Effect of Duration of Reclamation on Soil Quality Indicators of a Surface – Mined Acid Forest Oxisol in South – Western Ghana

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Abstract

The quality of degraded mined soils can be restored through effective reclamation practices. In this study, we evaluated the impact of varying duration of land reclamation on soil quality at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa, Ghana. Soil samples were taken from mined sites of the Company at various stages of phytoremediation: 2, 5, 9 and 11 year old reclaimed sites. The soils were analyzed for soil quality indicators. A nearby forest reserve representative of the pre-degraded condition was used as the control. Prior to phytoremediation with multipurpose agroforestry trees, the mined soils were subjected by the Company to earthworks/slope battering followed by spreading of oxide materials over the surface, construction of crest drains and cover cropping. Having determined the impact of the varying duration of reclamation on soil quality indicators, separate pot experiments involving maize and cowpea were set up using soils from the sites to assess heavy metals accumulation in the cultivated crops. Soil nutrient levels in the sites under reclamation were significantly higher ($P < 0.05$) than the nearby forest reserve. Soil pH though generally low, was relatively higher ($P < 0.05$) in sites under reclamation than in the control. Soil total nitrogen, available phosphorus and exchangeable potassium levels were highest ($P < 0.05$) in the 11 year old site. Zinc contents of all sites were below the maximum permissible levels. There was somewhat antagonistic interaction between zinc and phosphorus contents of maize in the unclaimed site. Though heavy metal concentrations in maize were lower than that of cowpea, the concentrations in both plants were generally beyond the permissible levels suggesting a possible transfer onto the food chain if the crops are included as part of rotation programmes from the agronomic perspective. Our results indicate that phytoremediation of mined lands using agroforestry multipurpose trees could be marginal even after a decade of reclamation.

Introduction

The mining sector is undoubtedly one of the most important sources of foreign exchange in many countries of the world, particularly in sub-Saharan Africa (Ethan and Rene, 2011). In Ghana, the sector contributes over 40% towards the country's foreign exchange earnings (Awotwi, 2003). Following mining's contribution to socio-economic development of the country (contributes to 6% of GDP and offers employment to citizens), the industry has attracted billions of dollars of direct foreign investment for development and expansion aimed at poverty reduction and improvement of living standards (Minerals Commission, 2000). This notwithstanding, mining activities pose

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serious threats to environmental quality in Ghana and elsewhere (BIRD, 2009).

According to Araujo (2015), there is an increasing trend of anthropogenic degradation of the land surface. In Ghana, surface mining is the greatest agent of land degradation, utilizing over 13% of the 240,000 km^2 forest reserves (Awotwi, 20003). In South-western Ghana alone, it is estimated that over 70% of the land previously used for farming activities is under mine concessions (Akabzaa and Darimani, 2001). Mining competition with farmlands often deprive farmers the right to ownership and employment, fraying the cultural and the socio-economic development of farming communities (Mate, 1998). Though mining is an economic booster, there is a growing awareness of its adverse effects and societies around the world are increasingly expecting the industry to apply higher standards of environmental and safety management through application of modern technologies (Blinker, 1999). This will enhance sustainable co-existence of mining and farming activities.

Reclamation is a desirable and necessary remedy ‘‘to return the degraded mined areas to an acceptable environmental condition’’ (Redgwell, 1992). According to Lamb (1994), the original biodiversity may not be recovered although the protective function and many of the ecological services may be re-established. Currently, most mining companies employ various reclamation techniques to impact on conservation values of degraded sites in anticipation of returning some pre-disturbance functions. As a requirement, reclamation strategies should bring about an improvement in soil quality and the development of pedogenic processes to ultimately support revegetation (Dimitriu *et al.*, 2010). Agroforestry multipurpose trees play vital roles in mined land reclamation due to their ability to establish and grow on marginal lands, subsequently improving soil conditions (Young, 1997).

Reclamation of degraded mined sites depends on the end-use objective of the site under reclamation. Prior to this study, a sociological survey conducted to identify the end-use objectives of the sites under reclamation indicated that arable crop production (maize, cowpea, etc.) was the pre-mining occupation of the indigenes of the mining area. Companies in Ghana however adopt their own processes and practices of reclaiming the degraded sites, this involving the use of agroforestry trees.

Research on mining activities majorly focus on their negative impacts on community health and safety as well as forest destruction. There is however, paucity of information on land reclamation practices and their impacts on soil quality. This study was therefore conducted to assess the impact of land reclamation on some soil quality indicators of mined soils under different stages of reclamation and to evaluate heavy metal composition of crops cultivated on such soils to inform agronomic practices. We hypothesized that phytoremediation of degraded mined soils will depend largely on the age of the trees in reclamation and that the quality of the degraded soils can be sufficiently restored in a decade of remediation.

Materials and methods

Study site

The study was conducted at AngloGold Ashanti, Iduapriem mine at Tarkwa in South-western Ghana. The area is characterized by a bimodal rainfall pattern with high humidity, ranging from 92–95%. The average annual rainfall ranges from 1750 mm to slightly over 2000 mm with minimum and maximum daily temperatures of 25 °C and 27.8 °C, respectively (EAU, 1990). The soils within the area are very acid forest Oxisols (Adu, 1979).

The Company uses the following reclamation processes to rehabilitate the degraded sites: 1. earthworks or slope battering, 2. spreading of oxide material (clay material to bind loose soil particles together), 3. spreading of top soil, 3. construction of crest drains and broadcasting of cover crops (*Centrosema*, *Stylosanthes*, *Mucuna*) to control run-off and erosion, 4. tree planting followed by field maintenance – weeding, pruning and monitoring. The process also include planting of agroforestry multipurpose trees (MPTs) (*Acacia mangium*, *Gliricidia sepium*, *Senna siamea and Leucaena leucocephala*) in a mixed stand. Success criteria for the Company's reclamation was the ability of the reclaimed sites to support plant growth and maximize productivity without any health risk of heavy metal accumulation beyond the safety thresholds. It also entails the ability of crops to establish well after planting and reach maturity without any impedance in growth as a result of unfavourable soil properties which hitherto emanated from the mining activities.

Soil sampling and analysis

Prior to the setting up of the pot experiments, soil samples were randomly taken within 0–15 cm depth at the experimental site for characterization. The sites, including an unclaimed site (T_1) were at different stages of reclamation with four MPTs (*Acacia mangium*, *Gliricidia sepium*, *Leucaena leucocephala* and *Senna siamea)* and consisted of 2 year old (T_2), 5 year old (T_3), 9 year old (T_4) and 11 year old (T_5) reclaimed sites. The $T_{2,}$ T_3, $T_{4,}$ and T_5 were in equal mixed stand of the four MPTs. T_1 was a degraded mined site yet to undergo reclamation. There was a nearby Neung Forest reserve representative of the pre-degraded condition and was used as the control (T_0).

Ten soil samples were taken at random from each site using hand auger. The ten samples from each site were then bulked, mixed thoroughly and sub-sampled, air-dried, passed through a 2 mm sieve and subjected to analysis (Anderson and Ingram, 1998). The analysis included the determination of soil *p*H using a *p*H meter (with glass electrode) in a soil: water ratio of 1:2.5 (Mclean, 1982, total N by the Kjeldahl method as described by Bremner and Mulvaney (1982) in Soils Laboratory Staff (1984), soil organic carbon (SOC) by the wet combustion method as described by Nelson and Sommers (1982), exchangeable bases were determined by the method described by Thomas (1982) and available phosphorus (P) by Bray's No.1 Method (Bray and Kurtz, 1945). Various micronutrients/heavy metals (Arsenic (As), Cupper (Cu), Zinc (Zn), Lead (Pb), Cadmium (Cd), Manganese (Mn), Iron (Fe) were analyzed by atomic absorption spectrophotometry (Anderson and Ingram, 1998). All soil analyses were carried out in the Laboratory of the Soil Research Institute (SRI), Kwadaso, Kumasi.

Experimental set up

Following the determination of the soil chemical quality indicators, viz. SOC, soil *p*H, total N, available P and exchangeable cations from the degraded sites of the Company under various stages of reclamation, two separate pot experiments were set up using maize (Obatanpa – local name) and cowpea (Nhyira – local name) as test crops. The soil samples from the degraded sites (representing the experimental treatments) were used for the pot experiments set up under field conditions at the nursery of the Environmental Department of the Company. Pots (27.0 cm – height, 30 cm – top diameter, 17.5 cm – bottom diameter) were each filled with 13 kg soil samples to bulk density of 1.30 gcm^{-3}. The treatments were arranged in a completely randomized design and replicated four times. The pots were watered to field capacity (-33 kPa) and left under field conditions a week before planting. In all, there were 32 plants per treatment in each experiment.

Twelve maize and cowpea plants per treatment were destructively sampled six weeks after planting to determine nutrient concentration and heavy metal accumulation in their aboveground biomass.

Statistical analysis

All parameters measured were subjected to Analysis of Variance using GenStat statistical package (GenStat, 2010). Treatment means were compared using Duncan's multiple range test (DMRT) at a 5 % probability.

Results

Chemical characteristics of soils

In general, we found significant effect of treatments on all soil chemical parameters measured (Table 1). The soil *p*H generally ranged from very acidic (4.0) to moderately acidic (6.0) with the lowest and highest values ($P < 0.05$) recorded under the forest reserve (control) and the 9 year old reclaimed site, respectively. The soil *p*H generally increased with the age at which the sites have been under reclamation. The *p*H of sites under reclamation differed significantly ($P < 0.05$) from that of the unclaimed site.

The SOC content of the different sites decreased significantly in the order of T5 > T4 = T0 > T3 > T2 > T1. The SOC content of the 11 year old site was about 95% higher than that of the unclaimed site emphasizing the extent to which phytoremediation can enhance soil quality. However, there were no significant difference ($P > 0.05$) in the SOC between T_0, T_4 and T_5 treatments.

Generally, the treatments had significant effect on the N content of the soils. The N content under the 11 year old site was significantly higher ($P < 0.05$) than that of the control. The available P content in all the sites was generally low with the highest value recorded under the 11 year old site. The exchangeable K content ranged from 0.09 $cmol_{(+)}$ kg^{-1} to 0.23 $cmol_{(+)}$ kg^{-1} respectively under the unclaimed site and the 11 year old site.

The highest Zn content ($P < 0.05$) was recorded under the unclaimed site with the least from the control. Apart from Cd, the sites under reclamation differed significantly ($P < 00.5$) in Cu, Pb, Mn, and Arsenic and Fe contents. Contrary to expectation, the highest ($P < 0.05$) Mn and As values of 133.0 mg kg^{-1} and 238.67 mg kg^{-1} respectively were recorded under the 9 year old reclaimed site.

Heavy metals concentration in maize

As, Zn, Fe, Mn and Cu contents of the maize plant differed significantly ($P < 0.05$) in the various sites (Table 2). The highest Arsenic content was recorded on the two year old reclaimed site with the least from the unclaimed site. The highest Fe content

TABLE 1

Soil chemical properties of sites at different stages of reclamation at Anglo Gold Ashanti, Iduapriem mine Ltd., Tarkwa

	pH 1:2.5	*SOC* gkg^{-1}	*Total N* gkg^{-1}	*Avail P* $mgkg^{-1}$	*Exc. K* $cmol_{(+)}kg^{-1}$	*Exc. Ca* $cmol_{(+)}kg^{-1}$	*Exc. Mg* $cmol_{(+)}kg^{-1}$	*Exc. A* $cmol_{(+)}kg^{-1}$	*%Base*	*Cd* $mgkg^{-1}$	*Cu* $mgkg^{-1}$	*Pb* $mgkg^{-1}$	*Fe* $mgkg^{-1}$	*Mn* $mgkg^{-1}$	*As* $mgkg^{-1}$	*Zn* $mgkg^{-1}$
T_0	4.0^{a}	13.0^{ab}	3.0^{b}	5.400^{d}	0.10^{a}	0.6^{a}	0.5^{a}	1.9^{c}	31.3^{a}	3.7^{ab}	5.3^{a}	71^{b}	5282^{d}	4.0^{a}	127.7^{c}	7.3^{a}
T_1	4.5^{b}	1.0^{a}	1.0^{a}	0.430^{b}	0.09^{a}	0.9^{b}	0.4^{a}	1.5^{b}	38.6^{a}	2.3^{a}	9.3^{bc}	64.67^{a}	2907^{b}	3.0^{a}	108.7^{a}	36.7^{d}
T_2	4.9^{c}	7.0^{a}	2.0^{a}	0.004^{a}	0.13^{b}	1.1^{c}	0.9^{b}	3.9^{d}	34.7^{a}	4.0^{b}	10.2^{c}	92.33^{d}	20916^{f}	20.7^{b}	184.0^{e}	26.7^{c}
T_3	5.2^{d}	10.0^{ab}	3.0^{b}	1.230^{c}	0.14^{b}	1.4^{d}	0.9^{b}	1.5^{b}	78.8^{b}	4.0^{b}	5.0^{a}	80.67^{c}	13752^{e}	34.3^{b}	177.7d	14.3^{b}
T_4	6.0^{e}	21.0^{b}	3.0^{b}	7.750^{e}	0.19^{c}	3.8^{f}	1.5^{c}	0.4^{a}	90.6^{c}	3.3^{b}	6.7^{ab}	72.00^{b}	4826^{c}	133.0^{c}	238.7^{f}	10.7^{a}
T_5	4.8^{c}	22.0^{b}	4.0^{c}	14.670^{f}	0.23^{d}	2.3^{e}	1.5^{c}	0.9^{a}	82.2^{bc}	6.7^{c}	5.3^{a}	90.33^{d}	2715^{a}	131.3^{c}	117.7^{b}	8.7^{a}
P value	< 0.05	> 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	> 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

T_0 = Forest Reserve (Control), T_1 = Unclaimed oxide waste rock dump, T_2 = 2 year old reclaimed site, T_3 = 5 year old reclaimed site, T_4 = 9 year old reclaimed site, T_5 = 11 year old reclaimed site. Means in each column followed by the same letter are not significantly different at 5%

(P < 0.05) of maize was recorded in plants grown in the soil from the 5 year old reclaimed site whilst the least was obtained in plants on soil from the 9 year old reclaimed site.

Heavy metals concentrations in cowpea

The cowpea plants on the different sites differed significantly (P < 0.05) in As, Zn, Fe, Mn, Cd and Cu contents (Table 3) except Pb (P > 0.05). The Arsenic content of the cowpea of all sites were found to be higher than that of the maize. The highest and lowest values (P < 0.05) were consistently recorded under the 2 year old reclaimed site and the unclaimed site respectively for both crops (Table 2 and 3).

Macronutrients concentrations in maize and cowpea

Maize on the different sites varied significantly (P < 0.05) in total N, P, Ca and Mg contents (Table 4) except K. The highest and the lowest total P contents were recorded in plants grown in soils from the unclaimed site and the 2 year old reclaimed site, respectively. There was an antagonistic P × Zn interaction as the highest P content was recorded in unclaimed sites which had the lowest Zn content (Table 3 and 4). Plants on the unclaimed site were significantly lower (P < 0.05) in N composition than plants on all other sites.

The treatments significantly affected (Table 5) the macronutrients composition in cowpea. Comparatively, the Ca content was higher in cowpea than in maize.

Discussion

Soil properties

Soil *p*H influences the availability of essential plant nutrients (Rahman & Ranamukhaarachchi, 2005). The generally

TABLE 2

Heavy metal content in maize as affected by soils from different reclamation sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa

Treatments	*As*	*Fe*	*Mn*	*Cu* *mg kg*$^{-1}$	*Cd*	*Zn*	*Pb*
T_0	24.8^{bc}	116.9^{b}	52.3^{c}	4.4^{a}	0.54^{a}	23.0^{bc}	42.1^{a}
T_1	13.1^{a}	90.8^{ab}	51.1^{c}	3.5^{a}	0.99^{a}	11.7^{a}	59.4^{a}
T_2	38.5^{d}	252.3^{c}	22.7^{b}	3.5^{a}	0.89^{a}	36.1^{d}	58.4^{a}
T_3	20.3^{b}	319.3^{c}	20.5^{b}	4.8^{a}	0.81^{a}	19.5^{b}	52.9^{a}
T_4	29.4^{c}	34.0^{a}	9.4^{a}	6.8^{b}	0.67^{a}	27.8^{c}	41.8^{a}
T_5	13.2^{a}	67.8^{ab}	137.7^{d}	4.5^{a}	0.78^{a}	12.0^{a}	38.5^{a}
CV (%)	15.8	27.1	8.8	23.1	49.1	18.5	33.6

$T_{0:}$ Forest (Control), T_1: Unclaimed site, $T_{2:}$ 2year old reclaimed site, $T_{3:}$5year old reclaimed site, T_4: 9 year old reclaimed sites, $T_{5:}$11year old reclaimed. Means in each column followed by the same letter are not significantly different at 5%.

TABLE 3

Heavy metal content in cowpea as affected by soils from different reclamation sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa

Treatments	*As*	*Fe*	*Mn*	*Cu* *mg kg*$^{-1}$	*Cd*	*Zn*	*Pb*
T_0	50.4^{c}	79^{ab}	138.7^{a}	10.4^{a}	0.4^{ab}	50.4^{c}	2.2^{a}
T_1	24.4^{a}	29^{a}	116.7^{a}	9.9^{a}	0.2^{a}	25.2^{a}	3.0^{a}
T_2	58.4^{d}	156^{ab}	139.7^{a}	19.5^{bc}	1.0^{b}	62.6^{d}	2.3^{a}
T_3	44.8^{c}	187^{b}	116.7^{a}	17.7^{b}	0.8^{b}	49.0^{c}	7.8^{a}
T_4	32.3^{b}	156^{ab}	249.7^{b}	22.6^{c}	0.8^{b}	32.8^{b}	1.8^{a}
T_5	35.7^{b}	154^{ab}	287.6^{c}	45.9^{d}	0.7^{b}	36.3^{b}	1.9^{a}
CV (%)	11.9	71.3	9.7	11.4	34.1	10.7	15.9

$T_{0:}$ Forest (Control), T_1: Unclaimed site, $T_{2:}$ 2 year old reclaimed site, $T_{3:}$5year old reclaimed site, T_4: 9 year old reclaimed sites, $T_{5:}$11year old reclaimed. Means in each column followed by the same letter are not significantly different by Duncan's multiple Range Test ($P \leq 0.05$)

low nutrient concentrations observed in the sites was due to the low pH of the soils. The low *p*H status of the reclaimed sites, the unclaimed site and the control at AngloGold Ashanti, Iduapriem mine was due to their relatively low exchangeable Ca contents (Table 1). This notwithstanding, there was an improvement in the *p*H of the reclaimed sites compared to the control due to the relatively higher Ca contents of the former. Acid mine drainage or sulphide oxidation might have resulted in acidification of the tailings at the mining site even though high rainfall could also cause leaching of the basic cations out of the topsoil.

The highest SOC obtained under the 11year old reclaimed site is attributable to the age of the tree species under reclamation due to more biomass production and leaf litter accumulation with time. This is evidenced

TABLE 4
Nutrients content in maize on unclaimed and reclaimed sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa

Treatments	*Macronutrients (%)*				
	N	*P*	*K*	*Mg*	*Ca*
T_0	2.5^b	0.44^{cd}	0.57^a	3.3^{ab}	0.25^a
T_1	1.0^a	0.49^d	0.69^a	6.3^c	0.52^c
T_2	2.3^b	0.34^a	0.44^a	1.1^a	0.50^c
T_3	3.0^b	0.41^{bc}	0.48^a	5.2^{bc}	0.36^b
T_4	2.6^b	0.35^{ab}	0.61^a	2.0^a	0.41^b
T_5	2.7^b	0.41^d	0.60^a	7.1^c	0.21^a
CV (%)	22.3	10.3	30.0	35.9	11.8

$T_{0:}$ Forest reserve (Control), T_1: Unclaimed oxide waste rock dump, $T_{2:}$ 2year old reclaimed site, $T_{3:}$5year old reclaimed site, T_4: 9 year old reclaimed site, $T_{5:}$11year old reclaimed site.

TABLE 5
Nutrients concentration in cowpea on unclaimed and reclaimed sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa

Treatments	*Macronutrients (%)*				
	N	*P*	*K*	*Mg*	*Ca*
T_0	5.0^c	0.49^b	0.86^{ab}	3.3^a	0.96^a
T_1	3.8^a	0.32^c	1.40^c	4.0^a	1.20^{ab}
T_2	3.7^a	0.50^b	1.10^{bc}	5.0^a	1.50^b
T_3	4.7^{bc}	0.29^c	1.20^{bc}	3.2^a	8.90^e
T_4	3.7^a	0.50^b	0.58^a	4.0^a	3.30^d
T_5	4.5^b	0.39^a	0.96^b	3.7^a	2.30^c
CV (%)	4.9	48.7	23.6	51.8	6.50

$T_{0:}$ Forest reserve (Control), T_1: Unclaimed oxide waste rock dump, $T_{2:}$ 2year old reclaimed site, $T_{3:}$5year old reclaimed site, T_4: 9 year old reclaimed site, $T_{5:}$11year old reclaimed site.

by the lowest SOC content recorded in the unclaimed site (Table 1). The unclaimed site had a bare soil surface with no tree cover and hence little or no accumulation of organic matter. The unclaimed site, 2 year and 5 year reclaimed sites were low in SOC whilst the control, 9 year and 11 year old reclaimed sites were found to be within the moderate range of 1.6–3.0% (Metson, 1961). Even though the SOC under the Neung forest reserve was expected to be the highest due to its organic matter accumulation, the situation was not so since the latter is a heterogeneous, dynamic substance with variable C content.

According to CSIR-SRI (2007) rating, the soil total N in the 5, 9 and 11 year old reclaimed sites were high. The higher N levels obtained was due to the use of the leguminous tree species in the reclamation exercise. Bino (1998) reported an increase in mean N from 0.48 % to 0.53 % in the surface soil after N fixing tree species (NFTS) were planted. The

NFTS on the 11 year old reclaimed site have contributed to the highest N recorded from that site because of more litter falls associated with the age of the trees. Therefore N increase could be expected from the site in comparison to the other sites which had the same tree species composition but of relatively younger age. The generally low concentration of P in the sites was due to the acidic nature of the soils resulting possibly in its fixation by Fe and Al at the low pH (Sheraz *et al.*, 2011).

As can be inferred from Table 1, the heavy metal contents in the soil in general were found to be very high due to the low pH and mining activities. It was observed that all the soils under the various treatments had pH below 7. The low pH gave room to more metal availability (Sauve *et al.*, 1997) implying accumulation of the heavy elements in plant tissues (Table 2 and 3) through uptake and a possible transfer onto the food chain. This calls for longer period of phytoremediation of the degraded mined sites or adoption of alternatives of reclamation, viz. bioremediation; soil amendment with biochar and enhanced phytoremediation using non-food crops of hyper accumulating features until the sites are fully reclaimed. Following addition of sludge to mined degraded land, Donna *et al.* (2006) reported that mined soils with amendments has good potential for horticultural crop production. However, since biosolids contain some levels of heavy metals, knowledge of their compositions with respect to permissible levels of such elements should be a requirement prior to application. Since it was apparent that the sites were generally acidic, pH should be corrected to safer levels.

Heavy metal concentrations in maize and cowpea

Cadmium concentrations in both plants at the different sites were found to exceed Food Safety Standards in most countries (0.1 mg kg^{-1}) (Benton, 1997). Markert (1994) indicated Cd and Pb normal levels in plants to be 0.05 and 1.0 mg kg^{-1} respectively. Markert (1994) also suggested 0.1 mg kg^{-1} as the normal level of Arsenic in plants. From the foregoing limits, the concentrations of the heavy metals were found to be toxic in both plants. According to O'Neill (1995), when *p*H is very low, the Arsenic binding elements like Fe and Al oxycompounds will become more soluble causing an increase in plant Arsenic uptake.

Plant permissible levels of Cu and Zn were respectively referenced at 6 mg kg^{-1} and 20 mg kg^{-1} (Epstein, 1972; Benton, 1997), this indicating the concentrations of Cu in maize plants in all the sites to be generally within the recommended threshold limits.

The average concentration of Mn and Fe were reported by Epstein (1972) as 50 and 100 mg kg^{-1} respectively in plant dry matter. It is therefore inferable that apart from Pb which was within the 0.1-5.0 mg kg^{-1}, all the other heavy metals concentrations were above the required range, reaching their toxic levels in the plants. However, cowpea plants cultivated on soil from the forest reserve and the unclaimed site had their Fe contents within the reference limit.

Conclusion

Our results generally indicate marginal soil quality restoration of degraded mined lands within a decade of reclamation. Soil quality indicators were relatively better under the 9 year old and 11 year old reclaimed sites than the 2 year old and 5 year old sites indicating that age of the trees in reclamation to some extent, influenced soil quality restoration of the degraded mined sites. SOC under the nine year old site was remarkably 95% higher than that of the unclaimed site at 15 cm depth. However, heavy metal concentrations in crops cultivated on soils from sites under reclamation were found to be above the recommended threshold levels even after eleven years suggesting the need for longer period of remediation or employing additional remediation measures to enhance the process. Since *p*H of the sites under reclamation were generally low, it is recommended that correction of soil *p*H through early liming be considered to speed-up the regenerative process.

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