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 ($P < 0.01$) in sites under reclamation than in the control. Soil total nitrogen, available phosphorus and exchangeable potassium levels were highest ($P < 0.01$) 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 (VSN International, 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

Institute, Washington, D.C. USA.

Mclean E. O. (1982). Soil pH and lime requirement. In *Methods of Soil Analysis*. Number 9 Part 2 (A. L. Page, R. H. Miller and D. R. Keaney, eds). *Am. Soc. of Agron.*

Metson A. J. (1961). Methods of chemical analysis for soil survey samples, New Zealand, DSIR, Soils Bulletin, 12 GVT Printer Wellington.

Minerals Commission Report (2000). Mineral production in Ghana: 1990–1999, Accra, Ghana.

Nelson D.W. and Sommers, L.W. (1982). Total a ml m e l a a ml l lm e l a rrc l ec c P l cclc P c crfm md m l r caml c r ml Afc a l a m m me a n mnc r c c a l ma cr md e mlm l m a clac ma cr md c a ml aml l n

O'Neill P. (1995). Arsenic. In *Heavy metals in soils.* (B. J. Alloway, ed), pp.105–121. London: Blackie Academic and Professional:

Ranamukhaarachchi S. L., Mizanur-Rahman M. D. and **Begum S. H.** (2005). Soil fertility and land productivity under different cropping systems in highlands and medium highlands of Chandina sub-district, Bangladesh. *Asia- Pacific Journal of Rural Development* **15**(1): 63–76.

Redgwell C. (1992). Abandonment and reclamation obligations in the United Kingdom. *Journal of Energy and Natural Resources Law* **10**(1): 59–86.

Sauve S. McBride M. B., Norvell W. A. and **Hendershot W. H.** (1997). Copper solubility and speciation of in situ contaminated soils: effects of copper level, pH and organic matter. *Water, Air and Soil Pollution*. **100**: 133–149.

Sheraz S. M., Mahdi G. I., Altaf H. and **Faisul-ur R.** (2011). Phosphorus availability issue- its fixation and role of phosphate. *Research Journal of Agricultural Sciences* **2**(1): 174–179

Thomas G. W. (1982). Exchangeable cations. In *Methods of Soil Analysis*. Number 9, Part 2. (A. L. Page, R. H. Miller and D. R. Keaney eds). *Am. Soc. of Agron.*

Young A. (1997). Agroforestry for soil management, 2nd edn. CAB International/ICRAF pp. 47–108.