The ammonium ion, which reacted with the excess of sulphuric acid to form ammonium sulphate, was distilled off in an alkaline medium into boric acid.

$$NH_3 + H_3BO_3 \rightarrow NH_4^+ + H_2BO_3^-$$

The $H_2BO_3^-$ that was formed was titrated with standard hydrochloric acid back to H_3BO_3. About 20.0 g oven-dried plant materials were ground in a stainless-steel hammer mill with a sieve mesh of 1 mm and mixed well to ensure homogeneity. Approximately 0.2 g of the plant material was weighed into a Kjeldahl flask, a tablet of selenium catalyst was added and 5 ml of concentrated H_2SO_4 was also added to the mixture. This was digested on the Electrothermal Kjeldahl apparatus for three hours. After the clear digest has cooled, about 20 ml of distilled water was poured into the Kjeldahl flask containing the digested material before it was transferred into a 100 ml distillation tube.

In the distillation tube, another 20 ml distilled water was added plus 20 ml 40 % NaOH then distilled for 4 minutes. The distillate was received in a conical flask containing 20 ml of 4 % boric acid with PT5 indicator (methyl red and bromocresol green indicators). The received greenish solution was titrated against 0.1 M HCl dispensed from a burette. % N was calculated from the volume of HCl used to attain end-point (Soil Laboratory Staff, 1984).

Calculation:

$$\%\mathrm{N\ DM}^{-1} = \frac{(a-b)\times M\times 1.4\times mcf}{s}$$

Where:

a = volume of 0.1 M HCl used for sample titration.

b = volume of 0.1 M HCl used for the blank titration.

M = molarity of HCl.$1.4 = 14 \times 0.001 \times 100\%$ (14 = atomic weight of N)

s = weight of sample in gram.

Determination of phosphorus, potassium, sodium, calcium and magnesium

A 1 g of milled and sieved plant material was weighed into a porcelain crucible and ashed in a muffle furnace between temperatures of 450 – 500 °C. The ashed sample was removed from the oven after cooling and then made wet with 1 – 2 drops of distilled water and 10 ml of dilute HNO_3. The crucible was then heated on a water bath until the first sign of boiling was observed. The crucible was removed and allowed to cool. The content was filtered into a 100 ml volumetric flask using a no. 540 filter paper. The crucible was washed two times with about 5 ml distilled water followed by the filter, which was also washed twice with about 20 ml distilled water. The filtrate was finally diluted to a 100 mL mark with distilled water.

Potassium and sodium

A 50 ml aliquot of the filtrate was used to determined potassium and sodium using the Atomic Absorption Spectrophotometer (AAS). Standard solutions of K and Na were prepared with concentrations of 1.0, 2.0, 4.0 and 8.0 ml in a 100 ml volumetric flask. Ten ml of lanthanum and caesium solution was added to each flask and made to volume with distilled water. A standard series was obtained for each element respectively. Each element was measured directly in the filtrate by the AAS at their respective wavelengths.

Phosphorus

The remaining 50 ml of the filtrate in the 100 ml volumetric flask was diluted to 100 ml with distilled water. An aliquot of 50 ml was transferred to an Erlenmeyer flask for calcium and magnesium determination, as described below. The 50 ml left was used to determined phosphorus using the Vanado-Molybdenum method. Ten ml each of ammonium vanadate and ammonium molybdate solutions were added and shaken thoroughly. The solution was allowed to stand for 10 minutes for full-colour development and then made to the

100 ml mark. A standard curve was also developed concurrently with P concentrations ranging from 0, 1, 2, 5, 10, and 15 to 20 µg P per millilitre of solution. The absorbance of the sample and standard solutions was read on the spectrophotometer (Spectronic 21D) at a wavelength of 470 nm. A standard curve was obtained by plotting the absorbance values of the standard solutions against their concentrations

Determination of calcium

A 25 ml portion of the filtrate was transferred to an Erlenmeyer flask. Hydroxylamine hydrochloride (1.0 ml), potassium cyanide (1.0 ml of 2 % solution) and potassium ferrocyanide (1.0 ml of 2 %) were added. After a few minutes, 4 ml of 8*M* potassium hydroxide and a spatula of murexide indicator were added. The solution obtained was titrated with 0.01*N* EDTA solution to a pure blue colour. The titre value was recorded.

Determination of calcium and magnesium

For the determination of the calcium plus magnesium, 25 ml of the extract was transferred into an Erlenmeyer flask. A 1.0 ml portion of hydroxylamine hydrochloride, 1.0 mL of 2.0 percent potassium cyanide buffer (from a burette), 1.0 ml of 2.0 percent potassium ferrocyanide, 10.0 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution were added. The solution was titrated with 0.01*N* EDTA (ethylene diamine tetraacetic acid) to a pure turquoise blue colour. The titre value was recorded.

The titre value for calcium was subtracted from this value to get the titre value for magnesium.

Calculation:

Exchangeable Calcium (cmol of Ca $(+)\mathrm{kg}^{-1}$plant)

$$\left[\frac{V1\text{-}V2}{V3} \times V4 \times N \times \frac{100}{w}\right] \times mcf$$

Exchangeable Calcium (cmol of Ca $(+)\mathrm{kg}^{-1}$plant)

$$\left[\frac{V1\text{-}V2}{V3} \times V4 \times N \times \frac{100}{w}\right] \times mcf$$

$$mcf = \text{moisture correcting factor} \frac{(100+\%\text{moisture})}{100}$$

Exchangeable Calcium plus Magnesium (cmol of Ca + Mgkg^{-1} plant)

$$= \left[\frac{V5\text{-}V6}{V7} \times V4 \times N \times \frac{100}{w}\right] \times mcf$$

Where:

V_5 = volume of EDTA required for sample aliquot, ml

V_6 = volume of EDTA required for blank aliquot, ml

V_7 = volume of aliquot taken, ml

V_4 = total volume of original HNO_3 filtrates, ml

N = normality of EDTA

w = weight of sample taken in g

$$\text{mcf=moisture correcting factor}\ \frac{(100+\%\text{moisture})}{100}$$

1ml 0.01 N EDTA=0.2004 mg Ca^{2+}=0.1216 Mg^{2+}

Nutrient Uptake

Nutrient uptakes were calculated following method by Du Preez and Bennie (1991). This was done by multiplying the dry matter yields with the N, P, K, Ca and Mg concentrations of the specific components.

$$\text{Nutrient uptake (kg/ha)} = \frac{(\%\text{ N, P, K, Ca, Mg *Yield})}{100}$$

Where:

% N, P, K, Ca, P, Mg = nutrient content in lettuce

Yield = Lettuce yield (kg ha^{-1})

Data Analysis

Data on all parameters/response variables (e.g., pH, SOC, N, P, K, Texture, exchangeable bases, growth and yield, etc.) were subjected to analysis of variance (ANOVA) using the GenStat (2012) statistical package. Means were separated using the Least Significant Difference (LSD) method at a 5 % level of probability.

CHAPTER FOUR

RESULTS AND DISCUSSION

The goal of this research work was accomplished to study the effects of combined application of organic and inorganic amendments on old gold mine tailings to test its efficacy in changing the substrate properties and to determine whether or not these changes were favourable to lettuce production. Some of the data have been presented and expressed in table(s) and others in figures for easy discussion, comparison and understanding. The results of each parameter have been discussed and possible interpretations where ever necessary have been given

Initial Chemical and Physical Characteristics of Mine Tailings

The initial chemical and physical characteristics of mine tailings used in the study are presented in Tables 2 and 3. Results of the initial tailing sample gave 64% sand, 9% clay and 27% silt with a sandy loam characterization. The result of the pH was 7.30, which was slightly alkaline. The initially available phosphorus was 21.88 cmolc kg-1 which was high (Soil laboratory staff, 1984). The potassium content was 0.04 cmolc kg-1 and was low (Soil laboratory staff). The results of the analysis of the initial tailing sample for total organic carbon was 1.12% and was low (Soil laboratory staff). The percentage of total organic nitrogen being 0.07 and was low. The percentage of total nitrogen had low organic nitrogen content. The exchangeable acidity was 0.10 cmolc kg-1. The base saturation was 98.66% which was very high. The ECEC of the initial tailing was 8.19 cmolc kg-1 and was moderate.

Table 2 - *Chemical Properties of GMT of the Experimental Field for the Top (0-20 cm) and their Ratings*

Tailings Properties	Reading	Ratings
pH	7.30	Slightly alkaline
O. C (%)	0.76	Low
Total nitrogen (%)	0.07	Low
P (cmolc kg^{-1})	21.88	High
K $^{+}$ (cmolc kg-^{1})	0.04	Low
Ca^{2+} (cmolc kg^{-1})	7.63	Medium
Mg^{2+} (cmolc kg^{-1})	0.33	Low
Na^{+} (cmolc kg^{-1})	0.08	Low
Total exchangeable bases (cmolc kg-^{1})	8.08	Low
Exch. acidity (AL^{3+} H^{+}) cmolc kg-^{1}	0.10	Low
ECEC (cmolc kg^{-1})	8.19	Moderate

Source: Field data (2020); (Soil laboratory staff, 1984).

Table 3 - *Selected Physical Properties of GMT at Obuasi for 0-20 cm Depth*

Parameter	Value	Texture
Particle size distribution		
% Sand	64.00	
% Clay	9.00	Sandy loam
% Silt	27.00	
Bulk density (g cm^{-3})	1.57	

Source: Field data (2020)

Heavy Metal Concentration of Gold Mine Tailings

Results of some selected initial heavy metal in gold mine tailings analysis are presented in Table 4 below. The result of the mercury (Hg) was 3.50 mg kg^{-1}which was above the acceptable limit of 2.00 mg kg^{-1} according to WHO/FAO (2001). The high levels of Hg concentration in the tailing could come from human influence, such as artisanal gold mining activities (Carrico, 1985). The initial arsenic content was 0.18 mg kg^{-1} which was below the permissible limit of 20.00 mg kg^{-1} according to WHO/FAO (2001). Arsenic (As) occurs naturally in the earth's crust, with levels ranging between 2.00 mg $kg^{-1}$and 5.00 mg kg^{-1} (Mandal & Suzuki, 2002). The Lead (Pb) content was 8.90 and was lower than the permissible limit of 50.00 mg kg^{-1} for soils according to WHO/FAO (2001) and also lower than the 65 mg kg^{-1} reported by Sanusi Hassan, Abbas and Kura (2017). The tailing showed a concentration of Cadmium (Cd) of 0.06 mg kg^{-1}. This was far below the permissible limit of 3.00 mg kg^{-1} in soils for cultivating plants, according to WHO/FAO (2001). These concentrations are still lower than the relatively relaxed criteria acceptable in Germany (Singh, Kalamdhad & Ajayi, 2011). The chromium content was 0.44 mg kg^{-1} and was low.

Table 4 - *Heavy Metal Composition of GMT at the Decommissioned Mine Site at Obuasi*

Properties	Concentration (mg kg^{-1})	Permissible level (mg kg^{-1}) (FAO/WHO, 2001)
Hg	3.50	2
As	0.18	20
Pb	8.90	50
Cd	0.06	3
Cr	0.44	14

Source: Field data (2020); (FAO/WHO,2001).

Initial Chemical Characteristics of the Poultry Litter Compost and Rice Husk Biochar

The initial chemical characteristics of the poultry litter compost and rice husk biochar used in the study are presented in Table 5. The results showed that the pH of the poultry litter compost was 9.1, rice husk biochar was 8.9. The percentage organic carbon of the poultry manure compost was 14.36, which was higher than that of the rice husk biochar, 7.98. The percentage of total organic nitrogen for poultry manure compost being 1.99 and was adequate when compared with Bruce and Rayment (1982) interpretation of percentage total nitrogen. The total percentage of nitrogen for rice husk biochar was 0.59% and was adequate. The available percentage of phosphorus was low both for poultry manure compost and rice husk biochar, recording 3.61% and 0.59%, respectively.

The percentage potassium for poultry litter compost was 0.80% and was low and the percentage potassium for rice husk biochar was 0.21% and was also low. The percentage calcium for poultry manure compost was 10.26, which was high and the percent calcium for rice husk biochar was 1.35, being low. The percentage magnesium for poultry litter compost and rice husk biochar was medium, being 1.56 and 0.43, respectively. Mengel, Kirkby, Kosegarten and Appel (2001) reported that organic fertilizers such as farmyard manure, slurries and green manure have most plant nutrients which include potassium, magnesium and phosphate and are present in an inorganic form.

Table 5 - *Percentage Nutrient Levels in the Poultry Litter Compost (PLC) and Rice Husk Biochar (RHB)*

Nutrient Composition	Poultry Litter Compost	Rice Husk Biochar
pH	9.1	8.9
% O.C	14.36	7.98
% T. N	0.99	0.59
% P	3.61	0.13
% K	0.80	0.21
% Ca	10.26	1.35
% Mg	1.56	0.43

Source: Field data (2020)

Heavy Metal Concentration of Poultry Litter Compost and Rice Husk Biochar

Results of the initial heavy metal in poultry litter compost and rice husk biochar analysis are presented in Table 5 above. The level of mercury in poultry litter compost was 0.20 mg kg^{-1} which was below the acceptable limit of 2.00 mg kg^{-1} according to WHO/FAO (2001). The level of the mercury of rice husk biochar was 0.26 mg kg^{-1} which was below the acceptable limit of 2.00 mg kg^{-}

^{1}according to WHO/FAO (2001). The initial arsenic content of poultry litter compost was 0.12 mg kg^{-1} which was below the permissible limit of 20.00 mg kg^{-1} according to WHO/FAO (2001). The initial arsenic content of rice husk biochar was 0.15 mg kg^{-1} which was below the permissible limit of 20.00 mg kg^{-1} according to WHO/FAO (2001). Arsenic occurs naturally in the earth's crust, with levels ranging between 2.00 mg kg^{-1} and 5.00 mg kg^{-1} (Mandal & Suzuki, 2002). The lead content was 0.05 mg kg^{-1} for poultry litter compost and was lower than the permissible limit of 50.00 mg kg^{-1} for soils according to WHO/FAO (2001) and also lower than the 65 mg kg^{-1} reported by Sanusi *et al.* (2017). The lead content was 0.06 mg kg^{-1} for rice husk biochar and was lower than the permissible limit of 50.00 mg kg^{-1} for soils according to WHO/FAO (2001). This study showed a maximum concentration of Cadmium of 0.06 mg kg^{-1}. This was far below the permissible limit of 3.00 mg kg^{-1}in soils for cultivating plants, according to WHO/FAO (2001). These concentrations are still lower than the relatively relaxed criteria acceptable in Germany (Singh *et al.*, 2011). The chromium content was 0.44 and was low.

Table 6 - *Percentage Heavy Metal Concentration in the Poultry Litter Compost (PLC) and Rice Husk Biochar (RHB)*

Nutrient Concentration	Poultry Litter Compost (mg kg^{-1})	Rice Husk Biochar (mg kg^{-1})
As	0.12	0.15
Cd	3.54	3.68
Pb	0.05	0.06
Cr	0.02	0.02
Hg	0.20	0.26

Source: Field data (2020)

Soil Amendments Effect on Total Dry Matter Yield of Lettuce

The total dry matter yield of lettuce was positively influenced by various treatments. The variation among the treatments corresponding to lettuce yield per pot was significant ($p<0.001$). The highest yield (433.9 kg ha^{-1}) was found in 2.5 t ha^{-1} RHB + 50% NPK followed by the 2.5 t ha^{-1} PLC+ 50% NPK, which had 405.4 kg ha^{-1}. There was no significant difference between the 2.5 t ha^{-1} RHB + 50% NPK and the 2.5 t ha^{-1} PLC+ 50% NPK. The 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC had 324.7 kg ha^{-1} total dry matter yield and the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK had 282.3 kg ha^{-1} total dry matter yield with no significant difference between them. The 100% NPK had 238.7 kg ha^{-1} total dry matter yield, while the 5 t ha^{-1} RHB had 167.2 kg ha^{-1} total dry matter yield. However, there was no significant difference between the 5 t ha^{-1} PLC and the Control. The 5 t ha^{-1} PLC had 234.2 kg ha^{-1} total dry matter yield. The lowest yield (144.9 kg ha^{-1}) was recorded in the Control.

It was generally observed that the 2.5 t ha^{-1} RHB + 50% NPK represented 1.99 folds increase compared to the Control. The 2.5 t ha^{-1} PLC+ 50% NPK had a 1.79 folds increase in total dry matter yield compared to the Control. The 100% NPK and the 5 t ha^{-1} RHB had 65% and 62% respectively increase over the Control. From the results, it could be deduced that application of inorganic fertilizer and biochar significantly ($p<0.001$) improved yield compared to Control Figure 2. This is because studies have demonstrated that the use of biochar could enhance the efficiency of chemical fertilizer (Oladele *et al*., 2019). This could be due to the synergistic effect of organic and inorganic fertilizers on crop performance Also, other studies have confirmed the synergistic effects of biochar and inorganic fertilizers (Xie, Wang, Xia, & Yao, 2011), but studies regarding the combined effect of biochar, inorganic fertilizers and organic manure have been limited (Sohi, Krull, Lopez-Capel, & Bol, 2010).

Also, the differences in soil properties, as seen in Table 2, may be a reason for the divergence of the yield. When comparing sole organic amendments, the 5 t ha^{-1} RHB performed significantly better than the 5 t ha^{-1} PLC. While biochar has proven to have a positive conditioning effect on soils, it may be limited as a sole nutrient supplier because of its relatively low nutrient composition and recalcitrance to biodegradation. The sole organic amendments were lower, perhaps due to the slow release of nitrogen by manure slowly after mineralization. These findings agreed with those of other researchers (Pang & Letey, 2000; Hartemink *et al*., 2000; Eghball, Wienhold, Gilley, & Eigenberg, 2002) who found that while nitrogen supplied by inorganic fertilizer was readily available, the nitrogen supplied by manure was released slowly.

For increases in crop yield, biochar applications have been reported for crops such as cowpea (Yamato, Okimori, Wibowo, Anshori, & Ogawa, 2006), maize (Rodríguez, Salazar, & Peterson, 2009), soybean (Tagoe, Horiuchi, & Matsui, 2008) and radish (Chan, Van Zwietan, Meszaros, Downie, & Joseph, 2008). Lettuce yields of about 40 t ha^{-1} had been recorded in the region of Dar-Es-Salaam, while in Benin and Nigeria, the yield of shoots of 4 weeks old *A. cruentus* was about 30 t ha^{-1} (Schippers, 2000). The increases in the dry matter yield after the addition of the soil amendments could be attributed to the benefits derived from the PLC and RHB, such as nutrient and moisture retention, increase in soil pH and the provision of nutrients for plants uptake and use (Mukherjee, & Lal, 2013). Also, the increases in the dry matter yield could be attributed to the improved growth characteristics such as height, leaf area and chlorophyll content. Increases in shoot biomass production and seed yield as a result of biochar application have been reported by Oram *et al*. (2014) and Tammeorg *et al*. (2014).

Other studies with rice husk biochar found increases in crop yields for rice, lentil, spinach, cabbage, maize and lettuce (Abrishamkesh, Gorji, Asadi Bagheri-Marandi, & Pourable, 2015, Carter, Shackley, Sohi, Suy, & Haefele, 2013, Haefele *et al*. 2011, Nguyen, Lehmann, Hockaday, Joseph, & Masiello, 2012). Our results also showed an increase in crop yield for compost and biochar treatments compared with the control. Recently higher yields of lettuce 'Veneza Roxa' were reported with chicken manure, and in decreasing order cattle manure, bounce back and lastly inorganic fertilizer (Masarirambi, Hiawe, Oseni, & Sibya, 2010). Increased vegetable yield with the use of manure has previously been reported for okra (Ogunlela, Masarirambi, Makuza, 2005). These results agree with work done in Brazil where chicken manure, compost, charcoal, forest litter and chemical fertilizer were tested during four cropping cycles with rice (*Oryza sativa* L.) and sorghum (S*orghum bicolor* L.) in five replicates in which the application of chicken manure amendments resulted in the highest cumulative yield (Fearnside, 2001).

A study done by Worthington (2001) on the effects of applying organic fertilizers and inorganic fertilizers on the yield and nutritive value of head lettuce obtained equivalent yields regardless of the type of fertilizer used. In their studies with tomato, results showed that two organic fertilizer treatments provided better yield than chemical fertilizers (Geboloğlu, Yanar, & Aydin, (2011). Much work has already been done to demonstrate the effects of biochar on plant productivity and crop yield. Jeffery, Verheijen, van der Velde and Bastos (2011) reviewed data on this issue with a meta-data analysis and found a mean increase in crop productivity by 25% in the treated samples.

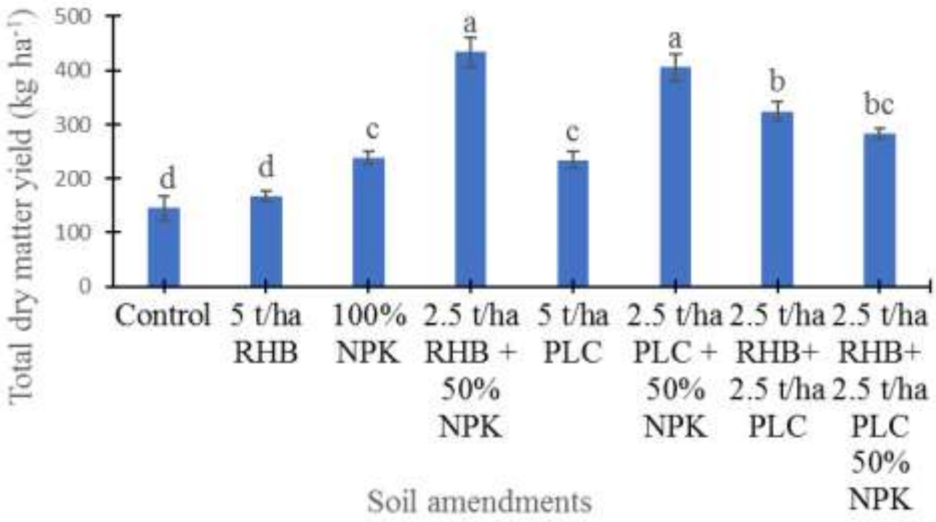

Figure 3 - Total dry matter yield of lettuce (*Lactuca sativa*) for the various amendments at six weeks after planting. Bars with the same letters for a particular soil amendment are not statistically different at $p<0.05$ LSD

Effect of Soil Amendment on Growth Parameters of Lettuce

Plant height

Figure 3 shows the effect of soil amendment application on lettuce mean height at 2, 4 and 6 weeks after planting. The results show that significant differences were observed for lettuce height among the treatments for week 2 ($p<0.001$), week 4 ($p<0.001$) and week 6 ($p=0.006$)

Lettuce mean height ranged from 8.17 cm to 16.15 cm for week 2 after planting. The 2.5 t ha^{-1} PLC+ 50% NPK recorded the highest plant height of 16.15 cm, which represents 97.67% over the control. This was followed by the 5 t ha^{-1} PLC recording 12.73 cm, which represents 55% over the control. However, there was no significant difference among the rest of the treatment except the Control recording the minimum height of 8.17 cm. At 4 weeks after planting, the 100% NPK gave the highest (16.57 cm) height, which was not significantly different from the 5 t ha^{-1} PLC (16.27 cm), 2.5 t ha^{-1} PLC + 50% NPK (15.93 cm) and the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK (15.8 cm). The 2.5 t ha^{-1} RHB + 50% NPK gave 15.53 cm, the 5 t ha^{-1} RHB gave 14.6 cm and the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC recorded 14.17cm but however, differed significantly from the Control which recorded the least height of 12.4 cm. Similarly, at 6 weeks after planting, the 5 t ha^{-1} RHB gave the maximum height (17.33 cm), which was not significantly different from the rest of the treatment except the Control, which produced the minimum (13.4 cm) height.

Plant height plays an important role in the final yield of fodder crops. Other studies reported that organic amendments and biochar have ameliorating effect on poor soils and that plant growth and nutrient uptake were enhanced by the addition of organic materials to soils (Brito, Monteiro, Mourão & Coutinho, 2014; Agegnehu, Bird, Nelson, & Bass, 2015). Buah and Mwinkara (2009) reported the influence of nitrogen-composed fertilizer on the organic content of the soil to promote germination and plant development.

Findings in this study agree with those of other researchers (Pang & Letey, 2000; Hartemink *et al*., 2000), who found that while nitrogen supplied by inorganic fertilizer was readily available, the nitrogen supplied by manure was released slowly. The smallest plant height was recorded from plots receiving no fertilizer. Authors such as Zhang *et al.* (2012), Khan *et al*. (2013) and Van Zwieten *et al*. (2010) have demonstrated a significant positive impact of biochar and other organic amendments through the provision of the necessary nutrients for plant growth and development. This could be seen in the high level of the nutrient in the biochar and compost (Table 4).

The observed increases in the height of lettuce from the application of the 5 t ha^{-1} RHB could be attributed to the relatively large concentrations of the biochar, which invariably results in higher nutrients and moisture availability for use by the plants. This finding agrees with the study of Tariku, Shiferaw, Muluken and Firew (2017), who reported increases in growth parameters following the application of biochar on garden peas. This effect could be due to the presence of phytohormones in organic fertilizers that stimulate plant growth (Gajalakshmi, Ramasamy, & Abbasi, 2001).

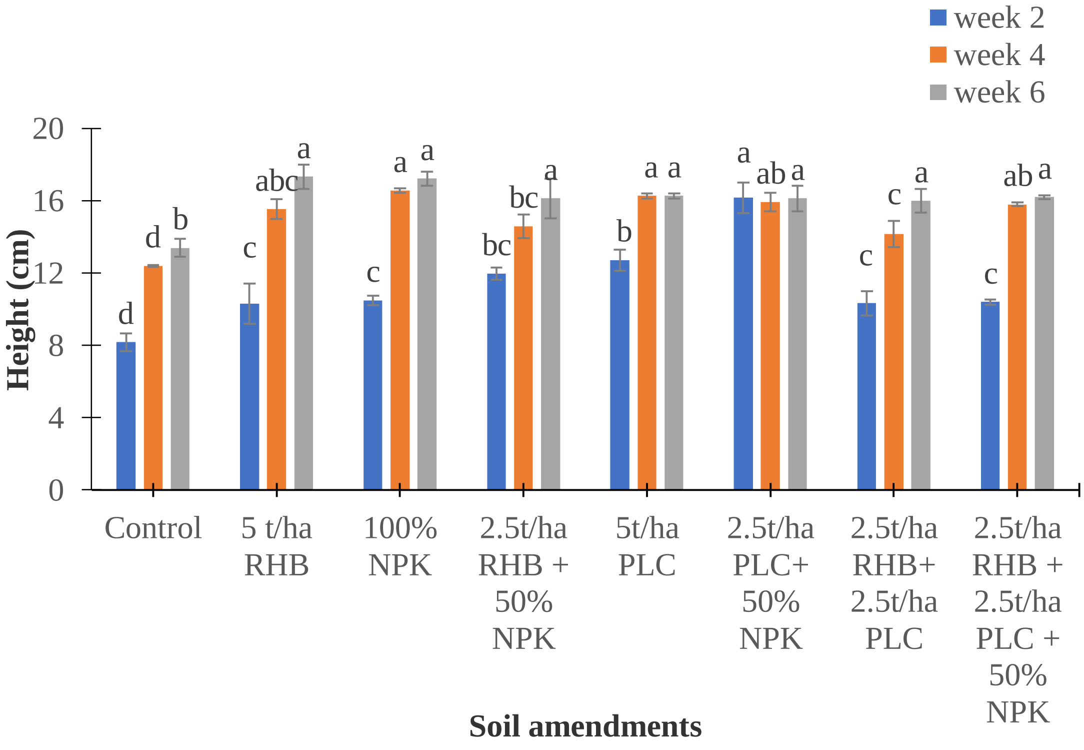

Figure 4 - Effect of soil amendments on the height of lettuce at 2, 4 and 6 weeks. Bars with the same letters for a particular soil amendment are not statistically different at $p<0.05$ LSD

Leaf area

Figure 4 shows the effect of soil amendment application on lettuce leaf area respectively at 2, 4 and 6 weeks after planting. The results showed that significant differences were observed for lettuce leaf area among the treatments for week 2 ($p<0.001$), week 4 ($p=0.034$) and week 6 ($p<0.001$).

At 2 weeks after planting, the leaf area in respect of leaf length and breadth was significantly higher in lettuce provided with 2.5 t ha^{-1} PLC + 50% NPK (21.35 cm^2). This treatment represents 121% over the Control. This was not significantly different from 2.5 t ha^{-1} RHB+ 50% NPK (21.05 cm^2), 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC (20.5 cm^2) and the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK (19.51 cm^2). The lowest leaf area was found in the Control but was not significantly different from the 5 t ha^{-1} RHB and the 100% NPK. At 4 weeks after planting, 2.5t ha^{-1} RHB + 2.5 t ha^{-1} PLC gave the highest leaf area of 33.33 $cm^{2,}$ followed by the 2.5 t ha^{-1} PLC + 50% NPK (32.14 cm^2). The 2.5 t ha^{-1} + 2.5 t ha^{-1} PLC + 50% NPK recorded 28.23 cm^2 leaf area. However, the lowest leaf area was found in the Control but was not significantly different from the 5 t ha^{-1} biochar. Similarly, at 6 weeks after planting, the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC recorded the maximum leaf size of 41.41 cm^2. This leaf area represented a 111% increase over the Control. This was not significantly different from the 2.5t ha^{-1} RHB + 50% NPK (40.07 cm^2) and the 2.5 t ha^{-1} RHB + 50% NPK (36.58 cm^2). There was no significant difference among the rest of the treatments except the Control that had a 19.62 cm^2 leaf area.

This might be due to the adequate moisture supply resulted in increasing leaf area similar response was discussed by Nehra (2000). In the first stages of growth, there was a small increase in the rate of leaf area formation but by increasing plant growth and leaf area, the amount of dry matter increased proportionally (Boroujerdnia & Ansari, 2007). The increase in the leaf area affected leaf dry weight because plant nutrients stimulate vegetative plant growth and as a result, increments in leaf area increase the rate of plant photosynthesis.

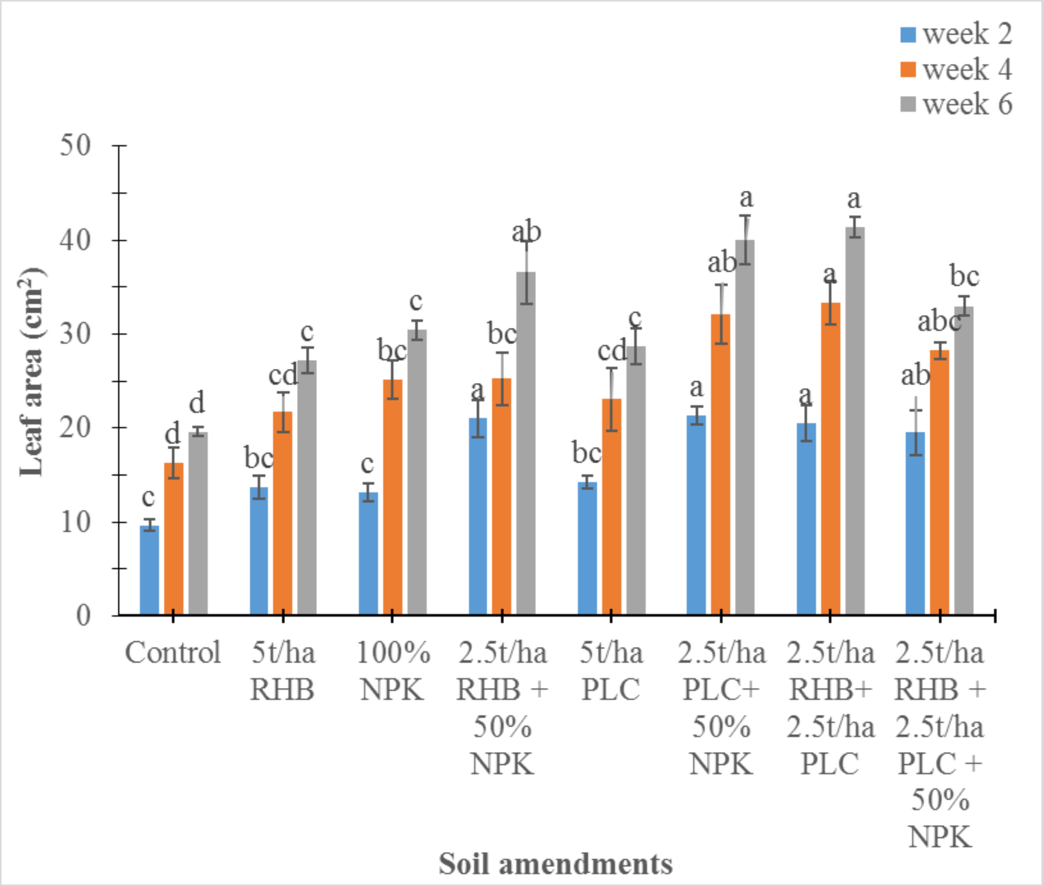

Figure 5 - Effect of soil amendments on leaf area of lettuce at 2, 4 and 6 weeks. Bars with the same letters for a particular soil amendment are not statistically different at P<0.05 LSD

Number of leaves

Figure 5 shows the effect of soil amendment application on lettuce leaf number respectively at 2, 4 and 6 weeks after planting. The results showed that no significant differences were observed for lettuce leaf number among the treatments for week 2 (p=0.86) and week 4 (p=0.089) but not for week 6 (p=0.039).

At 2 weeks after planting, the 2.5 t ha^{-1} RHB + 50% NPK had the highest mean number of leaves (3.7) but was not significantly different (p>0.05) from the rest of the treatments. At 4 weeks after planting, all the treatments had the same number of leaves (4.0). However, at 6 weeks after planting, the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC and the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK recorded the highest leaf numbers of 5.3 each. These two treatments were not significantly different from the rest of the treatments except the 2.5 t ha^{-1}RHB, 100% NPK and the Control that recorded a mean value of 4. Leaf number is known as the primary yield attribute, which also plays an important role in the yield formation of lettuce. Application of the 2.5 t ha^{-1} RHB + 2.5 st ha^{-1} PLC and the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK produced the maximum leaf number.

Similar observations were made by Makinde, Ayeni, Ojeniyi and Odedina (2010) and Olaniyi, Adelasoye and Jegede (2008), who reported that the application of each of N and P fertilizer sources significantly increased the number of leaves. Other authors also showed that municipal-industrial wastes stimulate plant growth, indirectly and with a long-term effect, by improving organic matter (Mantovi, Baldoni, & Toderi, 2005; Cherif *et al*., 2009).

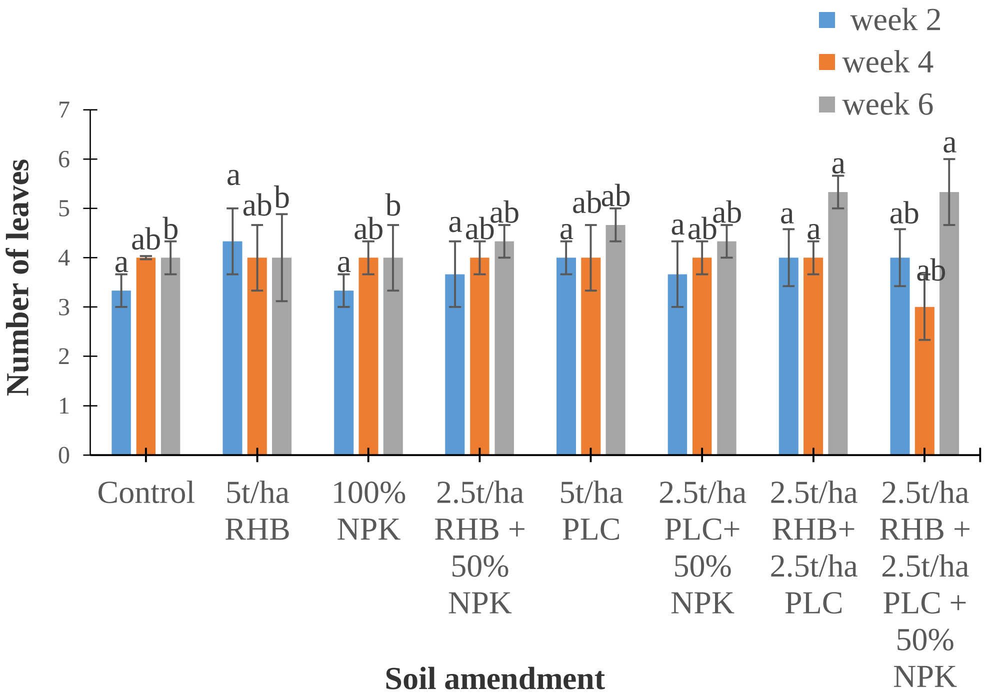

Figure 6 - Effect of soil amendments on the mean number of leaves of lettuce (*Lactuca sativa*) at 2, 4 and 6 weeks. Bars with the same letters for a particular soil amendment are not statistically different at P<0.05 LSD

Chlorophyll content

Figure 6 shows the effect of soil amendment application on lettuce chlorophyll content respectively at 2, 4 and 6 weeks after planting. The results show that significant differences were observed for lettuce chlorophyll content among the treatments for week 2 ($p<0.001$), week 4 ($p<0.001$) and week 6 ($p<0.05$).

Lettuce chlorophyll content ranged from 15.83 to 31 for week 2 after planting. The 2.5 t ha^{-1} RHB + 50% NPK recorded the highest mean chlorophyll content (SPAD) of 31, which represents 97.67% over the control. This was significantly the same as the 100% NPK with SPAD value of 28.8, which represents 55% over the control. However, there was no significant difference among the rest of the treatments except the 5 t ha^{-1} Biochar recording SPAD value of 19.83 with the Control recording the minimum SPAD value of 15.83. At 4 weeks after planting, the 100% NPK had the highest SPAD value of 34.47, which was not significantly different from 2.5 t ha^{-1} RHB + 50% NPK (24.33 SPAD value) and the 5t ha^{-1} Compost also with SPAD value of 33.1. The Control recorded the minimum SPAD value of 19.17. Similarly, at 6 weeks after planting, the 100% NPK had the highest SPAD value of 36.8, which was not significantly different from 2.5t ha^{-1} PLC+ 50% NPK with 35.33 SPAD value. The Control recorded the minimum SPAD value of 21.17. For chlorophyll content, the 100% NPK recorded the highest value.

Modisane, Beletse and Du Plooy (2009) reported the considerable influence of NPK on amaranthus in their studies which were similar to the findings of this study. This indicates that lettuce may have other beneficial effects on the soil in addition to the contribution from the NPK. An adequate supply of nitrogen is associated with high photosynthetic activity, vigorous vegetative growth and dark green colour of the leaves (Bairwa, & Fageria, 2008). With respect to the 2.5 t ha^{-1} RHB + 50% NPK, there was a positive effect of the fertilizer along with biochar amendments upon the functional activity of the photosynthetic apparatus that increased the content of photosynthetic pigments. This result is similar to research conducted by Zhu *et al*. (2020) to evaluate the effects of biochar and biofertilizer on cadmium-contaminated cotton growth and the antioxidative defence system. In their work, they concluded that biochar and biofertilizer have a positive impact on cotton chlorophyll content, net photosynthesis.

Leaf chlorophyll content was significantly higher when inorganic fertilizer with added with organic manure compared with using organic manure alone (Ouda & Mahadeen, 2008). In their study, application of the highest dosages of organic manure (80 t ha^{-1}) with the highest dose of inorganic fertilizer (60 kg ha^{-1}) induced the highest leaf chlorophyll content, while the lowest chlorophyll content obtained by control treatment (Ouda & Mahadeen, 2008). These results agreed with the previous 14 findings obtained on other vegetable crops (Al-Tarawneh, 2005). A promotion effect of organic and inorganic fertilizers on chlorophyll contents might be attributed to the fact that N is a constituent of the chlorophyll molecule.

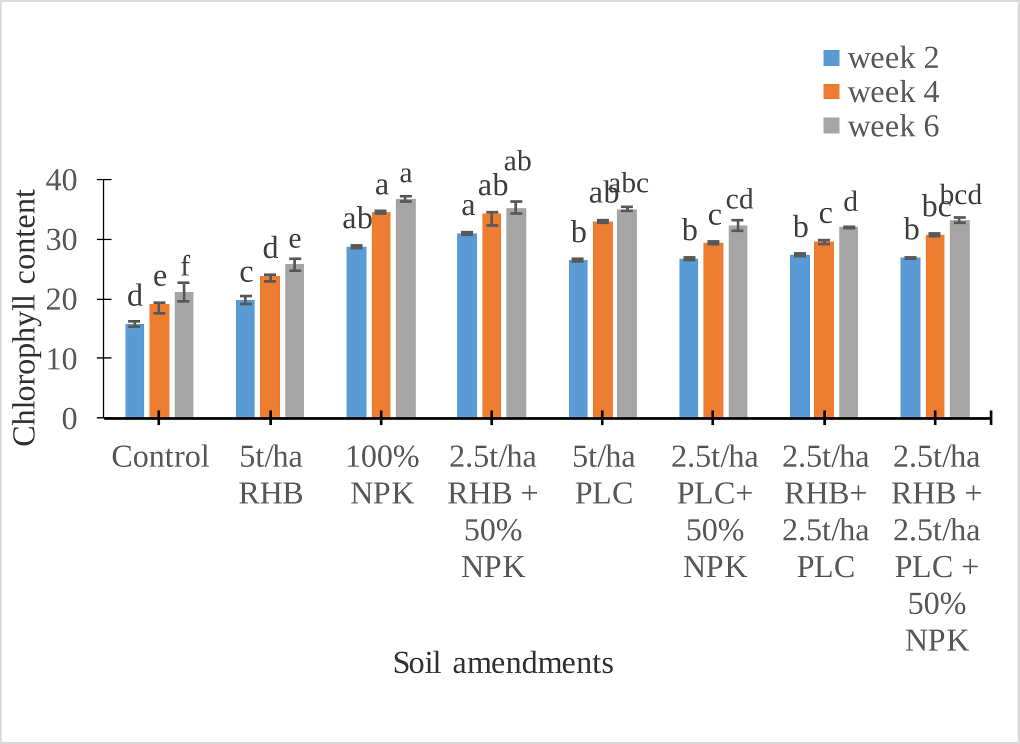

Figure 7 - Effect of soil amendments on mean chlorophyll content of lettuce (Lactuca sativa) at 2,4 and 6 weeks. Bars with the same letters for a particular biochar rate are not statistically different at $p<0.05$ LSD

Effects of Soil Amendments on some Properties of Gold Mine Tailings

Phytoremediation technologies are the most preferred remediation techniques in heavy metal contaminated soils, but unfavourable conditions in tailings substrates such as moderate or high levels of heavy metals, low levels of macronutrients and poor substrate structure hinder plant growth. This often requires additional soil amendment to achieve enhanced plant germination and may prolong the length of time required to stabilize and reduce the risk of pollution from tailings surfaces (Neuman and Ford, 2006; Robinson, Bañuelos, Conesa, Evangelou & Schulin, 2009).

The use of soil amendments is mainly to supply nutrients to improve crop yields but depending on the type, other soil properties such as organic matter (Mungai, Bationo, & Waswa, 2009). More specifically, Diaz, De Bertoldi and Bidlingmaier (2011) pointed out that the simplest method of examining the agronomic value of stabilized organic materials is the calculation of both organic matter supply and plant nutrients. Tables 7 and 8 below shows the effect of application of soil amendment on some selected soil properties of mine tailings taken from 0-20cm.

pH

The results of the various amendments on soil pH were observed to be significantly different ($P< 0.001$). Amongst the amendments, the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK recorded a mean pH of 7.81 on the tailings, which yielded the highest impact on Gold mine tailing with an increase of 14.68% over the Control. The 2.5 t ha^{-1} RHB + 2.5 t ha^{-1}PLC had a mean pH of 7.75, which yielded a pH increase of 13% over the control and was significantly similar to the 2.5 t ha^{-1} RHB + 50% NPK, which recorded a pH of 7.70. The 5 t ha^{-1} PLC and the 2.5 t ha^{-1} RHB + 50% NPK had pH values of 7. 63 and 7.57, respectively. The 100% NPK had mean pH of 7.37, and the 5 t ha^{-1}RHB recorded a pH of 7.34. The Control recorded the least mean pH of 6.81.

The observed increases in the soil pH from the compost and the biochar application could be attributed to the liming ability of these amendments, which were observed to be alkaline (Table 5). These amendments could reduce soil acidity and the contents of exchangeable acidity and Al through replacing the acidic cations from the exchange sites. This agrees with the findings of Angelova, Akova, Artinova and Ivanov (2013), who pointed out that the direction of the change in soil pH as a result of vermicompost application reflected the initial pH of vermicompost. A similar trend was observed by Chan, Van zwieten, Meszaros, Downie and Joseph (2007) when they investigated the agronomic values of green waste biochar in a pot trial. This confirms that the application of organic materials, as well as biochar, could improve the pH of the soil (Kaderi, 2004). Adjusting the pH of the soil to near neutral increases the cation exchange capacity level and is beneficial for the growth of the plants (Verheijen *et al*., 2009).

There are reports in the literature of long-term compost and manure application both increasing (Eghball, Wienhold, Gilley, & Eigenberg, 2002; García-Gil, Ceppi, Velasco, Polo, & Senesi, 2004; Butler & Muir, 2006) and decreasing (Meng, Ding, & Cai, 2005; Bastida, Kandeler, Hernández, & Garcia, 2008; Bi *et al*., 2008) the pH of soils, depending on their initial pH and organic residues. Butler and Muir (2006) observed that soil pH increased on average by 0.5 units as dairy manure compost rate nearly doubled in magnitude from 11.2 to 179.2 t ha $^{-}$1. Nguyen and Lehmann (2009) also observed a pH decrease with mineral-poor oak wood biochar from pH 4.9 to 4.7, but an increase with mineral-rich corn stover biochar from pH 6.7 to 8.1 over the course of one-year incubation and concluded that the pH after biochar application might increase or decrease depending on the type of feedstock.

Increases in soil pH result in deprotonation of the soil surface, resulting in an increase in soil surface negative charge, thus facilitating increases metal ion absorption. Also, hydroxyl species of metal cations, which have a higher affinity for the soil surface, are generated under alkaline conditions (Bolan, Adriano, Mani, & Duraisamy, 2003). Beesley *et al*. (2010) reported an increase in soil pH and decreases in both Cd and Zn soil pore water concentrations following application of hardwood biochar to a multi-element polluted soil. Manure addition may reduce acidity in unproductive low pH soils due to a liming effect (Eghball, Wienhold, Gilley, & Eigenberg,1999; Whalen *et al*., 2010).

Organic carbon

The effect of soil amendments on tailing organic carbon was observed and the results indicated no significant differences (P>0.05) among treatments (Table 7). However, the 5 t ha^{-1} PLC gave the highest organic carbon content of 0.82%. This treatment had an increase of 5.1% over the control. This was followed by the 100% NPK recording 0.80% organic carbon. The 2.5 t ha^{-1} RHB+ 50% NPK recorded organic carbon of 0.77%, similar to the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC+ 50% NPK, which also had 0.77%. The Control had 0.78% organic carbon. The 5t ha^{-1} RHB had the least organic carbon of 0.72%. However, in cases of high background levels and or high variability, changes in soil organic carbon following low or moderate application rates may not be measurable or detectable (Viaud, Angers, Parnaudeau, Morvan, & Menasseri Aubry, 2011).

The rate of decomposition of organic amendments and soil organic carbon remaining over the long term vary with the intrinsic quality of the amendment (Lashermes *et al*., 2009). Carbon in organic amendments was originally fixed by plants through photosynthesis. The decreases in soil organic carbon (SOC) in most biochar treated soils compared to the unamended soil could be as a result of what is termed the "priming effect." This is the acceleration of soil carbon decomposition by fresh carbon input to soil (Fontaine *et al*., 2004). The acceleration of the decomposition of SOC as a result of fresh carbon (C) input is attributed to changes in the microbial community composition. A study by Fontaine *et al*. (2004) revealed that the decomposition rate of soil humus stock in savannah soil increased by 55% following cellulose additions. This was further confirmed by Kuzyakov, Subbotina, Chen, Bogomolova and Xu (2009) when they observed that the Black Carbon (BC) in soil underwent increased decomposition upon the addition of glucose to the soil. They concluded that the decomposition of the BC came about through the metabolites of the microorganism after glucose decomposition, as it was evident in the very slow rate the BC had decomposed compared to the glucose. The mechanism which stimulates microbial growth and proliferation may be from changes in pH of the soil, changes in water-filled pore spaces, changes in habitat structure, or changes in nutrient availability.

The slow release of these nutrients is responsible for the increase in crop yields in the subsequent years, thus determining the difficulty of quickly evaluating the actual agronomic value of these organic materials as amendments.

The macronutrients N, P and sulfur (S), present in the organic chemical structures, are converted into inorganic forms. Subsequently, they are either immobilized and used to synthesize new microbial tissues or mineralized and released into the soil mineral nutrient pool (Baldock & Nelson, 2000). A similar report explained that the organic carbon increase, after the addition of municipal solid waste compost and olive pomace compost application, significantly increased the carbon content by 24% for cocksfeed in respect to the unfertilized control. This disagrees with Agusalim et al. (2010) observed an increase in soil organic carbon (SOC) upon application of rice husk biochar to rice cropping system in an acid sulphate soil. In their experiment, they observed that soil with an initial SOC of 0.78% increased to 4.09% upon the application of 10 tons of rice husk biochar. Again, Chan, Van Zwienten, Mesazaros, Downie and Joseph (2007) showed that biochars additions could increase soil organic carbon.

Total nitrogen

Application of amendments to the GMTs showed a significant difference ($p<0.05$) in the total nitrogen content of the tailings. Amongst the amendments, the 100% NPK and the 2.5 t ha^{-1} PLC + 50% NPK had the highest and similar impact on tailing nitrogen and was observed to be 0.08%, which yielded a nitrogen increase of 14.3% over the Control. However, apart from these two amendments, there was no significant difference between the Control and the rest of the other treatments. The observed increases in the total nitrogen could be attributed to the ash content of the biochar, which is known to contain small amounts of organic and inorganic N (Raison, 1979). Chan *et al.* (2008) observed increasing total N content of an Alfisol with an increasing rate of biochar applications.

The result is supported by the findings of Wells, Chan and Cornish (2000). This is in also agreement with Efthimiadou, Bilalis, Karkanis and Williams (2010), who stated that soil total N increases when biofertilizers are applied. In the study of Sarkhot, Ghezzehei and Berhe (2013), extractable N was decreased if the soil was amended with biochar and biochar enriched with dairy effluent as compared with the control. They explained this effect with decreased net N mineralization. Generally, biochar effects on N immobilization and crop uptake are inconsistent in the literature as reviewed by Clough *et al.* (2010). These authors concluded that alterations of N dynamics by biochar are strongly related to specific soil and biochar combinations. Wolkowski (2003) reported that relatively high applications of composted waste should be added to supplement crop N needs and produce yields similar to those found with recommended doses of commercial fertilizer

Available Phosphorus

Application of soil amendments to the GMTs showed a significant difference ($P<0.05$) on the soil available phosphorus content of the tailings. Available P was highest in treatment with 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC+ 50% NPK (26.54 mg kg^{-1}), which represents an increase of 1.32-fold compared to the Control, followed by the treatment with 2.5 t ha^{-1} RHB+ 50% NPK, which recorded available P (24.81 mg kg^{-1}) representing 1.18 fold increases over the Control. The 2.5 t ha^{-1} PLC + 50% NPK also had 23.74 mg kg^{-1} representing 1.09-fold increases over the Control. The Control had the least available phosphorus of 11.37 mg kg^{-1}.

The high increases in available P by 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC+ 50% NPK and 2.5 t ha^{-1} RHB+ 50% NPK application could largely be attributed to the corresponding increases in the pH of the tailings. The explanation given to the mechanism that led to increases in available P is thought to be due to decreasing solubility of Al emanating from increasing soil pH. However, increasing levels of available P with corresponding increases in biochar additions as observed has also been reported by Chan *et al.* (2008). Studies have also shown that compost and other materials used as a soil amendment in gardens, agricultural fields, and other landscaped systems; its incorporation into the soil increases the supply of valuable nutrients, including nitrogen (N), phosphorus (P) and carbon (C) (Fortuna, Harwood, Kizilkaya, & Paul, 2003).

Melese, Markku and Yitaferu (2015) also suggested that the application of mineral P fertilizer with other amendments can be used to improve P deficiency in acid soils. Again, the organic materials could have reduced the P-sorption capacity of the soil and increase P availability by (i) forming complex (or chelate) with ions of Fe and Al in soil solution, preventing the precipitation of phosphate, and also reducing Al and Fe toxicity, (ii) compete with P for sorption sites, and/or (iii) solubilize P from insoluble Ca, Fe, and Al phosphates. This observation concurs with findings made by Iyamuremye and Dick (1996), which concluded that organic materials could reduce the P-sorption capacity of the soil, enhance P availability, improve P recovery or result in better utilization by plants.

Electrical conductivity

Application of soil amendments to the GMTs showed a significant difference ($p<0.001$) in the electrical conductivity of the tailings. The 5 t ha^{-1}PLC recorded the highest electrical conductivity of 461µm/cm, followed by the 2.5 t ha^{-1} RHB + 50% NPK, which had 450.7µm/cm. The 2.5 t ha^{-1} PLC + 50% NPK and the Control had a significant EC of 441 µm/cm and 440.7 µm/cm, respectively. This trend may be due to factors such as the oxidation of the surface of the amendments and a greater negative charge releases ion and/or increases adsorption of cations. Walker and Bernal (2008) reported that compost application significantly improved soil electrical conductivity or soluble Na, Ca, or Mg concentration.

Total exchangeable bases

The results of the addition of soil amendment on total exchangeable bases of the GMTs were observed to be significantly different ($P< 0.001$). The 2.5 t ha^{-1} RHB + 50% NPK had the maximum response on mean total exchangeable bases of 15.14 cmol kg^{-1} and had an increase of about 51.6% to 71% above the control. This was followed by the 5 t ha^{-1} PLC which recorded a total exchangeable base of 12.10 cmol kg^{-1}, representing 21.1% over the Control. The Control recorded the least total exchangeable bases of 9.99 cmol kg^{-1}. This is supported by the report of Adeniyan, Ojo, Akinbode and Adediran (2011), who indicated that exchangeable soil bases increased when the biofertilizer was applied alone or in combination with the lime and P fertilizer. Ullah, Islam and Haque (2008) conducted a study to investigate the effect of bioslurry on soil properties, and their results support the results of the present study of the total exchangeable bases and water retention.

Exchangeable acidity

Exchangeable acidity was significantly ($P < 0.05$) reduced by the application of various amendments additions except for the Control (Table 8). The Control recorded the highest mean exchangeable acidity of 0.07 cmolc kg^{-1}. All the rest of the treatments had an exchangeable acidity of 0.05 cmolc kg^{-1}. The reduction of exchangeable acidity after the application of amendment could be attributed to the steady increases in pH and TEB, leading to the decline in solubility of Al in soil solution as well as an increase in Al chelation with negatively charged surfaces of organic, biochar-soil interactions. Similar observations were made by Chan *et al*. (2007), who reported as much as > 50% reduction in exchangeable Al at 50 and 100 t ha^{-1}of biochar applications. Abafita (2016) made it known that application of vermicompost showed marked improvements in the overall physical and biochemical properties, and at the same time, decreases exchangeable acidity, which can support a release of plant nutrients in the acidic soils.

Effective cation exchange capacity (ECEC)

Application of soil amendments to the GMTs showed a significant difference ($p<0.001$) on effective cation exchange capacity. Mean effective cation exchange capacity was highest in treatment with 2.5 t ha^{-1} RHB + 50% NPK (15.19 cmol kg^{-1}), which represents an increase of 51% compared to the control and is significantly different from the rest of the treatments. This was followed by the 5 t ha^{-1} Compost which recorded an effective cation exchange capacity of 12.15 cmolc kg^{-1} representing 21% increases over the Control. The Control had 10.06 cmol $kg^{-1,}$ which was not significantly different from the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC and 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC+ 50% NPK.

The effective cation exchange capacity (ECEC) is defined as the total amount of exchangeable cations, which are mostly sodium, potassium, calcium and magnesium (hereafter collectively termed as bases) in non-acidic soils and bases plus aluminium in acidic soils. The effective cation exchange capacity (ECEC) of the soil was significantly affected by all treatments. The ECEC increment might also be caused by deprotonation of pH-dependent charge sites arising from an increase in pH due to the application of the amendment. This agrees with the findings of Edmeades, Bolanos and Chapman (1996), who stated that ECEC increased with the increasing pH of soils. Also, a change in ECEC of the soil leads to the change of negative surfaces of the soil colloids. This leads to the overall improvement in the capacity of the soil to hold and release nutrients. This is important for retaining nutrients and making them available to plants (García-Gil *et al*., 2004; Ros, Hernandez & Garcia 2006b; Weber *et al*., 2007;

Kaur *et al*., 2008). The intrinsic cation exchange capacity of organic amendments can vary widely, and their application to soils will often increase cation exchange capacity, particularly in the case of degraded sandy soils (Kasongo, Verdoodt, Kanyankagote, Baert & Van Ranst, 2011).

Base saturation

Soil electrical conductivity affects yields, crop suitability, plant nutrient availability and soil microorganism activity such as emission of greenhouse gases and respiration. Excess salts hinder plant growth by affecting the soil-water balance. The base saturation was significantly ($p < 0.05$) improved by the application of various amendments addition (Table 7). The mean base saturation was highest in 5 t ha^{-1} PLC (99.65%) and was not significantly different from the rest of the treatment except the 100% NPK and the Control.

Table 7 - *Effect of Application of the Various Amendments on Some Selected Properties of Mine Tailing Soil at 0-20 cm Depth*

Soil Amendment	pH (H_2O) 1:2.5	% Organic Carbon	%Total Nitrogen
Control	6.81± 0.02g	0.78 ± 0.03^{ab}	0.07 ± 0.04^{b}
5 t ha^{-1} RHB	7.37± 0.03f	0.72 ± 0.01^{ab}	0.07 ± 0.03^{bc}
100% NPK	7.53 ± 0.03e	0.80 ± 0.04^{a}	0.08 ± 0.02^{a}
2.5 t ha^{-1} RHB + 50% NPK	7.57± 0.01de	0.77 ± 0.03^{ab}	0.07 ± 0.03^{c}
5 t ha^{-1} PLC	7.63± 0.02cd	0.82 ± 0.04^{a}	$0.07 \pm 0.04b^{c}$
2.5 t ha^{-1} PLC+ 50% NPK	7.70±0.03bc	0.75 ± 0.06^{ab}	0.08 ± 0.02^{a}
2.5 t ha^{-1} RHB+ 2.5 t ha^{-1} PLC	7.75±0.01ab	0.77 ± 0.03^{ab}	0.07 ± 0.04^{bc}
2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK	7.81 ±0.06a	0.75 ± 0.03^{ab}	0.07 ± 0.05^{bc}
CV (%)	0.6	4.3	3.5

Means with the same letters are not significantly different according to Duncan's Multiple Range Test at ($P < 0.05$)

Source: Field data (2020)

Table 7 - *Continued*

Soil Amendment	Available BRAY-P ppm	B.S (%)	EC_Us_cm
Control	11.37 ± 0.23^{g}	99.33± 0.12^{c}	440.7 ± 0.66^{c}
5 t ha^{-1} RHB	16.18 ± 0.2^{f}	99.56± 0.03^{ab}	291.0 ± 0.57^{f}
100% NPK	22.48 ± 0.37^{d}	99.48±0.03^{bc}	359.4 ± 0.65^{d}
2.5 t ha^{-1} RHB + 50% NPK	24.81 ± 0.09^{b}	99.63± 0.04^{ab}	450.7 ±0.37^{b}
5 t ha^{-1} PLC	22.87 ± 0.39^{d}	99.65± 0.04^{a}	461.1 ± 0.64^{a}
2.5 t ha^{-1} PLC+ 50% NPK	23.74± 0.10^{c}	99.60±0.06^{ab}	441.1 ± 0.59^{c}
2.5 t ha^{-1} RHB+ 2.5 t ha^{-1} PLC	21.17± 0.19^{e}	99.61± 0.04^{ab}	295.4 ± 1.29^{e}
2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK	26.54 ± 0.06^{a}	99.56±0.07ab	359.3 ± 1.26^{d}
CV (%)	1.7	0.1	0.5

Means with the same letters are not significantly different according to Duncan's Multiple Range Test at ($p < 0.05$)

Source: Field data (2020)

Table 8 - *Effect of Application of the Various Nutrient Sources on Some Selected Properties of Mine Tailing Soil at 0-20 cm Depth*

Soil Amendment	Ca cmolc kg^{-1}	K cmolc kg^{-1}	Na cmolc kg^{-1}	Mg cmolc kg^{-1}
Control	8.30 ± 0.03^{b}	0.12 ± 0.01^{g}	0.04± 0.02^{e}	1.53 ± 0.02^{c}
5 t ha^{-1} RHB	7.58 ± 0.31^{d}	0.30 ± 0.01^{d}	0.19± 0.21^{c}	2.82±0.04^{bc}
100% NPK	8.53± 0.04^{ab}	0.34 ± 0.02^{c}	0.11 ± 0.10^{d}	2.98 ±0.02^{b}
2.5 t ha^{-1} RHB + 50% NPK	8.35 ± 0.05^{b}	0.27 ± 0.04^{e}	0.07±0.15^{ef}	6.45± 0.92^{a}
5 t ha^{-1} PLC	8.74 ± 0.01^{a}	0.27 ± 0.03^{e}	0.11± 0.08^{d}	2.98 ±0.08^{b}
2.5 t ha^{-1} PLC+ 50% NPK	8.55± 0.02^{ab}	0.41 ± 0.05^{b}	0.42 ± 0.12^{a}	1.95 ± 0.03^{d}
2.5 t ha^{-1} RHB+ 2.5 t ha^{-1} PLC	7.93 ± 0.03^{c}	0.22 ± 0.01^{f}	0.07± 0.45^{e}	2.62 ± 0.04^{c}
2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK	8.73 ± 0.05^{a}	0.45 ± 0.04^{a}	0.24± 0.08^{b}	2.03 ±0.02^{d}
CV (%)	2.2	4.4	10.4	6.1

Means with the same letters are not significantly different according to Duncan's Multiple Range Test at ($p < 0.05$)

Source: Field data (2020)

Table 8 - *Continued*

Soil Amendment	T.E.B cmolc kg^{-1}	EXCH. Acidity cmolc kg^{-1}	E.C.E.C cmolc kg^{-1}
Control	9.99 ±0.03^{f}	0.07 ±0.001^{a}	10.06± 0.57^{cd}
5 t ha^{-1} RHB	10.89± 0.11^{e}	0.05 ± 0.002^{b}	10.94± 0.13^{c}
100% NPK	11.96±0.02^{cd}	0.05 ± 0.001^{b}	12.01± 0.52^{d}
2.5 t ha^{-1} RHB + 50% NPK	15.14±0.31^{a}	0.05± 0.002^{b}	15.19 ± 0.35^{a}
5 t ha^{-1} PLC	12.10±0.13^{b}	0.05±0.003^{b}	12.15± 0.12^{b}
2.5 t ha^{-1} PLC+ 50% NPK	11.33±0.06^{cd}	0.05± 0.001^{b}	11.38± 0.26^{bc}
2.5 t ha^{-1} RHB+ 2.5 t ha^{-1} PLC	10.84±0.08^{de}	0.05± 0.001^{b}	10.89± 0.01^{c}
2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK	11.46± 0.06^{c}	0.05± 0.002^{b}	11.46± 0.04^{bc}
CV (%)	2.2	11.9	5.0

Means with the same letters are not significantly different according to Duncan's Multiple Range Test at ($p < 0.05$)

Source: Field data (2020)

Effect of Application of Soil Amendments on Heavy Metal Concentration of Tailings

Metal-contaminated soils are notoriously hard to remediate with conventional technologies (Marques, Rangel & Castro, 2009) such as electrokinetics. The in-situ immobilization of metals using soil amendments processes has been given more and more importance and is seen as an attractive, low-cost remediation alternative (Mench, Vangronsveld, Lepp, Geebelen, & Bleeker, 2007; Kumpiene, Lagerkvist, & Maurice, 2008).

According to Séré *et al.* (2010), these processes constitute early pedogenesis in highly degraded soils subjected to reconstruction using organic amendments. Restoration of soil structure through biological aggregation is a crucial factor in kick-starting soil reclamation.

Various soil amendments were added to the tailings before planting the lettuce and heavy metals such as Lead, Cadmium, Mercury, Arsenic and Chromium were tested and their concentrations in the tailings were analyzed.

Arsenic concentration

Arsenic occurs naturally in the earth's crust, with levels ranging between 2.00 mg kg^{-1} and 5.00 mg kg^{-1} (Mandal & Suzuki, 2002). High arsenic concentrations have been reported in the soils close to the mining operations and ore processing plant (Zhang, Zhen, & Sharp, 2010).

The mean Arsenic concentration in the GMTs at various treatments was significant (p=0.009).

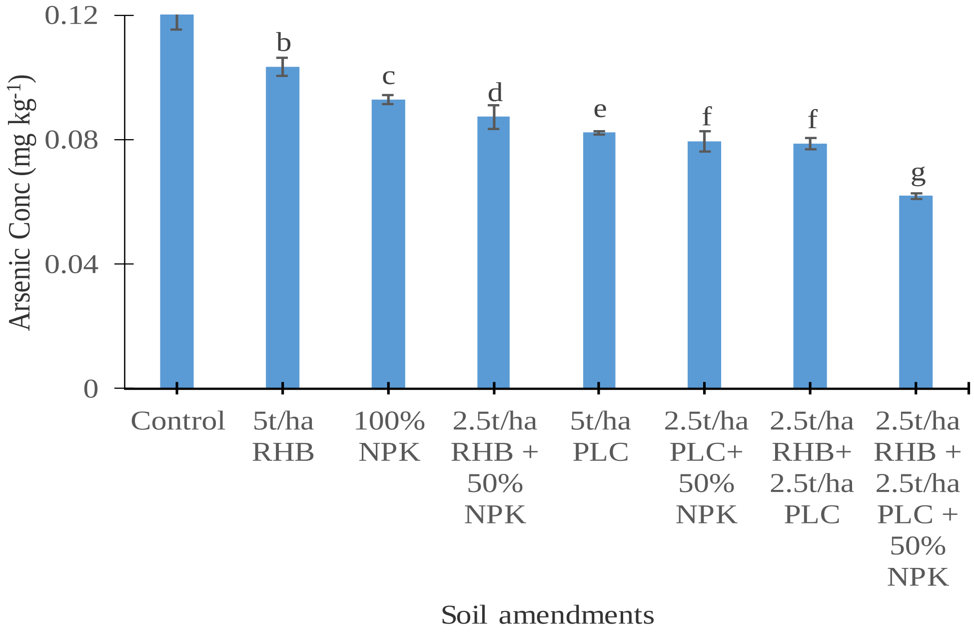

Figure 8 : Mean Arsenic concentration in GMTs at various soil amendments. Error bars are standard errors. Bars with different letters are significantly different at $p \leq 0.05$.

This study showed a mean Arsenic concentration range of 0.062 mg kg^{-1} to 0.12 mg kg^{-1} after the various amendments had been added. This value is below the permissible limit of 20.00 mg kg^{-1} according to WHO/FAO (2001). However, the mean Arsenic concentration was highest in the Control. The Control recorded a mean Arsenic concentration of 0.12 mg kg^{-1}. This treatment was significantly different from the rest of the treatments. The 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK treatment had the least arsenic concentration, which represents a decrease of 50% from the Control, the 2.5 t ha^{-1} RHB+ 50% NPK had a 33% decrease in mean Arsenic content while 5 t ha^{-1} Biochar had 16% decrease in mean Arsenic content.

Similarly, Hartley, Dickinson, Riby and Lepp (2009) found an increase in arsenic mobility in the presence of biochar due to the higher release of dissolved organic carbon. The high levels of metal immobilization observed following BC application were primarily attributed to BC-induced increases in soil pH, which has previously been shown to be the most important soil environmental factor influencing metal solubility (Kim, Owens, & Naidu, 2010; Kumpiene *et al*., 2008). Many previous studies have also reported that a wide diversity of alkaline materials including limestone, beringite, red mud, and furnace slag have increased soil pH and subsequently increased heavy metals immobilization when incorporated into soils (Lombi, Hamon, McGrath, & Mchaughlin, 2003; Lee, Choi, & Kim, 2009).

Lead (Pb) concentration

Concentrations of Pb measured in this study (Figure 8) were generally below those concentrations measured in other studies. The typical mean Pb concentration for surface soils worldwide averages 32 mg $kg^{-1}$and ranges from 10 to 67 mg kg^{-1} (Kabata-Pendias & Pendias, 2001). The mean lead concentration in GMT was significantly influenced by various treatments ($p<0.001$).

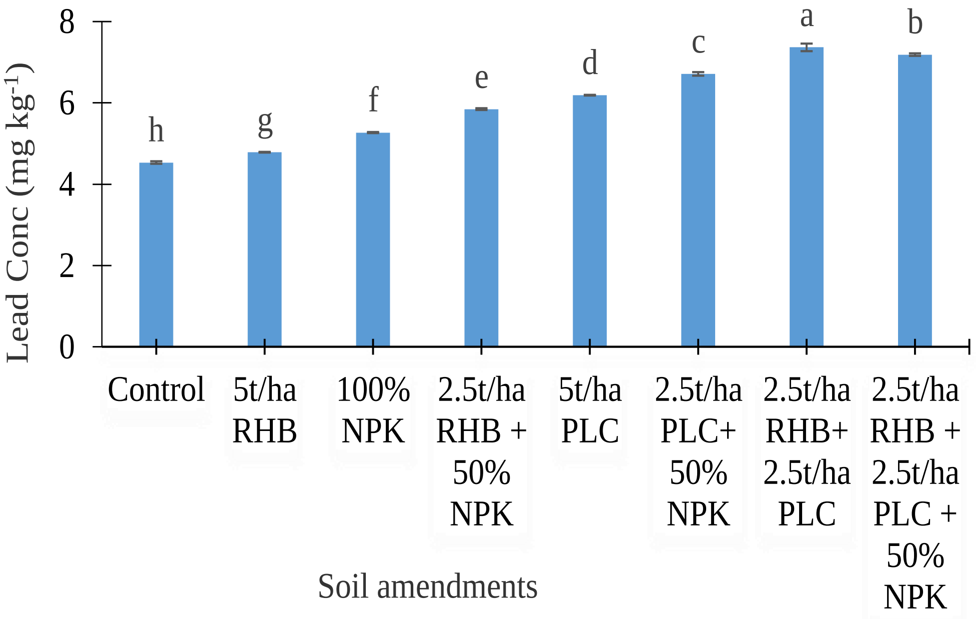

Figure 9 - Mean lead concentration in GMTs at various amendments. Bars with different letters are significantly different at $p \leq 0.05$.

This study showed a mean Pb concentration range of 4.53 mg kg^{-1} to 7.37 mg kg^{-1} after the various amendments had been added. This value is below the permissible limit of 50.00 mg kg^{-1} according to WHO/FAO (2001). However, the mean Lead concentration was highest in the 2.5 t ha^{-1} RHB+ 2.5 t ha^{-1} PLC (7.37 mg kg^{-1}). This was followed by the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK treatment which had 7.19 mg kg^{-1}. Control recorded the least mean Pb concentration of 7.19 mg kg^{-1}. This treatment was significantly different from the rest of the treatments.

The low levels of Pb are in line with those reported by Popoola, Abiodun, Oyelola and Ofodile (2011) in central Nigeria. According to Zhang *et al*. (2010), Pb accumulates in the surface ground layer and its concentration decreases with soil depth. This finding is confirmed by Trakal, Komarek, Szakova, Zemanova and Tlustos (2011) and concluded that biochar application enhanced Pb sorption.

Concentrations of Pb ions across 20, 25 and 30 days increased but there was no significant difference. The increased removal of Fe, Cu, Zn and Pb may be attributed to a gradual increase in pH with increasing application rate. Jiang, Xu, Jiang and Li (2012) also reported decreases in acid-soluble Cu and Pb following application of rice straw BC to an artificially contaminated soil concomitant with an increase in soil pH.

Cadmium (Cd) concentration

According to Zhang *et al*. (2010), the presence of Cd in the soils can be attributed to illegal mining activities, absorption of the metals from anthropogenic sources and the natural occurrence of heavy metals in some soils. Naturally, Cd levels in agricultural fields have risen as a result of human activities, although it is rare in the environment (Cranor, 2011). The mean Cd concentration in GMTs at various treatments was not significant ($p>0.05$). This study showed a mean concentration range of 0.01 to 0.02 mg kg^{-1} after the various amendments had been added. This value is below the permissible limit of 3 mg kg^{-1} according to WHO/FAO (2001). However, the mean Cd concentration was highest in the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC (0.02 mg kg^{-1}).

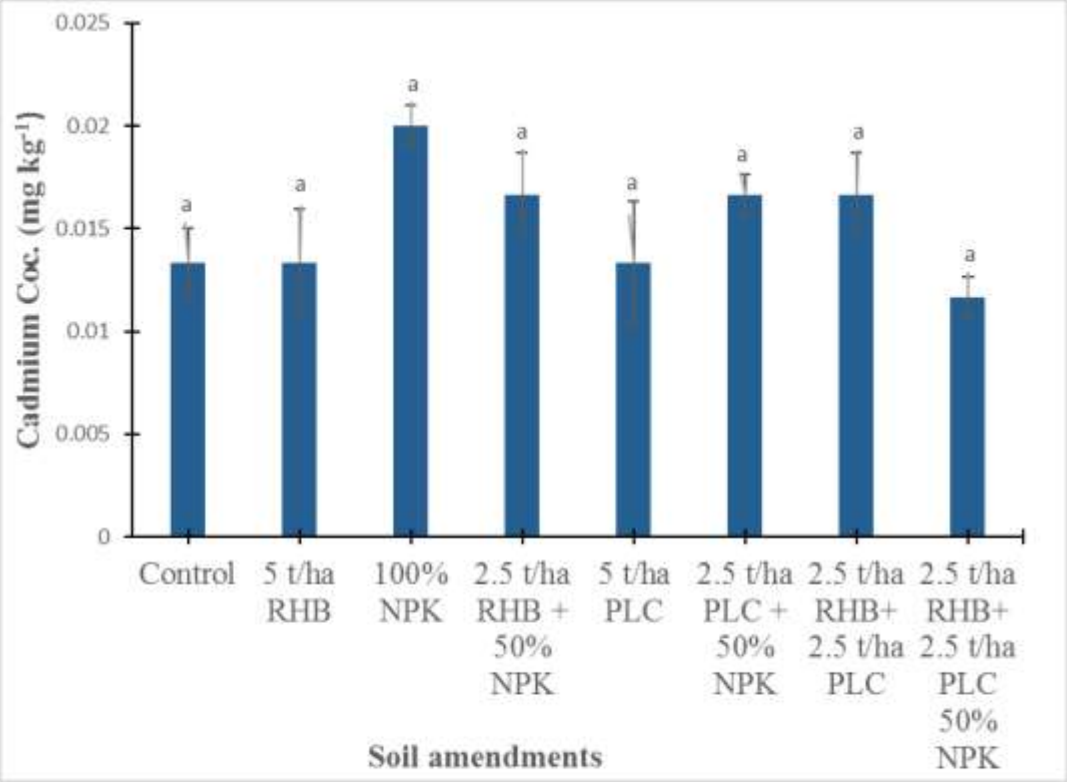

Figure 10 - Mean Cadmium Concentration of GMTs at soil amendments. Bars with different letters are significantly different at $p \leq 0.05$.

Alhassan *et al*. (2010) reported that the amount of Cd in soils is generally low, but once it has been added to the soil, it can take between 100 and 1000 years for the levels to drop by 50%. Kirkham (2006) reported toxic levels of Cd in soils to plants and tree seedlings which affect their growth. The soil amendment applied did not in reduce Cd ion concentrations. This contradicts the results by Beesely *et al*. (2010), which showed significant reduction of concentration of cadmium after application of hard wood-derived biochar. Trakal, Komarek, Szakova, Zemanova and Tlustos (2011) attributed this effect to the predominant fixation of Cd and Zn to Mn. This effect was attributed to metal ion complexation (Chen, Shinogi & Taira, 2010) in the substrates affecting metal ion sorption

Mercury (Hg) concentration

Obrist, Kirk, Zhang, Sunderland, Jiskra and Selin (2018) reported that Hg enters the landscape from the atmosphere, natural geologic sources, historic mining activities and re-released Hg stored in vegetation and soils. Hogar, Adu-Gyamfi, Nukpezah, Osei and Adu-Kumi (2016) reported that, given the haphazard nature of galamsey operations, the fine grinds that may contain some of these metals are all released directly into the soil.

The mean Mercury concentration in GMT at various treatments was significant (p<0.001).

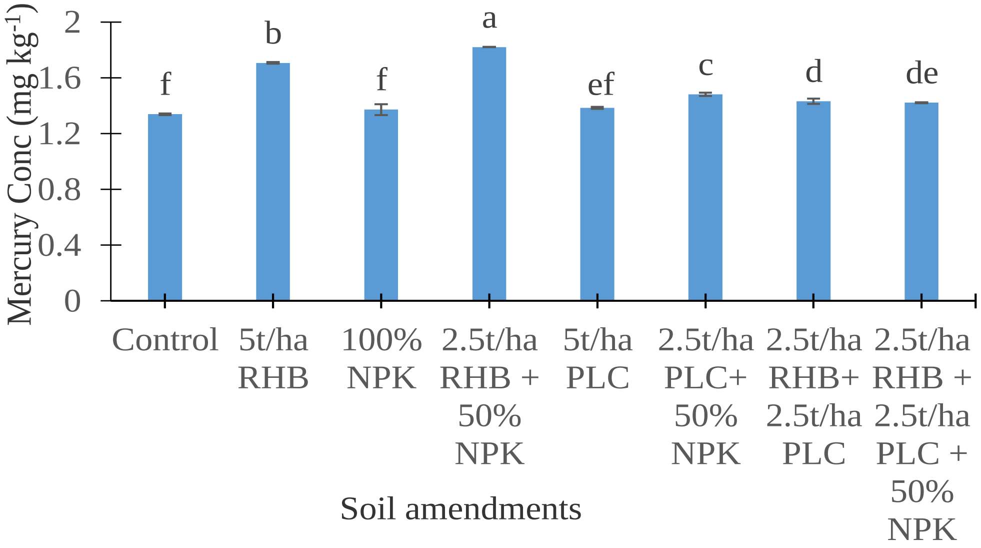

Figure 11 - Mean mercury concentration of GMTs at various amendments. Bars with different letters are significantly different at $p \leq 0.05$.

This study showed a mean mercury concentration range of 1.34 mg kg^{-1} to 1.82 mg kg^{-1} after the various amendments had been added. This value is below the permissible limit of 2 mg kg^{-1}according to WHO/FAO (2001). However, the mean mercury concentration was highest in the 2.5 t ha^{-1} RHB + 50% NPK which had 1.82 mg kg^{-1}. This was followed by the 5 t ha^{-1} RHB which recorded 1.71 mg kg^{-1}. The 2.5 t ha^{-1} PLC + 50% NPK treatment had 1.48 mg kg^{-1}. Control recorded the least mean mercury concentration of 1.34 mg kg^{-1} which was not significant from the 100% NPK. All the amendments showed a variable effect in the mean Hg concentration in GMT. Application of rice-derived biochars also resulted in increased metal immobilization during rice cultivation, as evidenced by declines in Cd, Pb, and Zn concentration in rice by 98, 72, and 83 % (Zhang *et al.*, 2012).

Chromium (Cr) concentration

The mean Cr concentration in GMTs at various treatments was significant (p=0.001). This study showed a mean Cr concentration range of 1.57 mg kg^{-1} to 4.05 mg kg^{-1} after the various amendments had been added. This value is below the permissible limit of 14 mg kg^{-1}according to WHO/FAO (2001). However, the mean Cr concentration was highest in the 2.5 t ha^{-1} PLC+ 50% NPK which had 4.05 mg kg^{-1}. This was followed by the 2.5 t ha^{-1}PLC + 2.5 t ha^{-1} RHB + 50% NPK, which recorded 3.95 mg kg^{-1}. The concentration at 5 t ha^{-1} PLC recorded the least mean Cr of 1.57 mg kg^{-1} which was significantly different from the rest of the treatments.

The lowered metal accumulation by lettuce was attributed principally to increases in pH, which induced a concomitant decrease in their photo available pools following organic amendment application. For example, the application of red mud resulted in a pH increase which induced immobilization of heavy metals in soil and subsequently decreased translocation of heavy metals to the above-ground tissues of Festuca rubra (Gray, Dunham, Dennis, Zhao & McGrath, 2006).

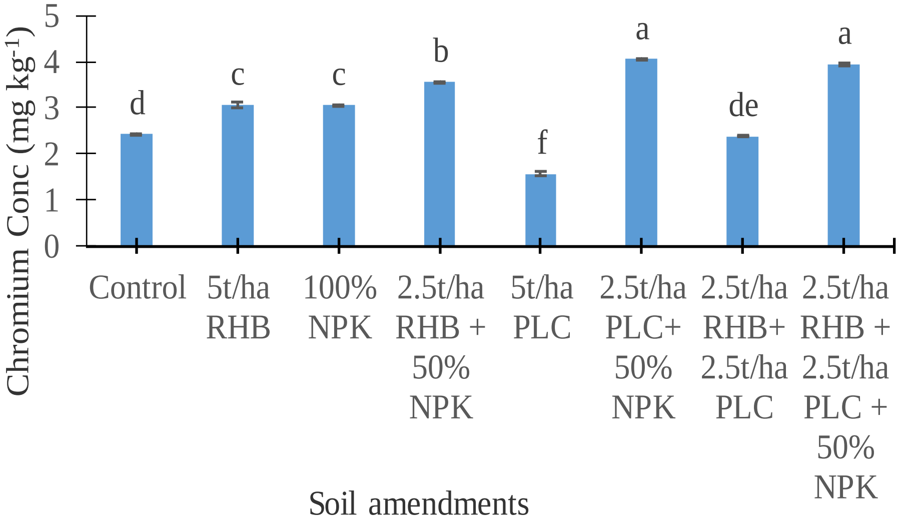

Figure 12 - Mean Chromium concentration in GMTs after application of various amendments. Bars with different letters are significantly different at P ≤ 0.05.

Effect of Soil Amendments on Nutrient Uptakes

Effects of the soil amendments on N, P, K, Ca and Mg uptake in lettuce uptake are presented in Table 9.

Nitrogen uptake

From the results, it is observed that nitrogen uptake amounts were significantly ($P < 0.05$) affected by the application of various amendments. The results of the various soil amendments on nitrogen uptake were observed to be significantly different ($P < 0.001$). Amongst the soil amendments, the 2.5 t ha^{-1}

RHB+ 50% NPK yielded the highest mean nitrogen uptake of 7.23 kg ha^{-1} by the lettuce on Gold mine tailing with an increase of 400% over the Control. This was followed by the 2.5 t ha^{-1} PLC + 50% NPK, which had a mean nitrogen uptake of 5.67 kg ha^{-1} which yielded an increase of 13% over the Control. The Control recorded the least mean nitrogen uptake of 1.79 kg ha^{-1} and was significantly similar to the 5 t ha^{-1} RHB.

From the results, it could be deduced that application of inorganic fertilizer and biochar significantly ($p<0.001$) improved nitrogen uptake compared to Control in Table 8. This is because studies have demonstrated that the use of biochar could enhance the efficiency of chemical fertilizer (Oladele, Adeyemo, Awodun, Ajayi, & Fasina, 2019). This could be due to synergistic effect of organic and inorganic fertilizers on crop performance. Also, other studies have confirmed the synergistic effects of biochar and inorganic fertilizers (Xie et al., 2011), but the combined effect of biochar, inorganic fertilizers and organic manure has been limitedly studied (Sohi, Krull, Lopez- chapel & Bol, 2010).

Phosphorus uptake

The results of the various soil amendments on phosphorus uptake amounts were observed to be significantly different ($P< 0.001$). Amongst the soil amendments, the 2.5 t ha^{-1} RHB + 50% NPK yielded the highest mean phosphorus uptake of 1.24 kg ha^{-1} by the lettuce on GMT with an increase of 350% over the Control. This was followed by the 2.5 t ha^{-1} PLC +50% NPK which had a mean phosphorus uptake of 1.05 kg ha^{-1} which yielded an increase of

13% over the Control. The Control recorded the least mean phosphorus uptake of 0.35 kg ha^{-1} and was significantly similar to the 5 t ha^{-1} RHB. The maximum uptake of macronutrients with the integration of biochar and inorganic fertilizers could be likened to the reason for the relatively high uptake of nutrients by the applied biochar and fertilizer. Thus, besides improving soil quality, also supplied micro, macronutrient to the soil, increase uptake of nutrients to plants that flourish the plant growth. Jeptoo, Aguyoh and Saidi (2013) conducted a study about the effect of bioslurry manure on carrot and found results which were in accordance with the results of the present study.

This observation agrees with the findings of Van Zwieten *et al*. (2010) and Chan *et al*. (2007, 2008), who found significant increases in nutrient uptake following the application of biochar in lettuce and radish plants, respectively. According to Liang *et al*. (2006), the large surface area, higher negative surface charge and greater charge density of biochar result in a higher capacity to absorb nutrients per unit carbon than other kinds of soil organic matter. Also, Masto, Ansari, George, Selvi and Ram (2013) related the several nutrients in plant tissues following the application of soil amendments to the production variables of biochar and complex physiochemical properties, which may be involved in the biochar–soil-plant interaction system.

Novak *et al.* (2009) reported that the application of biochar increases P uptake due to the increased soil pH and reduction in exchangeable acidity (Lehman *et al*., 2003). One of the benefits of organic amendments is that the mechanism of phosphorus release and the risk of subsequent binding or tie up are different from those of fertilizers derived from inorganic sources such as rock phosphate. Increases in P uptake with rice husk BC has also been reported by Nguyen, Lehmann, Hockaday, Joseph and Masiello (2012), which is in line with the plant-available P in the experiment

Potassium uptake

The results of the various soil amendments on mean potassium uptake amounts were observed to be significantly different ($P < 0.001$). Amongst the soil amendments, the 2.5 t ha^{-1} PLC+ 50% NPK yielded the highest mean potassium uptake of 10.79 kg ha^{-1} by the lettuce on GMTs with an increase of 133% over the Control. This was followed by the 100% NPK which had a mean potassium uptake of 8.77 kg ha^{-1} which yielded an increase of 13% over the Control. The 5 t ha^{-1} PLC recorded 6.21 kg ha^{-1} mean potassium uptake. The rest had no significant potassium differences.

The observed increases over the base value of the tailings may be due to the enhanced fertility and productivity due to the addition of amendments. The synergistic benefit of combined biochar and NPK could be explored as a viable strategy to improve the potassium uptake on GMTs. Findings agree with those of other researchers (Pang and Letey, 2000; Hartemink *et al*., 2000; Eghball *et al*., 2002) who found that while nutrient supplied by inorganic fertilizer was readily available, whole those supplied by manure was released slowly.

Calcium uptake

From the results, it is observed that calcium uptake amounts were significantly ($P < 0.001$) affected by the soil amendments. Amongst the soil amendments, the 2.5 t ha^{-1} PLC + 50% NPK yielded the highest mean calcium uptake of 6.14 kg ha^{-1} by the lettuce on GMT with an increase of 250% over the Control. This was followed by the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC which had a mean calcium uptake of 5.25 kg ha^{-1}. However, no significant differences were observed among the rest of the treatments.

The higher calcium uptake in the combined biochar, compost and NPK may be attributed to the relatively higher nutrient use efficiency of these amendments. This can be attributed to relatively ample amounts of calcium in the chemical composition of poultry manure compost. Similar results have been reported previously in lettuce (Masarirambi, Hiawe, Oseni & Sibya, 2010).

Magnesium uptake

From the results, it is observed that magnesium uptake amounts were significantly ($P < 0.001$) affected by the soil amendments. The results of the various soil amendments on mean magnesium uptake were observed to be significantly different ($P< 0.001$). Amongst the soil amendments, the 2.5 t ha^{-1} PLC + 50% NPK yielded the highest mean magnesium uptake of 3.93 kg ha^{-1} by the lettuce on GMTs. This was followed by the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC which had a mean magnesium uptake of 3.02 kg ha$^{-1.}$ However, no significant differences were observed among the rest of the treatments.

This is coupled with the known beneficial effects of animal manure on physical and chemical properties (Aliyu, 2000) and their ability to supply macro- and trace elements.

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Table 9 - *Effect of Application of the Amendments on Nutrient Uptake of Lettuce Planted on GMTs Soil*

Soil Amendment	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
Control	1.79 ± 0.33^{d}	0.35 ±0.07^{e}	4.57 ±0.68^{d}
5 t ha^{-1} RHB	1.91 ±0.09^{d}	0.49 ±0.02^{de}	3.61 ±0.16^{de}
100% NPK	4.23 ±0.23^{c}	0.66 ±0.05^{cd}	8.77 ±0.49^{b}
2.5 t ha^{-1} RHB + 50% NPK	7.23 ±0.49^{a}	1.24 ±0.08^{a}	3.08 ± 0.15^{e}
5 t ha^{-1} PLC	4.0 ±0.04^{c}	0.74 ±0.04^{c}	6.21 ± 0.27^{c}
2.5 t ha^{-1} PLC+ 50% NPK	5.67 ±0.51^{b}	1.05 ±0.07^{b}	10.79 ±0.79^{a}
2.5 t ha^{-1} RHB+ 2.5 t ha^{-1} PLC	4.55 ±0.09^{c}	0.98 ±0.03^{b}	3.95 ±0.09^{de}
2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK	4.73±0.05^{c}	0.75 ±0.01^{c}	2.74 ±0.08^{e}
CV (%)	11.8	12.2	14.3

Means with the same letters are not significantly different according to Duncan's Multiple Range Test at ($p < 0.05$)

Source: Field data (2020)

Table 9 – *Continued*

Soil Amendment	Ca uptake(kg ha^{-1})	Mguptake (kg ha^{-1})
Control	3.12 ± 0.47^{c}	2.05 ±0.31^{c}
5 t ha^{-1} RHB	1.63 ±0.08^{de}	0.87±0.03^{d}
100% NPK	2.58 ±0.14^{cd}	1.71 ±0.10^{c}
2.5 t ha^{-1} RHB + 50% NPK	4.47 ±0.29^{b}	2.70 ±0.16^{c}
5 t ha^{-1} PLC	2.76 ±0.12^{cd}	1.93 ±0.09^{c}
2.5 t ha^{-1} PLC+ 50% NPK	6.14 ± 0.46^{a}	3.93 ±0.30^{a}
2.5 t ha^{-1} RHB+ 2.5 t ha^{-1} PLC	5.25 ±0.01^{ab}	3.02 ±0.07^{b}
2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK	1.03 ±0.94^{e}	2.08 ± 0.03^{c}
CV (%)	22.1	14.3

Means with the same letters are not significantly different according to Duncan's Multiple Range Test at ($p < 0.05$)

Source: Field data (2020)

Effect of Soil Amendment on Heavy Metals Concentration in Lettuce after Harvest

The problem of heavy metal contamination in the environment is widespread. Taken up by plants, heavy metals may enter the food chain, and therefore, humans can also be exposed to them (Intawongse & Dean, 2006). Various soil amendments were added to the tailings before planting the lettuce and the concentrations of As, Pb, Hg, Cd, and Cr in lettuce samples were compared with the maximum permissible level of contaminants recommended for fresh leafy vegetables (FAO/WHO, 2001). The effect of soil amendment on heavy metals concentration of lettuce after harvest is illustrated in Tables 9. Permissible guidelines are standard values set by the Food and Agriculture Organization and World Health Organization (FAO/WHO, 2001) and other authorities to monitor levels of heavy metals in vegetables and are shown in Table 10 below

Arsenic (Ar) concentration

From the results, it is observed that mean Arsenic amounts in lettuce after harvest were significantly ($P < 0.009$) different among the soil amendments. This study showed a mean Arsenic concentration range of 0.03 to 0.05 mg kg^{-1} in lettuce after the harvest. This value is below the maximum permissible limit of (0.1 mg kg^{-1}) per contaminants recommended for fresh leafy (FAO/WHO, 2001). Amongst the soil amendments, the Control yielded the highest mean Arsenic of 0.05 mg kg^{-1} by the lettuce on GMTs. This was followed by the 5 t ha^{-1} PLC with a mean Arsenic concentration range of 0.03 mg kg^{-1}. The 5 t ha^{-1} RHB and the other amendments recorded lower values and showed a reduction of about 20% to

40% Arsenic amounts compared to the Control in lettuce after application. The heavy metals accumulation and translocation potential varied from metal to metal and from plant to plant and did not follow any particular pattern

McBride *et al.* (2015), on the other hand, found that Pb and As levels in vegetables were strongly correlated with a total content of these metals in the soil and not with organic matter content in the soil or a level of compost addition.

Lead (Pb) concentration

From the results, it is observed that mean Pb amounts in lettuce after harvest were significantly ($P < 0.001$) different among the soil amendments. This study showed a mean Pb concentration range of 0.12 to 0.23 mg kg^{-1} in lettuce after the harvest. This value is below the maximum permissible limit of (0.3 mg kg^{-1}) per contaminants recommended for fresh leafy vegetables (FAO/WHO, 2001)

Amongst the soil amendments, the Control gave the highest mean Lead concentration (0.23 mg kg^{-1}) of the lettuce on GMT. The 2.5 t ha^{-1} RHB + 2.5 t ha^{-1}PLC + 50% NPK recorded a mean Pb content of 0.21 mg kg^{-1} which represented a reduction of 9% compared to the Control. The 2.5 t ha^{-1} RHB + 50% NPK and the 5 t ha^{-1} PLC recorded the least Pb content of 0.12 mg kg^{-1} which represented a reduction of 47%. McBride et al. (2015), on the other hand, found that Pb and As levels in vegetables were strongly correlated with a total content of these metals in the soil and not with organic matter content in the soil or a level of compost addition.

Mercury (Hg) concentration

From the results, it is observed that mean Hg amounts in lettuce after harvest were significantly ($P < 0.001$) different among the soil amendments. This study showed a mean Mercury concentration range of 0.09 to 0.24 mg kg^{-1} in lettuce after the harvest. This value is below the maximum permissible limit of (0.3 mg kg^{-1}) per contaminants recommended for fresh leafy vegetables (FAO/WHO, 2001). Amongst the soil amendments, the Control yielded the highest mean Hg concentration of 0.24 mg kg^{-1} by the lettuce on GMTs. The 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC+ 50% NPK recorded the least Hg content of 0.09mg kg^{-1} which represented a reduction of 62.5% from the Control. The 2.5 t ha^{-1} RHB + 50% NPK recorded a mean Hg content of 0.15 mg kg^{-1} which represented a reduction of 37.5% from the Control.

The 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC recorded a mean Hg content of 0.13 mg kg^{-1} which represented a reduction of 45.5% from the Control. Adding materials rich in organic components, such as compost, sawdust, tree bark, or granulated or powdered lignite, is frequently recommended to reduce mobility and bioavailability of metals. Some researchers suggest that regular addition of organic matter in large quantities may inhibit metal uptake from the soil solution, and thus would be advantageous (Attanayake *et al*., 2014, 2015; Brown *et al*., 2011).

Cadmium (Cd) concentration

From the results, it is observed that mean Cd concentration lettuce after harvest were significantly ($P < 0.001$) influenced by the soil amendments. This study showed a mean Cd concentration range of 0.09 to 0.18 mg kg^{-1} in lettuce after the harvest. This value is below the maximum permissible limit of (0.2 mg kg^{-1}) per contaminants recommended for fresh leafy vegetables (FAO/WHO, 2001). Amongst the soil amendments, the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC yielded the highest mean Cadmium concentration of 0.18mg kg^{-1} by the lettuce on GMTs, which represented an increase of 50% over the Control. The 5 t ha^{-1} RHB recorded a mean Cd content of 0.17 mg kg^{-1} which represented an increase of 42% from the Control. The 100% NPK recorded the least Cd content of 0.09 mg kg^{-1} which represented a reduction of 25% from the Control.

Chromium (Cr) concentration

From the results, it is observed that mean Cr amounts in lettuce after harvest were significantly ($P < 0.001$) influenced by the soil amendments. This study showed a mean Cr concentration range of 0.07 to 0.98mg kg^{-1} in lettuce after the harvest. Amongst the soil amendments, the 5t ha^{-1} RHB yielded the highest mean Cr of 0.98 mg kg^{-1} by the lettuce on GMTs, which represented an increase of 237% compared to the Control. This value is above the maximum permissible limit of (0.3 mg kg^{-1}) per contaminants recommended for fresh leafy vegetables (FAO/WHO, 2001), meaning if one consumes will have health implications. The 2.5 t ha^{-1} PLC + 50% NPK recorded a mean Cr content of 0.95 mg kg^{-1} which represented an increase of 227% compared to the Control.

Again, this value is above the maximum permissible limit of (0.3 mg kg^{-1}) per contaminants recommended for fresh leafy vegetables (FAO/WHO, 2001). The 2.5 t ha^{-1} RHB + 50% NPK recorded the least Cr content of 0.07 mg kg^{-1}

which represented a reduction of 72% from the Control. However, this value was below the maximum permissible limit of (0.3 mg kg^{-1}) per contaminants recommended for fresh leafy vegetables (FAO/WHO, 2001). The level of these compounds' accumulation in plants depends on, amongst others, soil type, pH, humidity, and micronutrients content, as well as on the time of crop harvesting (Järup, 2003)

Table 10 - *Effect of Soil Amendment on Heavy Metals Concentration in Lettuce after Harvest*

Soil Amendment	As (mg kg^{-1})	Pb (mg kg^{-1})	Hg (mg kg^{-1})	Cd (mg kg^{-1})	Cr (mg kg^{-1})
Control	0.05 ± 0.00^{a}	0.23 ± 0.00^{a}	0.24 ± 0.007^{a}	0.12 ± 0.01^{c}	0.29 ± 0.03^{f}
5 t ha^{-1} RHB	0.03 ± 0.00^{c}	0.13 ± 0.001^{f}	0.18 ± 0.003^{b}	0.17 ± 0.01^{a}	0.98 ± 0.02^{a}
100% NPK	0.03 ± 0.01^{bc}	0.12 ± 0.001^{d}	0.15 ± 0.004^{c}	0.11 ± 0.02^{c}	0.07 ± 0.00^{g}
2.5 t ha^{-1} RHB + 50% NPK	0.04 ± 0.02^{ab}	0.13 ± 0.002^{f}	0.13 ± 0.002^{d}	0.09 ± 0.01^{d}	0.67 ± 0.01^{c}
5 t ha^{-1} PLC	0.04 ± 0.00^{bc}	0.12 ± 0.003^{e}	0.16 ± 0.007^{b}	0.15 ± 0.01^{b}	0.44 ± 0.02^{e}
2.5 t ha^{-1} PLC+ 50% NPK	0.03 ± 0.01^{bc}	0.21 ± 0.002^{b}	0.17 ± 0.004^{b}	0.13 ± 0.03^{c}	0.95 ± 0.01^{a}
2.5 t ha^{-1} RHB+ 2.5 t ha^{-1} PLC	0.03 ± 0.01^{bc}	0.21 ± 0.004^{b}	0.13 ± 0.004^{d}	0.18 ± 0.02^{a}	0.50 ± 30.03^{d}
2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK	0.04 ± 0.02^{ab}	0.21 ± 0.003^{bc}	0.09 ± 0.006^{e}	0.14 ± 0.01^{b}	0.92 ± 0.00^{b}
CV (%)	0.6	1.7	1.4	5.6	1.4
WHO/FAO (2001): Max. Permissible Limit	0.10	0.30	0.10	0.20	0.30

Means with the same letters are not significantly different according to Duncan's Multiple Range Test at ($p < 0.05$)

Source: Field data (2020)

Effect of Soil Amendments on Water Holding Capacity of Gold Mine Tailing

The results showed that the effect of the amendment on tailing water holding characteristics was significant (p=0.026). Figure 13 shows the effect of the amendment on the water holding capacity of the tailings. The results of the various amendments on the tailings water holding capacity were observed to be significantly different (P=0.026). Amongst the soil amendments, the 2.5t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK recorded the highest water holding capacity tailings (11.65%), which yielded the highest impact on GMTs with an increase of 11.9% over the Control. The 5 t ha^{-1} RHB had a mean water holding capacity of 11.22%, which yielded an increase of 7.8% over the Control. The 5 t ha^{-1} PLC had the least water holding capacity of 10.22%.

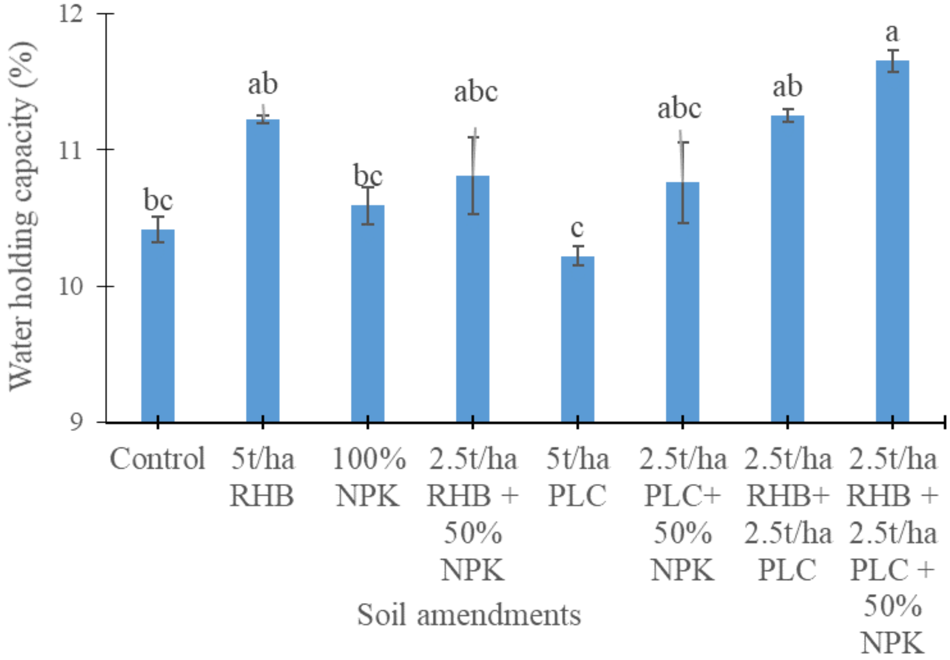

Figure 13 - Effect of soil amendments on water holding capacity of Gold Mine Tailing

Novak *et al*. (2009) found that the addition of switch grass biochar (made at 500 °C) to a sandy Ultisol increased soil water retention by 15.9% relative to no-biochar (controls). Increasing the water-holding capacity of sandy soils may be critical for providing enough energy and food for an increasing global population. The effect of organic amendment on soil water-holding capacity is mainly related to the physical attributes of the amendment itself (Tsadilas *et al.*, 2005), but alterations in soil structure due to biosolid application also impacts soil water storage capacity. The high surface area of organic amendments can help raise the water holding capacity of sandy soil (Laird *et al*., 2010). This implies that soils amended could retain more water from rainfall, which could increase crop production (Jeffery, Verheijen, van der Velde, & Bastos, 2011), and reduce the amount of irrigation water needed to grow crops in irrigated regions.

Unreclaimed mine wastes tend to have low water holding capacity, and therefore, amendments are essential to reduce water limitation in reclamation soils. Numerous amendments have been proposed to increase water holding capacity, primarily organic amendments. With respect to moisture holding capacity and improvement of soil structure, chemical fertilizers have an insignificant effect since they primarily consist of water-soluble salts. In the absence of sufficient detritus, soil organisms starve, humus content declines and all the desirable properties of the soil decline as the top soil mineralizes. The intrinsic water-holding capacity of organic amendments is greater than that of most mineral soils (Camberato, Gagnon, Angers, Chantigny, & Pan, 2006), so degraded soils with organic amendments can show an immediate increase in water-holding capacity (Fierro, Angers, & Beauchamp, 1999).

Available water (estimated as water held at field capacity minus that retained at the permanent wilting point) is probably a more relevant factor affecting plant growth than water-holding capacity at any given water tension. Organic amendments may (e.g., Zibilske *et al*., 2000) or may not (e.g., Gupta, Dowdy & Larson, 1977) increase available water. Incorporating organic amendments will usually increase saturated hydraulic conductivity (Leroy, Schmidt, Van den Bossche, Reheul & Moens, 2008), although contrasting and inconclusive results have often been reported (Schneider *et al.*, 2009). This variation might be due to the availability of nutrients, especially nitrogen and could be due to the improvement of soil water holding capacity, as mentioned earlier by Roe and Cornforth (2000).

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

An evaluation of the effects of different soil amendment was carried out on the growth and yield of lettuce and properties of a twenty-year-old decommissioned GMTs. The treatments included Control, 5 t ha^{-1}rice husk biochar, 60 kg N - 80 kg P_2O_5 - 80 kg K_2O, 2.5 t ha^{-1} rice husk biochar + 30 kg N-40 kg P_2O_5 - 40 kg K_2O, 5 t ha^{-1} poultry litter compost, 2.5 t ha^{-1} poultry litter compost + 30 kg N - 40 kg P_2O_5 - 40 kg K_2O, 2.5 t ha^{-1} rice husk biochar + 2.5 t ha^{-1} poultry litter compost and 2.5 t ha^{-1} rice husk biochar + 2.5 t ha^{-1} poultry litter compost + 30 kg N-40 kg P_2O_5-40 kg K_2O. A complete randomized design with three replications was used to determine their effect on the tailings.

Measurements taken included plant height, leaf area, number of leaves, chlorophyll content and totally fresh and dry matter yield of lettuce. Soil parameters that were measured after plant harvest were pH, total nitrogen, soil organic carbon, available phosphorus, base saturation, total exchangeable bases, exchangeable acidity, effective cation exchangeable capacity and water holding capacity. The Arsenic, Lead, Mercury, Cadmium and Chromium heavy metal concentration of the tailings before and after harvest were also determined. The nitrogen, phosphorus, potassium, calcium and magnesium content of the lettuce tissues were also determined. The heavy metal concentrations of the lettuce samples were also determined. Correlation analysis of yield of lettuce and some chemical properties of the tailings were determined as well.

The highest yield (433.9 kg ha^{-1}) was found in 2.5 t ha^{-1} RHB + 50% NPK followed by the 2.5 t ha^{-1} PLC+ 50% NPK, which had 405.4 kg ha^{-1}. The lowest yield (144.9 kg ha^{-1}) was recorded in the Control. It was generally observed that the 2.5 t ha^{-1} RHB + 50% NPK represented 1.99 fold increases compared to the control. The 2.5 t ha^{-1} PLC+ 50% NPK had a 1.79 fold increases in total dry matter yield compared to the Control.

At 2 weeks after planting, the 2.5 t ha^{-1} PLC+ 50% NPK recorded the highest plant height of 16.15 cm, which represent 97.67% over the control. At 4 weeks after planting, the 100% NPK gave the highest (16.57 cm) height, which was not significantly different from the 5 t ha^{-1} PLC (16.27 cm). Similarly, at 6 weeks after planting, the 5 t ha^{-1} Biochar gave the maximum height (17. 33 cm), which was not significantly different from the rest of the treatment except the Control, which produced the minimum (13.4 cm) height. At 2 weeks after planting, the leaf area in respect of leaf length and breadth was significantly higher in lettuce provided with 2.5 t ha^{-1} PLC + 50% NPK (21.35 cm^{2}). This treatment represents 1.21 folds over the Control. At 4 weeks after planting, 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC gave the highest leaf area of 33.33 cm^{2,} followed by the 2.5 t ha^{-1} PLC + 50% NPK (32.14 cm^{2}). Similarly, at 6 weeks after planting, the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC recorded the maximum leaf area of 41.41 cm^{2}. This leaf area represented 1.11 fold over the Control.

At 2 weeks after planting, the 2.5 t ha^{-1} RHB + 50% NPK had the highest mean number of leaves (3.7) but was not significantly different (p>0.05) from the rest of the treatments. At 4 weeks after planting, all the treatment had the same number of leaves (4.0). However, at 6 weeks after planting, the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC and the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK recorded the highest leaf numbers of 5.3 each. After week 2 of planting, the 2.5 t ha^{-1} RHB + 50% NPK recorded the highest mean chlorophyll content (SPAD) of 31, which represent 97.67% over the control. At 4 weeks after planting, the 100% NPK had the highest SPAD value of 34.47, which was not significantly different from 2.5 t ha^{-1} RHB + 50% NPK (24.33 SPAD value) and the 5 t ha^{-1} Compost also with SPAD value of 33.1. Similarly, at 6 weeks after planting, the 100% NPK had the highest SPAD value of 36.8, which was not significantly different from 2.5 t ha^{-1} PLC+ 50% NPK with 35.33 SPAD value.

Amongst the soil amendments, the 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK recorded a mean pH of 7.81 on the tailings, which yielded the highest impact on GMTs with an increase of 14.68% over the Control. The 5t ha^{-1} PLC gave the highest organic carbon content of 0.82%. This treatment had an increase of 5.1% over the control. Amongst the amendments, the 100% NPK and the 2.5t ha^{-1} PLC + 50% NPK had the highest and similar impact on tailing nitrogen and was observed to be 0.08%, which yielded a nitrogen increase of 14.3% over the Control. Available P was highest in treatment with 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC+ 50% NPK (26.54 ppm), which represents an increase of 132% compared to the Control.

The 5 t ha^{-1} PLC recorded the highest electrical conductivity of 461µm/cm, followed by the 2.5 t ha^{-1} RHB + 50% NPK, which had 450.7µm/cm. The 2.5 t ha^{-1} RHB + 50% NPK had the maximum response on mean total exchangeable bases of 15.14 cmol kg^{-1} and had an increase of about 51.6% to 71% above the Control. The Control recorded the highest mean exchangeable acidity of 0.07 cmol c kg $^{-1.}$ All the rest of the treatments had an exchangeable acidity of 0.05 cmolc kg^{-1}. Mean effective cation exchange capacity was highest in treatment with 2.5 t ha^{-1} RHB + 50% NPK (15.19 cmol kg^{-1}), which represents an increase of 51% compared to the Control and is significantly different from the rest of the treatments. The mean base saturation was highest in 5 t ha^{-1} PLC (99.65%) and was not significantly different from the rest of the treatment except the 100% NPK and the Control.

The mean Arsenic concentration was highest in the Control with a mean concentration of 0.12 mg kg^{-1}. This value is below the permissible limit of 20.00 mg kg^{-1}. The 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK treatment had the least arsenic concentration, which represents a decrease of 50% from the Control. The mean Lead concentration was highest in the 2.5 t ha^{-1} RHB+ 2.5 t ha^{-1} PLC (7.37 mg kg^{-1}). This value is below the permissible limit of 50.00 mg kg^{-1}. The mean Cadmium concentration was highest in the 2.5 t ha^{-1} Biochar + 2.5 t ha^{-1} Compost (0.02 mg kg^{-1}). This value is below the permissible limit of 3 mg kg^{-1}. The mean Mercury concentration was highest in the 2.5 t ha^{-1} RHB + 50% NPK which had 1.82 mg kg^{-1}. This value is below the permissible limit of 2mg/kg. The mean Chromium concentration was highest in the 2.5 t ha^{-1} PLC+ 50% NPK which had 4.05 mg kg^{-1}. This value is below the permissible limit of 14 mg kg^{-1}.

Amongst the soil amendments, the 2.5 t ha^{-1} RHB + 50% NPK yielded the highest mean nitrogen uptake of 7.23 kg ha^{-1} by the lettuce on GMTs with an increase of 400% over the Control. Amongst the soil amendments, the 2.5 t ha^{-1} RHB + 50% NPK yielded the highest mean phosphorus uptake of 1.24 kg ha^{-1} by the lettuce on GMTs with an increase of 350% over the Control. Amongst the soil amendments, the 2.5 t ha^{-1} PLC + 50% NPK yielded the highest mean potassium uptake of 10.79 kg ha^{-1} by the lettuce on GMTs with an increase of 133% over the Control. Amongst the soil amendments, the 2.5 t ha^{-1} PLC + 50% NPK yielded the highest mean calcium uptake of 6.14 kg ha^{-1} by the lettuce on GMTs with an increase of 250% over the Control. Amongst the soil amendments, the 2.5 t ha^{-1} PLC + 50% NPK yielded the highest mean magnesium uptake of 3.93 kg ha^{-1} by the lettuce on GMTs.

Amongst the soil amendments, the Control yielded the highest mean Arsenic of 0.05 mg kg^{-1} by the lettuce on GMTs. This value is below the maximum permissible limit of (0.1 mg kg^{-1}) per contaminants recommended for fresh leafy vegetables. The 5 t ha^{-1} RHB and the other amendments recorded lower values and showed a reduction of about 20% to 40% Arsenic amounts compared to the Control in lettuce after application. Amongst the soil amendments, the Control yielded the highest mean Lead of 0.23mg $kg^{-1}$by the lettuce on GMTs. The 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK recorded a mean Lead content of 0.21 mg kg^{-1}which represented a reduction of 9% compared to the Control. This value is below the maximum permissible limit of (0.3 mg kg^{-1}) per contaminants recommended for fresh leafy vegetables. Amongst the soil amendments, the Control yielded the highest mean Mercury concentration of 0.24 mg kg^{-1} by the lettuce on GMTs. This value is below the maximum permissible limit of (0.3 mg kg^{-1}) per contaminants recommended for fresh leafy vegetables. The 2.5 t ha^{-1} RHB + 2.5 t ha^{-1} PLC+ 50% NPK recorded the least Mercury content of 0.09 mg kg^{-1}which represented a reduction of 62.5% from the Control.

Amongst the soil amendments, the 2.5 t ha^{-1} RHB + 2.5t ha^{-1} PLC yielded the highest mean Cadmium concentration of 0.18 mg kg^{-1} by the lettuce on GMTs, which represented an increase of 50% over the Control. The 2.5 t ha^{-1} PLC + 50% NPK recorded a mean Chromium content of 0.95 mg kg^{-1} which represented an increase of 2.27 folds compared to the Control. Again, this value is above the maximum permissible limit of (0.3 mg kg^{-1}) per contaminants recommended for fresh leafy vegetables. Amongst the soil amendments, the 2.5t ha^{-1} RHB + 2.5 t ha^{-1} PLC + 50% NPK recorded the highest water holding capacity tailings (11.65%), which yielded the highest impact on GMTs with an increase of 11.9% over the Control.

Conclusions

Incorporation of half rate of RHB and half rate of NPK produced higher yield followed by half rate of PLC and half rate of NPK. The treatments significantly improved soil pH, total nitrogen, available phosphorus, exchangeable bases and effective cation exchange capacity of GMT. In a nutshell, addition of amendments could improve growth and yield parameters of lettuce and also improve physical and chemical properties of GMT in the semi-deciduous forest zone of Ghana.

The hypotheses of the study on the application of biochar, compost with NPK fertilizer will improve the fertility status of mine tailings and also increase growth and yield components of lettuce is accepted. Again, the study confirmed that combined application of biochar or compost with NPK have an effect on selected GMT properties. The soil amendments improved the GMT properties because they contained higher concentrations of nutrients than the tailings. The relative contribution of the fertility enhancement depends on the initial nutrient status of the soil amendment and the ratio of the tailings. The soil amendments also enhanced the uptake of macronutrients by lettuce. The increase in the fertility of the tailings by the soil amendments significantly enhanced lettuce growth and yield.

The results showed that amendments are ideal for rapidly accelerating soil regeneration processes and hence land reclamation. With world population forecasts showing increased growth until later this century, there is the potential for biochar and inorganic amendments to become more available in the future as demand for food, fuel and fibre increases; for example, biosolids from urban areas or manure from intensive livestock operations. The study concluded that GMTs would show the greatest benefits in improving substrate structure and nutrient status by adding organic and inorganic amendments for lettuce production.

Recommendations

Biochar applications in combination with inorganic fertilizer (2.5 t ha^{-1} RHB + 50% NPK) significantly improved growth and yield of lettuce compared to other treatments. Insight into the micronutrient of heavy metals in the tailing is an important step in estimating the hazards that the metals may pose to the vital roles of tailings in the ecosystem and also in comparison with the quality of set standards. The study can further be enhanced by the analysis of plant nutrient uptake of the micro nutrients so as to better explain amendments effects on the overall productivity of the test crop. Future research on this study could target the capture and measurement of some of the major global warming implicated gases such as CO_2, CH_4 and various oxides of nitrogen on mine tailings.

There is the need to repeat the study over a longer period of time to provide the opportunity to evaluate the residual effects of these treatments on the measured parameters so as to afford better insight into this type of tailing for future recommendations to farmers. The induction of soil biological activity (faunal and microbial) by organic amendments represents a fundamental mechanism by which soil reclamation occurs and must also be assessed.

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