KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF RENEWABLE NATURAL RESOURCES

DEPARTMENT OF AGROFORESTRY

EVALUATION OF LAND RECLAMATION PRACTICES AT ANGLOGOLD ASHANTI, IDUAPRIEM MINE LTD, TARKWA.

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AGROFORESTRY.

BY

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DECLARATION

I declare that except for references to other people's research which have been duly cited, this thesis submitted to School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi for the degree of Master of Science in Agroforestry is my own investigation.

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ABSTRACT

Reclamation is a desirable and necessary remedy to return the mined areas to an acceptable environmental condition whether for resumption of the former land use or for a new use and to allow such lands to achieve their optimum economic value. The reclamation study was carried out to assess the land reclamation practices at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa in the western region of Ghana. The study was in two parts: a sociological survey and a field experiment. The survey was conducted in the 8 neighbouring communities namely: Iduapriem, Adieyie, Adisakrom, Abonpuniso, Techiman, Wangarakrom, Badukrom and Teberebie. The survey methodology comprised of interviews using semi-structured questionnaires, focus group discussions and personal

observations. Ten(10) environmental experts of the mining company, Chiefs/Opinion leaders and the Community Relation Officer were interviewed. The field experiment was carried out using soils from the four reclaimed sites of different ages, an unclaimed site and the nearby Neung forest reserve (control) and these constituted the treatments. Soil samples were taken at the depth of 0 – 15cm from the four reclaimed sites, the unclaimed site and the nearby Neung forest reserve (control) with a hand auger and analysed for soil fertility parameters including heavy metal contaminants. The remaining soil samples for each site were put in plastic containers and arranged in a Complete Randomized Design with four replications on the field for testing their suitability for cultivation of maize (*Zea mays*) and cowpea (*Vigna unguiculata)*. Four plastic containers each filled with the soil constituted a plot. Foliar analysis for nutrients and heavy metal contaminants, yield and other growth characteristics were measured for the maize and cowpea. The study from the sociological survey revealed that the mining company adheres to reclamation security agreement signed with EPA-Ghana in 2004 and the company won the best reclaim mine in Ghana for 2007. There was high community participation in the reclamation exercise ranging from weed and fire control, consultation, seedling establishment, security and maintenance of trial farms. Agroforestry multipurpose trees; *Acacia magium, Gliricidia sepium, Senna siamea* and *Leucaena leucocephala* are used in reclaiming mined out sites. The company uses the following reclamation processes and procedures to rehabilitate the disturbed sites: earthworks/slope battering, spreading of oxide material, spreading of top soil, construction of crest drains and broadcasting of cover crops to control run-off and erosion, tree planting and field maintenance. In the field experiment from 2yr old, 5yr old, 9yr old and 11yr old reclaimed sites of the company, the nutrient levels from the reclaimed sites soils were higher than the forest reserve (control). The reclaimed practices had significant effect on the pH of the soil such that, there is general improvement in the pH of the soils from the reclaimed sites compared to the forest reserve (control). The highest pH of 6.02 was recorded from the 9yr old reclaimed site with the least (4.01) from the forest reserve (control). The 9yr old reclaimed site recorded the highest percentage base saturation of 90.6 and the lowest exchangeable acidity of 0.39%. The concentration of nitrogen in the 9yr old (T_4) and 11 yr old reclaimed (T_5) sites (0.34%) and (0.38%) respectively were high. The highest P content (14.67mg/kg) which indicates a moderate level was recorded in the 11yr old reclaimed site soil (T_5). The K content (40.28mg/kg) and (35.00mg/kg) for the forest site (control - T_0) and the unclaimed site (T_1) respectively were low but the reclaimed sites recorded moderate level of the K content ranging from 50.33mg/kg in the 2 yr old reclaimed site to 90.48mg/kg in the 11 yr old reclaimed site. The highest zinc content (36.67mg/kg) was recorded from the unclaimed site (T_1) with the least (7.33mg/kg) from the forest reserve (T_0) (control). Iron (Fe) was found to be in the highest concentration of 20915.7mg/kg recorded from the 2yr old reclaimed site soil. The P and Mg contents in the maize plant were above the average concentration (0.2%) sufficient for plant growth. Apart from the unclaimed site, the N contents in the maize and cowpea plants from all the sites were higher than the average (1.5%) for plant growth. Generally, heavy metal contents in the leaf tissue of cowpea were higher than that of maize. Apart from Cd and Pb which were within the critical concentration of 3(mg/kg) and 10(mg/kg) respectively, the remaining heavy metals (Mn, Fe, Zn, Cu, As) in the leaf concentration of cowpea were too high with Fe having the highest concentration of 20915.7mg/kg recorded from the 2yr old reclaimed site soil and hence very toxic to the crop. Growth characteristics (stem diameter, height, above and below ground biomass) of the maize and cowpea plants differed significantly ($P < 0.05$) in the different sites soils except in the below ground biomass (BG) and the number of effective nodules (ENOD) of the cowpea plant. The 9yr old reclaimed site recorded the highest of all the measured growth characteristics. The highest yields of 1800.5kg/ha and 791kg/ha were obtained from the 9 year-old reclaimed site for maize and cowpea respectively. These yields are equivalent to 1800kg/ha and 800kg/ha for maize and cowpea respectively that farmers get in that part of the western region of Ghana where the study was conducted.

CHAPTER ONE

INTRODUCTION

Mining is traditionally regarded as the world's oldest and the most important activity after agriculture. Throughout history, mining activities have made tremendous and significant contributions to the world's civilization. However, all these benefits have been offset by considerable negative impacts on the environment and on the health and safety of mine workers and mining communities. As a result of the growing public awareness of these costs and of the challenge of sustainable development, societies around the world are increasingly expecting the mining industry to apply higher standards of environmental, safety and community management to all projects through the application of modern technologies and management tools (Blinker, 1999).

The United Nations Environment Programme (UNEP) explains mining as a process that begins with exploration for and discovery of mineral deposits and continues through ore extraction and processing to the closure and rehabilitation of mined-out sites (UNEP, 2000). In terms of benefits, the mining sector is undoubtedly one of the most important sources of foreign exchange particularly in many sub-Saharan African countries. In Ghana, the mineral sector contributes in excess of 40% towards the country's foreign exchange earnings with gold accounting for 95% of most of the mineral export (Awotwi, 2003). It is estimated that gold together with manganese and bauxite provide about 100,000 jobs in the country (Aryee, 2001). Following its contribution to the socioeconomic transformation in the country, the industry has between 1984 and 1999, attracted about 4 billion dollars of direct foreign investment for mine development, expansion and extraction aimed at poverty reduction and enhancement of living standards (Minerals Commission, 2000). Some mining companies undertake infrastructural development such as schools and hospitals for their surrounding communities. Mining creates employment for both skilled and unskilled personnel of their surrounding communities.

Notwithstanding the benefits of mining, many communities and organizations see the benefits of mining being achieved at a high cost to environment namely access to portable water, loss of biodiversity, soil fertility, agricultural lands, increased fragmentation of communities as well as decline in the livelihoods of individuals, groups and communities.

These have over the years remained issues of great concern to conservationists, ecologists, policy-makers and all environmental advocates. Surface mining is perhaps the greatest agent of land destruction, utilizing over 13% out of the 240,000 km^2 of the remained forest in Ghana for mining activities (Awotwi, 2003). In the Tarkwa area alone, it is estimated that over 70% of the land previously used for farming activities is under mine concessions (Akabzaa and Darimani, 2001). It is on record that most of our productive forest reserves are sitting on precious mineral deposits and most of the mining concessions in Ghana are found in and around farming areas, forests and human settlements. Mining competition with farmlands often deprive farmers the right to ownership and employment. This situation usually frays the cultural, social and economic development of many farming communities (Mate, 1998). In spite of all these concerns, many view the industry as a necessary evil whose resources are required for development and at the same time need to be conserved. This therefore makes it more imperative for communities, mining companies and regulatory agencies to ensure that nexus between accrued benefits and conservation of environmental resources are grounded on ecologically sustainable principles (Grigg *et al.*, 1998).

It has been widely recognized since the late 20th century that reclamation is a desirable and necessary remedy ‘‘to return the mined areas to an acceptable environmental condition whether for resumption of the former land use or for a new use’’ (Redgwell, 1992), or to allow such lands to achieve their optimum economic value as much as possible (Bastida, 2002). In addition, reclamation is generally considered as an ongoing programme because of progressively growing environmental effects as mining evolves through the different stages of development (Walde, 1993). According to Lamb (2001), reclamation is widely used to refer to revegetation of highly degraded site such as mined or salt-affected lands. It aims to recover productivity of a degraded site mostly using exotic tree species. The original biodiversity is not recovered although the protective function and many of the ecological services may be re-established. Mining is a temporary use of land and; mine land reclamation is clearly justified from the perspective of sustainable development. Thus, it has become important part of the sustainable development strategy in many countries (Gao *et al*., 1998). Currently, most mining companies employ various reclamation techniques to impact on conservation values of degraded sites in anticipation of returning some pre-disturbance functions. It has therefore become necessary for governments, regulatory agencies, local communities and the industry itself to adopt strategies attributing landscape, flora and fauna properties to ensuring the functionality of reclaimed ecosystems (Elliot *et al*., 1996). Central to the process of sustainability of reclaimed sites is the integration of socioeconomic and ecological values of communities into mine design, planning and extraction consistent with the desired end used objectives. The re-vegetation process in some cases is manipulated to reflect such ultimate objectives. Even though reclamation is perceived to go concurrently with mining so that lands will be made available to the resource-poor farmers after decommissioning, little is known about the effects of the reclaimed sites on soil fertility indicators as well as their suitability for crop production.

Anglogold Ashanti, Iduapriem mine has won the best reclaimed mine site in 2007. It has therefore been perceived to adhere strictly to sound environmental principles. This study would enable the effectiveness of the already existing methods/strategies adopted by the mining companies for reclamation to be ascertained for possible conservations recommendations to be made. Working on the hypothesis that different reclaimed sites would affect soil nutrients and the yield of crops differently, it was the main objective of this study to assess the land reclamation practices at Anglogold Ashanti, Iduapriem mine Ltd., Tarkwa in the western region of Ghana.

The specific objectives were:

i. to identify reclamation practices adopted in AngloGold Ashanti, Iduapriem mine, Tarkwa;

ii. to assess the effect of reclamation practices on soil fertility indicators; and

iii. To monitor growth and yield of maize and cowpea on reclaimed lands

CHAPTER TWO

LITERATURE REVIEW

2.1 The mining industry of Ghana

In Ghana gold continuous to be the main focus of Ghana's mining industry although the country possesses other mineral reserves which include bauxite, diamond and manganese

(EIU, 1999). Ghana is Africa's second largest gold producer and has been the leading exporter since the 6th century (Morris, 1996; Grubaugh, 2002). The mineral industry has been the leading recipient of foreign direct investments (Boocock, 2002).

Mining activities dates as far back as the 5th century as the main indigenous economic endeavors in Ghana (Grubaugh, 2002). Just before independence however, Africa's share by value of world mining output declined steadily from 23% to 10% as a result of poor policies, political interference, poor investment climates, weak institutions, inadequate indigenous technical and processional manpower, as well as poor infrastructures (Allaoua and Atkin, 1993; Quashie, 1996).

Governments in many African countries including Ghana were consequently stressed with finance in fuelling the economic potential of the industry and no new mine was opened in Ghana over the past four decades until 1980 (Aryee, 2001).To remedy the situation, Ghana's mineral industry become state controlled immediately after independence to prevent mine closure, protect employment, increase state revenue as well as access the foreign currency generated from the mines (Tsikata, 1997).

Aside technological innovations, specific mineral and mining legislations had been promulgated in resuscitating the financial and institutional framework of the industry (Akabzaa and Darimani, 2001). The policy reforms bordering on tax breaks, tax exemption, labor policy, assets transfer, personal remittance quota, as well as reduction of imports duties had been vigorously effected (Campbell, 2003).

The implementation of these reforms had impacted positively on investment and production in the sector, attracting huge Foreign Direct Investment (FDI) in Ghana (Pigato, 2001). In 1999, a total of 19 operating companies and 128 local and foreign companies with exploration licenses were registered in Ghana (Coakley, 1999).

Productivity has subsequently increased steadily in Ghana over the past decade. The sector's contribution for instance, to the national Gross Domestic Products grew progressively from 15.6%, through 27% to 46% in 1986, 1990 and 1995 respectively (Minerals Commission, 2000). Gold production experienced the most rapid growth accounting for over 2.5 million ounces in 1999 alone.

Although the sector contributes to the socioeconomic development in the country, the reputation of the industry had been slipping over the past decade (Boateng, 1997). Public concern had over the years centered on health, safety, changes in non-renewable natural resources, habitat of flora, fauna, topography, hydrology as well as the stability of the landscapes resulting from the activities of the industries (Mulligan *et al*., 1999). Reported cases of cyanide spillage into various water bodies including Angonaban in 1996 and Huni in 2001 streams, increased land use conflicts as well as the liquidation and closure of Bonte mines and its implications in March, 2004 are some of the developments that had created bad legacy for the industry (Ayeboafo, 2005). These negative developments had necessitated the establishment of various legislative instruments to ensure that natural resources in the mining concessions and the local communities are well protected. The implementation of Environmental Management Plan (EMP) during mining operation encourages self regulation, compliance and the development of practical approach to environmental legislation and impact prevention (Acquah, 1995).

In Ghana as in many countries, the EPA Act (Act 490) and the LI (1652) contain provisions for mandatory environmental management plan in all undertakings. Companies are required by law to submit an EMP with one or every three years for a new and already existing undertakings respectively, again, proponents or companies whose activities are covered by EMP or Environmental Impact Statement (EIS) are also expected to submit annual environmental report, as well as copies of audits undertaken to the Environmental Protection Agency of Ghana for auditing. Although, the audit reports are unavailable to the public under the present legislation, it demonstrates companies' compliance with sound environmental protocols and also improves relations with regulators, neighbours and employees (Acquah, 1995). As a means of promoting self regulation and good environmental stewardship, the chamber of mines, a non-governmental mining advisory council has been created in Ghana to educate the public on mining laws and to promote the welfare of members.

2.2 Surface mining and its environmental impacts

The impact of the mining industry in the environment has been a public concern following the growing appreciation of the natural environment and the possible harmful effects that the industry's activities can cause. Although the activities of the mining industry occupy a relatively small part of the land surface, the scale and significance of environmental impacts had been more severe than other disturbances of the earth (Danielson and Logos, 2001). Interestingly, environmental impacts occur in all the phases of mine development (Farell and Kratzing, 1996).

The nature and extent of impacts can range from minimal to significant depending on various factors ranging from the nature of ore, type of technology, extraction methods and the sensitivity of the local environment to the mining operation. Mining is responsible for the destruction of fauna and flora habitats, changes in topography, hydrology and landscape stability (Mulligan, 1996). In the absence of lay down environmental regulations, mining activities can induce water and wind erosions of non stabilized waste rocks, tailing dams, air and water pollution, predation, pest and disease infestation (Knight, 1998).

In addition to waste management issues, mines also oppose environmental and social challenges due to potential disruptions to ecosystems and local communities. Mining requires access to land and other natural resources which have the tendency to compete with other land uses including agriculture (Ashton *et al*., 2002). Mining companies are often limited by the location of economically viable reserves some of which may overlap with sensitive ecosystems or traditional indigenous community lands.

Despite the introduction of various technologies at reducing the various environmental impacts, mining stills exerts strong pressure on the conservation of water, biodiversity and landscape ecosystems (Brooks, 1997).

2.2.1 Biodiversity and mining

Biological diversity describes the variety of organisms from the genetic, species, genera, families as well as higher taxonomic levels of ecosystem, interacting within particular habitats and the physical conditions under which they live. Despite its innumerable environmental services at the local, national and global levels (Doherty *et al*., 2000), losses to biological wealth had been a recurrent global issue in recent times.

In some conservation circles, the loss is related to developmental projects, land use changes, as well as variations in knowledge and application of biodiversity concepts .To other scientists, the decline results from the segregation of biodiversity legal frameworks from protected areas and other legislations.

Consequently, mining activities are sometimes permitted in protected and theory environmentally sensitive areas in some countries which conflicts principles underlying the conservation of biological diversity. In Ghana, for instance, government had lifted the moratorium placed in 1996 to pave way for forest zones mining within the forest reserves of Subri, Supuma, shelterbelts, Opon mansi, Tano suraw, Ajenjua, three points and Atewa range (Tassells, 2001).

Mining however within these forest reserves is likely to impact negatively on rivers; Densu, Ayensu, Birim, Bonsa, Ankobra and others considered to be biologically significant zones.

Some mining companies, many conservationists and non-governmental organizations have initiated various measures to safeguard biodiversity in the face of the continuing onslaught on ecosystems. Apart from declaring the protected zones as 'no – go areas' (Batini, 1997) in many countries, many scientists view the involvement of local communities in all phases of mining as the best way in protecting biological wealth in the industries.

2.2.2 Vegetation clearance and fragmentation

Indisputably, vegetation clearance presents one of the most significant threats to the conservation of biodiversity. It is estimated that, about 40% of the global terrestrial vegetation had been exchanged for mineral exploration, exploitation, and infrastructural development (Myers *et al*., 2000). In Ghana, mining together with other anthropogenic disturbances is believed to be responsible for annual loss of 22,000 hectares of the existing forest cover (EPA, 1996).

Vegetation clearance has devastating consequence on soil ecosystems. Apart from exposing the soil to higher temperatures, vegetation clearance depletes the soil nutrient levels ironically required for the growth of vegetation (FAO, 1993).

Despite various efforts at arresting deforestation; frequent clearance and non-sustainable conversion of forests to other forms of land use, including mining unabatedly threatens many ecosystems (FAO, 1993). Apart from the destruction of key ecological processes including habitat, soil fertility, hydrological functions, pollination, dispersal and species richness (ITTO, 2002), vegetation clearance promotes forest and habitat fragmentation into isolated, smaller habitat patches.

2.2.3 Mining and species invasion

The degree to which ecosystems respond to species invasion has been a major challenge to many ecologists (Lavorel *et al*., 1999). In fact their spread has been described as the ranging biological wildfire (Dewey *et al*., 1995). Plant species invasion according to Hall (2003) is defined as those species that have or are likely to spread into native plant communities causing environmental harm by developing self sustaining populations and disrupting other systems. Species invasion is influenced by many biotic and abiotic factors reflecting ecosystem properties, attributes of invading species and propagules pressure (Lonsdale, 1999). In general, site disturbances including mining activities that change habitat conditions and /or disrupt resource availability of ecosystems is known to facilitate or predispose ecosystem to species invasion (Perrings *et al*., 2002).

In many places of the world, the characteristics and use of exotic species for improving environmental value and restoration programme had impacted negatively on native biodiversity (Maron and Connor,1996; GISP,2001).The use of nitrogen fixing plants in restoration programme had been shown to facilitate the development of structures required for successful species invasion (Lonsdale, 1999). For instance, the high reproductive abilities as well as the vigor of many exotic species such as *Leucaena leucocephala, Casuarina equisitifolia, Chromolaena odorata*, are known to invade and modify community structure of many ecosystems (Ambika, 1996).

2.3 Heavy metals contamination in Mining

Mining and smelting operations are important causes of heavy metal contamination in the environment due to activities such as mineral excavation, ore transportation, smelting and refining, and disposal of the tailings and waste waters around mines (Dudka and Adriano, 1997; Navarro *et al*., 2008). Adverse environmental impacts from excessive heavy metals dispersed from mine and smelter sites include contamination of water and soil, phytotoxicity, soil erosion, and potential risks to human health (McLaughlin *et al*.,1999; Adriano 2001; Pruvot *et al*., 2006). Heavy metal contamination of agricultural soils and crops in the vicinity of mining areas has been regarded as a great environmental concern (Wcisło *et al*., 2002; Liu *et al*.,2005a; Kachenko and Singh, 2006).

Several studies in China, South Korea, and the USA have shown that water (Lin *et al*., 2007), vegetables (Chang *et al*., 2005; Zheng *et al*., 2007), rice (Yang *et al*., 2006), and even fish (Schmitt *et al*., 2007) are often contaminated by heavy metals dispersed from mining and smelting operations. Li *et al*., (2006b) found that Chinese cabbage growing in the vicinity of non-ferrous metals mining and smelting sites in Baiyin, China, contain high concentration of Cd exceeded the maximum permitted levels (0.05 mg kg^{-1}) by 4.5 times. In the vicinity of a Pb/Zn mine in Shaoxing, eastern China, it was reported that the respective Pb and Cd concentrations of some vegetables were 20 and 30 times higher than the permitted standards (Li *et al*., 2006a). Clearly, not only the ingestion or inhalation of contaminated particles, but also the ingestion of plants produced in the contaminated area is another principal factor contributing to heavy metal of exposure for population. It has been recognized that food crops can be an important source of heavy metals for humans and animals (Dudka and Miller, 1999). Both heavy metal uptake via roots from contaminated soils and surface water, and direct deposition of contaminants from the atmosphere onto plant surfaces can lead to plant contamination by heavy metals.

Lead and Cd are considered potential carcinogens and are associated with etiology of a number of diseases, especially cardiovascular, kidney, blood, nervous, and bone diseases (Jarup, 2003). Although Zn and Cu are essential elements, their excessive concentration in food and feed plants are of great concern because of their toxicity to humans and animals (Kabata-Pendias and Mukherjee, 2007). Cultivation of crops for human or livestock consumption can potentially lead to the uptake and accumulation of these metals in edible plant parts with a resulting risk to human and animal health (Gupta and Gupta,1998; Lim *et al.*, 2008). Serious systemic health problems can develop as a result of excessive dietary accumulation of heavy metals such as Cd and Pb in the human body (Oliver, 1997). Lacatusu *et al*., (1996) reported that soil and vegetables polluted with Pb and Cd in Copsa Mica and Baia Mare, Romania, significantly contributed to decreased human life expectancy within the affected areas, reducing average age at death by 9–10 years. In France (Pruvot *et al*., 2006) and Brazil (Bosso and Enzweiler ,2008), it was reported that children living around a former smelter had high blood Pb levels. Turkdogan *et al.*, (2002) suggested that the high prevalence of upper gastrointestinal cancer rates in the Van region of Turkey was related to the high concentration of heavy metals in the soil, fruit, and vegetables. Dietary intake is the main route of exposure for most people, although inhalation can play an important role in highly contaminated sites (Tripathi *et al.*, 1997). Thus information about heavy metal concentrations in food products and their dietary intake is very important for assessing the risk to human health.

In China, there are over 9,000 state-owned and 30,000 private mining companies, and large amounts of hazardous wastes are released from base-metal mining and smelting operations annually. Cumulative use of land by mining was approximately 1,500,000 ha by 2006, with 60% of this area impacted by mine tailings (MEPPRC, 2006). Metal ore processing usually leads to multimetal contamination of the environment, and topsoil in the vicinity of mines and smelters contains elevated concentrations of heavy metal (Dudka and Adriano, 1997). Dabaoshan mine area (Guangdong, southern China) has been confirmed to have soils and waters severely pollution by heavy metals (Zhou *et al*., 2007; Lin *et al*., 2007). Mining activities during the past four decades have generated large quantities of mine waste materials without any proper treatment. It has been reported that mining activities polluted approximately 83 villages, 585 ha of paddy fields and 21 ha of ponds around this mine. In the vicinity of Dabaoshan mine area, the number of cancer cases (oesophageal cancer, liver cancer, etc.) is about nine times above the normal incidence of cancer, and the mortality rate approaches 56% (Liu *et al*., 2005b). Environmental surveys conducted by the Ministry of Health have shown that children living around the mine area had higher blood lead levels than those living in non contaminated sites (Liu *et al*., 2005b). This exposure has been probably attributed to the consumption of drinking water and crops contaminated by mining activities.

The use of hazardous chemicals in mining operation constitutes a major source of pollution to both surface and underground water bodies. Chemicals leaching from waste rocks, tailings dams and the surface of open pits often create long term effects of acid mine drainage. Acid mine drainage (AMD) occurs when sulfide bearing minerals, such as pyrite or pyrrhotite, are exposed to oxygen or water rock piles, mine openings, and pit walls. Apart from altering the pH of soil and water bodies, AMD is responsible for the release of more common pollutants including iron, manganese, aluminum, zinc, cadmium, lead and other metals, sulfate, acids, nitrate and suspended solids (Younger, 2000).

While small amounts of heavy metals are considered essential for the survival of many organisms, higher levels of these metals are toxic to many organisms and often cause avoidance behavior in fishes as well as death in birds, fishes, man and some micro invertebrate communities in many places of the world. The use of cyanide and mercury in beneficiation processes is known to pose serious health and safety threats to many communities. Despite its high ore recovery rate and rapid decomposition (Kelly, 1998), cyanide complexing with other metals for mineral processing is believed to adversely affect fishes, birds and humans. Moreover, traces of mercury used in amalgamating gold particles during the beneficiation processes has been found in some plant and animal tissues in some aquatic ecosystems (Hilson, 2002). Once stored in tissues, it can be passed on to offspring; often producing anorexia, lethargy, muscle ataxia, visual impairment and other central nervous system disorders in young birds, fishes and man (Hilson, 2002). To address these impacts, many countries including Ghana have put in place legislations to ensure compliance with water quality standards or guidelines in many industries including the mining sector.

2.4 Tailings

Tailings consist of ground rock and process effluents that are generated in a mine processing plant. Mechanical and chemical processes are used to extract the desired product from the run of the mine ore and produce a waste stream known as tailings. This process of product extraction is never 100% efficient, nor is it possible to reclaim all reusable and expended processing reagents and chemicals. The unrecoverable and uneconomic metals, minerals, chemicals, organics and process water are discharged, normally as slurry, to a final storage area commonly known as a Tailings Management Facility (TMF) or Tailings Storage Facility (TSF). Not surprisingly the physical and chemical characteristics of tailings and their ability to mobilise metal constituents are of great and growing concern (ICOLD and UNEP, 2001).

Tailings are generally stored on the surface in retaining structures but can also be stored underground in mined out voids by a process commonly referred to as backfill. Backfilling can provide ground and wall support, improve ventilation, provide an alternative to surface tailings storage and prevent subsidence (EC, 2004). The challenges associated with tailings storage are ever increasing. Advances in technology allow lower grade ores to be exploited, generating higher volumes of waste that require safe storage. Environmental regulations are also advancing, placing more stringent requirements on the mining industry, particularly with regard to tailings storage practices. This ultimately places added pressure on the operators of a tailings facility who carry out the day to day roles of tailings discharge and water management. The majority of historical tailings related incidents have been influenced by poor day to day management, which has resulted in the strengthening of regulations controlling tailings storage today. Tailings are a waste product that has no financial gain to a mineral operator at that particular point in time. Not surprisingly it is usually stored in the most cost effective way possible to meet regulations and site specific factors. Dams, embankments and other types of surface impoundments are by far the most common storage methods used today and remain of primary importance in tailings disposal planning (Vick, 1990). The particular design of these retaining structures is unique to a particular environment and mining operation. When considering the design of a tailings storage facility there are many parameters which impact on the optimum site selected and the storage and tailings discharge methods used (Ritcey, 1989). The environment is the most crucial parameter constraining tailings storage which ultimately affects the way a facility is designed, built, operated and closed. For this reason a range of alternate methods of tailings storage and discharge techniques need to be considered when designing a facility for a particular location.

2.4.1 Tailings and Acid Mine Drainage

The process of beneficiation of run of the mine ores and subsequent disposal to surface containment facilities exposes elements to accelerated weathering and consequently increases mobilisation rates. The addition of reagents used in mineral processing may also change the chemical characteristics of the processed minerals and therefore the properties of the tailings and waste rock (EC, 2004). Problems arise when this accelerated weathering process generates toxic levels that create short and long term tailings management challenges. The processing of hard rock sulphidic bearing ores is just one example of the potential problems associated with accelerated weathering. In this case the sulphide minerals more readily oxidise in the tailings facility as a result of the size reduction from milling increasing the surface area and thus exposure of the tailings to air and water. Acid generation and metal mobilisation occur that eventually find their way into the surrounding environment through runoff or seepage. This phenomenon is a well known problem affecting the mining industry and is commonly known as Acid Mine Drainage (AMD) or Acid Rock Drainage (ARD) (Garcia *et al.*, 2005; Ritcey, 2005).

Globally, the release of Acid Mine Drainage (AMD) poses a great challenge to many restorationists. Currently, AMD managements in many companies entail strategies for preventing and / or containing processes of acid mine drainage. Surface mining companies operating on sulphidic areas usually rely on strategies that reduce water contact with waste rocks, tailings, exposed rocks as well as other potential acid generating materials.

In some companies, the establishment of surface water diversion structures including drainage and collection ditches, alkaline loading ponds, soil and plastic linings, installation of water pump, peripheral deep wells on or around the waste dumps and other acid generating materials are intended to decrease water contact and effect of AMD materials on down streams (Perrings *et al.,* 2002; Gentile and Duggin, 1997). Moreover, impounding or flooding acid generating rocks to reduce pyrite oxidation processes and metal contaminating and AMD effects had been employed in many places (Pedersen *et al*., 1997). In addition to recycling over 98% of water used for mineral processing, the existence of collection ditches and rapid revegetation techniques are intended to reduce the ingress of water and its consequent AMD discharged on the Waste dump within the concession of AngloGold, Iduapriem mine (pers. comm., 2009). Rapid revegetation controls erosion, enhances evapotranspiration, fauna abundance and soil fertility (Loch, 2000).

The disposal of tailings is commonly identified as the single most important source of environmental impact for many mining operations (Vick, 1990). This is not surprising when considering that the volume of tailings requiring storage can often exceed the in-situ total volume of the ore being mined and processed. Over the last century the volumes of tailings being generated has grown dramatically as the demand for minerals and metals has increased and lower and lower grades of ore are being mined. In the 1960's 10's of thousands of tonnes of tailings were produced each day and by 2000 this figure has increased to 100's of thousands (Jakubick and McKenna, 2003). Understanding the mineral processing techniques can help to determine how tailings are produced and the challenges associated with their storage.

2.5 Health issues in mining

Apart from environmental and socio-economic concerns, there has also been an illuminating public health concerns regarding mining activities. Issues of mine sites accidents including HIV/AIDS infections, respiratory tract infections, skin diseases, malaria and other related diseases have become common in many mineral – rich communities (Labonne and Gilman, 1999). Standing waters in mine pits and other structures have contributed significantly to high prevalence rates of malaria in many cases, health problems are exacerbated by lack of health services in many remote communities where mining activities are conducted. The health impact of mercury in many artisanal mining operations in Ghana and other parts of the world including Brazil, Guinea, and Philippines, is well documented in literature including Frey, N.R. and Maury – Brachet (2001). Also, mining related air pollutants including dust, sulphur dioxide, carbon monoxide, and nitrogen dioxide resulting from site clearance, drilling, blasting, haulage, vehicular movements, as well as ore and waste handling have increased respiratory related infections in many communities (Akabzaa and Darimani, 2001).

In Tarkwa area of Ghana for example, respiratory tract infections together with skin diseases and acute conjunctivitis were ranked among the top ten diseases in the region (Avotri, 2001). In many places in the world, dust with silicon content had been linked to high prevalence rates of Silocosis and Silico-tuberculosis (Akabzaa and Daramani, 2001). The World Health Organization (WHO) adopted a strategy on health and environment in Africa with the cardinal objective of stimulating the development of health policies towards sound management of environmental determinants of health. In responses to this policy, many mining institutions have formulated safety policies to reduce the potential health hazards in the industry. In addition health posts have also been established at various work places to deal with issues on site.

2.6 Reclamation

Mining companies undertake reclamation of degraded areas to comply with state environmental regulations in many countries. Apart from adhering to the preparation and submission of the reclamation plan, mining companies are mandated in many countries to post a pre-mining financial assurance or security in the form of cash, letters of credit, surety bonds, or trust fund to cover the cost of environmental damages in circumstances of insolvency during the closure (Laurence, 1999). In the United States for instance, a bank surety or the operator itself guarantees funding sufficient for a regulatory authority to undertake or complete the mine reclamation obligation.

Generally, reclamation bonds are calculated and periodically reviewed to equilibrate operational cost, closure as well as addressing long term impacts to wildlife, soil and water quality (Mining environmental Management, 1999). Ghana's reclamation bond is reminiscent of the United State legislation. Act 490, the PNDC Law 153 as well as LI 1652, entrench reclamation of mined surface upon cessation of mining activities. Closure certificate as in many countries is issued only if the reclamation plan has been implemented to the satisfaction of the communities, and regulatory authorities. In pursuance of section 24 of the Environmental Assessment Regulations (1999), reclamation policies in Anglogold, Iduapriem mine had been implemented in tandem with mining in order to return the land to its pre-mining state. Policies bordering reclamation of pits, waste dumps, and rompads, tailing dams, water bodies, and the final land use objective had been set up (EPA, 2005).

2.6.1 Main objectives of mine land reclamation

Since the Brundtland Commission first put forward the concept of sustainable development, all industries have been seeking ways to perform in a more sustainable manner. The mining sector is no exception. The extraction of minerals can have a number of impacts, topographical, ecotoxicological and socio-economic, from operation to closure. To achieve sustainability, the mining industry should pursue ‘‘the combination of enhanced socioeconomic growth and development, and improved environmental protection and pollution control’’ (Hilson and Murck, 2000). Mine land reclamation constitutes an integral component part of mine sustainability, which is, as Morrey (1999) explains, to achieve ‘‘physical stability, waste management and acceptable land use’’, and as Kahn *et al*. (2001) add, to improve resilience, productivity and biodiversity of the land. The amelioration sometimes is both technically and economically difficult; therefore, the realistic objectives of land reclamation may differ significantly from the ideal goal of site rehabilitation. However, in the context of long-term land sustainability, reclamation may provide the potential for ecological adjustment or for practical reuse of mined land. Specifically, the principal objectives include but are not limited to the following (partly adopted from Warhurst and Noronha, 1999; Morrey, 1999):

- to eliminate health and safety hazards (e.g. dismantling all facilities and structures threatening human health and safety);
- to restore impacted land and water resources (e.g.revegetating progressively and stabilizing residues to reduce potential of acid mine drainage or water contamination);
- to eliminate off-site environmental impacts (e.g. cleaning up sites to conform to the community’s surrounding landscape);

- to ensure that post-mining land has a viable self sustaining future with respect to both environmental and socio-economic benefits (e.g. developing publicly owned land for recreation, historic purposes, conservation purposes, or open space benefits, or for constructing public facilities in communities);
- to encourage better use of energy and natural resources and to guarantee sustained mining operations.

Different mines have different rationales and methods for site rehabilitation, and it is not feasible to restore all mine sites, as restoring or backfilling very large pits may be very difficult and uneconomic. But, ultimately, all land disturbed by mining activities has some potential for economic, recreational and aesthetic use. So the core of reclamation is to identify the unique potential of mined land and to choose appropriate technologies and measures to transform this potential into a sustained capability (Morrey, 1999). Reclaimed sites have a wide range of potential functions such as pasture, hay land, recreational areas, wildlife habitat, wetlands, fishing ponds, and swimming pools. Some scholars insist that the achievement of sustainable mining requires proactive mine management (Hilson and Murck, 2000). Despite the validity of this argument, it is also imperative to have accompanying legislation and regulatory frameworks in place to provide the incentives and frameworks for these mining companies.

The absence of either of them would possibly lead to failure or at least lower effectiveness of the mine management, and would thus undermine the goals of sustainable mining. The following section examines the importance of legislation and regulatory frameworks to mine land reclamation.

2.6.2 Institutional frameworks on reclamation

Regulatory effectiveness over reclamation performance, to a large extent, is dependent on sound cooperation between authorities at all levels of government towards common reclamation objectives, and also by a clear definition of responsibilities. The early 1970s saw global efforts to control and mitigate environmental impacts through institutional reform, with a trend characterized by a shift from a dispersed obligation mechanisms towards the creation of separate environmental authorities with increasingly independent powers (Walde, 1993; Wagner, 1998). The US Environmental Protection Agency (EPA) was created in 1970, empowered to promulgate regulations for the implementation of environmental laws covering water, solid waste, air and radiation, pesticides and toxic substances, to minimize conflicts and inconsistencies, to facilitate compliance and regulatory enforcement, and to conduct environmental research on problems and their mitigation methods. Since then it has become the only regulatory agency in the federal environmental bureaucracy that reports directly to the President.

Developing countries have also founded their state environmental agencies. Venezuela first set up its Ministry of the Environment in 1977. This was followed by the creation of the Ministry of Sustainable Development and Environment in Bolivia, the Secretariat of Environment, Natural Resources and Fisheries in Mexico, the Secretariat of Natural Resources and Sustainable Development in Argentina and the Ministry of Environment in Colombia. Some Asian countries as China, Mongolia, Vietnam and Indonesia have also established their independent state environmental protection agencies. But unfortunately, some of these institutions are functioning poorly (Weber-Fahr *et al*., 2002) and it is rare for all environmental matters to be handled in these countries within the jurisdiction of a single agency as is the case of the US EPA. More often, multiple departments will be involved commonly with confused tasks. China's State Environmental Protection Agency (SEPA) was promoted to a ministerial status in 1998, but so far it has not been empowered to have a final say on key projects, nor had direct responsibility for the implementation of environmental laws and regulations.

Likewise, although tasked with overall monitoring and diagnosing environmental problems including mining issues, the capability of Zimbabwe's Department of Natural Resources has been limited to date (Hollaway, 2000). In this respect is the division of authority over environmental issues among a number of ministries: for example, water pollution falls to the ministry of water, reclamation to the ministry of land, and hazardous substances to the ministry of health. This results in either duplication and inefficiency or omission and non-implementation. Weber-Fahr *et al*., (2002) have given a forcible illustration with the example of Peru where, within the Ministry of Energy and Mines (MEM), some groups are tasked with promoting the mining sector, while others have the authority to prevent environmental damage in the sector and to monitor performance.

It is clear that competent and independent institutions with balanced interests are needed. The process of institutional reform in many developing countries has been encouraging and impressive. But, at the same time, the complexity in jurisdiction and the regulatory frameworks has revealed more or less a contradictory ideology for objectives and benefits of various departments. As Otto *et al*., (1999) noted, these frameworks generally seek to reconcile the benefits between mining and the costs to control or mitigate resultant negative environmental effects.

In reality or in perception, different parties apply different measurements in calculating cost and benefit, therefore arriving at a different assessment of the balance (Andrews-Speed *et al*., 2002). The key to resolving the complexity lies in the assessment and the balance of the tradeoffs between environmental protection and the various invested interests. It may indeed be utterly groundless to deny a sectoral approach to environmental management where technical expertise is easily accessible and issues involved are better understood. However, an integral approach is usually preferable with an environmental governance institution established detached from any specific sector but forming part of the overall development planning scheme (Weber-Fahr *et al.,* 2002).

2.6.3 Ecosystem Restoration strategies

Increased public concern for ecosystems destruction has led to the unprecedented interest in ecological restoration (Bradshaw, 2002). Though frequently used interchangeably with rehabilitation, reclamation and replacement to cover large array of activities involved with ecosystem repairs (Harris *et al.*, 1997), a clearer understanding regarding these terminologies is necessary. Ecological restoration refers to the reinstatement of the original ecosystem that has the capacity to repair, enhance, capture and retain processes of energy, water, nutrient and species from the structural and functional perspectives (Hobbs and Norton, 1996). Rehabilitation describes progressive efforts towards the reinstatement of original ecosystems (Johnson and Tanner, 2004). Also, reclamation describes various activities aimed at improving the quality of the ecosystem by impacting some valuable ecosystem functions desirable of communities, government and individuals and replacement is the creation of an alternative ecosystem of the original (Bradshaw, 2002). In simple terms, ecological restoration may be equated to primary succession or recovery of mined land when it is largely left to natural processes after disturbance (Johnson and Tanner, 2004).

In most places, technique for restoring degraded mine sites had relied on the priorities and objectives of the stakeholders, the cost, benefits as well as the socioeconomic and environmental values of land resources in their current and desired future states (Carnorgo *et al.,* 2002). Studies on abandoned mining areas had lent support to the recovery of ecosystems without intervention (Bradshaw, 2002). Though highly embraced in the industry, the sequence of sucesssional trajectory associated with this technique is complex and unpredictable (Parker, 1997). In some places, the reclaimed site may yield a biodiversity different from the original ecosystems (Johnson and Tanner, 2004). Despite reducing biological wealth, there is an increasing interest in plantations techniques in harmonizing long term forest ecosystem restoration goals with near-term socio-economic development objectives (Lamb and Gilmour, 2003). Plantation is known to enhance soil moisture, litter accumulation, vegetation growth and temperature reduction, towards ecosystem recovery (Parrotta and Knowles, 1997). In practice however, the principal restoration option for highly disturbed sites involves the amelioration or reclamation towards site improvement and species adaptation in a way which seek to conserving biodiversity and ecosystems functions (Johnson and Tarmer, 2004).

2.6.4 Revegetation

According to Lamb (1994), techniques for revegetation depend on the priorities and objectives of the stakeholders, cost, benefits, and economic, social and environmental values of the reclaimed sites. At AngloGold Iduapriem, the initial revegetation or reclamation strategies involve the use of vetiver grass, centrosema, pluraria and other leguminous cover species to be proceeded with woody or shrub species which promote long term ecosystem processes. The establishment of the woody species stage is usually either left to the natural invasion of locally adaptable species or may be accomplished via direct seeding or transplanting techniques (Withes, 1999).

Known to be economical and reliable strategy for revegetation in many places, the success of direct seeding is contingent upon seed viability, supply and vigor (Parrotta and Knowles, 1997). Nonetheless, increased innovations in broadcasting and dormancy breaking techniques in recent times had contributed to the success of direct seeding in revegetation (Dixon *et al*., 1995,).

Decision to use local or wide range of provenances has become critical in global reclamation programme (Faulconer *et al*., 1996). Local provenance is known to preserve the genetic integrity representative of original ecosystems. In many places however, the cost of topsoil re-spread, as well as the physical and chemical properties of degraded sites necessitate the use of wide range of provenances.

2.6.5 Completion criteria and success indicators

Completion criteria have been defined as reclamation success objectives (Johnson and Tanner, 2004). The success indicators are usually generated on site specific basis to enable regulatory agencies, communities and mining companies to judge the success or otherwise of reclamation programme (Elliot *et al*., 1996).

Despite meeting the expectations of communities and regulatory agencies (Hobbs and Norton, 1996), the scientific basis for establishing reclamation success criteria had been widely criticized in recent times (Walker and del Moral, 2003). In the past, success indicators were based on narrow set of vegetation parameters measuring only early stages on revegetation.

Present indicators however integrate approaches embracing self regularity, impacts mitigation, predictability as well as socially relevant components of the reclaimed ecosystems (Ludwig *et al*., 1997). In reality, judging reclamation success is not amenable to hypothesis but depend upon actual demonstration of frequent monitoring of change associated with ecosystem processes (Bell, 1996). Reclamation is only deemed successful and agreed upon only when the site can be managed for its designated land use without any greater management input compared to other lands used in the same way (Laurence, 1999). In AngloGold Iduapriem, reclamation success is measured by company's performance regarding erosion control, canopy formation, species complexity, water quality, weed control, soil enrichments, and public safety issues alongside time, cost and benefits to the local communities (pers. comm., 2009).

2.6.6 Monitoring and reclamation success

The principal objective of environmental monitoring in many mine sites is the integration of mitigation actions into mining and reclamation activities towards good environmental performance (Asher and Bell, 1999). Regular monitoring of flora and fauna on both reclaimed and adjacent undisturbed areas enable environmental mangers to understand annual variation in species diversity and abundance which could otherwise be misinterpreted. During mining, monitoring provides feedback mechanism regarding the success and maintenance of mitigation measures, requirement for additional and /or corrective mitigation measures, as well as appraisal of the overall EIA processes (EPA-Ghana, 1996). At closure, monitoring contributes remarkably towards the success of ecosystem recovery (Asher and Bell, 1999). Monitoring creates the platform for detecting changes in water, air and land properties associated with the implementation of reclamation plan (Viljoen, 1998). In Ghana, monitoring is strictly mandatory particularly in areas with high environmental sensitivities and significance, where impacts are uncertain as well as fragile habitats (Fitzgerald, 1993; Allen *et al.,* 2004 EPA-Ghana, 1996).

Until recently, biodiversity monitoring programme in many companies had concentrated on few vegetation indices with no or few passing reference to fauna. In practice however, credible appraisal of biodiversity units measures complexity of species, resilience to fire, disease, and pest disturbances (Purvis and Hector, 2000).

Currently, mining companies employ monitoring techniques including Remote Sensing (RS), Regional Significance Analysis (RSA) and Ecosystem Functional Analysis (EFA) in assessing ecosystem composition (Kearns and Barnett, 2001)

Monitoring programme in AngloGold Iduapriem, include increases associated with diameter at breast height (dbh), leaf length, leaf area index, canopy cover, litter accumulation, water quality and soil fertility as well as ability of reclaimed sites to support plant growth (Addo, 2008). In assessing the progress towards soil fertility and its sustainability, a trial farm cropped with oil palm, banana, pineapple and cocoa had been established at some portions of the old tailings dam site within the concession to monitor the fertility level of the soil (Addo, 2008).

2.6.7 The level of community participation in reclamation success

The inclusion of the socioeconomic welfare of the local communities is an investment of critical importance in today's mining operations. To many, it is a process of concern revelation and door to success. The establishment of mining companies arguably in the rural areas comes along with it infrastructural developments, employment opportunities and building capacity of communities. In return for their investments, the mineral industry expects the local communities to assist in reclamation programme and other related closure activities.

Apart from land acquisition and payment of royalties, extensive consultations with the affected communities throughout the mine life assist in diagnosing potential points of conflict. This requires maintenance of constant dialogue with the public, informing them of planned mitigation measures and their inputs. Advance consultation prior to exploration or mining is a key not only to win community support, but promote positive corporate image, competitive advantage, and sustainable resource management for the mining companies.

Consequences of poor consultation however, result in significant cost to humans, environment and the states. Usually, it escalates social ills including stealing, molestation, family disintegration, unnecessary confrontation as well as threat to desired objectives of reclamation. In September, 2003, for instance, equipment valued 5.5 million dollars belonging to KAS mining company in the Amansie West District of Ashanti were allegedly vandalized by the local communities as a result of perceived poor consultation.

Again, in 2002, the Peruvian community of Tambogrande voted to reject mining in their community due to the projected displacement of half of its residents as well as fears about the potential impacts on the community's traditional livelihood. According to a study, displacement may result in serious social problems, including marginalization, food insecurity, and losses of access to common resources, public services, and social breakdown (Digby, 2002).

As a step in reducing pressure on reclaimed sites, many mining companies currently employ local communities in various stages of their reclamation efforts. These include weed and fire control, supply of native seeds, seedling establishment and maintenance of trial farms and soil conservation research (Fitzgerald, 1993). In AngloGold Iduapriem, the local community is employed in various stages of their reclamation efforts. These include weed and fire control, supply of native seeds, seedling establishment and maintenance of trial farms (Addo, 2008).

In addition, communities are periodically consulted to make inputs into the current reclamation projects. Again, relinquishing unmined lands to landowners for farming as well as granting site access to indigenous people are additional steps towards ensuring the success of reclamation activity.

2.7 Soil chemical properties

The soils under the reclaimed sites must have the ability to support plant growth in order to satisfy the end-use objectives. The reclaimed sites must contain appreciable soil nutrients required to support plants growth so that the resource-poor farmer can do farming in a similar manner as the nearby undisturbed lands.

2.7.1 Nitrogen

Nitrogen (N) is the nutrient that is most frequently limiting to crop production and the nutrient applied in the greatest amounts (Campbell *et al.*, 1986). It is a part of all plant proteins and component of DNA and RNA. Nitrogen is required for assurance of optimum crop quality as protein content of crops is directly related to N supply (Grant and Flaten, 1998). It is also of major concern with regards to environmental sustainability because nitrate leaching can reduce water quality and N_2O emission can contribute to the greenhouse gas effect and global warming (Campbell *et al.*, 1995). Reclaimed soils are therefore supposed to attain a very good nitrogen status to support plant growth.

2.7.2 Phosphorus

Phosphorus (P) is involved in energy dynamics of plants (Zublena, 1997). Without it, plants cannot convert solar energy into the chemical energy needed for the synthesis of sugars, starches and proteins. Phosphorus, Nitrogen and other nutrients need to be available to the crop in balance to optimize crop yield and quality and efficiency of crop production (Halvorson and Black, 1985).

2.7.3 Potassium

Except nitrogen, potassium is a mineral nutrient plant require in the largest amounts (Marschner, 1995). Potassium (K) is involved in photosynthesis, sugar transport, water and nutrient movement, protein synthesis and starch formation (Zublena, 1997). It also helps to improve disease resistance, tolerance to water stress, winter hardiness, tolerance to plant pests and uptake efficiency of other nutrients.

2.7.4 Exchangeable calcium and magnesium

Calcium (Ca) is one of the essential elements obtained from the soil by plants and used in relatively large quantities. It is a macronutrient and also a secondary elements since it is usually added to the soil indirectly during the application of materials containing the primary fertilizer elements - NPK (Hesse, 1998). Magnesium (Mg) is an essential part of the chlorophyll molecule. It is also involved in energy metabolism in the plant and is required for protein formation (Zublena, 1997). According to Hesse (1998), Mg occurs in soils, principally in the clay minerals, being common in micas, vermiculites and chlorites. Welte and Werner (1963) investigated the uptake of Mg by plants as influenced by hydrogen, calcium and ammonium ions. They found that hydrogen ions suppressed Mg uptake most and with a strongly acid substrate, Mg deficiency could be remedied by applying Mg and the pH raised. Zublena (1997) state that depletion of Ca and Mg reserve in the soil by crop removal is rarely a problem in limed soil because of the large quantity of these nutrients that are present in liming materials. However, some crops, such as peanuts, may require more Ca than the crops can remove.

2.7.5 Soil pH and Acidity

Soil pH is the deciding factor for the availability of essential plant nutrients (Rahman and Ranamukhaarachchi, 2003). Nitrates and phosphates are taken up at higher rates in weak acidic conditions (Mengel and Kirkby, 1982). Fageria and Baligar (1998) found the soil pH and base saturation are important soil chemical properties that influence nutrient availability and crop growth. The soil pH influences the occurrence and the activities of soil microorganisms and eventually affects both organic matter decomposition and nutrient availability (Mengel and Kirkby, 1982). Although temperature, soil moisture and the quality of carbon and nutrients determine the overall organic carbon turnover in soil, soil matrix characteristics (such as clay content, Al and Fe content and soil pH) moderate carbon turnover in soil (Dalal, 2001). Soil pH less than 5.5 promotes fungal activity and at higher levels makes bacterial more abundant (Trolldenier, 1971). The nitrification process and its rate brought about by *Nitrosomonas* and *Nitrobacter* bacteria depends considerably on soil pH because these bacteria prefer more neutral soil conditions. In strongly acidic soils the native nitrate content is therefore, extremely low (Mengel and Kirkby, 1982). Bacterial growth rates are generally more sensitive to low pH than fungal growth rates (Walse *et al.,* 1998). Microbial biomass and lignin decomposition appears to be not significantly affected by soil acidity at pH range of 4.5-6.5 (Donelly *et al.,* 1990). However, in acidic pH less than 4.5, microbial activity as well as nutrient turnover is greatly reduced (Santa, 2000). The combined impact of H^+ and Al^{3+} on microbial activity and organic matter decomposition could be modeled with ion exchange expression, such as vanselow expression (Walse *et al.,* 1998). Acidic soil pH dissolves Al and other metals from the mineral soil surfaces, which enter the soil solution. In podosols, Al is mobilized in the alluvial horizons under the predominant influence of organic acidity, and then leaches down the profile as organically bound to bidentate organic sites (Nissinen *et al*., 1999).

2.8 Soil physical properties and soil fertility relationship

Soil texture is the most fundamental attribute of soil fertility. Farmers around the world recognized that soil fertility increases with clay content and that high clay soil are prone to drought in dry areas and to flood in wet areas (Woomer and Swift, 1994). The quantity of ions that a soil can retain against leaching is determined by the magnitude by the ion exchange capacity. The ion exchange is located on soil organic matter (SOM) and clay surface. SOM also follows a linear relationship with clay content. Most of the N in terrestrial ecosystems and a large part of the P is found within the SOM. The soil properties that contribute to the formation and stabilization of macro aggregates include soil texture, clay and mineralogy, exchangeable cations, Fe and Al oxides, calcium carbonate as well as SOM (Le Bissonnais, 1996).

2.9 Summary of Literature Review

The literature review suggests that reclamation practices have significant impact on soil fertility indicators and crop production. It indicates the immense importance of community participation in mined land reclamation. Reclamation is often perceived to have been done before the decommissioning of the mine to the Government and subsequently to the affected communities whose main occupation is farming. However, information and knowledge on the suitability of the mined reclaimed sites for plants growth is lacking. Issues and information of heavy metal contaminants that can result from mining activities and entering food chains with its associated health risks to the resource-poor farmers are limited in our studies. The review indicates that success criteria for mined land reclamation is based on meeting the end-use objectives of the reclamation which is contained in a Reclamation Security Agreement signed between the EPA and the mining companies. The review also indicated that there is an institutional framework guarding mine land reclamation in Ghana and this must be adhered to by all mining companies in conjunction with the surrounding communities. Since most of the precious mineral deposits are situated in forest reserves and farming communities, effective mined land reclamation is needed to make land available to the resource-poor farmers. There is therefore the need to make sure the accrued benefits of mining and conservation of the resources are grounded on sound ecological principles. These observations further substantiated justification for this study and this formed the basis for the formulation of its objective

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of study area

The research was carried out at Anglogold Ashanti, Iduapriem concession area. The Iduapriem Gold Mine, a subsidiary of the AngloGold Ashanti Limited operates an open pit gold mining involving drilling and blasting as well as hauling and dumping; and the processing of ore by Carbon-In-Leach (CIL) methods near Tarkwa in the Western Region of Ghana. The mine operations started in June 1992 and have so far produced more than two million ounces of gold (EMP, 2007).

Geologically, the Iduapriem Mine is located along the southern end of the Tarkwa basin. The topography of the concession area consists of series of ridges and hills within the Tarkwaian system; which mainly comprises the Banket Series. The Banket series of rocks in the mine area form prominent, accurate ridges extending southwards from Tarkwa, westwards through Iduapriem and northwards through Teberebie to Mantraim. There are seven major ridge segments within the Iduapriem/Teberebie mining lease and the Banket series rocks they comprise extend over a total strike length of some 15 km. The Ajopa Range, part of the mining lease is enlogated, narrow, steep sided ridge which is oriented in a south-west to north-east direction and reaches a maximum height of 251m above sea level. The Ankobra Range which lies to the west of the Ajopa Range is orientated in a north-south direction and again in a narrow and steep sided. Gold mineralization occurs throughout the Banket Reef Zone predominantly within the matrix of the conglomerates. Ore mineralization occurs within seven specific areas at Iduapriem/Teberebie and within Ajopa Range. The mining interests cover three main concession areas; namely, the

Idaupriem mining Lease of 34 hectares; the acquired part of the Teberebie Mining Lease (TML) adjacent Ajopa – North Range (Ajopa Prospecting License) of 48 hectares area in the northwest (Fig. 3.2).

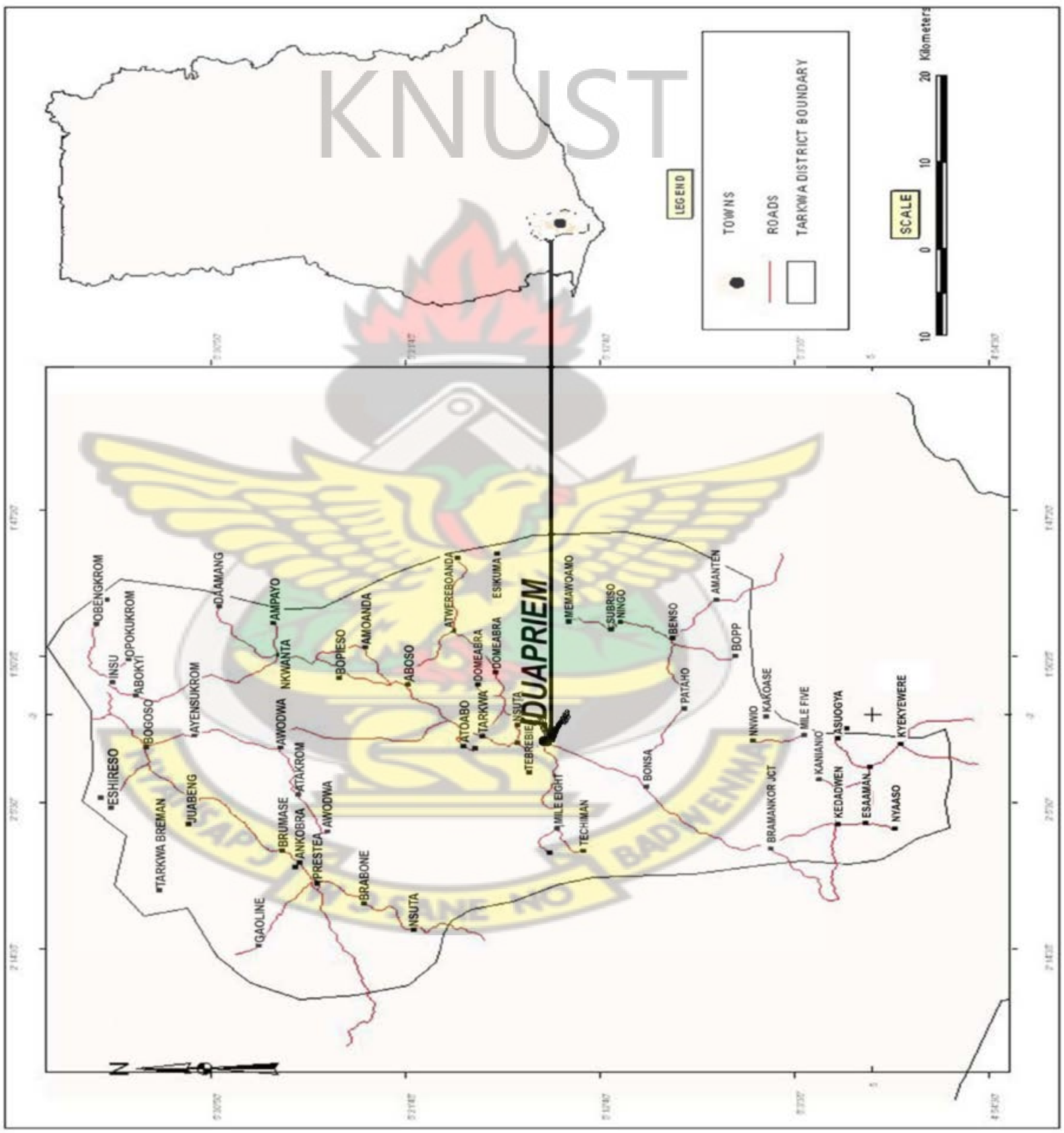


Fig. 3.1: Location map of Iduapriem mine. Source: Resource Management Support centre (RMSC, 2010), Forestry Commission, Kumasi.

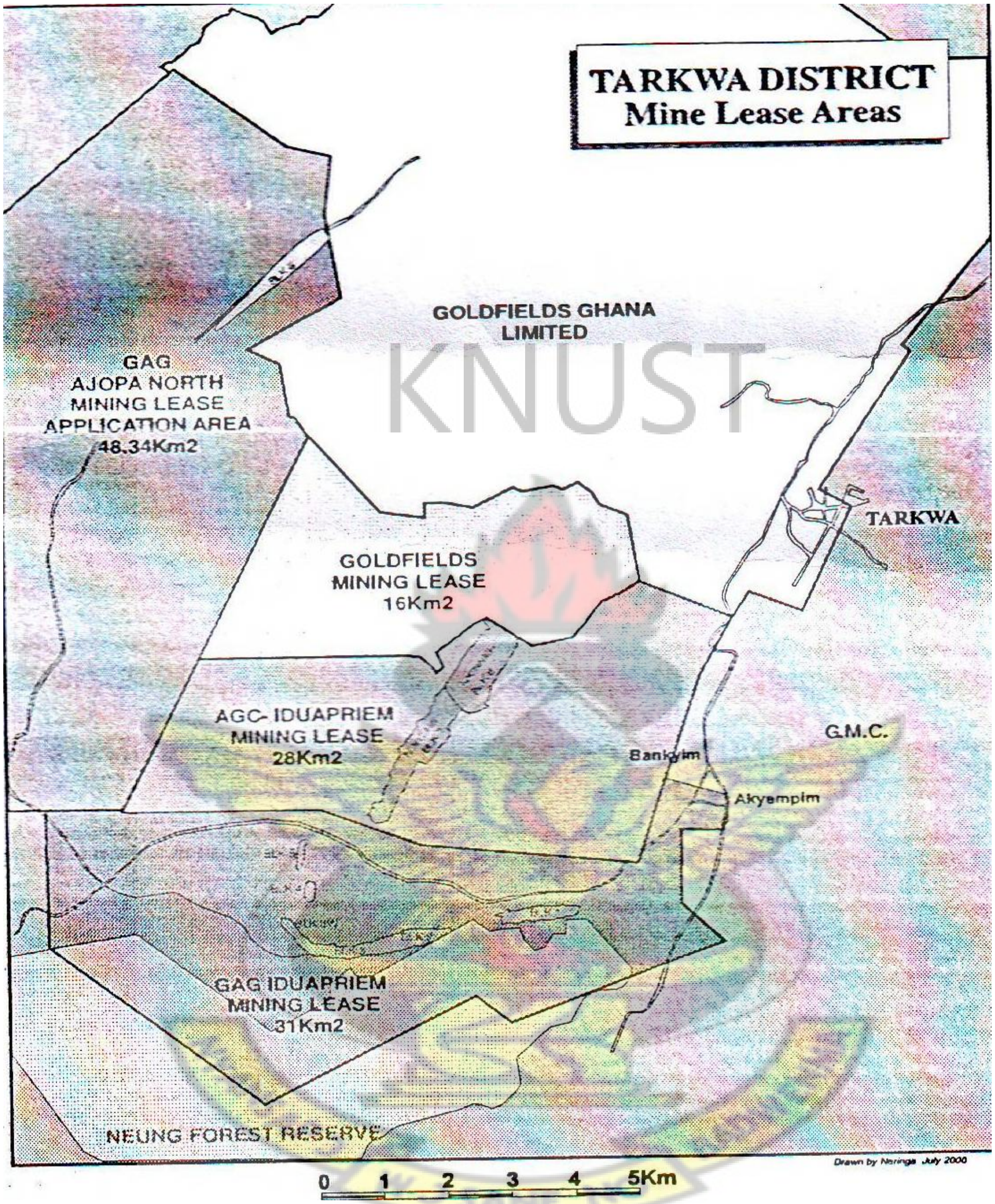


Fig.3.2: Map of AngloGold Ashanti, Iduapriem mine Ltd.'s Concession Area

Source: EAU (1990)

3.2 Climate

The climatic conditions are transitional between the high rain forest (very humid) zone and the semi-deciduous rain forest (humid) zone. The climate is characterized by high rainfall in two main wet seasons and uniformly high temperatures. From March to October, the climate is cool and wet. From November to February, the climate is hot and dry (EAU, 1990).

3.2.1 Rainfall

The area is characterized by heavy rainfall. The average annual rainfall ranges from 1750 to slightly over 2000mm. The major wet season generally covers the period March to July with a peak in June and the minor wet season extends from September to October. The major dry season starts in November and ends in February and the minor dry season covers only the month of August. The highest and lowest average monthly rainfalls of 317mm and 412mm occur in June and January respectively (EUA, 1990).

3.2.2 Temperature

The area is characterized by high temperatures. The temperatures are high and relatively constant throughout the year. The highest mean monthly temperature of 27.8 ^{0}C occurs in February and March. The lowest of 25 ^{0}C occurs in August (EUA, 1990).

3.2.3 Relative Humidity

The area is characterized by high humidity (92 – 95%) throughout the year in the early mornings when temperatures are lower. The period of highest relative humidity occurs in May and June during the main wet season. It falls considerably to a minimum of 50% during the main dry season in January and February (EAU, 1990).

3.3 Soil and land use

The soils within the area are a mixture of the very acid forest oxysols of the high rain forest zone and the moderately acid forest ochrosols of the semi-deciduous rain forest zone because the climatic conditions are transitional between the high rain forest (very humid) zone and the semi-deciduous rain forest (humid) zone. The area is underlined by rocks of the Tarkwaian formation. Along a typical catena, the soils formed or as weathering products of Tarkwaian rocks consist of the following:

(a) Very shallow, immature, excessively drained soils (Mpeo and Damphia series) directly over hard little weathered parent rock on the summits and steep slope sites.

(b) Red and brown, well to moderately drained, gravelly sedentary soils (Juaso and Mawso series) on the upper and middle slopes.

(c) Yellow-brown, imperfectly drained, non-gravelly, colluvial sandy clays (Asuboa series) on the lower slopes (EMP, 2007)

Grayish brown to grey, poorly to very poorly drained, non-gravelly alluvial sandy loam (Pamusua Series) and sandy clays (Debia Series) in the valley bottoms (Environmental Management Plan (EMP, 2007). The primary landuse in the mining lease area is agricultural crop cultivation. The second major landuse activity is small scale mining of alluvial gravel and gold. Shifting agricultural cultivation has been practiced over a wide area in the past. The land is used for the cultivation of oil palm, cassava, cocoa, coconut, etc.

3.4 Vegetation

The natural vegetation cover of the area is forest, with swamps occurring along drainage lines. Human activities have had a profound effect on the original forest cover. Most part of the forest has been cleared and converted into farmlands and only a few of the original canopy trees are left for shading. In other parts of the forest, extensive timber logging activities have taken place; however, several areas of primary forest still exist.

The largest block of primary forest occurs within the Neung Forest Reserve, with the Northern Hills and Iduapriem ridge retaining good forest cover. A large area of forest block also exists within the Ajopa hills. Within the primary forest, the emergent trees consist of *Piptadeniastrum africanum, Ceiba pentandra, Canarium schweifurthiini, Tieghemella heckelii, Milicia excelsa, Petersianthus*. These blocks of secondary forest are characterized by colonizing species such as *Musanga cecropioides, Trema orientalis, Anthrocleista rogelii and Harungana madagascariensis*. The forest timber tree *Lophira alata* is also regenerating. Swamps vegetation occurs in the valley floor. The vegetation is characterized by *Raphia hookeri, Sclerosperma mannii, Anthonotha vogelii and Mitragyna stipulsa.*

3.5 Fauna

A variety of monkeys species are known to occur in the forest areas, primarily in the Neung Forest Reserve area. Ungulates such as Bush Pig, Black Duiker, Royal Antelope and Bushbuck are also present.

3.6 Socio-economic environment

The population within the catchment area of the Iduapriem mining concession boundaries is relatively large but scattered. An estimated 10,200 people live within the eight neighbouring communities. The following communities constitute the major population: Iduapriem, Adieyie, Adisakrom, Abonpuniso, Techiman, Wangarakrom, Badukrom, Teberebie and some hamlet with little population.

3.7 Study Methodology

The study was in two phases, a sociological survey and a field experiment. The study was carried out in the eight (8) communities within the catchment area of the mining concession; Iduapriem, Adieyie, Adisakrom, Abonpuniso, Techiman, Wangarakrom, Badukrom, Teberebie and four reclaimed sites (Fig. 3.1). A 2yr old reclaimed site, 5yr old reclaimed site, 9yr old reclaimed site, 11yr old reclaimed site, an unclaimed site as well as a nearby pre-disturbed forest reserve (Neung forest reserve) were selected for the study.

3.7.1 Sociological Survey

A survey was undertaken in the eight communities involving workers of the Environmental Department of the mining company and the Community Relation Officer. Chiefs and Opinion Leaders were consulted and focus group discussions were also held.

The purpose of the survey was to identify the various land reclamation practices in the selected areas and their respective management. Interviews were conducted on the following:

- Reclamation security bond agreement between EPA and AngloGold, Iduapriem mine Ltd
- Adopted reclamation practices (sustainability and performance),
- Levels of communities participation in the reclamation
- The biological /tree species used in the reclamation exercise
- The processes involved in the reclamation of a mined out site.
- Identification of the success criteria/indicators in the reclamation of a site.
- Identification of the indigenous tree species before the mining commenced.

- Determining the benefits of land reclamation by the communities
- Level of perceived satisfaction of the reclamation exercise by the respondents

Personal observation and prepared semi-structured questionnaires (appendix 1&2) were administered to all the concerned bodies mentioned above. The interviews were carried out during the 'rest days' (taboo days) in the communities and normal working days in the offices of the Environmental Department and the Community Relation Officer. Participatory Rural Appraisal as described by Chambers (1992) which optimizes local people input to research and development process and encourages decision makers to make appropriate schemes on current development process was used to interview the chiefs and opinion leaders. The focus group discussion covered all the eight communities and ninety respondents were interviewed (Table 3.1).

Table 3.1 Respondents interviewed in the survey

	Number of Respondents interviewed
	10
Adieyie community	10
Adisakrom community	10
Abonpuniso community	10
Techiman community	10
Wangarakrom community	10
Badukrom community	10
Teberebi community	10
The Environmental Department	9
The Community Relation Officer	1
Total	**90**

3.7.2 Field experiment

3.7.2.1 Experimental Design and field layout

The field experiment was arranged in a Complete Randomized Design (CRD) with four replications each of six treatments. The treatments were the four different reclaimed sites at the study area, the unclaimed site and the Neung forest as a control as follows:

Nearby Neung Forest Reserve (control): T_0

Unclaimed site: T_1

2 yr old reclaimed site: T_2

5 yr old reclaimed site: T_3

9 old reclaimed site: T_4

11 yr old reclaimed site: T_5

The treatment combinations and field layout for each crop are shown in fig.3.3 and plate 3.1

Plot 1 $\mathbf{T_0}$	**Plot 2** $\mathbf{T_2}$	**Plot 3** $\mathbf{T_3}$	**Plot 4** $\mathbf{T_4}$	**Plot 5** $\mathbf{T_4}$	**Plot 6** $\mathbf{T_3}$
Plot 7 $\mathbf{T_5}$	**Plot 8** $\mathbf{T_3}$	**Plot 9** $\mathbf{T_3}$	**Plot 10** $\mathbf{T_0}$	**Plot 11** $\mathbf{T_1}$	**Plot 12** $\mathbf{T_2}$
Plot 13 $\mathbf{T_5}$	**Plot 14** $\mathbf{T_1}$	**Plot 15** $\mathbf{T_0}$	**Plot 16** $\mathbf{T_5}$	**Plot 17** $\mathbf{T_5}$	**Plot 18** $\mathbf{T_1}$
Plot 19 $\mathbf{T_0}$	**Plot 20** $\mathbf{T_2}$	**Plot 21** $\mathbf{T_1}$	**Plot 22** $\mathbf{T_2}$	**Plot 23** $\mathbf{T_4}$	**Plot 24** $\mathbf{T_4}$

Fig 3.3: Plot layout showing the randomization of the treatments for each crop

Plate 3.1: Field experiment showing the layout of the various sites soils for each crop before sowing at AngloGold Iduapriem mine Ltd, Tarkwa

3.7.2.2 Soil sampling

In order to assess the effect of the reclaimed sites on soil nutrients status and plant growth, soil samples were randomly taken from all the four reclaimed sites, the unclaimed sites and the Neung forest (control) at a depth of 0 – 15 cm. Each sample was bulked and homogenized as four composite samples representative of the treatments. About 50g of sample from each site were then air-dried, grounded and passed through a 2 mm sieve and analyzed for pH, SOC, N, P, K, Ca, Mg, Na, CEC, ECEC, T.E.B, Exchangeable acidity and heavy metal contaminants at the Soil Research Institute, Kwadaso-Kumasi. The remaining soils were used on the field for testing their effect on the cultivation of maize and cowpea

3.7.2.3 Land preparation and sowing

The experiment was set up at the nursery of the Environmental Department. Half an acre of land was cleared for the experimental set up. The soil samples from each treatment were put in plastic containers/pots (Size: 27cm-Length, 30cm- top diameter, 17.5cm- Bottom diameter) with four containers constituting a plot with 24 plots for each crop making 48 plots in all. The seeds of maize and cowpea were sowed at the beginning of the major season in April. The maize seeds were sown at 80cm x 40cm between and within rows respectively at 3 seeds /rubber container and were thinned to two per container/pot one week after germination. A 60cm x 20 cm spacing was employed for sowing cowpea seeds at a rate of three seeds per pot which was later thinned to 2 one week after germination.

3.7.2.4 Cultural practices

Weed control was carried out manually in-between the pots using the hand hoe and machete every two weeks after sowing. Weed on the pots were removed with the hands. To control pests on the cowpea, karate agro-chemical was sprayed twice at the 3rd and 5th weeks of growth.

3.7.2.5 Data collection and growth parameters monitored

To monitor and assess the effects of the reclaimed sites on crop growth, the height and stem diameter of maize and cowpea were measured at the end of the 3rd and 6th weeks after sowing using a measuring tape and digital caliper respectively. The number of pods/plant and number of seeds/pod for the cowpea were measured alongside the weight of the yield of the maize and cowpea after harvesting.

3.7.2.6 Plant sampling and preparation for analysis

A few representative fresh leaf samples of the cowpea and maize were randomly collected from each plot with the help of a sharp stainless steel cutter at the end of sixth week of growth. The plant materials collected were characterized for quality parameters. The samples were washed with 0.2 % detergent to remove the greasy coating on the leaf surface. They were then washed with 0.1 *M* HCl followed by thorough washing with plenty of tap water and a final wash with distilled water. The samples were washed again with double deionised (DDW) water because of heavy metal analysis. They were then put onto a tissue paper and air-dried on a perfectly clean surface at room temperature for 3 days. The samples were oven-dried at 70 ^oC for 48 hours and ground to pass through a 0.5 mm sieve and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, lead, cadmium, copper, zinc and arsenic.

3.7.2.7 Biomass estimation

Three representative samples from each plot of cowpea and maize were removed for above and below ground biomass estimation as well as the estimation of the number and weight of cowpea nodules at the end of the 6th week. They were cut at the base with a sharp stainless steel cutter to separate the above and the below ground portions and were put in a brown envelope after the below ground portions were washed and air-dried. The number of nodules and effective nodules of the cowpea were counted and weighed. The samples were oven-dried at 70 ^oC for 48 hours to a constant weight.

3.7.2.8 Harvesting

Harvesting was done at the end of the 11^{th} week when all the pods of the cowpea were dried and the maize husks were also well dried.

3.8 LABORATORY/ANALYTICAL METHODS

3.8.1 Soil analysis

The physico-chemical properties of the soils under the treatments were determined in the laboratory of the Soil Research Institute, Kwadaso, Kumasi.

3.8.2 Soil pH

Soil pH was determined using a H1 9017 Microprocessor pH meter in a 1:2.5 suspension of soil and water. A 20 g soil sample was weighed into plastic pH tube to which 50ml distilled water was added from a measuring cylinder. The suspension was stirred frequently for 30 minutes. After calibrating the pH meter with buffer solutions at pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

3.8.3 Soil organic carbon

A modified Walkley and Black procedure as described by Nelson and Sommers (1982) was used in the determination of organic carbon. One gram of soil sample was weighed into an Erlenmeyer flask. A reference sample and a blank were also prepared. Ten milliliters of 1.0 *N* (0.1667*M*) potassium dichromate was added to the sample and the blank flasks. Concentrated sulphuric acid (20 ml) was carefully added to soil from a measuring cylinder, swirled and allowed to stand for 30 minutes in a fume cupboard. Distilled water (250 ml) and 10 ml concentrated orthophosphoric acid were added and allowed to cool. A diphenylamine indicator (1ml) was the added and titrated with 1.0 m ferrous sulphate solution.

Calculation

The organic carbon content of the soil was calculated as:

$$\%\ \text{Organic carbon} = \frac{M \times 0.39 \times \text{mcf} \times (V_1 - V_2)}{w}$$

where

M = molarity of ferrous sulphate

V_1 = ml ferrous sulphate solution required for blank

V_2 = ml ferrous sulphate solution required for blank

w = weight of air – dry sample in gram

mcf = moisture correcting factor (100 + % moisture) / 100)

0.39 = 3 × 0.001 × 100% × 1.3 (3 = equivalent weight of carbon, 1.3 = compensation factor for incomplete oxidation of the organic carbon)

3.8.4 Total Nitrogen

This was determined by the Kjeldahl digestion and distillation procedure as described in SRI, (1984). A 0.5 g soil sample was weighed into a Kjeldahl digestion flask. To this 5 ml distilled water was added. After 30 minutes, concentrated sulphuric acid (5 ml) and selenium mixture were added and mixed carefully. The sample was then digested for 3 hours until a clear digest was obtained. The digest was diluted with 50 ml distilled water and mixed well until no more sediment observed and allowed to cool. The volume of the solution was made to 100 ml with distilled water and mixed thoroughly. A 25 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of 40 % NaOH solution added followed by distillation. The distillate was collected in 2.0 % boric acid and was titrated with 0.02 *N* HCl using bromocresol green as indicator. A blank distillation and titration was also carried out to take care of the traces of nitrogen in the reagents as well as the water used.

Calculation:

The % N in the sample was expressed as:

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

where

N = concentration of HCl used in titration

a = ml HCl used in sample titration

b = ml HCl used in blank titration

w = weight of air-dry soil sample

mcf = moisture correcting factor (100% + moisture)/100)

1.4 = 14 × 0.001 × 100% (14 = atomic weight of N)

3.8.5 Available phosphorus (Bray's No. 1 phosphorus)

The available phosphorus was extracted with Bray's No. 1 extraction solution (0.03 *M* NH_4F and 0.025 *M* HCl as described by Bray and Kurtz (1945). Phosphorus in the extract was determined by the blue ammonium molybdate method with ascorbic acid as the reducing agent using a 21 D spectrophotometer. A 5 g soil sample was weighed into a shaking bottle (50 ml) and 35 ml of extracting solution of Bray's No. 1 added. The mixture was shaken for 10 minutes on a reciprocating shaker and filtered through a Whatman No. 42 filter paper. An aliquot 0f 5 ml of the blank, the extract, and 10 ml of the colouring reagent (ammonium molybdate and tartarate solution) were pipetted into a test tube and uniformly mixed. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21 D spectrophotometer at a wavelength of 660 nm at medium sensitivity.

A standard series of 0, 1,2,3,4 and 5 mgP/1 was prepared from 20 mg/1 phosphorus stock solution.

Calculation:

$$\text{P (mg/kg soil)} = \frac{(a - b) \times 35 \times 15 \times mcf}{w}$$

where

a = mg/1 P in sample extract

b = mg/1 P in blank

mcf = moisture correcting factor

35 = ml extracting solution

15 = ml final sample solution

w = sample weight in gram

3.8.6 Exchangeable cations

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 *M* ammonium acetate extract (Black, 1986) and the exchangeable acidity (hydrogen and aluminium) was determined in 1.0 *M* KCl extract (Page *et al.*, 1982)

3.8.7 Exchangeable bases extraction

A 5 g soil sample was weighed into a leaching tube and leached with 100 ml buffered 1.0 *M* ammonium acetate solution at pH 7.

3.8.8 Determination of calcium and magnesium

To analyze for calcium and magnesium, a 25 ml aliquot of the extract was transferred into an Erlenmeyer flask. To 1 ml portion of hydroxylamine hydrochloride, 1 ml of 2.0 % potassium cyanide, 1 ml of 2.0 % potassium ferrocyanide, 10 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution were added. The solution was titrated with 0.01 *M* EDTA (ethylene diamine tetraacetic acid) to a pure turquoise blue colour.

3.8.9 Determination of calcium only

A 25 ml aliquot of the extract was transferred into a 250 ml Erlenmeyer flask and the volume made up to 50 ml with distilled water. 1 ml hydroxylamine, 1 ml of 2.0 % potassium cyanide and 1 ml of 2.0 *M* potassium ferrocyanide solution were added. After a few minutes, 5 ml of 8.0 *M* potassium hydroxide solution and a spatula of murixide indicator were added. The resultant solution was titrated with 0.01 *M* EDTA solution to a pure blue colour.

Calculation:

$$\text{Ca + Mg (or Ca) (cmol/kg soil)} = \frac{0.01 \times (\text{Va} - \text{Vb}) \times 1000}{\text{w}}$$

where

w = weight (g) of air – dried soil used

Va = ml of 0.01 *M* EDTA used in sample titration

Vb = ml of 0.01 *M* EDTA used in in blank titration

0.01 = concentration of EDTA

3.8.10 Determination of exchangeable potassium and sodium

Potassium (K) and sodium (Na) in the leachate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg/1 K and Na solutions to 100 mg/1. In doing this, 25 ml portion of each solution was taken into 250 ml volumetric flask and made up to the volume with distilled water. Portions of 0, 5, 10, 15, 20 ml of the 100 mg/1 standard solution were put into 200 ml volumetric flasks respectively. One hundred millilitres of 1.0 *M* NH_4OA_C solution was added to each flask and made to volume with distilled water. This resulted in standard series of 0, 2.5, 5.0, 7.5 and 10 mg/1 for K and Na. Potassium and sodium were measured directly in the leachate by flame photometry at wavelengths of 766.5 and 589.0 nm, respectively.

$$\text{Exchangeable K (cmol/kg soil)} = \frac{(a-b)\times 250 \times \text{mcf}}{10 \times 39.1 \times w}$$

$$\text{Exchangeable Na (cmol/kg soil)} = \frac{(a-b)\times 250 \times \text{mcf}}{10 \times 23 \times w}$$

where

a = mg/1 K or Na in the diluted sample percolate

b = mg/1 K or Na in the diluted blank percolate

w = weight (g) of air-dried sample

mcf = moisture correcting factor

3.8.11 Determination of exchangeable acidity (Al^{3+} and H^+)

The soil sample was extracted with unbuffered 1.0 *M* KCl solution. Ten grams of soil sample was weighed into a 200 ml plastic bottle and 50 ml of 1.0 *M* KCl solution added.

The mixture was shaken on a reciprocating shaker for 2 hours and filtered. An aliquot of 25 ml of the extract was pipetted into a 250 ml Erlenmeyer flask and 4-5 drops of phenolphthalein indicator solution added. The solution was titrated with 0.025 *N* NaOH until the colour just turned permanently pink. A blank was also included in the titration.

Calculation:

$$\text{Exchangeable acidity (cmol/kg soil)} = \frac{(a-b) \times M \times 2 \times 100 \times \text{mcf}}{w}$$

where

a = ml NaOH used to titrate with sample

b = ml NaOH used to titrate with blank

M = molarity of NaOH solution

w = weight (g) of air – dried sample

2 = 50/25 (filtrate/pipette volume)

mcf = moisture correcting factor (100 + % moisture)/100

3.8.12 Effective Cation exchange capacity (ECEC)

This was calculated by summation of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and exchangeable acidity (Al^{3+} and H^{+})

3.8.13 Determination of micronutrients

The soil samples were air-dried at room temperature, then pulverized and sieved through a 150-mesh stainless-steel screen. Samples were wet-digested with a concentrated acid mixture (HNO_3, $HClO_4$ and HF) (Allen *et al.,* 1986; Markert *et al.,* 1996). The soil solutions were cooled to room temperature, filtered, transferred quantitatively to 50 ml volumetric flasks made up to volume with distilled water, and kept in clean plastic vials before metal analysis. The total metal concentrations were determined by flame atomic absorption spectrophotometer (AAS, GBC932AA). Pb and Cd concentrations in leaf tissues were, however, determined using graphite furnace atomic absorption spectrophotometry (GFAAS, GBC932AA).

3.9 Plant analysis

Plant samples (section 3.7.2.6) were analyzed for nitrogen phosphorus, potassium, calcium, magnesium, zinc, copper, iron, arsenic, cadmium, lead and manganese.

3.9.1 Nitrogen

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

$$NH_3 + H_3BO_3 \longrightarrow NH_4^+ + H_2BO_3^-.$$

The $H_2BO_3^-$ that was formed was titrated with standard hydrochloric acid back to H_3BO_3.

About 20 g oven-dried plant sample was ground in a stainless steel hammer mill with a sieve mesh of 0.5 mm, and mixed well to ensure homogeneity. Following this, 0.5 g plant sample was digested in a 10 ml concentrated sulphuric acid with selenium mixture as a catalyst. The clear digest obtained was transferred into a 100 ml conical flask and made to the mark with distilled water. Five millilitres each of a blank and sample were pipetted separately into the Kjeldahl distillation apparatus. To this, 5 ml solution of 40 % sodium hydroxide was added and distilled. Ammonia evolved was trapped in a 25 ml of 2 % boric acid-indicator solution. The ammonium borate formed was titrated with 0.1 *N* HCl with bromocresol green-methyl red indicator to determine the amount of nitrogen in the sample (Soil Laboratory Staff, 1984).

Calculation:

$$\% \text{ N/DM} = \frac{(\text{a} - \text{b}) \times M \times 1.4 \times \text{mcf}}{\text{w}}$$

where

a = ml 0.1 M HCl used for sample titration

b = ml 0.1 M HCl used for blank titration

M = Molarity of HCl

1.4 = 14 × 0.001 × 100% (14 = atomic weight of nitrogen)

w = weight of sample in mg.

3.9.2 Phosphorus, potassium, calcium, magnesium, zinc, copper, iron, arsenic, cadmium, lead and manganese

Half a gram (0.5g) each of cowpea and maize leaves was ashed in a muffle furnace, after which the ash was dissolved in 1.0 *M* HCl solution and filtered. The filtrate was diluted to 100 ml with distilled water and analyzed for phosphorus, potassium, calcium, magnesium, zinc, copper, iron, arsenic, cadmium, lead and manganese.

3.9.2.1 Phosphorus determination

A 5.0 ml aliquot of the filtrate above was taken into a 25 ml volumetric flask. Following this, 5.0 ml of ammonium vanadate solution and 2.0 ml stannous chloride solution were added and made to the 25 ml mark with distilled water. The solution was allowed to stand for 10 minutes for full colour development. A standard curve was developed concurrently with phosphorus concentrations ranging from 0, 1, 2, 5, 10 to 20 mg P per kg organic material. The absorbance of the sample and standard solutions were read on the spectrophotometer (spectronic 21D) at a wavelength 470 nm. A standard curve was obtained by plotting the absorbance values of the standard solutions against their concentrations. Phosphorus concentration of the samples was determined from the standard curve.

3.9.2.2 Potassium

Potassium in the ash solution was determined using a Gallenkamp flame analyser. Potassium standard solutions were prepared using the following concentrations: 0, 10, 20, 40, 60 and 100 mg K per litre of solution. The emission values were read on the flame analyser. A standard curve was obtained by plotting emission values against their respective concentrations.

3.9.2.3 Calcium and magnesium

A 10.0 ml aliquot of the ash solution was put in an elementary flask. Potassium cyanide and potassium ferrocyanide solutions were added to complex (remove) interfering cations Cu and Fe. In calcium + magnesium determination, the solution was titrated with 0.01 M EDTA solution in the presence of Eriochrome Black T murexide indicator. To determine calcium content, potassium hydroxide was added to raise the pH to about 12. At this pH magnesium, is precipitated leaving calcium in solution. The solution was titrated again with EDTA using as the murexide indicator. The difference between the first and the second titres represents magnesium concentration in the solution.

3.9.2.4 Zinc, copper, iron, arsenic, cadmium, lead and manganese

Zinc, copper, iron, arsenic, cadmium, lead and manganese in the ash solution were determined using the atomic adsorption spectrometer, by comparing the absorbance of Cu, Zn, Fe, Mn, Cd, Ar and Pb atoms with respect to a series of standard solutions. The micronutrients contents were measured directly from the digest.

Graphs relating the absorbance to the amount of Cu, Zn, Fe, Mn, Cd, Ar and Pb in the plant tissues were plotted.

Calculation:

$$\text{ppm (Cu, Zn, Fe, Mn, Cd, Ar and Pb/DM)} = 100 \times (a - b) \times M$$

Where:

a = sample absorbance

b = absorbance of blank

100 = percentage

M = moisture correcting factor

DM = dry matter

3.10 Data collection and Analysis

The data collected were the heavy metal contaminants in the soil and the leaves of cowpea and maize, above and below ground biomass of the maize and cowpea, yield of cowpea and maize, number of nodules and effective nodules of the cowpea, number of pods per plant and seeds per pod of the cowpea, Stem diameters and heights of the maize and cowpea at the 3rd and 6th weeks, the primary and secondary nutrients in the soil and leaves of the crops. Data on all parameters/response variables (e.g. N, P, K, exchangeable bases, Zn, Cu, etc) were subjected to analysis of variance (ANOVA) using the Genstat statistical package (GenStat, 2008). Separation of means were done using Least Significance Difference (LSD) and Duncan multiple Range test at $p = 0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Reclamation Security Agreement between EPA-Ghana and AngloGold Iduapriem mine Ltd, Tarkwa.

A Reclamation Security Agreement document between EPA-Ghana and the Company was produced by the mining company that describes how the areas affected by the company could be reclaimed. An amount of Five million seven hundred thousand United States dollars (US$5,700,000) was deposited by the company with the Stanbic Bank Ghana Ltd at the end of 2007 and held in an interest bearing joint account in United States Dollars for the company and EPA (EPA, 2004). This amount was to be used as a guarantee and could be used to rehabilitate the degraded mined lands in case the company refuses to do so. This was in conformity with EPA Act 494 of 1994 and LI 1652 of 1999 which further requires mining companies to obtain an environmental permit after submitting a favorable environmental impact assessment of their activities, and also commit to pay a reclamation security bond to Environmental Protection Agency. Laurence (1999) also reported that apart from adhering to the preparation and submission of the reclamation plan, mining companies are mandated in many countries to post a pre-mining financial assurance or security in the form of cash, letters of credit, surety bonds, or trust fund to cover the cost of environmental damages in circumstances of insolvency during the closure.

4.2 Reclamation practices at AngloGold Ashanti, Iduapriem mine Ltd, Tarkwa

AngloGold Ashanti, Iduapriem mine which was started since 1992 has five (5) reclaimed sites. The reclaimed sites identified were: a 2yr old reclaimed, 5yr old reclaimed, 9yr old reclaimed, 11yr old reclaimed and 7 year old site which was inaccessible because active mining was on-going. The reclamation practices identified were the processes involved in reclaiming the disturbed sites, the tree species used and the communities' involvement in the reclamation exercise.

4.2.1 Land reclamation processes at Anglogold Ashanti, Iduapriem mine, Tarkwa

The identified processes involved in the reclamation were; Earthwork/slope battering, Spreading of oxide material, Spreading of topsoil, Construction of crest drains, Raising of cover crops, Tree planting, Field maintenance, Monitoring and Measuring of success criteria.

Earthworks/Slope battering is done to get a visual blend of the disturbed area and the nearby undisturbed land. The slopes are buttered at an angle of not exceeding 30^o. Immediately following the slope buttering is the spreading of oxide material to bind all the aggregate soil particles and to make the land surface stable. It also covers all the uneconomic or waste rocks. The top soil is then spread on the surface of the oxide material to promote plant growth. Soil amendments like poultry and cow manure are used to facilitate early succession. Fertilizer is applied as and when the need is required. Crest drains are then constructed to check run-off and control erosion. Bamboo cuttings, vetiver grass, gliricidia cuttings and stones are used as barrier approach to control erosion (plate 4.1). Jute mats filled with sand and stones are also put on the surface to control run-off.

Plate 4.1: Plate showing a barrier approach using vetiver, bamboo strips, stones and *Gliricidia* at the 2yr old site under reclamation at AngloGold Iduapriem mine Ltd, Tarkwa.

The system of strips of vetiver grass (*Vetiveria zizanioides*) has been widely promoted as a vegetative barrier to runoff (Greenfield, 1988; National Research Council, 1993; Smyle and Magrath, 1993; Young, 1997).Vetiver grows under a wide range of climates, it is relatively non-invasive and non- competitive and can be established as narrow strips, 0.5-1.0m wide. It is a tufted perennial grass, which creates a dense physical barrier or filter to runoff. Cover crops are then broadcast on the surface of the topsoil. The cover crops are raised in order to further enhance erosion control.

Tree planting is the next process after the cover crops are broadcasted. Seedlings of *Acacia magium*, *Gliricidia sepium*, *Leucaena leucocephala* and *Senna siamea* from the nursery are planted in a mixed stand. The tree planting is followed by field maintenance where pruning, weeding and fertilizer application are done.

Success criteria and monitoring are the next processes climaxing the reclamation procedure and processes. The company monitors against Acid Mine Drainage (AMD) at the tailings dam site. The company checks that the embankments are stable and free from erosion. Monitoring detects changes in water, air and land properties associated with the implementation of reclamation plan (Viljoen, 1998). In Ghana, monitoring is strictly mandatory particularly in globally significant biodiversity areas, where impacts are uncertain as well as fragile habitats (Fitzgerald, 1993; Allen *et al*., 2004; EPA-Ghana, 1996).

Success criteria according to the company are based on the end-use objectives. For the purposes of agriculture/farming, the following were the completion criteria stipulated by EPA (2004) for the company's reclamation:

i. Appropriate topsoil cover
ii. Topsoil cover should be 0.5 m thickness
iii. Soils stable and free from erosion
iv. Completion of three food crop cycle
v. Qualitative and quantitative analysis of vegetative cover
vi. Creation of conditions favourable for the return of fauna
vii. Planted cash crop species sustainable

A site is deemed to have a final completion of reclamation if it continues to retain the criteria for land use when no additional monitoring and maintenance are required after reclamation works have been achieved after 3 seasonal cycles, excluding sites experiencing Acid Mine Drainage (AMD) phenomenon. AMD occurs when the sulphide minerals more readily oxidise in the tailings facility as a result of the size reduction from milling increasing the surface area and thus exposure of the tailings to air and water. Acid generation and metal mobilisation occur that eventually find their way into the surrounding environment through runoff or seepage. This phenomenon is a well known problem affecting the mining industry and is commonly known as Acid Mine Drainage (AMD). Where AMD phenomenon occurs, an area will be deemed to have a final completion when no additional monitoring and maintenance are required after reclamation works have been achieved after a period of not less than 7 years (EPA, 2004). These are done according to Environmental Protection Agency L1 1652 of 1999 which make it mandatory to all mining companies to rehabilitate the lands disturbed during their operations, almost close to the original state and to fill the pits with the waste material, to re-build soil fertility levels and restore the ecosystem resilience as close as possible to pre-mining conditions where practicable. Completion criteria have been defined as reclamation success objectives (Johnson and Tanner, 2004). The success indicators are usually generated on site specific basis to enable regulatory agencies, communities and mining companies to judge the success or otherwise of reclamation programme (Elliot *et al*., 1996).

4.3 Indigenous tree species before the mining started

According to a baseline survey by the Environmental Advisory Unit contained in a document at the Environmental Department of the Company, within the primary forest, the emergent trees were *Piptadeniastrum africanum, Ceiba pentandra, Canarium sp, Tieghemella heckelii, Milicia excelsa* and *Petersianthus*. Secondary forest were characterized by colonizing species such as *Musanga cecropioides, Trema orientalis, Anthrocleista rogelii* and *Harungana madagascariensis*. The forest timber tree *Lophira alata* was also regenerating.

Swamps vegetation occurs in the valley floor. The vegetation is characterized by *Raphia hookeri, Sclerosperma mannii, Anthonotha vogelii and Mitragyna stipulsa.*

4.3.1 Tree species used in the reclamation exercise

The tree species used in the reclamation were *Acacia magium, Gliricidia sepium, Senna siamea* and *Leucaena leucocephala.* All the reclaimed sites were dominated by equal species diversity of these tree species except *Acacia magium* which was said to inhibit undergrowth hence it is less in species richness as compared to the other three tree species. The reasons given to the choice of the tree species were that, they are fast growing and have the ability to establish and survive on degraded sites. In addition to this, *Acacia*, *Gliricidia*, and *Leucaena* are nitrogen fixing. Nitrogen-fixing tree species (NFTS) are an ideal class of trees for afforestating degraded sites (Mac Dickens, 1994) because they are able to establish and thrive in nitrogen deficient soils. In addition to their nitrogen-fixing capacity, NFTS grow quickly and tolerate a variety of adverse soil conditions. It is widely believed that 75% of nitrogen is contributed by the root nodules of leguminous plants (Lawrie, 1981). The reasons given to the choice of the tree species used agree with Young (1997) that the woody perennials suitable for soil fertility maintenance or improvement should have: a high rate of production of leafy biomass, a dense network of fine roots, with a capacity for abundant mycorrhizal association, extensive deep roots, a high rate of nitrogen fixation, a capacity to grow on poor soils and other productive or service functions other than soil improvement. Legumes also have the ability to rehabilitate degraded land by improving the physical, chemical and biological characteristics of soil (Thomas, 1995).

Even though *Senna siamea* is not nitrogen fixing, its association with vesicular-abuscular mycorrhiza (VAM) might have contributed to the resultant nitrogen fixing ability of *Acacia* *magium*, *Gliricidia sepium* and *Leucaena leucocephala* at the reclaimed sites. Van Noordwijk and Dommergues (1990) reported that when roots of nitrogen fixing trees are in close contact with roots of non- nitrogen fixing plants, greater number of nodules and the resulting N_2-fixation is stimulated in the N_2-fixing plants. These might indicate the ability of the *Acacia magium*, *Gliricidia sepium* and *Leucaena leucocephala* to survive and improve their nitrogen fixing ability in these mined out sites and hence their selection for reclaiming these degraded sites. According to Huan *et al.*, (1985) and Osinubi *et al., (*1991), drought tolerance of woody plants has been shown to be improved by VAM colonization. Bethelfalvay *et al.*, (1988) pointed out the fact that VAM plants can absorb soil moisture below the levels accessible to non-mycorrhizal plants indicates that VAM association can be important during periods of drought-stress or on degraded lands.

4.4 Community participation in the reclamation practices

Areas of community participation as identified include weed and fire control, supply of local seeds, seedling establishment and maintenance of trial farms. In addition, communities are periodically consulted to make inputs into the current reclamation projects. The Chiefs, unit committee members and other opinion leaders are taken round the sites under reclamation three times in every year to see progress of work and solicit for further comments/concerns. Workshops and focus group discussions are organized for the communities and their traditional authorities to allow them determine the final land use which is incorporated into the decommissioning and closure cost document. All the casual workers are taken from the various communities. Some are engaged in activities such as weeding, collection of seeds, clearing and maintenance of the trial oil palm, cocoa, pineapple and maize farms at the old tailings dam site which is 9 years under reclamation.

Fitzgerald (1993) observed that as a step in reducing pressure on reclaimed sites, many mining companies employ local communities in various stages of their reclamation efforts. These include weed and fire control, supply of native seeds, seedling establishment and maintenance of trial farms and soil conservation research. This collaboration with the communities has brought peace between the company and the communities. Maikhuri *et al.*, (1997) reported that, relinquishing unmined lands to landowners for farming as well as granting site access to indigenous people are additional steps towards ensuring the success of reclamation activity.

4.5 Benefits of land reclamation as perceived by the communities at Anglogold Ashanti, Iduapriem mine, Tarkwa.

The benefits associated with land reclamation as reported by the various communities are shown in table 4.1. Generally, all the eight (8) communities see the reclamation to be beneficial to them. Apart from Teberebie community, all the other 7 communities do not see the protection of traditional activities such as indigenous plant medicines as beneficial but considered the improvement of aesthetic beauty of the land as beneficial. These benefits as enumerated by the communities are in conformity with the perceived views of land reclamation benefits by the communities as reported by FESS (2007) at a Consultative Workshop on Land Reclamation and Alternative Land Use, Satta Kumba Amara Resource Centre, Koidu, Kono District, Sierra Leone by the Foundation for Environmental Security and Sustainability (FESS) under the auspices of the United States Agency for International Development (USAID). The communities see the use of the same land for both agricultural purpose and also for the mineral exploitation as increasing the monetary value on the land.

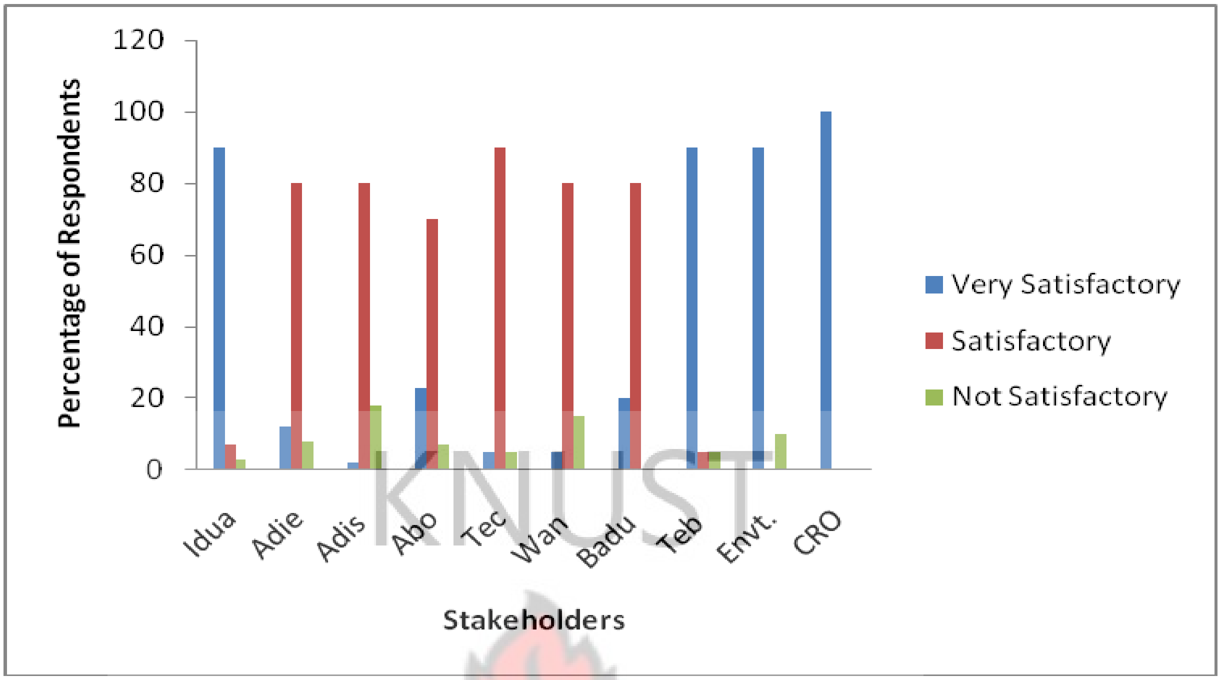
Table 4.1 Perceived benefits of reclamation from the (8) communities

BENEFITS	C1	C2	C3	C4	C5	C6	C7	C8
1. Create opportunities for marginalized groups to access land	+	+	+	+	+	+	+	+
2. Restore authority to original landowners	+	+	+	+	+	+	+	+
3. Increase the monetary value of the land	+	+	+	+	+	+	+	+
4. Create safe playgrounds for children	+	+	+	+	+	+	+	+
5. Create employment.	+	+	+	+	+	+	+	+
6. Increase the skills and capacity of youths to find employment	+	+	+	+	+	+	+	+
7. Prevent conflict and enhance peace and stability	+	+	+	+	+	+	+	+
8. Protect traditional activities such as indigenous plant medicines								+
9. Improve aesthetic beauty of the land	+	+	+	+	+	+		

C1-Iduaprie, C2-Adieyie, C3-Adisakrom, C4-Abonpuniso, C5-techiman, C6-Wangarakrom, C7-Badukrom C8-Teberebie, + beneficial

4.6 Overall satisfactory level of the reclamation practices by the various respondents

The various stakeholders at the study area came out with their perceived level of satisfaction of the reclamation exercise. All the eight communities (Iduapriem, Adieyie, Adisakrom, Abonpuniso, Techiman, Wangarakrom, Badukrom, Teberebie) and the Community Relation Officer as well as workers of the Environmental Department rated the reclamation practice as either very satisfactory, satisfactory or not satisfactory. Ninety percent of Teberebie, Iduapriem, Techiman communities and the Environmental Department workers see the reclamation practice to be very satisfactory but 80% of Badukrom, Wangarakrom, Adieyie and Adisakrom communities viewed the reclamation practice to be satisfactory (Figure 4.1). It was only Abonpuniso community that only 70% rated the practice to be satisfactory. The Community Relation Officer (CRO) of the company also viewed the reclamation as satisfactory. Their views were representatives of the fact that the communities were always in contact with the company and as a matter of fact, the company goes about its duty as stipulated in the reclamation security agreement with the EPA (EPA, 2004). Majority of the community members have also been employed by the company both casually and permanently and the communities are always aware of what is going on. According to the respondents, none of the sites affected by the mining exercise have been left without reclamation. Also, frequent conflicts associated with mining between mining communities and mining companies are not prevalent. These have affected their decision on their rating on the level of satisfaction of the reclamation practice because most local communities are fundamentally concerned with questions of control over their own destinies, both in relation to the state and in terms of the management of projects, the flow of benefits, and the limitation or redistribution of mining impacts (Wesley-Smith 1990; Banks, 2002).



Idua (Iduapriem community), Adie (Adieyie community), Adis (Adisakrom community), Abo (Abonpuniso community), Tec (techiman community), Wan (Wangarakrom community), Badu (Badu community), Teb (Teberebie) Envt (Environmental department), CRO (Community relation officer)

Fig.4.1 Level of satisfaction of reclamation processes/practices by the various stakeholders at Anglogold Ashanti, Iduapriem mine, Tarkwa.

4.7 Soil chemical properties in the reclaimed and unclaimed sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa

Table 4.2 shows the effect of the sites on the soil pH, soil Organic Carbon, soil Nitrogen, Base Saturation, exchangeable acidity, available Phosphorus and Potassium as well as the heavy metals: Zinc, Copper, Iron, Cadmium, Lead, Manganese and Arsenic.

Table 4.2: Soil chemical properties under the various sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

Treatments	pH 1:2.5	SOC %	N %	P mg/kg	K mg/kg	Ca cmol/kg	Exch.A cmol/kg	%Base
T_0	4.01^{a}	1.32^{b}	0.28^{c}	5.4^{d}	40.28^{b}	0.88^{b}	1.90^{d}	31.3^{a}
T_1	4.46^{b}	0.09^{a}	0.08^{a}	0.43^{b}	35.00^{a}	0.63^{a}	1.52^{c}	38.6^{a}
T_2	4.86^{c}	0.68^{a}	0.22^{b}	0.004^{a}	50.33^{c}	1.14^{c}	3.92^{c}	34.7^{a}
T_3	5.19^{d}	1.04^{a}	0.28^{c}	1.23^{c}	53.65^{d}	1.44^{d}	1.54^{c}	78.8^{b}
T_4	6.02^{c}	2.09^{b}	0.34^{d}	7.75^{e}	73.75^{e}	3.84^{f}	0.39^{a}	90.6^{c}
T_5	4.8^{c}	2.28^{b}	0.38^{c}	14.67^{f}	90.48^{f}	2.25^{e}	0.87^{b}	82.2^{bc}

T_0: Forest Reserve (Control), T_1: Unclaimed oxide waste rock dump, T_2: 2yr old reclaimed site, T_3: 5yr old reclaimed site, T_4: 9 yr old reclaimed site, T_5: 11yr old reclaimed site.

Means in each column followed by the same letter are not significantly different by Duncan's multiple Range Test ($P \leq 0.05$) and n = 4

4.7.1 Soil pH

The different sites differed significantly with respect to the soil pH (Table 4.2). The mean values of soil pH of various sites showed that, the soil pH under the different sites were low. The highest pH value of 6.02 which was below neutrality (pH=7) was recorded from the 9 year old reclaimed site (T_4). The least value of 4.01 was recorded from the soil under the Neung forest reserve which was used as a control (T_0). It can be deduced from this that the reclaimed sites have improved the pH of the soil. The soil pH increased in the reclaimed sites in comparison to the control. The major causes for soils to become acid are: Acidic parent material, Organic matter decay and rainfall associated with leaching (Gordon, 2010). Due to differences in chemical composition of parent materials, soils will become acidic after different lengths of time. Thus, soils that developed from granite material are likely to be more acidic than soils developed from calcareous shale or limestone (Gordon, 2010). It could be inferred that the low pH values of the soils under the reclaimed sites, the unclaimed site and the control at Anglogold Ashanti, Iduapriem mine, were indication that the soils might have developed from acid rocks as the parent material. According to the environmental baseline survey by Environmental Advisory Unit of Liverpool University Ltd, EAU (1990) which was commissioned to take the survey by the company, the soils within the area are a mixture of the very acid Forest Oxysols of the high rain forest zone and the moderately acid Forest Onchrosols of the semi-deciduous rain forest. Inspite of this, the reclaimed sites had caused an improvement in the soil pH as compared to the control. The area is characterized by heavy rainfall. The average annual rainfall ranges from 1750 to slightly over 2000mm (EAU, 1990). Excessive rainfall is an effective agent for removing basic cations over a long time period (thousands of years). Rainfall is most effective in causing soils to become acidic if a lot of water moves through the soil rapidly (Gordon, 2010). Therefore the general low pH could be attributed to the heavy rainfall pattern of the study area. The amount of rainfall affects the pH in the sense that water passing through the soil leaches basic nutrients such as calcium and magnesium from the soil. They are replaced by acidic elements such as aluminium and iron. For this reason, soils formed under high rainfall conditions are more acidic than those formed under arid (dry) conditions. Also according to Snyder (2007), rainfall contributes to soil acidity in the following ways**:** Water (H_2O) combines with carbon dioxide (CO_2) to form a weak acid — carbonic acid (H_2CO_3). The weak acid ionizes, releasing hydrogen (H^+) and bicarbonate (HCO3). The released hydrogen ions replace the calcium ions held by soil colloids, causing the soil to become acid. The displaced calcium (Ca^{++}) ions combine with the bicarbonate ions to form calcium bicarbonate, which, being soluble, is leached from the soil. The net effect is increased soil acidity. Decaying organic matter produces H^+ which is responsible for acidity. The carbon dioxide (CO_2) produced by decaying organic matter reacts with water in the soil to form a weak acid called carbonic acid (Gordon, 2010). The accumulated effects of many years might contribute to the soil being more acidic.

4.7.2 Soil organic carbon (SOC)

The mean SOC values under the various reclaimed sites, the unclaimed site and the control showed the highest value (2.28%) in the 11 year old reclaimed site (T_5) and the least value (0.09%) in the unclaimed site (T_1) (Table 4.2). According to CSIR-SRI (2009) of Ghana's ranking, the unclaimed site (T_1), 2yrs and 5yrs reclaimed sites were low in SOC whiles the control (T_0 – Forest Reserve), 9yr and 11yr old reclaimed sites were found to be within the moderate range (1.6 – 3.0 %) . There were no significant difference in the SOC of the T_0, T_4 and T_5. Even though the SOC from the soils under the Neung forest reserve (T_0) was expected to be the highest due to its organic matter accumulation, the situation was not so. The results of the SOC values could be attributed to the nitrogen fixing trees used in the reclamation. Tree species differ in biomass production and tissue nutrient concentrations and in their effects on soil properties such as pH, nutrient cycling, and soil biota (Binkley 1996; Binkley and Giardina, 1998). All comparisons of N–fixers and non–N–fixers have found 20%–100% more soil C under N–fixers (Johnson 1992; *Cole et al.*,1995; Rhoades and others 1998); this would equate to 0.05–0.12 kg m^{-2} y^{-1} greater soil C accumulation under N–fixer forests than under comparable non–N–fixer forests (Tarrant and Miller 1963; Binkley *et al.*, 1982; Binkley 1983; Binkley and Sollins, 1990; Cole *et al.*, 1995; Rhoades *et al.*, 1998; Kaye *et al* 2000). In addition, the highest SOC of the 11yr old reclaimed site

(T_5) can be attributed to the age (11yrs) of the tree species under reclamation which produced high biomass and hence high organic matter because SOC is closely related to the amount of organic matter in the soil (SOM), according to the approximation: SOC x 1.724 = SOM (Young *et al.*, 2001). This could also be the reason why the SOC recorded under the unclaimed site (T_1) was the least value. The unclaimed site (T_1) has a bare soil surface with no tree growth and hence no accumulation of organic matter. Inputs of soil C would increase if N-fixing species increased the rates of litterfall or fine root and mycorrhizal production (Perera *et al.*, 1992). It could be generalised from the results that the reclaimed areas produced higher SOC in comparison to the control – Forest site.

4.7.3 Soil nitrogen

The least value of nitrogen (0.08) was recorded in the soil from the unclaimed site (T_1) and the highest value (0.38) was recorded from the soil under the 11 year reclaimed site (T_5) (Table 4.2). Apart from the unclaimed site (T_1) and the 2 year old reclaimed site (T_2), the nitrogen values from the remaining sites were all surprisingly greater than that from the Neung forest reserve, the control. The treatments had significant effect on the nitrogen content of the soil. There are significant differences in the nitrogen content of the 5, 9 and 11 yr old reclaimed sites.

The nitrogen content from the unclaimed site (T_1) was low but that from the Forest (T_0 - control) and the 2 year old reclaimed site (T_2) were moderate according to CSIR-SRI (2009) ranking. Also according to CSIR-SRI (2009) ranking, the concentration of nitrogen in the 5, 9 and 11 yr old reclaimed sites were high. These higher values of nitrogen could be attributed to the use of the leguminous tree species in the reclamation exercise. Bino (1998) has reported an increase in mean nitrogen from 0.48% to 0.53% in the surface soil after nitrogen fixing trees (NFTS) were planted. The presence of N-fixing trees generally increases the N content of litterfall by 4-10 times (Binkley and Giardina, 1998). The NFTS on the 11yr old reclaimed site (T_5) have contributed to the highest N recorded from that site because of more litterfalls associated with the age. Therefore nitrogen increase could be expected from the site in comparison to the other sites which have the same tree species composition but of younger age. The nitrogen-fixing efficiency of the legumes provides a substantial amount of fermentable organic matter for satisfactory microbial activity (Perera *et al.,* 1992) and subsequently the release of N. It is also widely believed that 75% of nitrogen is contributed by the root nodules of leguminous plants (Lawrie, 1981).

On the other hand, it could clearly be seen that, the least value recorded under the unclaimed site (T_1) was due to the absence of the nitrogen fixing trees. Even though the forest reserve used as a control had more older trees than the tree species used for the reclamation, its species might not be nitrogen fixing hence the mean moderate value of 0.28 (Table 4.2). The introduction of legumes into forest ecosystems holds some promise for maintaining soil nitrogen without the use of inorganic nitrogenous fertilizer (Mishra and Pritchett, 1980; Prasad, 1979). The highest mean value of soil total nitrogen (Table 4.2) can also be attributed to the highest level of soil organic carbon (SOC) (Table 4.2) hence SOC in nitrogen fixing soils has positive correlation with soil total nitrogen.

4.7.4 Percent base saturation (base sat. %) of the soil

The sites had significant effect on the percentage base saturation of the soil (table 4.2). The least value of 31.3 for the percent base saturation was recorded from the forest site (T_0) with the highest value (90.60) from the 9yr old reclaimed site (T_4). The next highest value of 82.2 was obtained from the 11yr old reclaimed site (T_5) followed by 78.8 from the 5yr old reclaimed site (T_3) (Table 4.2). These results have a positive relation with the pH. The soils from the reclaimed sites with high pH values (Table 4.2) also have high percent base saturation. The 9yr old reclaimed site (T_4) which had the highest pH value of 6.02 also had the highest percent base saturation value of 90.60.

The high base saturation value is an indication that the exchange sites on such soil particles are dominated by the non-acidic ions (Ca^{2+}, Mg^{2+}, K^+, Na^+). Since low pH resulted in the availability of heavy metals in the soil, the higher percent base saturation recorded in the 9yr old reclaimed site (T_4) could be attributed to its comparative higher pH. Generally, the soils under the reclaimed sites, the unclaimed site and the control were found to be acidic hence the exchange sites comparatively are dominated by acidic cations with less basic cations resulting in the low % base saturation.

4.7.5 Soil available phosphorus (p) and potassium (k).

The sites had significant effect on the available P and K in the soil. The highest values of K and P were recorded in the 11yr old reclaimed site (T_5) but the lowest value of the K was recorded from the unclaimed waste rock dump (T1) and the lowest value of P was recorded from the 2yr old reclaimed site (T_2) (Table 4.2) According to the CSIR-SRI (2009), P < 10mg/kg is low, P = (10 – 20) mg/kg is moderate and P > 20 is high. K < 50 is low, K = (50 – 100) mg/kg is moderate and P > 100 is high (Appendix 3). Based on these ranking of soil nutrients (mineral) content, The P content in all the sites were found to be very low except the moderate level (14.67mg/kg) recorded in the 11yr old reclaimed site (T_5). The K content of 40.28mg/kg was found to be low under the forest site (control - T_0) and the unclaimed (T_1) which was 35.00mg/kg. The rest of the sites recorded moderate level of the

K content. According to Achille (2010) in his study on turf, he found out that the availability of phosphorus to turf can be affected by soil moisture, soil temperature, fertilizer application, and soil clay content, but the primary factor in phosphorus availability is soil pH. Soil pH levels do not have a direct affect on phosphorus, but are an indicator on how certain minerals will interact with phosphorus in the soil. Soils with a pH levels less than 5.0 or higher than 7.0 will have reduced phosphorus availability (Achille, 2010). At pH levels lower than 5.0, phosphorus will react with high levels of iron and aluminium, creating iron or aluminium phosphate minerals. Soil with a pH level higher than 7.0 has a high concentration of calcium which will react with phosphorus, producing unavailable calcium phosphate. If a soil pH problem is not addressed, any phosphorus addition through fertilizer applications can become bound up in forms that are not available for turf (Achille, 2010). Therefore, the general low concentration of phosphorus in the sites could be attributed to the very acidic nature of the soils.

Sandy soils have minute amounts of clay and organic matter, resulting in very few exchange sites. Potassium, as all other cations are subjected to rapid leaching from sand-based, low organic matter soils (Achille, 2010). The evidence of this has been seen in the unclaimed (T_1) and forest (T_0) sites hence recording low K content. T_1 and T_0 are sandy in nature and hence had few exchange sites for K rendering T_1 and T_0 to have low K content and low ECEC of 2.38 and 3.11 (cmol(+)/kg) respectively.

The sites also had significant effect on the exchangeable acidity of the soil. The 9yr reclaimed site (T_4) with the highest base saturation of 90.6% had the least exchangeable acidity of 0.39cmol$_c$/kg which is significantly different from the other sites (T_0, T_1, T_2, T_3 and T_5).

4.7.6 Heavy metal contaminants in the soil under reclaimed and unclaimed sites

Although some heavy metals are required for life's physiological processes (e.g., components of metalloenzymes), their excessive accumulation in living organisms is always detrimental. Generally, toxic metals cause enzyme inactivation, damage cells by acting as antimetabolites or form precipitates or chelates with essential metabolites (Carlson *et al.*, 1975; Clijsters & Van Assche, 1985). Since the study was carried out in an active mining environment and the main objective of the reclamation practice was to make lands available for farming which is the main occupation of the indigenous people, it was therefore imperative to look at the heavy metal content of the soil and its adverse effects on the soil and the communities. The results of the metal content of the soil under the various treatments are presented in (Table 4.3). Generally, the heavy metal contents in the soil were found to be very high. The highest zinc content (36.67mg/kg) was recorded from the unclaimed site (T_1) with the least value from the forest (control-T_0). The least contents of Cd, Pb, Mn, and Ar were consistently recorded from the unclaimed waste rock dump (T_1) with the values 2.33, 64.67, 3.0 and 108.67 ($mgkg^{-1}$) respectively. The highest values of 133.0 and 238.67 (mg/kg) were recorded for Mn and Ar respectively from the 9yr old reclaimed site (T_4). Fe was found to be in a highest concentration of 20915.7mg/kg in comparison to all the other treatments.

The high content of the heavy metal concentration in the soil could be attributed to the pH status of the soil from the various treatments. It was found out that all the soils under the various treatments were having a pH below 7 (Table 4.2) which indicates their acidity status. The equilibrium between metal speciation, solubility, adsorption and exchange on solid phase sites is intimately connected to solution pH (Olomu *et al.*, 1973; Kalbasi *et al.*, 1978; Cavallaro and McBride, 1984; Sauve *et al.*, 1997).

Table 4.3: Heavy metal contaminants in the soil under the different sites at Anglogold Ashanti, Iduapriem mine Ltd., Tarkwa.

Treatment	Zn				Cu				Fe				Cd			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
To (Forest –control)	3	12	7.33	4.51	1	10	5.3	4.51	5275	5289	5281.67	7.02	1	8	3.67	3.79
T_1 (Unclaimed site)	2	6	36.67	2.08	8	11	9.33	1.53	2904	2911	2907	3.61	1	4	2.33	1.53
T_2 (2yr reclaimed site)	26	4	26.67	7.02	90	114	102	12.00	20912	20919	20915.67	3.51	1	8	4.0	3.61
T_3 (5yr reclaimed site)	10	19	14.33	4.51	3	8	5.0	2.65	13745	13760	13752.33	7.51	2	7	4.0	2.65
T_4 (9yr reclaimed site)	9	13	10.67	2.08	3	10	6.67	3.51	4824	4828	4825.67	2.08	2	5	3.33	1.53
T_5 (11yr reclaimed site)	7	11	8.67	2.08	2	8	5.33	3.06	2712	2718	2714.67	3.06	4	9	6.67	2.52

SD: standard deviation, values are means of triplicate samples

Table 4.6 cont.

Treatment	Pb				Mn				As			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
T_0 (Forest –control)	65	78	71	6.56	2.0	6.0	4.0	2.0	118	138	127.67	10.02
T_1 (Unclaimed site)	63	67	64.67	2.08	1.0	5.0	3.0	2.0	107	111	108.67	2.08
T_2 (2yr old reclaimed site)	88	97	92.33	4.51	17	24	20.67	3.51	180	189	184	4.58
T_3 (5yr old reclaimed site)	77	84	80.67	3.51	30	38	34	4.0	170	185	177.67	7.51
T_4 (9yr old reclaimed site)	70	74	72	2.0	130	137	133	3.61	237	241	238.67	2.08
T_5 (11yr old reclaimed site)	88	93	90.33	2.52	129	134	131.33	2.52	116	120	117.67	2.08

SD: standard deviation, values are means of triplicate samples

Hence, numerous studies have found soil pH to have a large effect on metal bioavailability (Turner, 1994; McBride *et al*., 1997).

Both Mn and Zn bioavailability are strongly affected by soil pH (Fergus, 1954; McGrath *et al*., 1988; Turner, 1994). As soil pH decreases, Mn and Zn must compete with the extra H^+ and Al^{3+} for positions on the exchange sites, solubility of Mn and Zn increases in the soil solution and a greater proportion is present as highly available free metal ions in the soil solution (Kalbasi *et al*., 1978; McBride, 1982; Bar-Tal *et al*., 1988; Msaky and Calvet, 1990; Suave *et al*., 1997). This increases the concentrations of Mn and Zn in the directly bio available fraction, i.e., the soil solution (Jeffery and Uren, 1983). In accordance with the changes in metal bioavailability associated with a change in pH, many studies have found that plant uptake of Mn and Zn increases as soil pH decreases. Hence, in Zn contaminated soils as pH decreased Zn concentration increased in shoots of *Arachis hypogaea* (peanut) (Parker *et al*., 1990; Davis-Carter and Shuman, 1993) and the potential for Mn toxicity in *Phaseolus vulgaris* (bean) (Fergus, 1954) and *Vigna unguiculata* (cowpea) (Vega *et al*., 1992) increased in acid soils.
Acidic soil pH dissolves Al and other metals from the mineral soil surfaces, which enter the soil solution. In podosols, Al is mobilized in the alluvial horizons under the predominant influence of organic acidity, and then leaches down the profile as organically bound to bidentate organic sites (Nissinen *et al*., 1999). As pH drops below 5.5, aluminium containing materials began to dissolve. Because of its nature as a cation (Al^{3+}), the amount of dissolved aluminium is 1000 times greater at pH 4.5 than at 5.5, and 1000 times greater at 3.5 than at 4.5 (Gordon, 2010). Most metal toxicity occurs as a result of anthropogenic disturbance, such as mining, where unnaturally high amounts of metals are released during various processes (e.g. Helmisaari *et al*., 1995). As a result of the strong influence of pH on metal solubility (McBride *et al*., 1997),

anthropogenic processes which result in the lowering of substrate pH can cause metal toxicities, even if no extra metal has been added to the system (Fergus, 1954; Kelly *et al*., 1990; Robinson *et al.*, 1995).

4.8 Effects of unclaimed and reclaimed sites on the growth and nutrient uptake of maize and cowpea.

4.8.1 Heavy metal uptake in maize

Table 4.4 shows the heavy metal uptake in maize on the unclaimed reclaimed sites. Arsenic Zinc, Iron, Manganese and copper contents of the maize plant differed significantly ($P < 0.05$) in the various sites. The highest value (38.5mg/kg) in the Arsenic content of the maize plant was recorded for plots under the two year old reclaimed site (T_2) and the least value (13.1mg/kg) was recorded for the plots under the unclaimed site (T_1). Duncan Multiple Range Tests (DMRT) results show no significant difference in the Arsenic content of the maize plants between the 11yr old reclaimed site (T_5) and the unclaimed site (T_1). No significant difference was observed between the plots under the nearby Neung forest reserve (T_0) which was used as the control and the 5yr old reclaimed sites (T_3). The Arsenic content in the maize leaf tissues were found to be higher than the maximum suggested limit of 2 mg/kg, dry wt. According to Melsted (1973), the concentration of Arsenic in the leaf tissue of maize should range between 0.01 – 1mg/kg, dry wt. with the maximum being 2 mg/kg, dry wt. Marker (1994), also gave 0.1 mg/kg as the normal level of Arsenic that a plant must have. The concentrations were therefore found to be toxic to the maize plants because they have exceeded the maximum suggested limit. These very high concentrations of Arsenic might be attributed to the low pH values of the

Table 4.4: Heavy metal content in foliar of maize plant of unclaimed and reclaimed sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

	Maize						
	Heavy Metals(mg/kg)						
Treatments	**As**	**Fe**	**Mn**	**Cu**	**Cd**	**Zn**	**Pb**
T_0	24.82^{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}
DMRT (0.05)	5.4	59.2	6.4	1.6	0.57	6.0	31.3

T_0: Forest reserve (Control); T_1: Unclaimed site; T_2: 2yr old reclaimed site; T_3: 5yr old reclaimed site; T_4: 9 yr old reclaimed sites; T_5: 11yr old reclaimed.

Means in each column followed by the same letter are not significantly different by Duncan's multiple Range Test ($P \leq 0.05$) and n = 4

soils under the various treatments. With very low pH, the As-binding elements such as Fe and Al oxycompounds become more soluble (O'Neill, 1995) and Arsenic extractability increased. Acidification, due to oxidation of the sulphidic tailings (Marshman *et al.*, 1995), further enhanced Arsenic availability (see table 4.2). No significant differences existed between the sites in the lead and cadmium contents of the maize plant. The cadmium concentrations in all the maize plants in different sites were found to be lower than the maximum 3mg/kg suggested for maize tissue concentration (Melsted, 1973). However, lead concentrations were higher than the range of 0.1-5.0 mg/kg and the suggested maximum of 10 $mgkg^{-1}$ by Benton, (1997) and Melsted, (1973). With the Iron (Fe) content of the maize plants, the highest value (319.3 mg/kg) was recorded from plant grown in the 5 yr old reclaimed site (T_3) and the least value (34.0mg/kg) was recorded for plants in the 9yr old reclaimed site (T_4). Duncan multiple range tests show no significant differences existing between plants under the following treatments: forest (control –

T_0) and the unclaimed waste rock dump (T_1), between the unclaimed waste rock dump (T_1), the control (T_0) and 11yr old reclaimed site. Among all the heavy metals analyzed in maize leaves, the highest concentrations were recorded in the iron (Fe) content of the plant in all the sites. This might be due to pH< 7 that results from all the soils under the various sites (see table 4.2). This has corroborate the fact that in calcareous soils of alkaline pH, Fe is usually present as insoluble ferric iron and most pH values below 7, or a redox potential of around 100 mV (Patrick and Jugsujinda, 1992), ferric iron is reduced to bio available iron, leading to the uptake of toxic concentrations of the metal (Schmidt, 1999). Epstein (1965), and Benton (1997), gave the sufficient level of Fe for adequate plant growth as 100 mg/kg (ppm). In view of this value, the maize plant Fe contents of 116.9 mg/kg in the forest (control -T_0), 252.3 mg/kg in the 2yr old reclaimed site (T_2) and 319.3 mg/kg in the 5yr old reclaimed site (T_3) (Table 4.4) were therefore found to be above the recommended range in the foliar of maize and could be rendered as being toxic. Cu and Zn were referenced at 6 mg/kg and 20 mg/kg respectively (Epstein, 1965, Benton, 1997) for adequate plant growth. Therefore the concentrations of Cu in plants in all the sites were within the normal recommended value except a slight deviation of 0.8 in the 9yr old reclaimed site (T_4) (Table 4.4). Zn contents of plants in all the sites were also in the normal sufficiency range except the higher toxicity levels in the forest (control - T_0), the 2yr old reclaimed site (T_2) and the 9yr old site (T_4).These higher levels could be attributed to the general low pH of the soil at the sites which allowed for more metal availability (EAU, 1990).

4.8.2 Heavy metal uptake in cowpea

Table 4.5 shows the heavy metal contents in cowpea leaves 6 weeks after planting on the different sites. The cowpea plant differed significantly ($P < 0.05$) in Arsenic, Zinc, Iron, Manganese, cadmium and copper contents. No significant differences were recorded in the Lead (Pb) content of the cowpea leaves.

Table 4.5: Heavy metal content in foliar of cowpea plant of unclaimed and different reclaimed sites at Anglogold Ashanti, Iduapriem mine, Tarkwa.

	Cowpea						
	Heavy Metals						
Treatments	**As**	**Fe**	**Mn**	**Cu**	**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}
DMRT (0.05)	7.1	134.4	25.3	3.6	0.3	7.3	1.2

$T_{0:}$ Forest reserve (Control); T_1: Unclaimed site; $T_{2:}$ 2yr old reclaimed site; $T_{3:}$5yr old reclaimed site; T_4: 9 yr old reclaimed sites; $T_{5:}$11yr old reclaimed. Means in each column followed by the same letter are not significantly different by Duncan's multiple Range Test ($P \leq 0.05$) and n = 4

The trend in Cadmium was also the same as in the maize leaves except that significant differences existed between the unclaimed site (T_1) and the other sites except the forest reserve (control – T_0). The Arsenic (As) content in the cowpea of all the sites were found to be higher than that found in maize with the highest value (58.4 mg/kg) from the 2yr old reclaimed site (T_2) and the lowest value (24.4 mg/kg) from the unclaimed site (T_1). However, the highest and the lowest values were consistently recorded from the 2yr old reclaimed site (T_2) and the unclaimed site (T_1) respectively for both maize and cowpea (Table 4.4, table 4.5). The concentrations of the Arsenic in the cowpea leaves were found to be higher than the referenced normal level of 0.1 mg/kg (Markert, 1994). Melsted (1974) also referenced the normal range of Arsenic in a plant to be between 0.01 – 1mg/kg, dry wt. with a suggested maximum being 2 mg/kg, dry wt. Based on these facts, the Arsenic concentrations in the leaf tissues of the cowpea were toxic.

These very high concentrations of Arsenic might be attributed to the acidic contents of the soils of different sites (table 4.2) where the cowpea was grown. With strongly acidic pH, the As-binding species such as Fe and Al oxycompounds become more soluble (O'Neill, 1995) and Arsenic extractability increased. Acidification, due to oxidation of the sulphidic tailings (Marshman *et al.,* 1995), might further enhance Arsenic availability. As a result of the strong influence of pH on metal solubility (McBride *et al*., 1997), anthropogenic processes which result in the lowering of substrate pH can cause metal toxicities, even if no extra metal has been added to the system (Fergus, 1954; Kelly *et al*., 1990; Robinson *et al*., 1995).

It was observed that the level of intake of heavy metals into the leaves of cowpea follows the same trend as in the maize but with higher magnitudes (Table 4.4, table 4.5). However the highest heavy metal content in the cowpea was manganese (Mn) with a value of 287.6 mg/kg from the 11yr old reclaimed site (T_5). This has been contrary to the highest heavy metal content in maize which was Iron (Fe) with a value of 319.3 mg/kg and was recorded in the plants in the 5yr old reclaimed site (T_3). The maximum levels of As, Cd and Pb in crop plants are 2, 3 and 5 mg/kg dry wt. respectively (Benton 1997, Melsted 1973). Markert (1994) also gave As, Cd and Pb normal levels in plants to be 0.1, 0.05 and 1.0 mg/kg respectively. The average concentration of Cu, Zn, Mn and Fe were 6, 20, 50 and 100 mg/kg respectively in plant dry matter (Epstein, 1965). It could therefore be inferred from this that apart from lead which contents were within the 0.1-5.0mg/kg, all the other six remaining heavy metals (Ar, Zn, Cu, Cd, Fe, Mn) were found to be higher than the required range hence reaching their toxic level. However, it has also been realised that plants in the forest reserve (control – T_0) and the unclaimed site (T_1) had their Iron content within the reference limit (100mg/kg) (Markert, 1994).

Generally, no significance differences existed in the heavy metal content between the plants from the reclaimed sites and the nearby Neung forest reserve (control) because heavy metal could result from a natural source e.g. soil parent material, windblown dusts, volcanic eruptions, marine aerosols, and forest fires (Fergus, 1954). Although metal toxicity might be inherent in the soil of the study area because metals are a natural part of terrestrial systems and occur in soil, rock, air, water, and organisms, generally, metal toxicity issues do not arise in natural soils with their native vegetation. Even if the soil is naturally high in a particular metal, native plants will often have become adapted over time to the locally elevated levels (Brooks *et al.*, 1992; Ouzounidou *et al.*, 1994). However, if humans bring new growth regimes, such as agriculture, mining, etc with plants not evolved on these specialized soils, then toxicity issues can develop (Fergus, 1954). Most metal toxicity occurs as a result of anthropogenic disturbance, such as mining, where unnaturally high amounts of metals are released during various processes (e.g. Helmisaari *et al*., 1995). As a result of the strong influence of pH on metal solubility (McBride *et al*., 1997), anthropogenic processes which result in the lowering of substrate pH can cause metal toxicities, even if no extra metal has been added to the system (Fergus, 1954; Kelly *et al*., 1990; Robinson *et al*., 1995). Therefore the high level of heavy metals on the nearby forest reserve can also be attributed to dusts and other processes from the mine including transportation since high level of heavy metals can result from mining and smelting e.g. tailings, smelting and refining, transportation (Brooks *et al*., 1992; Helmisaari *et al*., 1995). Soil acidity is also known to inhibit rhizobial growth, colonization of the host rhizosphere, infection, and the activity of established nodules (Munns 1976, 1977, 1978). In accordance with the changes in metal bioavailability associated with a change in pH, many studies have found that plant uptake of Mn and Zn increases as soil pH decreases. Hence, in Zn contaminated soils as pH decreased Zn concentration increased in shoots of *Arachis hypogaea* (peanut) (Parker *et al.*, 1990; Davis-Carter and Shuman, 1993) and the potential for Mn toxicity in *Phaseolus vulgaris* (bean) (Fergus, 1954) and *Vigna unguiculata* (cowpea) (Vega *et al.*, 1992) increased in acid soils. The main sources of the higher levels of some of the metals could probably be atmospheric emissions from the smelter smoke stack(s) as well as dust from the complex site and the tailings management area located around the study area.

4.8.3 Primary and secondary nutrients uptake in maize in the reclaimed and unclaimed sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

Table 4.6 shows the effect of the treatments on the macro nutrients uptake in maize upon foliar analysis from different sites. The sites differed significantly in the P, Mg, Ca and N contents of the maize leaves at $P < 0.05$. No significant differences were found in the potassium contents of the plant leaves. The highest Phosphorus content (0.49%) was recorded from plants in the unclaimed site (T_1) and the lowest content (0.35%) was recorded from the 2 yr old reclaimed site (T_2). In the magnesium content, the highest value of 7.1% was recorded from plants in the 11yr old reclaimed site (T_5) and the lowest value of 1.1% was recorded from plants in the 2yr old reclaimed site (T_2). The highest value of 0.52% for Ca was recorded from plots under the unclaimed site (T_1) and the lowest value of 0.21% from plants under the 11yr old reclaimed site (T_5). Plants in the unclaimed site (T_1) recorded significantly lower nitrogen (N) content (1.0%) than plants in other sites.

Table 4.6: Nutrients uptake in maize on unclaimed and reclaimed sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

	Macro nutrients (%)				
Treatments	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}
DMRT (0.05)	0.87	0.06	0.25	2.2	0.07

$T_{0:}$ Forest reserve (Control); T_1: Unclaimed site; $T_{2:}$ 2yr old reclaimed site; $T_{3:}$5yr old reclaimed site; T_4: 9 yr old reclaimed sites; $T_{5:}$11yr old reclaimed. Means in each column followed by the same letter are not significantly different by Duncan's multiple Range Test ($P \leq 0.05$) and n = 4

The average concentrations of mineral nutrients in plant dry matter that are sufficient for adequate growth are 0.2, 0.2, 0.5, 1.0 and 1.5 in percentages for Phosphorus(P), Magnesium(Mg), Calcium(Ca), potassium(K) and Nitrogen (N) respectively(Epstein, 1965, Benton, 1997). It followed from these that the P contents in the maize was above the average concentration (0.2%) (Table 4.6). However, the K content in the maize foliar was found to be less than the average concentration (1.0%) in all the sites. In contrary to this, all the sites recorded higher Mg concentration than the average concentration (0.2%) sufficient for plant growth. Apart from unclaimed (T_1) and 2yr old reclaimed (T_2) sites that have the Ca content to be significantly equal to the average concentration of 0.5%, the rest of the sites have their Ca content to be lower than the average value (0.5%). The unclaimed site (T_1) was the only treatment with the foliar concentration of N lower than the average. The rest of the treatments have their N content to be higher than the average (1.5%) for plant growth. This might be attributed to the use of the leguminous species in the reclamation of the sites. International Institute of Tropical Agriculture(IITA) studies showed that Leucaena tops maintained maize grain yield at a reasonable amount even with no nitrogen input on a low-fertility sandy Inceptisol, the nitrogen contribution by Leucaena mulch on maize grain yield being equivalent to about 100kg ha^{-1} for every 10 t ha^{-1} of fresh punning (Kang *et al.*, 1981). The tree species might have contributed some amount of nutrients to the degraded soil. The most decisive factor for the success of agroforestry is the choice of suitable, useable tree species (Nair *et al.*, 1984). This choice should be based on economic and agronomic criteria. In order to fulfill the second criterion, the highest priority should be given to selecting trees that can improve the soil, and identifying species or clones that will fix or absorb large amounts of N (and also other elements, especially P) and then return them to the soil (Huxley, 1983). Nitrogen-fixing tree species are probably the best choice, if they can actively fix nitrogen and thus significantly contribute to the improvement of the nitrogen status of the soil. Therefore the higher nitrogen contents in the leaves of the crop apart from the control site can be attributed to the effect of the nitrogen fixing trees that were used in the reclamation exercise which in turn affect the availability of other nutrients.

4.8.4 Primary and secondary nutrients uptake in cowpea in the unclaimed and reclaimed sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

The sites had significant effect (Table 4.7) on the macro nutrients in cowpea leaves (Table 4.7). The P and Mg contents of the cowpea followed the same trend as in maize.

Table 4.7: Nutrients uptake in cowpea on unclaimed and reclaimed sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

	Macro nutrient (%)				
Treatments	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]	1.4[c]	4.0[a]	1.2[ab]
T_2	3.7[a]	0.50[b]	1.1[bc]	5.0[a]	1.5[b]
T_3	4.7[bc]	0.29[c]	1.2[bc]	3.2[a]	8.9[e]
T_4	3.7[a]	0.50[b]	0.58[a]	4.0[a]	3.3[d]
T_5	4.5[b]	0.39[a]	0.96[b]	3.7[a]	2.3[c]
LSD (0.05)	0.31	0.03	0.36	3.0	0.29

$T_{0:}$ Forest reserve (Control); T_1: Unclaimed site; $T_{2:}$ 2yr old reclaimed site; $T_{3:}$5yr old reclaimed site; T_4: 9 yr old reclaimed sites; $T_{5:}$11yr old reclaimed. Means in each column followed by the same letter are not significantly different by Duncan's multiple Range Test ($P \leq 0.05$) and n = 4

The sites differed significantly ($P<0.05$) in the nitrogen(N), phosphorus(P), potassium(K) and calcium contents of the cowpea leaves. The highest N content (5.0%) was recorded in the forest reserve (T_0) with the least (3.7%) from the 9yr old reclaimed and the 2yr old reclaimed sites. The highest K, P and Ca contents were (1.2%), (0.50%) and (8.9%) recorded from the 11yr old, 9yr old and 5yr old reclaimed sites respectively. These values were found to be higher than the average concentration required for plant growth by Benton (1997) and Epstein (1965). The N content in the cowpea was very high and this was very obvious as could be attributed to the nitrogen fixing ability of the cowpea (Staehelin *et al.*, 2006). The nutrient contents of the cowpea were comparatively higher than that found in the maize plant.

4.9 Growth and yield of *Zea mays* in the unclaimed and reclaimed sites soils

Table 4.8 shows growth characteristics and yield of maize plant. Growth characteristics (stem diameter, height, above ground biomass, below ground biomass and yield of the

Table 4.8: Growth characteristics and yield of maize in the reclaimed and unclaimed sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

Treatments	SD1 (mm)	SD2 (mm)	H1 (cm)	H2 (cm)	AG (kg)	BG (kg)	Yield (kg/ha)
T_0	4.4^{cd}	4.9^{ab}	32.5^{bc}	45.5^{b}	8.7^{ab}	4.7^{ab}	0^{a}
T_1	2.3^{a}	3.1^{a}	12.5^{a}	30.0^{a}	2.8^{a}	1.3^{a}	0^{a}
T_2	3.1^{ab}	3.9^{ab}	18.8^{a}	41.8^{b}	19.6^{b}	6.5^{b}	0^{a}
T_3	3.8^{bc}	5.0^{b}	26.3^{b}	38.8^{ab}	17.2^{b}	5.4^{ab}	0^{a}
T_4	5.9^{e}	12.3^{c}	47.5^{d}	106.2^{c}	86.4^{c}	26.5^{c}	1800.5^{b}
T_5	5.5^{de}	6.1^{b}	35.0^{c}	46.2^{b}	54.6^{c}	15.4^{c}	0^{a}
DMRT (0.05)	1.0	2.2	7.1	9.2	10.8	4.0	0^{a}

T_0: Forest reserve (Control); T_1: Unclaimed oxide waste rock dump; T_2: 2yr old reclaimed site; T_3: 5yr old reclaimed site; T_4: 9 yr old reclaimed sites; T_5: 11yr old reclaimed; SD1: stem diameter at the 3rd week; SD2: Stem diameter at the 6th week; H1: height at the 3rd week; H2: height at the 6th week; AG: Above ground biomass of maize; BG: Below ground biomass of maize

Means in each column followed by the same letter are not significantly different by Duncan's multiple Range Test ($P < 0.05$) and n = 4

maize plant) differed significantly ($P < 0.05$) in the different soils. Plants from the 9yr old reclaimed site (T_4) were consistently found to be higher in the stem diameter and height of the maize plant than the other treatments at the end of both the 3rd and the 6th weeks. The above and below ground biomass measured at the end of the 6th week also showed the highest in the plots under the 9yr old reclaimed site (T_4) and the least in the unclaimed site.

No yield of maize was recorded from the sites except the 9yr reclaimed site (T_4). The yield recorded from the 9yr old reclaimed site (T_4) was 1800.5 Kg/ha and this could be attributed to the pH level, low exchangeable acidity and high base saturation of the site as compared to the other sites. These might have affected maize plant growth and consequently its yield. A trace element/heavy metal is toxic to plants because it directly or indirectly affects the metabolic processes such as respiration, photosynthesis, CO_2-fixation, and gas exchange (Clijsters and Van Assche, 1985; Van Assche and Clijsters, 1990a; Vangronsveld and Clijsters, 1994), and other processes. Plants assimilate easily heavy metals, e.g. Zn, Cd, Ni, Cu, Hg... (Foy *et al*., 1978; Lepp, N.W. (1981).They are strongly phototoxic: environmental pollution by these metals causes growth inhibition and even plant death. The stunted growth and death of some of the maize plants recorded from the field might be attributed to the accumulation of heavy metals in the roots, stem and foliar of the maize plants (table 4.4).

Low pH in the soil may affect plant growth indirectly, e.g. by elevated aluminum or manganese solubility and by limited availability of molybdenum, phosphorus, calcium, or magnesium (Adams F. 1981; Noble *et al*., 1988; Fageria *et al*., 1989). On the other hand, low pH (high H^+ activity) may directly inhibit plant growth (Andrew, 1976; van Beusichem 1982; Mahler and McDole 1987; Wilkinson and Duncan 1989, Schubert E. *et al*., 1990; Schubert S. *et al*., 1990), probably by adverse effects at the root plasmalemma level. Reduction of biomass production and nutritional quality is observed on crops grown in soils contaminated with moderate levels of heavy metals (Cottenie *et al.*, 1976; Lepp, 1981). These elements generally inhibit physiological processes, e.g. photosynthesis (Carlson *et al.*, 1975; Clijsters & Van Assche, 1985), phloem translocation (Samarakoon & Rauser, 1979) and transpiration (Carlson *et al*, 1975); respiration is less sensitive (Lee *et al.*, 1976a, b; Van Assche *et al.*, 1979). As can be seen in Table 4.10, yield of the *Zea mays* was recorded only from the 9 yr old reclaimed sites (T_4). This could be attributed to the pH of the soil. All the sites recorded very low pH indicating they were very acidic except the 9 yr old reclaimed site (T_4) with a pH of 6.02 which is near neutral. According to Motsara and Roy (2008), generally, plants prefer soils that are close to either side of neutrality. The pH value of 6.02 in the 9 year old site (T_9) (Table 4.2) is an indication that it could comparatively support plants growth. pH is a simple but very important estimation for soils as soil pH has a considerable influence on the availability of nutrients to crops It also affects microbial population in soils. Most nutrient elements are available in the pH range of 5.5 – 6.5 (Motsara and Roy, 2008).

4.10 Growth and yield of cowpea in the unclaimed and reclaimed sites soils

Table 4.9 shows the growth characteristics (stem diameter, height, above ground biomass, below ground biomass, number of nodules per plant, number of effective nodules per plant, number of pods per plant, yield and number of seeds per pod of the cowpea plant. Growth characteristics of the plant differed significantly ($P<0.05$) in all the different sites soils except in the below ground biomass (BG) and the number of effective nodules (ENOD). The highest yield of cowpea (791kg/ha) was recorded in the 9yr old reclaimed site and the least (291kg/ha) in the 2yr old site. No yield was recorded in the control (T_0) and the 5yr old reclaimed site (T_3). The highest number of pods per plant and the seeds per pod were also recorded in the 9yr old reclaimed site (T_9). Unlike the maize where yield was only recorded from the 9yr old reclaimed site (T_4), yield in the cowpea was recorded from the unclaimed site (T_1), 2yr old reclaimed site (T_2) and 11yr old reclaimed site (T_5) in addition to the 9yr reclaimed site (T_4). Even though the soils were the same for both cowpea and

Table 4.9: Growth characteristics and yield of cowpea in the reclaimed and unclaimed sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa

Treatments	SD1 (mm)	SD2 (mm)	H1 (cm)	H2 (cm)	AG (kg)	BG (kg)	Yield (kg/ha)	NOD	ENOD	PP	SP
T_0	2.2^{b}	2.7^{ab}	12.8^{a}	15.8^{ab}	23.6^{ab}	12.5^{a}	0^{a}	0.00^{a}	0.00^{a}	0.00^{ab}	0.00^{a}
T_1	1.6^{a}	3.1^{b}	13.0^{a}	15.4^{ab}	29.0^{b}	13.3^{a}	291^{ab}	0.00^{a}	0.00^{a}	0.75^{ac}	3.5^{ab}
T_2	2.1^{b}	2.5^{a}	14.0^{ab}	14.8^{a}	23.9^{ab}	12.8^{a}	291^{ab}	0.75^{a}	0.25^{a}	0.75^{abc}	2.00^{ab}
T_3	2.2^{b}	2.6^{ab}	16.3^{b}	17.3^{ab}	22.7^{a}	13.4^{a}	0^{a}	0.50^{a}	0.00^{a}	0.00^{a}	0.00^{a}
T_4	2.8^{c}	5.7^{c}	16.8^{b}	21.8^{c}	43.4^{c}	19.7^{a}	791^{c}	9.5^{b}	0.50^{a}	3.00^{d}	8.00^{c}
T_5	2.3^{b}	3.1^{b}	16.9^{b}	18.4^{b}	27.5^{ab}	13.7^{a}	509^{bc}	6.5^{ab}	0.25^{a}	1.5^{c}	4.8^{bc}
DMRT (0.05)	0.35	0.51	2.8	2.9	5.3	1.8	343.1	6.5	0.55	0.74	3.7

T_0: Forest (Control); T_1: Unclaimed site; T_2: 2yr old reclaimed site; T_3: 5yr old reclaimed site; T_4: 9 yr old reclaimed site; T_5: 11yr old reclaimed; SD1: stem diameter at the 3rd week; SD2: Stem diameter at the 6th week; H1: height at the 3rd week; H2: height at the 6th week; AG: Above ground biomass of maize; BG: Below ground biomass of maize; NOD: Number of nodules per plant; ENOD: Number of effective nodules per plant; PP: Number of pots per plant; SP: Number of seeds per pod.

Means in each column followed by the same letter are not significantly different by Duncan's multiple Range Test ($P \leq 0.05$) and n = 4 maize, the yield from cowpea in the other treatments could be attributed to the ability of the cowpea to fix the atmospheric nitrogen. Cowpea is a plant generally recognized as being nodulated by a range of soil rhizobia. The tropical cowpea is reported to exhibit a very effective symbiotic relationship in the sense that its nitrogen requirements can be almost wholly met by biological nitrogen fixation (Summerfield *et al.*, 1977). Legumes also have the ability to rehabilitate degraded land by improving the physical, chemical and biological characteristics of soil (Thomas, 1995).

The highest yield (791kg/ha) that was recorded from the 9yr old reclaimed site (T_4) could be attributed to the highest number of nodules (9.5) and effective nodules (0.5) recorded from the plants from the site (Table 4.9). Optimum seed yields in cowpea depends on the number of main stem and, especially, side branch nodes produced during vegetative growth (Summerfield *et al.,* 1976) and on effective nodulation and prolonged symbiotic nitrogen fixation (Summerfield, 1976). Cowpeas relying on their nodules for most of their N uptake seem well adapted to the fluctuations likely to occur in soil nitrogen and which are, generally, most marked early in the season (Staehelin *et al.*, 2006). Several factors have been pointed out as being capable of influencing rhizobia populations which includes soil fertility, physical properties such as pH and clay content, biotic factors such as distribution of host plant and prevalence of predators and, climatic effects including temperature and rainfall (Hirsch, 1996). Abiotic factors, such as temperature, osmotic pressure, UV light, and pH, and the relevant variation of these factors also play a role in the selection and activity of microbes in soils or at the plant surface (Savka *et al.*, 2002). Neutral and slight alkaline soil pH favour legume nodulation, but in acidic soils many legumes do not nodulate (Toro, 1996). Carbon exudates by the plant root decreases in acidic soils thereby reducing the supply of substrate to the microorganisms living in the rhizosphere. Acidic soils lead to an increased availability of aluminium and manganese which become toxic, as well as to a low concentration of phosphate, calcium and molybdenum ((Toro, 1996). This could be the reason why the forest site (control – T_0) with the least mean pH (4.01) (Table 4.2) did not produce nodules. The lower yield and growth parameters (stem diameter and height) (Table 4.9) from the other sites could all be attributed to the lower pH values (Tables 4.2) since most nutrient elements are available in the pH range of 5.5 – 6.55 (Motsara and Roy, 2008). Soil acidity is also known to inhibit rhizobia growth and colonization of the host (Toro, 1996).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The company uses the following reclamation processes and procedures to rehabilitate the disturbed sites: earthworks/slope battering, spreading of oxide material, spreading of top soil, construction of crest drains and raising of cover crops to control run-off and erosion, tree planting and field maintenance. Anglogold Ashanti, Iduapriem mine Ltd, Tarkwa has 2yr old, 5yr old, 7yr old, 9yr old and 11yr old reclaimed sites. The company adheres to reclamation security agreement signed with EPA-Ghana in 2004.

There is high community participation in the reclamation exercise ranging from weed and fire control, consultation, seedling establishment, security and maintenance of trial farms.

Agroforestry multipurpose trees: *Acacia magium*, *Gliricidia sepium*, *Senna siamea* and *Leucaena leucocephala* are used in reclaiming mined out sites at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

The nutrient levels from the reclaimed sites were found to be higher than the forest reserve (control). The concentration of nitrogen in the 9yr old (T_4) and 11 yr old reclaimed (T_5) sites (0.34%) and (0.38%) respectively were high. The highest P content (14.67mg/kg) which indicates a moderate level was recorded in the 11yr old reclaimed site soil (T_5). The K content (40.28mg/kg) and (35.00mg/kg) for the forest site (control - T_0) and the unclaimed site (T_1) respectively were low but the reclaimed sites recorded moderate level of the K content ranging from 50.33mg/kg in the 2 yr old reclaimed site to 90.48mg/kg in the 11 yr old reclaimed site.

The 9yr old reclaimed site recorded the highest percentage base saturation of 90.6 and the lowest exchangeable acidity of 0.39%.

The reclaimed sites had significant effect on the pH of the soil such that, there is general improvement in the pH compared to the forest reserve soils (control). The highest pH of 6.02 was recorded from the 9yr old reclaimed site with the least (4.01) from the forest reserve.

Generally, heavy metal contents in the leaf tissue of cowpea were higher than that of maize. Apart from Cd and Pb which were within the critical concentration of 3(mg/kg) and 10(mg/kg) respectively, the remaining heavy metals (Mn, Fe, Zn, Cu, As) in the leaf concentration of cowpea were too high with Fe having the highest concentration of 20915.7mg/kg recorded from the 2yr old reclaimed site soil and hence very toxic to the crop. The highest Iron (Fe) content (319.3 mg/kg) of the maize was recorded from plants grown in the 5 yr old reclaimed site (T_3) and the least value (34.0mg/kg) was recorded for plants in the 9yr old reclaimed site (T_4). The least contents of Cd, Pb, Mn, and Ar were consistently recorded from the unclaimed site (T_1) with the values 2.33, 64.67, 3.0 and 108.67 ($mgkg^{-1}$) respectively.

Growth characteristics (stem diameter, height, above ground biomass, below ground biomass and yield of the maize plant) differed significantly ($P < 0.05$) in the different sites soils. Maize growth from the 9yr old reclaimed site (T_4) was consistently found to be higher in the stem diameter and height than the other sites at the end of both the 3rd and the 6th weeks. Growth characteristics of the cowpea plant differed significantly ($P<0.05$) in all the different sites soils except in the below ground biomass (BG) and the number of effective nodules (ENOD). The highest number of pods per plant and the seeds per pod were also recorded in the 9yr old reclaimed site (T_9). The 9yr old reclaimed site recorded the highest of all these measured growth characteristics in both cowpea and maize.

The highest yields of 1800.5kg/ha and 791kg/ha were obtained from the 9 year-old reclaimed site for maize and cowpea respectively. These yields are equivalent to 1800kg/ha and

800kg/ha for maize and cowpea respectively that farmers get in that part of the western region of Ghana where the study was conducted.

5.2 RECOMMENDATIONS

Selection of crops is needed on reclaimed lands with crop production as end use objective because heavy metal uptake by the cowpea were higher than that of the maize hence different crops will perform differently in different reclaimed soils.

Liming and phytoremediation of mined reclaimed soils is needed if crop production is required to raise the pH of the soils which are generally characterised as being acidic.

Agroforestry multipurpose trees with nitrogen fixing ability can be ideal for mine land reclamation due to their ability to establish on degraded lands and soil improvement capabilities.

The analysis of the heavy metals in the maize and cowpea were done in the leaves at the end of the 6th week, further analysis can be done to examine heavy metals in the yield component (seeds) which can directly affect human health. Therefore, the status of heavy metal contamination of food crops around mining areas in Ghana and the implications for human health should be identified urgently by more detailed study.

Species that are capable of extracting heavy metals from the soil should be included in reclamation practices that have agriculture as end use objective to avoid toxic level of heavy metals in the food chain.

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LIST OF APPENDICES

APPENDIX 1: Questionnaire for the mining company

Tick where appropriate

A. History of Mine site

1. Years in operation:

( ) 1 – 5 ( ) 6 – 10 ( ) 11–16 ( ) 17–21 ( ) other..

2. What was the land-use before the mining operation started?

Agriculture ( ), Forestry ( ), Others...

3. What were the indigenous tree species?

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B. RECLAMATION PRACTICES

C.

4 a. How many reclaimed sites do you have?

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4b. Name them with their corresponding ages

Site	Age

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5 a. Enumerate and give a chronological order of the adopted processes in the reclamation of a site

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5 b. Give the ecological implications of the listed processes in 5a above

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6 a. What is/are the tree/s species used in the reclamation exercise?

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6 b. Why have you chosen this/ these species?

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7. When do you expect the area under reclamation to be fully reclaimed or be viable to be put to its end use?

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8 a. Is the reclamation practice participatory? Yes ( ) No ( )

8 b. If yes how is the community involved?

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8 c. If no why is the community left out?

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9. How do you deal with heavy metal contaminants in your reclamation practice?

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10. What is/are the end / final use of your land(s) under reclamation?

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11. How do you deal with the problem of runoff and erosion?

( ) 1. use of earth structures (terraces, ditch-and –bank structures, etc

( ) 2. biological method

( ) 3. combination of both

4. any other

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12 a. Do you add trees to support erosion control structures? Yes/no

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12 b. If yes, what type of trees do you use?

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13a. Have you done any cultivation on any of your reclaimed site? .....Yes ( ) No ( )

13b. If yes, how old was the site used in the cultivation?

....

14. Which tree species was/ were used in that particular reclamation exercise? ....

15. Which crop/s was/were grown in that reclaimed site?

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....

16 a. Have you won any prize in land reclamation?

....

16 b. If yes, where did it come from?

....

....

16c.What is the nature of the award?

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D. MANAGEMENT AND PERFORMANCE OF RECLAMATION PRACTICES

17. How do you maintain an area under reclamation (biological composition and ecological considerations)?

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18. How do you monitor the performance of the reclamation practice?

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19. How do you determine the overall success of a reclamation practice (measurable indicators)?

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APPENDIX 2. Questionnaire for the Communities

1. Name of respondent...

2. Age..

3.Village/town/community...

4. Educational Background (i) No formal education [ ] (ii) Primary [ ] (iii) JSS/Middle [ ] (iv) Secondary [ ] (v) Tertiary [ ]

5.Occupation?...

6. How long have you been living here? (I) 1-3years [ ] (ii) 3-6years [ ] (iii)>6years

7. Were you here when this mining company started its operations? Yes [ ] No [ ]

8. Mention some of the pre-mining activities you people were engaged in?

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....

9. Are you aware that Iduapriem mine is rehabilitating the disturbed Lands? Yes [ ] No [ ]

10. Have you been to any of the reclaimed sites? Yes [ ] No [ ]

11. If yes, which of the sites?

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....

12.Can you enumerate some of the trees/shrubs

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....
....
....

13. Do you have any idea why those trees/shrubs were planted?

....
....
....

14. How was the nature of the land?

(i)Eroded Yes [ ] No [ ] (ii) Fertile Yes [ ] No [ ]

(iii)Very steep Yes [ ] No [ ] (iv) Rocky Yes [ ] No [ ]

(v)Waterlogged Yes [ ] No [ ]

15a. Did you see any of the demonstration farms at the reclaimed sites? Yes [ ] No [ ]

15b.What crop/s was grown there?

....

16a. Do you think the reclaimed sites can support plant growth in future? Yes [ ] No [ ]. Explain

....
....
....

16b.If yes to the above, name crops you think can thrive well on the reclaimed sites and why?

....
....

17. In terms of labour and cost, how will you compare working on reclaimed lands to that of the natural lands?

18. Is reclamation very necessary and why? Perceived benefits of the reclamation

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....

....

19. Is the community involved in the reclamation exercise? Yes [ ] No [ ]

20. If yes, how is the community involved?

(i) casual labourers [ ]

(ii)Permanent workers [ ]

(iii) Seed collection for sale [ ]

(iv) All 0f the above [ ]

21. In general, how will you classify the reclamation practices at the mining site?

Satisfactory [ ]

Very Satisfactory [ ]

Not Satisfactory [ ]

Destructive [ ]

APPENDIX 3. Soil physical and some chemical properties

Soil ECEC under the treatments

Treatment	Min	Max	Mean	SD
T_0	3.01	3.3	3.11	0.16
T_1	2.27	2.58	2.38	0.17
T_2	5.85	6.17	5.96	0.18
T_5	6.78	7.19	6.95	0.21
T_9	2.54	2.83	2.64	0.16
T_{11}	4.76	5.04	4.86	0.15

$T_{0:}$ Forest (Control); T_1: Unclaimed site, $T_{2:}$ 2yr old reclaimed site; $T_{3:}$5yr old reclaimed site; T_4:9 yr old reclaimed sites; $T_{5:}$11yr old reclaimed.

Soil T.E.B under the treatments

Treatment	Min	Max	Mean	SD
T_0	1.21	1.52	1.32	0.17
T_1	0.86	1.07	0.93	0.12
T_1	2.01	2.1	2.05	0.46
T_5	5.4	5.74	5.53	0.19
T_9	2.27	2.38	2.31	0.06
T_{11}	3.89	4.00	3.93	0.06

SD: standard deviations, values are means of triplicate samples.

W.R.D. (waste rock dump), W.D. (Waste dump)

T_0: Forest (Control); T_1: Unclaimed site; T_2: 2yr old reclaimed site; T_3:5yr old reclaimed site; T_4:9 yr old reclaimed sites; T_5:11yr old reclaimed.

APPENDIX 4. CSIR-SOIL RESEARCH INSTITUTE OF GHANA

Soil Nutrient (mineral) content.

Nutrient	Rank/Grade
Phosphorus, P (ppm), (Blay-1)	
< 10	Low
10 – 20	Moderate
> 20	High
Potassium, K (ppm)	
< 50	Low
50 – 100	Moderate
> 100	High

Calcium, Ca (ppm)/Mg = 0.25 Ca	
< 5.0	Low
5.0 – 10.0	Moderate
> 10.0	High
ECEC (cmol(+)/Kg)	
< 10	Low
10 – 20	Moderate
> 20	High
Soil pH (Distilled Water Method)	
< 5.0	Very Acidic
5.1 – 5.5	Acidic
5.6 – 6.0	Moderately Acidic
6.0 – 6.5	Slightly Acidic
6.5 – 7.0	Neutral
7.0 – 7.5	Slightly Alkaline
7.6 – 8.5	Alkaline
> 8.5	Very Alkaline
Organic Matter (%)	
< 1.5	Low
1.6 – 3.0	Moderate
> 3.0	High
Nitrogen (%)	
< 0.1	Low
0.1 – 0.2	Moderate
> 0.2	High
Exchangeable Potassium(cmol(+)/Kg	
< 0.2	Low
0.2 – 0.4	Moderate

> 0.4	High

APPENDIX 5. ANOVA for studied parameters in *Zea mays*

Analysis of variance for (% P)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	0.068000	0.013600	7.80	<.001
Residual	18	0.031400	0.001744		
Total	23	0.099400			

Analysis of variance for (Above ground biomass/g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	20953.13	4190.63	79.18	<.001
Residual	18	952.69	52.93		
Total	23	21905.82			

Analysis of variance for (As) content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	1939.26	387.85	28.86	<.001
Residual	18	241.95	13.44		
Total	23	2181.21			

Analysis of variance for (Below ground biomass/g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	1760.417	352.083	50.19	<.001
Residual	18	126.263	7.015		
Total	23	1886.680			

Analysis of variance for (Ca)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	0.322871	0.064574	33.47	<.001

Residual	18	0.034725	0.001929
Total	23	0.357596	

Analysis of variance for (Cd)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	0.4952	0.0990	0.68	0.647
Residual	18	2.6352	0.1464		
Total	23	3.1305			

Analysis of variance for (Cu)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	28.953	5.791	5.16	0.004
Residual	18	20.197	1.122		
Total	23	49.150			

Analysis of variance for (Fe)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	255486	51097	32.23	<.001
Residual	18	28541	1586		
Total	23	284027			

Analysis of variance for (Height 1/cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Treatments	5	3100.00	620.00	27.05	<.001
Residual	18	412.50	22.92		
Total	23	3512.50			

Analysis of variance for Height 2/cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	15123.83	3024.77	78.23	<.001
Residual	18	696.00	38.67		
Total	23	15819.83			

Analysis of variance for (K)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	0.16688	0.03338	1.17	0.362
Residual	18	0.51345	0.02853		
Total	23	0.68033			

Analysis of variance for (Mg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	118.746	23.749	10.64	<.001
Residual	18	40.196	2.233		
Total	23	158.942			

Analysis of variance for (Mn)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	43802.23	8760.45	469.01	<.001
Residual	18	336.22	18.68		
Total	23	44138.44			

Analysis of variance for (N)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	1.1072	0.2214	0.64	0.669
Residual	18	6.1870	0.3437		
Total	23	7.2943			

Analysis of variance for (Pb)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	1682.9	336.6	0.76	0.590
Residual	18	7968.1	442.7		
Total	23	9651.0			

Analysis of variance for (Stem diameter 1/mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	34.8519	6.9704	14.61	<.001
Residual	18	8.5901	0.4772		
Total	23	43.4420			

Analysis of variance for (Stem diameter 2/mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	232.091	46.418	22.29	<.001
Residual	18	37.492	2.083		
Total	23	269.583			

Analysis of variance for Yield/Kgha^{-1}

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	4645268	929054	26.23	<.001
Residual	18	637553	35420		
Total	23	5282820			

Analysis of variance for (Zn)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	1786.18	357.24	22.22	<.001
Residual	18	289.39	16.08		
Total	23	2075.57			

APPENDIX 6. Anova for studied parameters in cowpea

% P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	0.1727708	0.0345542	95.32	<.001

Residual	18	0.0065250	0.0003625
Total	23	0.1792958	

Analysis of variance for (Above ground biomass/g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	1211.84	242.37	18.75	<.001
Residual	18	232.61	12.92		
Total	23	1444.45			

Analysis of variance for (As)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	3149.64	629.93	27.31	<.001
Residual	18	415.22	23.07		
Total	23	3564.86			

Analysis of variance for (Below ground biomass/g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Treatments	5	148.084	29.617	20.51	<.001
Residual	18	25.993	1.444		
Total	23	174.076			

Analysis of variance for (Ca)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	178.73698	35.74740	947.37	<.001
Residual	18	0.67920	0.03773		
Total	23	179.41618			

Analysis of variance for Cd

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	1.35612	0.27122	3.00	0.038
Residual	18	1.62817	0.09045		
Total	23	2.98430			

Analysis of variance for (Cu)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	3483.814	696.763	120.90	<.001
Residual	18	103.739	5.763		
Total	23	3587.554			

Analysis of variance (Fe)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Treatments	5	71965	14393	1.76	0.172
Residual	18	147254	8181		
Total	23	219219			

Analysis of variance for Height1/cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	72.719	14.544	4.09	0.012
Residual	18	63.938	3.552		
Total	23	136.656			

Analysis of variance for (K)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	1.67032	0.33406	5.70	0.003
Residual	18	1.05488	0.05860		
Total	23	2.72520			

Analysis of variance for (Mg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	8.376	1.675	0.41	0.833
Residual	18	72.799	4.044		
Total	23	81.175			

Analysis of variance for (Mn)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	110608.1	22121.6	76.52	<.001
Residual	18	5203.8	289.1		
Total	23	115811.9			

Analysis of variance for (N)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	6.23217	1.24643	28.56	<.001
Residual	18	0.78553	0.04364		
Total	23	7.01770			

Analysis of variance for (Nodules)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	334.88	66.97	3.47	0.023
Residual	18	347.75	19.32		
Total	23	682.62			

Analysis of variance for (Pb)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	106.6753	21.3351	31.90	<.001
Residual	18	12.0381	0.6688		
Total	23	118.7133			

Analysis of variance for (Pods/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	25.5000	5.1000	20.40	<.001
Residual	18	4.5000	0.2500		
Total	23	30.0000			

Analysis of variance for (Seeds/pod)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	189.208	37.842	6.10	0.002
Residual	18	111.750	6.208		
Total	23	300.958			

Analysis of variance for Stem diameter 1/mm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	3.00428	0.60086	10.63	<.001
Residual	18	1.01770	0.05654		
Total	23	4.02198			

Analysis of variance for (Stem diameter 2/mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	29.0567	5.8113	50.21	<.001
Residual	18	2.0832	0.1157		
Total	23	31.1400			

Analysis of variance for (Yield Kg/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	1854505	370901	6.95	<.001
Residual	18	960156	53342		
Total	23	2814661			

Analysis of variance for (effective nodules)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	0.8333	0.1667	1.20	0.349
Residual	18	2.5000	0.1389		
Total	23	3.3333			

Analysis of variance for (Zn)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	3766.08	753.22	32.12	<.001
Residual	15	351.75	23.45		
Total	23	4139.08			

Analysis of variance for Height 2/cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	5	134.083	26.817	7.03	0.001
Residual	15	57.250	3.817		
Total	23	219.458			

APPENDIX 7: List of plates

Plate A: Plot showing maize at week 1 after germination at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

Plate B: Field experiment showing the randomization of the different sites soils for growing maize at week 2 after germination at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

Plate C: Plot showing cowpea grown in the plastic containers at week 2 after germination at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

Plate D: Field experiment showing cowpea at maturity at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

Plate E: Field experiment showing the effect of the different sites soils on maize at maturity at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

Plate F: Plate showing a 2 yr old *Senna siamea* in reclamation at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

Plate G: Plate showing the 5 yr old site under reclamation at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

Plate H: An unclaimed site at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa being prepared for reclamation

Plate I: Plate showing the nearby Neung forest reserve used as the control

Plate J: Plate showing Oil palm plantation cultivated from the 9yr old reclaimed site (T_4) at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.

Plate K: Cocoa grown from the 9 yr old reclaimed site (T_4) at AngloGold Ashanti, Iduapriem mine Ltd., Tarkwa.