

Review

Role of revegetation in restoring fertility of degraded mined soils in Ghana: A review

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The topsoil gets seriously damaged during mineral extraction. The consequences of physical disturbance to the topsoil during stripping, stockpiling and reinstatement results in soil degradation through loss of soil structure, accelerated soil erosion, excessive leaching, compaction, reduced soil pH, accumulation of heavy metals in soils, depletion of organic matter, decreased plant available nutrients, reduced cation exchange capacity, decreased microbial activity and consequent reduction in soil fertility. Management of topsoil is important for reclamation plan to reduce nutrient losses and eventually restore the fertility. Revegetation constitutes the most widely accepted and useful way to improve the fertility of degraded mined lands. A review was conducted to assess the contribution of revegetation to improvement of soil fertility of mined lands. The results obtained in this study indicate that revegetation through forest vegetation is one of the efficient means of restoring soil fertility through improvement in soil organic matter content, available nutrients, cation exchange capacity, increased biological activities as well as improvement in physical conditions of the soil. However, it will require longer periods to restore the fertility as closely as possible to the original level. The efforts to rehabilitate mined lands have focused on N-fixing species of legumes, grasses, herbs and trees. Some of the promising tree species that can be used for revegetation are Acacia, Leucaena and other legume trees that are acid-tolerant and can add substantial amount of organic matter to the soil. Long term revegetation using legume species of high metal accumulation and are acid tolerant should therefore be considered in mining areas.

Key words: Mining, soil physical properties, soil chemical properties, soil degradation, land rehabilitation, revegetation.

INTRODUCTION

Mineral extraction and processing are responsible for 10% of Ghana's industrial pollution resulting from emission of sulphur dioxide (SO₂), arsenic trioxide

(As₂O₃), nitrous oxide (NO_x) and particulate matter. For example, arsenic (As) emissions at Anglo Gold Ashanti, Obuasi are 1000 times higher than any world

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standards (Aubynn, 1997). Many research findings indicate that Ghana soils are impacted by mining activities especially that resulting from surface mining. This mining process uses heavy machinery and involves blasting during the extraction period. The blasting process alone kills soil beneficial organisms, disrupts the stable soil aggregates, and eventually deprives the soil of organic matter. These soils, or newly created substrates/growth media are often inhospitable to vegetation due to combination of physical, chemical and microbiological factors.

Many areas disturbed by mining in Ghana are highly susceptible to erosion due to lack of existing vegetation, the presence of fine, dispersed particles and steep slopes, huge gullies and pits are created. Substrates, usually called the overburden or mine spoil, are often the characteristic of all gold mined lands in Ghana. Nearly all mine substrates have very low levels of macronutrients (especially nitrogen (N), phosphorus (P) and potassium (K)). Low pH is a particularly intransigent problem in wastes that contain iron pyrites, which, on weathering, will generate sulphuric acid and (if there is no acidic neutralizing capacity in the waste) induce pH values of <2.0. Toxicity, especially of aluminium, zinc and other metals in acidic wastes, can be a significant problem for plant growth. For instance, Assel (2006) reported pH level in soils of one mining area called Prestea/Bogoso in western region as low as 3.96. Low pH is a characteristic of all gold mined substrates of Ghana.

Some of these affected soils as a result of these gold mining activities are restored (Figure 2) according to Environmental Protection Agency's (EPA) directive; others are just left bare (especially those resulting from illegal small scale mining activities). Typical examples are the vast mining areas of the western region of Ghana, where many illegal mining activities abound (Figure 1).

Mining removes the vegetation and inevitably leads to the loss of some plant nutrients from the site (Amegbey, 2001). The process also scrapes the topsoil with bulldozers and other heavy machinery and the soil samples are taken to the laboratory for the purpose of extracting mineral. As topsoil is only about 20 cm deep, and have most of their plant available nutrients in the top soil, the scraping action of the bulldozers depletes the soils of the fertility and productivity exposing the unfavorable subsoil which are unsuitable for crop production (Bonsu and Quansah, 1992).

Furthermore, practices that remove the vegetative material prevent addition of organic matter into the soil. The loss of organic matter has been found to lead to reduction in soil fertility, deterioration of soil structure, water holding capacity and biological activities in the soil (Asiamah et al., 2001).

In Ghana, for instance, these developments coupled with other kinds such as manufacturing, construction, agriculture, and tourism strengthened the desire for formal legis-

lative backing for environmental impact assessment. Consequently, an act (Act 490) to legally establish the Environmental Protection Agency (EPA) was passed by Parliament in December 1994. Under the act, Ghana's EPC which became the EPA was given more powers to ensure environmentally sound development (Appiah-opoku and Mulamootil, 1997). In accordance with Section 12 (1) of the Act, the EPA: ". . . may by notice in writing require any person responsible for any undertaking which in the opinion of the Agency has or is likely to have adverse effect on the environment to submit to the Agency in respect of the undertaking an environmental impact assessment containing such information within such period as shall be specified in the notice" (Environmental Protection Council, 1994 cited in Appiah-opoku and Mulamootil, 1997).

Thus, the Act gives the EPA legal backing to request project proponents to conduct and submit environmental impact assessment studies for approval. Where it appears to the EPA that the activities of any undertaking pose a serious threat to the environment or to public health, the agency may serve enforcement notice on the person(s) responsible for the undertaking to take such steps as the agency thinks necessary to prevent or stop the activities (Appiah-opoku and Mulamootil, 1997).

It is from this legal instrument that EPA requires all mining companies to "clean up and repair" lands degraded during their extraction process through various rehabilitation strategies. Part of the reclamation/rehabilitation phase is revegetation of the mined sites. According to Said (2009), revegetation is believed to be an efficient phytoremediation strategy for removing contaminants/pollutants from soil or water, adding organic matter to the soil and thus improving fertility of degraded lands. This is so because, vegetation cover and consequently topsoil richness have been linked to both soil fertility and productivity as established by Young (1997). He established that trees have long been used to reclaim areas of degraded lands due to the capacity to grow under difficult climatic and soil conditions, coupled with their potential for soil conservation, and that decline in organic matter, which to a large extent is provided by the crown and roots of trees, almost invariably accompanies land degradation.

Organic matter not only supplies plant nutrients, but also plays a major role in the maintenance of the physical, chemical and the biological properties of the soil (Asiamah et al., 2001). In tropical soils, organic matter supplies most of the soil nitrogen, phosphorus and sulphur (Asiamah et al., 2001). Also, vegetation plays a major role in the process of erosion control on gullied areas, landslides, sand dunes, construction sites, road embankments, mine-spoils and pipe line corridors (Morgan, 2005).

It is against this background that this study, therefore sought to review literature on how revegetation



Figure 1. Degraded land left bare as a result of gold mining activity in Prestea, one of the small towns in Western Region of Ghana. Source: Mensah (2014).



Figure 2. Justice reclaimed refilled pit revegetated with *Senna siamea*, AngloGold Ashanti, Obuasi, Ghana. Age of plantation is 10 years. Source: Said (2009).

contributes to soil fertility improvement of the degraded mined soils. The study reviews data and published

information concerning mining, their degradation processes on soil properties and the revegetation methods

employed for rehabilitation.

LITERATURE REVIEW

Impacts of mining on soil physical, chemical properties and biological properties

The mining disrupts the aesthetics of the landscape and along with it disrupts soil components such as soil horizons and structure, soil microbial populations, and nutrient cycles of those are crucial for sustaining a healthy ecosystem and hence results in the destruction of existing vegetation and soil profile (Kundu and Ghose, 1997). The overburden dumps include adverse factors such as elevated bioavailability of metals; elevated sand content; lack of moisture; increased compaction; and relatively low organic matter content. Acidic dumps may release salt or contain sulphidic material, which can generate acid-mine drainage (Ghose, 2005). The effects of mine wastes can be multiple, such as soil erosion, air and water pollution, toxicity, geo-environmental disasters, loss of biodiversity, and ultimately loss of economic wealth (Wong, 2003; Sheoran et al., 2008).

Stripping operations at many open-cut coal mines in central Queensland, Australia resulted in spoil (waste rock) materials of tertiary origin being deposited on the surface (Grigg et al., 2006). Deeply weathered tertiary sediments can be highly sodic and moderately to extremely saline (Gunn, 1967), forming surface seals that limit infiltration and reduce plant available water. Following drying, they often form strong crusts that impede seedling emergence. These materials are also deficient in many nutrients, particularly nitrogen and phosphorus (Grigg et al., 2006).

Regardless of the overburden type used, plant available N and P tend to be low on mine soils, which may limit tree growth (Howard et al., 1988). Consequently, fertilization at some point during the rotation is usually needed to obtain rapid growth of trees planted on reclaimed mine sites (Koe et al., 1999). The top-soil is seriously damaged during mineral extraction. The consequences of physical disturbance to the topsoil during stripping, stockpiling and reinstatement, cause unusually large nitrogen transformations and movements with eventually substantial loss (Sheoran et al., 2010).

Loss of organic matter is characteristic for contaminated soils (Viventsova et al., 2005), as toxic levels of metals hinder soil biological activity, vegetation development and generation of OM. According to Stark (1977) and Dutta and Agrawal (2002), low level of organic carbon in mine spoil might be due to the disruption of ecosystem functioning, depletion of soil organic pool and also due to the loss of litter layer during mining which is an integral storage and exchange site for nutrients.

Impacts of mining on soil chemical properties

Soil pH

Soil pH is a measure of active soil acidity and is the most commonly used indicator of mine soil quality. The pH of a given mine soil can change rapidly as the rock fragments weather and oxidize. Pyritic minerals (FeS_2), when present, oxidized to sulfuric acid and drastically lower the pH, while carbonate (Ca/MgCO_3) bearing minerals and rocks tend to increase the pH as they weather and dissolve. Un-weathered (or un-oxidized) mine soils that contain a significant amount of pyritic-S in excess of their neutralizers (carbonates) will rapidly drop the pH to a range of 2.2-3.5 after exposure to water and oxygen. When the soil pH drops below 5.5, reduced legume and forage growth occur due to metal toxicities such as aluminum or manganese, phosphorus fixation, and reduced population of N-fixing bacteria. This growth hence inhibits plant root growth and many other metabolic processes. Vegetation achieves optimal growth in soils at neutral pH. A mine soil pH range in the range of 6.0 to 7.5 is ideal for forages and other agronomic or horticultural uses (Gitt and Dollhopf, 1991; Gould et al., 1996). Maiti and Ghose (2005) reported that the pH vary from 4.9 to 5.3 in a mining dump site situated in Central Coalfield Limited's (CCL), North Karanpura area, in the Ranchi district of Jharkhand State of India and thus indicated the acidic nature of the dumps. This acidic nature arose due to the geology of the rock presented in the area. It has been reported earlier that at pH less than 5, along with Fe, the bioavailability of toxic metal such as nickel, lead and cadmium also increases (Maiti, 2003).

Soil fertility

The three macronutrients with major importance for plants, namely nitrogen, phosphorus and potassium are generally found to be deficient in overburden dumps (Coppin and Bradshaw, 1982; Sheoran et al., 2008). All newly created mine soils, and many older ones, will require significant fertilizer element applications for the establishment and maintenance of any plant community. Organic matter is the major source of nutrients such as, available P and K in unfertilized soils (Donahue et al., 1990). A level of organic carbon greater than 0.75% indicates good fertility (Ghosh et al., 1983). The level of organic carbon in overburden was found to be 0.35 to 0.85%. Organic carbon is positively correlated with available N and K and negatively correlated with Fe, Mn, Cu and Zn (Maiti and Ghose, 2005).

Some of the important metallic micronutrients that are essential for plant growth are Fe, Mn, Cu and Zn. These micronutrients are available in the soil due to continuous weathering of minerals mixed with primary minerals. These metals are more soluble in acidic solution, and

they dissolve to form toxic concentrations that may actually hinder plant growth (Donahue et al., 1990; Barcelo and Poshenrieder, 2003; Das and Maiti, 2006).

Impacts of mining on soil physical properties

Rock content

Soil particles, those smaller than 2 mm are responsible for majority of water and nutrient holding capacity in the mine soils. Particles larger than 2 mm are referred to as "coarse fragments". Soils constituting high coarse fragments have larger pores that cannot hold enough plant available water against leaching to sustain vigorous growth over the summer months. The coarse fragment contents in a typical mine spoil that vary (< 30- >70 %) due to differences in rock hardness, blasting techniques and spoil handling (Sheoran et al., 2010).

Particle size distribution of mine soils is directly inherited from their parent rocks or spoils. The rock content in the surface of a reclaimed bench or out slopes will decrease overtime due to weathering of rock fragments to soil sized particles. Top soil materials, when they can be salvaged, are typically present in much lower quantity in rock content than spoils and therefore have better water retention characteristics (Nicolau, 2002; Moreno-de las Heras et al., 2008). Hu et al. (1992) are of the opinion that soil with stone content greater than 50% should be rated as poor quality. Stone content of coal mine overburden dumps has been reported to be as high as 80-85% (Maiti and Saxena, 1998). Maiti and Ghose (2005) reported stone content in overburden dumps in range of 35-65%, with an average value of 55%.

Soil texture

Relative amount of sand (2.0 - 0.05 mm), silt (0.05- 0.002 mm), and clay (< 0.002 mm) sized particles determine the texture of soil (Sheoran et al., 2010). Mine soils with sandy textures cannot hold as much water or nutrients as finer textured soils like loams and silts. The silts are finer textured soils and have a tendency to form surface crusts, often contain high level of soluble salts, and have a poor "tilth" or consistence. The particle size distribution of the soils with loamy textures is generally ideal. Silt loam textures are common where spoils are dominated by siltstones (Ghose, 2005). Ghose (2005) reported the maximum sand content of 66% and clay only 8.6% in mined soil. Singh et al. (2004) and Singh (2006) also reported maximum content of sand (80 %) and least content of clay (11%) at the Singrauli Coal field in India. Low clay content means low cation exchange capacity of the soil. If the cation exchange capacity is high, then relatively larger doses of nutrients can be applied to the soil at one time and can retain sufficient moisture for

plant growth than if the cation exchange capacity is low because applied nutrients will not be easily leached down in the former case in contrast with the latter case when the applied nutrients will easily be leached down (Kolay, 2000).

Soil aggregation

Soil aggregation controls soil hydrology, affects soil diffusion and the degree of nutrient availability into the soil (Lindemann et al., 1984; Heras, 2009), and may reduce erosion potential (Elkins et al., 1984), and constitutes a pathway of organic carbon stabilization and long term sequestration (Six et al., 2004). Aggregate structure breaks down as successive layers of soil are removed and stockpiled elsewhere on the site when mining begins. The resulting compaction reduces water holding capacity and aeration. Macro aggregate stability is largely responsible for macro porosity, which determines soil drainage rate and aeration; it changes seasonally and is often affected by cultivation and other landuse activities such as that of mineral mining. Micro-aggregate stability is more resilient than macro aggregate stability as the organic matters responsible for binding the soil particles together reside in pores too small for microorganisms to occupy (Gregorich et al., 1989). Micro-aggregates are less sensitive to cropping practices than macro-aggregates (Dexter, 1988) and are responsible for crumb porosity which controls the amount of available water for vegetation (Davies and Younger, 1994).

Moisture, bulk density, compaction and available rooting depth

Moisture content in a dump is a fluctuating parameter which is influenced by the time of sampling, height of dump, stone content, amount of organic carbon, and the texture and thickness of litter layers on the dump surface (Donahue et al., 1990). During the winter, the average moisture content of 5% was found to be sufficient for the plant growth. During high summer (May-June), moisture content in overburden dumps was reported to be as low as 2-3% (Maiti et al., 2002). Again, Maiti and Ghose (2005) reported average field moisture content of the entire dumps was 5% in a mining dump site situated in Central Coalfield Limited's (CCL), North Karanpura area, in the Ranchi district of Jharkhand State of India.

Bulk density of productive natural soils generally ranges from 1.1 to 1.5 gcm⁻³. High bulk density limits rooting depth in mine soils. In seven year old overburden dumps, the bulk density was found to be as high as 1.91 Mgm⁻³ (Maiti and Ghose, 2005). Bulk density in the soil under a grass sward in the United Kingdom has been found to be as high as 1.8 Mgm⁻³ (Rimmer and Younger, 1997). Soil compaction directly limits plant growth, as most species are unable to extend roots effectively through

high bulk-density mined soils (Sheoran et al., 2010).

Severely compacted (bulk density >1.7 g/cc) mine soils, particularly those with less than two feet of effective rooting depth, shallow intact bedrock and the presence of large boulders in the soil simply cannot hold enough plant-available water to sustain vigorous plant communities through protracted drought. Three to four feet of loose non-compacted soil material is required to hold enough water to sustain plants through prolonged droughts. Compacted zones may also perch water tables during wet weather conditions, causing saturation and anaerobic conditions within the rooting zone. Repeated traffic of wheeled mining machineries (loaders and haulers), and bulldozers to a lesser extent, form compacted zones in the mining dumps (Sheoran et al., 2010).

Slope, topography and stability

Rehabilitated mine soils with slopes greater than 15% are generally unsuitable for intensive land uses such as vegetable or crop production, but they may be suitable for grazing and reforestation. Broad flat benches and fills with slopes less than 2% often have seasonal wetness problems. Many benches with an overall gentle slope contain areas of extreme rockiness, pits, hummocks and ditches.

Average slope of most reclaimed modern mines is quite a bit steeper than the older benches, but the newer landforms are considerably smoother and more uniform in final grade. Bench areas directly above intact bedrock on older mined lands are usually fairly stable but maybe subject to slumping, especially when near the edge of the out slope.

Tension cracks running roughly parallel to the out slope indicate that the area is unstable and likely to slump (Sheoran et al., 2010). Decreased soil stability can lead to increase in bulk density because the matrix does not resist slaking, dispersion by water and the forces imparted by wheels, hooves and rainfall (Daniels, 1999). This, in turn, leads to decreased aeration and water infiltration rate and the development of anaerobic conditions. Nitrogen losses by denitrification may follow under such environment (Davies and Younger, 1994).

Mine spoil/soil color

Mining activities remove surface earth, piling it over unmined land and forming chains of external dumps (mine spoil/wasteland). Mine spoils possess very rigorous conditions for both plants and the microorganism culture. Biological functionality along with the nutrient cycle is disturbed leading to a non-functional soil system. This is mainly due to low organic matter contents and other unfavorable physico-chemical and microbiological charac-

teristics (Singh and Singh, 1999, 2006; Jha and Singh, 1993). The color of a mine spoils or weathered mine soil can tell us much about its weathering history, chemical properties and physical make up. Bright red and brown colors in spoils and soils generally indicate that the material has been oxidized and leached to some degree. These materials tend to be lower in pH and free salts, less fertile, low in pyrites and more susceptible to physical weathering than darker colored materials. Gray colors in rocks, spoils and soils usually indicate a lack of oxidation and leaching and these materials tend to be higher in pH and fertility. Very dark gray and black rocks, spoils, and mine soils contain significant amounts of organic materials and are often quite acidic (Sheoran et al., 2010).

Dark colored spoils are difficult to revegetate during the summer months because they absorb a great deal of solar energy and become quite hot (Daniels, 1999). Evidence has indicated that the unassisted process of natural colonization of this spoil, like many others, can be very powerful and deliver fully developed and functional ecosystems within 100 years (Prach and Pysek, 2001; Bradshaw, 1997; Sheoran et al., 2010). The restoration of mine wasteland often therefore, requires active human intervention (what is called assisted regeneration) if the restoration goal is expected to achieve rehabilitation within a reasonable timeframe (Gathuru, 2011).

Top soil

The top soil has an important role, particularly in the establishment of native species (Amegbey, 2001). Top soil is used to cover poor substrate and to provide improved growth conditions for plants (Sheoran et al., 2010). Stockpiling of top soil in mounds during mineral extraction has been shown to affect the biological, chemical and physical properties of soil (Hunter and Currie, 1956; Barkworth and Bateson, 1964; Harris et al., 1989; Johnson et al., 1991; Davies et al., 1995). According to Amegbey (2001), stockpiling reduces the quality of the soil resources. Also, stockpiles become anaerobic, other plant propagules die and populations of beneficial soil micro-organisms are reduced significantly. For example, fresh soil contained about five to ten times as many seeds as soil stockpiled for three years at sand mine at Eneabba in western Australia (Amegbey, 2001). Top soil is a scarce commodity, and it is never stored in the majority of potential sources (Sheoran et al., 2010). Also, in a tropical climate where 90% of rainfall is precipitated within three months of the rainy season, storing of the top soil and preservation of soil quality remains problematic. Top soil is never stored for reuse; instead it is borrowed from nearby areas for the reclamation of the degraded mined-out areas (Sheoran et al., 2010). At a depth about 1 m in the stockpile, the num-

ber of anaerobic bacteria increases whereas those of aerobic bacteria decrease (Harris et al., 1989). This inhibits nitrification due to poor aeration within the stockpile leading to an accumulation of ammonia in the anaerobic zones. Once the soil is removed from the stockpile and reinstated, aerobic microbial population rapidly reestablishes, usually higher than the normal level (Williamson and Johnson, 1991) and nitrification restarts at higher than the normal rates (Sheoran et al., 2010). If high level of ammonia is present in a reinstated soil, the amount of nitrate generated is likely to be much greater than the normal. Consequently there is high potential for nitrogen loss to the environment via leaching and/or denitrification (Johnson and Williamson, 1994). Nitrate leached to water courses is not only a threat to aquatic environment and drinking water supplies (Addiscott et al., 1991) but if nitrogen is lost from soil in the form of gaseous nitrogen or nitrous oxides; this will contribute to the degradation of ozone layer (Isermann, 1994; Davies et al., 1995).

The period between the initial removal of top soil and the final laying of the same soil over the reclaimed area might have a long time elapsed. Hence, properties of stockpiled soil continually deteriorate and ultimately become biologically non-productive if it is not preserved properly (Ghose, 2005). Whenever possible, the topsoil should be replaced on an area where the landform reconstruction is complete (a phenomenon known as "direct return") (Amegbey, 2001). Direct return has several advantages when compared with placing the topsoil in stockpiles and storing it then later used for rehabilitation. First, it avoids double handling. Second, the need to create stockpiles may mean that extra land must be cleared. Third, and most importantly, stockpiling reduces the quality of soil resources (Amegbey, 2001). Other researchers have shown that both the density and numbers of species of native plants are significantly decreased when an area is rehabilitated with stockpiled rather than direct-returned topsoil.

If the topsoil must be stockpiled then it should be for as short a time as possible and the stockpiles should be as low as possible with a large surface area 2 m high or less; the stockpiles should be revegetated to protect the soil from erosion, discourage weeds and maintain active populations of beneficial soil microbes; the stockpiles should be located where they will not be disturbed by future mining, as excessive handling will adversely affect soil structure (Amegbey, 2001).

Impacts of mining on soil biological properties

Soil microbe

Soil microbe populations must be addressed deliberately as another soil component. It plays a major role in aggre-

gate stabilization, which is important for maintaining suitable structural conditions for cultivation and porosity for crop growth (Ghose, 2005). Their activity declines when soil layers are disrupted and is slow to resume independently. Soil microbes include several bacterial species active in decomposition of plant material as well as fungal species whose symbiotic relationship with many plants facilitates uptake of nitrogen and phosphorus in exchange of carbon. They produce polysaccharides that improve soil aggregation and positively affect plant growth (Williamson and Johnson, 1991). Sites with an active soil microbe community exhibit stable soil aggregation, whereas sites with decreased microbial activity have compacted soil and poor aggregation (Edgerton et al., 1995). Microbial activity decreases with depth and time as topsoil continues to be stored during mining operations (Harris et al., 1989). Microbial activity, measured in adenosine tri phosphatase (ATP) concentrations, plummets to very low levels within a few months. Response to glucose is slower by microbes at all depths, suggesting that metabolic rates decrease with time (Visser et al., 1984).

Bacteria

Bacteria play an important role in decomposition of organic materials, especially in the early stages of decomposition when moisture levels are high. In the later stages of decomposition, fungi tend to dominate. Rhizobia are single celled bacteria, belongs to family of bacteria *Rhizobiaceae*, form a mutually beneficial association, or symbiosis with legume plants. These bacteria take nitrogen from air (which plant cannot use) and convert it into a form of nitrogen called ammonia (NH_4^+) used by plants (Gil-Sotres et al., 2005).

Free living as well as symbiotic plant growth promoting rhizo-bacteria can enhance plant growth directly by providing bio-available P for plant uptake, fixing N for plant use, sequestering trace elements like iron for plants by siderophores, producing plant hormone like auxins, cytokinins and gibberilins, and lowering of plant ethylene levels (Glick et al., 1999; Khan, 2005).

When soil layers are removed and stockpiled, the bacteria inhabiting the original upper layers end up on the bottom of the pile under compacted soil. A flush of activity occurs in the new upper layer during the first year as bacteria are exposed to atmospheric oxygen. After two years of storage there is little change in the bacterial numbers at the surface, but less than one half the initial populations persist at depths below 50 cm (Williamson and Johnson, 1991).

Mycorrhizal fungi

Arbuscular mycorrhiza (AM) fungi are ubiquitous soil

microbe occurring in almost all habitats and climates. The hyphae network established by mycorrhizal fungi breaks when soils are initially moved and stockpiled (Gould et al., 1996). It is well documented that mycorrhizal associations are essential for survival and growth of plants and plant uptake of nutrient such as phosphorus and nitrogen, especially phosphorus deficient derelict soils (Khan, 2005).

An important *Arbuscular mycorrhiza* genus is *Glomus*, which colonize a variety of host species, including sunflower (Marschner, 1995). Dual inoculation with *Trichoderma koningii* and AM fungi increased plant growth of *Eucalyptus globulus* under heavy metal contamination conditions (Arriagada et al., 2004, 2005).

There is a little decrease in viable mycorrhizal inoculum potential during the first two years of storage (Miller et al., 1985). Viability of mycorrhiza in stored soils decreases considerably and possibly to the levels 1/10 those of the undisturbed soil (Rives et al., 1980). Miller et al. (1985) indicate that soil water potential is a significant factor affecting mycorrhizal viability. When soil water potential is less than -2 MPa (drier soil), mycorrhizal propagules can survive for greater lengths of storage time; when soil water potential is greater than -2 MPa, length of storage time becomes more important. In drier climates, deep stockpiles may not threaten mycorrhizal propagule survival. In wetter climates, shallow stockpiles are more important to maximize surface-to-volume ratios with regard to moisture evaporation (Sheoran et al., 2010).

REHABILITATION OF MINED SITES/SOILS

Rehabilitation is the process by which the impacts of mining on the environment are repaired. It is an essential part of developing mineral resources in accordance with the principles of sustainable development (Amegbey, 2001).

Rehabilitation normally comprises two stages: land form design and the reconstruction of a stable land surface; and revegetation or development of an alternative land use on the reconstructed land form (Amegbey, 2001). This paper, however, concentrates on the revegetation stage of rehabilitation and its influence on the soil fertility status.

Revegetation of mined lands

The traditional way of restoring damaged soils is by long rotation forest fallowing (Blum, 1988). Soil provides the foundation for this process, so its composition and density directly affect the future stability of the restored plant community (Sheoran et al., 2010). Reclamation strategies must address soil structure, soil fertility, microbe populations, top soil management and nutrient

cycling in order to return the land as closely as possible to its pristine condition and continue as a self-sustaining ecosystem (Sheoran et al., 2010). Reclamation and revegetation of abandoned mined lands are often limited by physical and chemical properties existing in the soil, including (but not limited to) low pH, high metal levels (including metal salts), low nutrient levels and poor or no soil structure (Said, 2009).

Soil structure and functions are degraded or lost during mining activities, which often result in soil toxicity, low nutrient availability and poor soil texture. Soil structure and function, although only a part of an entire ecosystem, are microcosm of the entire ecosystem. If these factors are not remediated, vegetation re-establishment and restoring ecosystem function will be difficult or impossible (Bradshaw, 1997).

Studies and analyses of biological and physiological characteristics of regenerated trees or newly planted trees and of the processes influencing productivity in such areas are necessary in order to improve the success of rehabilitation and reforestation activities (Kobayashi, 2004). Saline-sodic clay mine spoil materials excavated during open-cut coal mining in central Queensland, Australia, pose significant challenges for revegetation, particularly where suitable topsoil capping is not available (Grigg et al., 2006). While mulches lead to improved spoil moisture conditions in the laboratory, successful revegetation in the field also requires the removal of salts from the root zone (Grigg et al., 2006). High salinity constitutes a major limitation for plant establishment, reducing the level of seedling emergence by slowing germination (Bewley and Black, 1978) and thus increasing the time that the growth media must remain moist (Harwood, 1998). It also retards plant growth through osmotic stress, compounding the problem of a limited moisture supply from rainfall (Grigg et al., 2006).

Management of top soil is important for reclamation plan to reduce the N losses and to increase soil nutrients and microbes. Revegetation constitutes the most widely accepted and useful way to reduce erosion and protect soils against degradation during reclamation (Sheoran et al., 2010). Ecological restoration and mine reclamation have become important parts of the sustainable development strategy in many countries. Good planning and environmental management will minimize the impacts of mining on the environment and will help in preserving eco-diversity (Sheoran et al., 2010).

When attempting to restore a native ecosystem, the initial revegetation effort is unlikely to produce vegetation identical to the original. The initial revegetation effort must establish the building blocks for a self-sustaining system, so that successional processes lead to the desired vegetation complex (Amegbey, 2001; Sheoran et al., 2010).

The best time to establish vegetation is determined by

the seasonal distribution and reliability of rainfall. All the preparatory works must be completed before the time when seeds are most likely to experience the conditions they need to germinate and survive (that is, reliable rainfall and suitable temperatures) (Amegbey, 2001; Sheoran et al., 2010).

According to Coppin et al. (2000), revegetation is defined as the process of vegetation establishment and aftercare undertaken as part of reclamation, rehabilitation or restoration. Surface mines, for instance, can be filled and the ground recontoured and planted to establish a suitable vegetative cover that protects the soil (Owen et al., 1998). Mine restoration efforts have focused on N-fixing species of legumes, grasses, herbs and trees. Metal tolerant plants can be effective for acidic and heavy metals bearing soils (Sheoran et al., 2010). Restoration of vegetation cover on overburden dumps can fulfill the objectives of stabilization, pollution control, visual improvement and removal of threats to human beings (Wong, 2003).

Recent studies suggest that phytoextraction (remediation using green plants) is a viable method of cleaning large areas of soil and that it may be an effective alternative to current soil cleanup methods (Blaylock et al., 1997; Huang et al., 1997; Watanabe, 1997; Ensley, 2000; Van der Lelie et al., 2001).

Vegetation has an important role in protecting the soil surface from erosion and allowing accumulation of fine particles (Tordoff et al., 2000; Conesa et al., 2007b). They can reverse degradation process by stabilizing soils through development of extensive root systems. Once they are established, plants increase soil organic matter, lower soil bulk density, and moderate soil pH and bring mineral nutrients to the surface and accumulate them in available form. Their root systems allow them to act as scavengers of nutrients not readily available. The plants accumulate these nutrients and redeposit them on the soil surface in organic matter from which nutrients are much more readily available by microbial breakdown (Li, 2006; Conesa et al., 2007a; Mendez and Maier, 2008a).

Methods used to revegetate mined lands

According to Williams and Bellitto (1998), revegetation work can generally be categorized into one of three basic approaches: agricultural; ameliorative; or adaptive approach. Most modern revegetation projects, and especially more difficult ones, utilize a combination of the ameliorative and adaptive approaches.

Agricultural approach

Williams and Bellitto (1998) explained that the agriculture approach, although somewhat outdated, has been used

most often for revegetation in the past and is still the approach dictated by the Surface Mining Control and Reclamation Act of 1977 (SMCRA) regulations for coal mining projects. This approach utilizes the standard methods in the U.S.A of replacing the topsoil, fertilizing, and planting typical reclamation species to revegetate disturbed lands. Unfortunately, topsoil was not routinely salvaged during most historic mining activities and is not always available for use. Since the soils in the area surrounding most mine sites are naturally mineralized, importing suitable soils typically requires long, uneconomic haul distances. Therefore, the ameliorative and adaptive approaches, which directly revegetate mined lands without topsoil, are often desirable.

Although developed and used in Europe since the 1960s, it is believed that the first successful utilization of these approaches on the North America continent was at California Gulch Superfund site located near Leadville, Colorado in 1992. The approach used for the revegetation of this site was documented in the May/June 1996 issue of land and water magazine.

One of the cases of the practical application of the agricultural approach was the reclamation strategy employed by the AngloGold Ashanti Company limited at Obuasi in Ghana, to reclaim some of their mined lands (Appendix 1 and figure 4).

Ameliorative approach

Williams and Bellitto (1998) also indicated that the ameliorative approach involves chemically altering the soils to correct whatever problems are encountered. The approach can be used to raise the pH, and lower the solubility and availability of heavy metals to plants. In addition, the ameliorative approach can be used to stop further acid generation potential, and total and leachable metal concentrations. Standard agricultural analyses are also typically run on the soils. Based on this information, a site specific combination and rate of low cost waste materials and standard reclamation amendments, such as organic matter, lime and phosphate fertilizers, are specified to accomplish the required chemical reactions in the soil. Major nutrients identified as lacking in the soil can also be specified and included in the amelioration mixture.

Experience has shown that without some form of amendment, the spoils pose severe problems for vegetation establishment and growth (Bell et al., 1991; Philip, 1992; Harwood et al., 1999), even after 8 to 10 years of exposure at the surface (Banks, 1990; Grigg and Catchpoole, 1999). Grigg et al. (2006) examined the ability of sawdust or straw mulch amendments to ameliorate the adverse properties of these mine spoils and improve the success of revegetation efforts. In laboratory studies, mulch application improved infiltration, increased

soil moisture retention and reduced surface crust strength. In the field, mulches incorporated to a depth of 0.15 m at application rates of at least 20 t/ha straw or 80 t/ha sawdust were needed to mitigate against capillary rise of salts during drying cycles and support satisfactory vegetation cover.

Application of salvaged topsoil to a depth of 0.3 m appears to offer a successful solution for revegetation of these materials (Grigg and Catchpoole, 1999). However, reserves of suitable topsoil material may not always be available, therefore alternative amendments are needed.

In the laboratory, gypsum addition can decrease dispersion, improve hydraulic conductivity, and reduce crust strength with drying (Bell et al., 1992), but improvements in vegetation establishment and growth with gypsum application in the field have not been demonstrated (Emmerton, 1984; Philp, 1992). Philp (1992) found that addition of gypsum increased the electrical conductivity of the treated material, thereby exacerbating the problems of high salinity for plant growth and survival.

In contrast, organic mulch amend-ments can improve revegetation success on saline-sodic bentonite spoils (Smith et al., 1985; Belden et al., 1990) and Philp (1992) reported encouraging preliminary plant establishment results using a straw mulch treatment. Organic mulches may therefore, provide a successful alternative amendment for the revegetation of saline-sodic spoils in central Queensland (Grigg et al., 2006).

A field trial was established on an out-of-pit dump at the Goonyella Riverside open cut coal mine in central Queensland, Australia by Grigg et al. (2006). They found out that typical physical and chemical characteristics of the spoil depict that clay content is relatively high, and the clay types are reactive in the presence of sodium, which, together with magnesium, dominates the soil exchange capacity, salinity is very high due to abundant chloride, organic matter content is low, as are the levels of major plant nutrients.

The spoil, therefore, presents an extremely hostile environment for plant establishment and survival. In the absence of amendment, natural plant colonization is sparse and dominated by salt-tolerant species (Carroll et al., 2000). Productivity of soil can be increased by adding various natural amendments such as saw dust, wood residues, sewage sludge, animal manures, as these amendments stimulate the microbial activity which provides the nutrients (N, P) and organic carbon to the soil (Sheoran et al., 2010).

Adaptive approach

Williams and Bellitto (1998) further explained that the adaptive approach involves identifying, specifying and establishing plants which are ecotypically differentiated,

or adapted and tolerant of the site conditions. An *in vitro* plant tolerance testing method can be used to rapidly and cost-effectively screen a large number of plants for their tolerance to the specific conditions found at the site. This method involves utilizing tissue culture techniques and growth media adjusted chemically to emulate the specific site conditions. A plant's germination and initial root growth response are indicative of its response to actual site conditions. Varieties of some of these particular species were previously unknown to be tolerant of these typical site conditions.

In addition to low pH, high metal concentrations, and the often erodible nature of the soils, reclamation at historic mine sites is often further complicated by steep slopes and severe exposure problems related to mountainous area and high altitude. The combination of poor soil physical and chemical conditions and severe exposure difficulties can make natural recovery impossible and human rehabilitation very difficult in disturbed areas. Disturbed areas which have remained barren since their initial disturbance over 100 years ago are common. Previous attempts to revegetate these areas have often produced results which were less than acceptable to the concerned parties (Williams and Bellitto, 1998).

Other practical example of the use of adaptive approach to land revegetation could be made of the reclamation efforts at Haller Park at Bamburi Cement Mines in Mombasa, Kenya. Land reclamation started in 1971, by initially planting 26 tree species in open quarries. After six months, only three species survived. These were *Casuarina equisetifolia* sp., *Conocarpus lancifolius* sp. and coconut palm. *Casuarina* sp. was identified as a better pioneer because it could tolerate saline water despite being adapted to dry conditions; it can fix atmospheric nitrogen in the root system; it is an evergreen tree which constantly drops and renews foliage; and it grows fast, reaching 2 m in six months. The *Casuarina* tree or 'Whistling Pine', *C. equisetifolia* originated from Australia, but is now a common tree along the East African coast.

Casuarina trees have leaves with high tannin content. This makes their decomposition by micro-organisms difficult. In order to contain the problem, millipede (*Epibolus pulchripes*) was introduced, which was able to digest the *Casuarina* needle leaves and create the desired humus for the system. For more than 20 years, humus has been created partly in this way. As a result of the re-vegetation, insects and other life forms colonized the initial two square kilometers area which was under rehabilitation. By 1989, systematic introduction of indigenous coastal vegetation began.

By the year 2000, more than 300 indigenous plant species had been introduced, 30 species of mammals and 180 species of birds had found a home in the park. Some of the animals were introduced as 'orphans';



Figure 3. Revegetation of a residue from bauxite mining with nodulating and non-nodulating legume species, 3 months after transplanting the seedlings to the field, Amazon, Southeast Brazil. Franco et al. (1995).

others took refuge while some were deliberately introduced (Siachoono, 2010).

Species used in revegetation and their impacts

Revegetation of mine spoils requires designing a plant succession which will give adequate surface cover and increase the fertility of the soil (Morgan, 2005). Ideally, the succession should include rapid growing grasses to give ground cover as quickly as possible and stabilize the surface; legumes, to fix nitrogen; and other grasses and shrubs to provide a long term cover (Morgan 2005). Also, nodulating and non-nodulating legume species can be considered in the revegetation process (Figure 3).

Use of trees

Sometimes trees are considered in restoring degraded mined soils. Besides, trees have also been found to improve the soil fertility (Assel, 2006). Frequently, spoil bank areas are planted with trees in order to provide an income and also to remove the unsightly banks from view (Kohnke and Bertrand, 1959).

Dutta and Agrawal (2002) carried out a study on the effect of tree plantations on the soil characteristics and microbial activity of coalmine spoil land and realized that higher values of total N in comparison with fresh mine is due to the organic matter accumulation in soil by roots and leaching of N from the herbaceous vegetation of the plots. They also indicated that, during rainy season, the dead microbial population provides additional substrate, which further stimulates mineralization. Higher values of mineral N during rainy season may be due to easily decomposable substrate such as glucose, sucrose, amino acids and amides (Birch, 1958, Dutta and Agrawal, 2002). Decrease in N mineralization in winter and summer may be explained as increased microbial biomass which immobilizes the nutrients and build up their biomass in dry periods (Singh et al., 1989; Dutta and Agrawal, 2002).

Reclamation forestry, the afforestation of eroded or otherwise degraded land, has demonstrated the power of trees to build up soil fertility (Young, 1989). He also adds that the practice of shifting cultivation provides a demonstration of the capacity of forest to restore fertility lost during cultivation, for example.

Trees are very efficient biomass generators adding more organic matter to the soil, both above and below



Figure 4. Dokyiwa waste dump revegetated with mixed stand of *Acacia mangium* and *Senna siamea*, AngloGold Ashanti mines, Obuasi, Ghana. Age of plantation is 10 years. Source: Said (2009).

ground, than other plants. Their deep roots involve a greater depth of the raw mine stones than grass and, with a little encouragement, penetrate to the less compacted spoil layers beneath the “cap” of trapped clays (Blum, 1988). Root depth is typically 50 cm for herbaceous species or 3 m for trees, although certain *phreatophytes* that tap into groundwater which have been reported to reach depths of 15 m or more, especially in arid climates (Negri, 2003).

Trees can potentially improve soils through numerous processes, including - maintenance or increase of soil organic matter, biological nitrogen fixation, uptake of nutrients from below and reach roots of under storey herbaceous vegetation, increase water infiltration and storage, reduce loss of nutrients by erosion and leaching, improve soil physical properties, reduce soil acidity and improve physical properties, reduce soil acidity and improve soil biological activity. Also, new self-sustaining top soils are created by trees. Plant litter and root exudates provide nutrient-cycling to soil (Pulford and Watson, 2003; Coates, 2005; Padmavathiamma and Li, 2007; Mertens *et al.*, 2007).

Furthermore, rehabilitating mine spoils with trees may help reduce the tendency for compaction. If this new soils drain more easily, less water remain at the soil surface and possibility of soil erosion is reduced (Blume, 1988).

Also, there is a plausible hypothesis that trees in general are more efficient than herbaceous plant in taking up nutrients released by weathering. Potassium, phosphorus, bases and micro nutrients are released by rock weathering particularly in the B/C and C soil horizons into which tree roots often penetrate (Young, 1989).

Grasses are considered as pioneer crops for an early vegetation purpose. Grasses have both positive and negative effects on mine lands. They are frequently needed to stabilize soils but they may compete with woody regeneration. Grasses, particularly C4 ones, can offer superior tolerance to drought, low soil nutrients and other climatic stresses. Roots of grasses are fibrous that can slow soil erosion and their soil forming tendencies eventually produce a layer of organic soil, stabilize soil, conserve soil moisture and may compete with weedy species. The initial cover must allow the development of diverse self-sustaining plant communities (Shu *et al.*, 2002; Singh *et al.*, 2002; Hao *et al.*, 2004).

Mixed species

Generally, a mix of plant species is required because it is impossible to predict the success of any one species in

marginal environments where the vegetation is going to receive little or no maintenance (Morgan, 2005). Monocultures are disadvantaged due to the vulnerability to pests and diseases, they do not satisfy fully the multiple use and conservation roles, do not provide a balanced ecosystem and also they fail in providing more balance stable system in the face of environmental variability and directional change than mixed cultures. Mixed forestry systems, on the other hand, might be more stable as they sequester carbon more securely in the long term. In short, mixed systems could offer more to mitigating climate change than monocultures.

The species mix should include grasses, forbs and woody species, both bushes and trees, except where specific requirements make such a mix undesirable, as with some types of gully reclamation or along pipe line corridors (Morgan, 2005). For instance, evidence and induction, according to Young (1989), therefore suggest that for erosion control, the direct effects of the tree canopy in providing cover and reducing soil loss are less than those of ground cover/cover crops. Thus, the direct prevention of soil erosion, for example, is most effectively achieved by a cover of surface litter, consisting of crop residues, tree pruning or both.

For example, Liao et al. (2000) had reported that through 10-year observation, the total litter production of mixed plantation of *Cunninghamia lanceolata* and *Michelia macclurei* in the proportion of 1:1 was 43% higher than that of pure *C. lanceolata* plantation. Parrotta (1999) also observed that litter production was generally higher in mixed plantations than in mono-specific *Eucalyptus* plantations in Puerto Rico. Zhang et al. (1993) had also found that the annual litter amount of 55-year old *Pinus massoniana* and *M. macclurei* mixed forest was 11.2% higher than that of a similar-aged *P. massoniana* stand. Species composition is important for litter production within the same climate range (Sundarapandian and Swamy, 1999; Yang et al., 2004). Kelly (2006) also reviewed the role of species mixtures in plantation productivity. However, the effects of broadleaved trees in mixed plantations on amount and pattern of litter fall are not clearly understood.

Nutrient return through litter plays an important role in maintaining soil fertility and primary productivity of forest ecosystems. Wang et al. (1997) found that the amount of nutrient return via leaf litter to forest floor in the mixed plantation of *C. lanceolata* and *M. macclurei* was two and three times as much as that in the pure *C. lanceolata* plantation.

The results of Forrester et al. (2005) also demonstrated that mixing *Acacia mearnsii* with *Eucalyptus globules* increased the quantity and rates of N and P cycled through aboveground litter fall when compared with *E. globules* monocultures. Other researchers have also found quantities of N and P cycled through litter fall were higher in mixtures of N-fixing trees and non-N-fixing

trees than monocultures of the non-N-fixing species (Binkley, 1992; Binkley et al., 1992; Binkley and Ryan, 1998; Parrotta, 1999).

Indigenous/native/local species versus exotic/introduced/foreign species

Role of exotic or native species in reclamation needs careful consideration as newly introduced exotic species may become pests in other situations. Therefore, candidate species for vegetation should be screened carefully to avoid becoming problematic weeds in relation to local to regional floristic. For artificial introduction, selection of species that are well adapted to the local environment should be emphasized. Indigenous species are preferable to exotics because they are most likely to fit into fully functional ecosystem and are climatically adapted (Li et al., 2003; Chaney et al., 2007).

Wherever possible, native species should be chosen. A study of the neighboring sites often gives a good indication of what species are most likely to survive and thrive (Morgan, 2005). Singh et al. (2002) also reported that native leguminous species show greater improvement in soil fertility parameters in comparison with native non-leguminous species. Also, native legumes are more efficient in bringing out differences in soil properties than exotic legumes in the short term (Sheoran et al., 2010).

The use of introduced or exotic species should not be ruled out, however, especially where the local environment has deteriorated beyond that of adjacent sites or where numbers of local species are limited. The revegetation plan should allow for plant succession to take place naturally. In many cases, the objective is to establish pioneer species to give immediate cover and improve the soil, permitting native species to come in and take over as the colonizing plants decline (Morgan, 2005).

On mine spoils, nitrogen is a major limiting nutrient and regular addition of fertilizer nitrogen may be required to maintain healthy growth and persistence of vegetation (Yang et al., 2003; Song et al., 2004). An alternative approach might be to introduce legumes and other nitrogen-fixing species. Nitrogen fixing species have a dramatic effect on soil fertility through production of readily decomposable nutrient rich litter and turnover of fine roots and nodules. Mineralization of N-rich litter from these species allow substantial transfer to companion species and subsequent cycling, thus enabling the development of a self-sustaining ecosystem (Zhang et al., 2001).

Factors to consider in selecting species for revegetation

According to Morgan (2005), species to be used for

revegetation should be selected based on their following parameters; properties of rapid growth; toughness in respect of diseases and pests; ability to compete with less desirable species; adaptability to the local soil; and adaptability to the local climatic conditions.

When the species to be used in the revegetation programmes are trees, they should possess the following qualities, according to Young (1997), for it to be qualified for use in soil fertility improvement/restoration: Primarily have the capacity to grow on poor soils; High rate of nitrogen fixation; High and balanced nutrient content in foliage litter; Litter low in lignin and polyphenols; Either rapid litter decay where nutrient release is desired or moderate rate of litter decay where soil cover is required; Absence of toxic substances in litter or root residues; Well-developed tap root system; High rate of leafy biomass production; and dense network of fine roots with a capacity for mycorrhizal association.

Species selection will depend on local soil and climatic conditions but should aim to provide a uniform rather than clumpy pattern of vegetation to avoid concentrations of runoffs and localized erosion. The ideal condition is difficult to achieve, however, where the soils have low water retention capacity or are toxic, or where cold, drought or exposure inhibits plant growth.

Choosing vegetation which has beneficial effect is important (Morgan, 2005). For instance, in order to reduce the cost of reclamation of mine spoil mounds from tin mining on the Jos Plateau, Nigeria, the Mine Lands Reclamation Unit chose *Eucalyptus* sp. which could be cropped as a source of fuel and pole timber but these have resulted in significant declines in the base status and pH of the soil (Alexander, 1990) to the detriment of other plant growth (Morgan, 2005).

The revegetation of eroded ecosystems must be carried out with plants selected on the basis of their ability to survive and regenerate or reproduce under severe conditions provided both by the nature of the dump material, the exposed situation on the dump surface and on their ability to stabilize the soil structure (Madejon et al., 2006). Normal practice for revegetation is to choose drought-resistant, fast growing crops or fodder which can grow in nutrient deficient soils. Selected plants should be easy to establish, grow quickly, and have dense canopies and root systems. In certain areas, the main factor in preventing vegetation is acidity (Sheoran et al., 2010). Plants must be tolerant of metal contaminants for such sites (Caravaca et al., 2002; Mendez and Maier, 2008b).

THE ROLE OF REVEGETATION IN IMPROVING AND RESTORING SOIL FERTILITY

Fertility regeneration and maintenance is especially critical in areas devoid of the tropical forest vegetation necessary for quicker natural restoration (Asafu-Agyei,

1995). Apart from the fact that, trees and their litter prevent direct impact of torrential raindrops on soils and impede the movement of run off as well as preventing further erosion (Bonsu et al., 1996) on de-surfaced soils; forest biomass also decomposes to yield organic matter which improves soil fertility, structure, and other hydro-physical properties (Anane-Sakyi, 1995; Bonsu et al., 1996; Ingram, 1990). Anane-Sakyi (1995) also adds that, herbs, shrubs and trees supply organic materials in the form of litter to the soil under fallow and hence hastens the rate at which natural fertility returns to the fallow land.

Agboola (1990) also observed that, in undisturbed fallow, the nutrients move from the soil to the mat layer to the vegetation, and back to the soil and mat layer through the litter fall. The mat layer mechanism also serves as a means for nutrient conservation because most of the nutrients are located in the mat of roots and humus that occur on or near the soil surface. According to Anane-Sakyi (1995), the more the litter produced under the fallow, the more the soil organic matter, and the more fertile the land.

According to Dutta (1999), litter fall acts as a critical regulating component to enrich the microbial biomass on mine spoil. Root biomass and above ground plant biomass are considered to be the main source of soil organic and the latter is highly correlated with microbial biomass (Schnurer et al., 1985; Dutta and Agrawal, 2002). Kimaro et al. (2007) carried out a study on nutrient use efficiency and biomass production of tree species; it was observed that after 5 years rotation, top soils under *Gliricidia sepium* (Jaqua), *Acacia polyacantha* Wild and *Acacia mangium* Wild were the most fertile with soil organic carbon and exchangeable cation status raised close to those in natural systems. Soil inorganic nitrogen and extractable phosphorus levels reached sufficiency levels for subsequent maize culture.

Several processes have been identified by which trees can enhance the chemical and physical properties of the soils (Ingram, 1990). Other researchers like Troeh et al. (1980), also point out that the establishment of the vegetation on soils disturbed by constructional activities, and the subsequent increase in soil organic matter on these soils, results in the improvement in soil hydro-physical and chemical properties. These improvements, according to Ingram (1990), Asafu-Agyei (1995) and Cooper et al. (1996) include the following:

1. Improved soil physical structure (better soil aggregation and stabilization; reduced bulk density; increased available water capacity; improved infiltration; improvement in the soil texture) resulting from the higher levels of organic matter, old tree root channels and increased macro faunal activities. Although these are influenced by texture and clay type; organic gums and fungal and bacterial mycelia can bring soil particles into aggregates resulting in structural stability and good pore-

size distribution, which in turn provides good water holding capacity, favorable permeability and aeration as well as a good rooting depth and resistance to surface erosion.

2. Improved activity of soil organisms (such as fungi, arthropods, termites and worms) through a cooler and moister microclimate; as well as improved substrate for microbes which can contribute to nutrient needs in addition to the production of growth promoting substances.

3. Increase in nutrient status. A more closed nutrient cycle through the capture of nutrients which will otherwise be leached from beyond the tree or crop routine zone.

4. Improvement in cation exchange capacity (CEC) to enhance nutrient retention as well as enabling efficiency of nutrient utilization.

5. Reduced aluminium toxicity and low pH through enhanced cycling bases and the production of metabolic substance which temporally complex aluminium as well as buffering of the soil against rapid changes in acidity, alkalinity and salinity.

Furthermore, Young (1989) points out that soils developing under natural woodland or forest; the classic brown earth of temperate regions or red earth of the tropics is fertile. The soil is well structured, has good moisture-holding capacity, is resistant to erosion and possess a store of fertility in a nutrients bound up in organic molecules.

Role of revegetation in improving the soil physical properties

Maintenance or improvement of soil physical conditions

The superior soil structure, porosity, moisture characteristics and erosion resistance under forest is well documented, as is their decline on forest clearance. Porosity is a key to many physical properties: pores of 5-50 μm in diameter determine available water holding capacity, while those of over 250 μm in diameter are necessary for root penetration (Young, 1989). Compaction occurred during degrading of overburden and topsoil, mining, and reclamation activities at the time of unfavourable moisture conditions, and because of insufficient time for the soil-forming processes to decrease bulk density (Yao and Wilding, 1995; Bradshaw, 1997). Akala and Lal (2001) explained that abrupt increase in bulk density at the 30 cm depth is due to overburden and spoil material being extensively graded before topsoil application and the presence of large amounts of rock fragments at depths below 30 cm. Agodzo and Adama (2003) explained that water content of the soil is an important property that controls its behaviour. Moreso, bulk density is an indicator of problems

of root penetration, soil aeration and also water infiltration.

Improvement of infiltration and soil moisture availability/content

Ground vegetation, such as grasses will protect the slope against erosion by rain drop impact and run off, and also trap moving sediments, while shrubs and trees will increase the strength of the soil through root reinforcement. Vegetation increases the infiltration of water into the soil (Morgan, 2005). However, this can cause problems where rainfall amounts and intensities are very high. Whilst the resulting reduction of in runoff will help control surface erosion, the increased moisture content of the soil may exacerbate the rate of mass soil failure (Morgan, 2005). Young (1997) reported that the reduction in runoff is, to a small degree, caused by canopy interception and direct transpiration, but the greater part of its results from higher soil infiltration capacity under trees. Hamilton and Pearce (1987) also report that the dense surface-root system, under both natural forest and plantations, serves both to improve infiltration and to hold the soil in place.

Breaking of compact or indurated layers by roots

The improvement in surface protection causes a reduction in crusting and effect in compaction leading to increased infiltration; less leaching and prevention of erosion (Ingram, 1990; Asafu-Agyei, 1995; and Cooper et al., 1996).

Modification of extremes of soil temperature

There is experimental evidence from studies of minimum tillage that a ground surface litter cover greatly reduces the extremely high ground temperatures sometimes over 50°C, that is expected on bare soils in the tropics (Young, 1989). Again, Kolay (2000) points out that bare soil absorbs heat and becomes very hot during summer very quickly and becomes very cold during the winter, but this will not happen if the surface of the land is kept covered with vegetation which serves to insulate the soil. In this case, the soil will neither become too hot or too cold.

Improvement of soil texture and soil structure

According to Dutta and Agrawal (2002), significant variations in silt and clay suggest that plantations are capable of changing the soil texture after their establishment and growth in due course. Jha and Singh (1991)

indicated that the textures of mine spoils are drastically disturbed due to irregular piling of overburden materials. The naturally revegetating mine spoil of five years ago showed percentages of sand, silt and clay as 61, 25 and 14. Particle size distribution is a major soil physical factor governing a successful revegetation on reclaimed land as it influences water holding capacity, bulk density, soil moisture availability and nutrient contents as well as availability.

Role of revegetation in improving the soil chemical properties

Reduction of soil acidity

Trees tend to motivate the effect of leaching through addition of bases to the soil surface (Young, 1989). However, whether tree litter can be a significant means of raising pH of acid soils is doubtful, owing to the orders of magnitude involved (Young, 1989). One of the reasons for the above is that the calcium which trees supply through litter fall is insufficient to reduce the acidity even by a one pH point (Young, 1989). According to Young (1989), there are even cases where, in the temperate zone, trees produce acid, mor-type humus, which can lead to appreciable increase in soil acidification. However, experiments have also proven that the bases released by litter decay can check acidification. The increase in pH due to plantations suggests that the organic matter input modifies the pH of the soil. Since most plant species used for revegetation are dicotyledonous, these may release more base cations like Ca^{2+} into the soil and thus increase the pH of the soil more than the fresh mine spoil (Dutta and Agrawal, 2002). Richart et al. (1987) and Dutta and Agrawal (2002) also observed that the change in pH of opencast spoil was directly related to the tree growth. For plant nutrient availability (Ghose, 2004) optimum pH is 6.5 to 7.5.

Reduction of salinity or sodicity

Afforestation has been successfully employed as a means of reclaiming saline and alkaline soils (Young, 1989). For example, under *Acacia nilotica* and *Eucalyptus tereticornis* in Karnal, India, lowering of top soil pH from 10.5 to 9.5 in five years and of electrical conductivity from 4 to 2 dSm^{-1} have been reported, but with trees establishment assisted by additions of gypsum and manure (Gill and Abrol, 1986; Grewal and Abrol, 1986).

Reduction of the rate of organic matter decomposition

It is known that the rate of loss of humified organic matter

is lower in forest than agriculture. Shading by the canopy and litter cover of trees, given reduced temperature, is one of the reasons for this effect (Young, 1989).

Availability of nitrogen

Nitrogen is believed to be absorbed from the atmosphere and stored in the soil, which is then taken up in the form of nitrates by plants for use. The root nodules found on especially leguminous species help to achieve this. Leguminous cover crops such as *Pueraria*, *Centrosema* and *Calapogonium* are more effective. Tree species such as *Leucaena leucocephala* and other leguminous tree species are also equally effective. The nitrogen absorbed from the atmosphere in turn contributes to improving the soil fertility. The litter fall which improves the organic matter status of the soil eventually provides a favourable soil environment for N-fixation. Proteins present in this organic matter as well as the bodies of soil micro-organisms are decomposed to amino acids which are further oxidized to nitrates (Kolay, 2000), of which plants can make use of. Useful legume tree species may contribute around 12 tons of dry litter and 190 kg of N/ha/yr to renovate degraded soils (Franco and de Faria, 1996). Some legumes like *Leucaena* may provide above 500 kg of $\text{N ha}^{-1} \text{y}^{-1}$ (Sanginga et al., 1986).

Availability of phosphorus (P)

Mineralized P is found to be higher in soils treated with organic matter. Mbagwu et al. (1994) found soils treated with increasing rates of organic matter to have a corresponding increasing content of P. However, the total P accumulation in stem and bark is far greater than in leaves alone. P in the surface litter only accounts for small percentage of the total accumulation in the forest (Ren and Yu, 2008). It has been suggested that P deficiency is the inhibitive factor resulting in slow growth of *Acacia mangium* (Ribet and Devron, 1996; Xu et al., 1998; Ren and Yu, 2008).

Exchangeable cations

Vanlauwe et al. (2005) carried out a study to evaluate the functioning of trees as a safety-net for capturing nutrients leached beyond the reach of crop roots by investigating changes in exchangeable cations (Ca, Mg and K) and pH in a wide range of medium to long term alley cropping trials in savanna of West Africa. They noticed that the topsoil Ca content, effective cation exchange capacity, and pH were substantially higher under *Senna siamea* than under *L. leucocephala*, *Gliricidia sepium*, or the no-tree control plots in sites with a Bt horizon rich in exchangeable Ca. They attributed this to the recovery of Ca from the subsoil under *Senna* sp. The increase of the

Table 1. Soil properties under vegetated fields.

Available nutrients at two soil levels (kg/ha)	Under <i>Prosopis cineraria</i>	Under <i>Prosopis juliflora</i>	Open field
N: 0- 15 cm	250	203	-
15- 30 cm	193	212	196
P: 0-15 cm	22	10	8
15- 30 cm	10	5	4
K: 0- 15 cm	633	409	370
15- 30 cm	325	258	235

Source: Aggarwal (1980), cited by Young (1989), page 94.

Ca content of the topsoil under *Senna* sp. relative to the no-tree control treatment was related to the total amount of dry matter applied since trial establishment. The lack of increase in Ca accumulation under the other species was related to potential recovery of Ca from the topsoil itself and/or substantial Ca leaching. The accumulation of Ca in the topsoil under *Senna* sp. had a marked effect on the topsoil pH, the latter increasing significantly compared with the *Leucaena*, *Gliricidia* and no-tree control treatments.

Table 1 shows the possible effects of vegetation establishment (revegetation) on soil rehabilitation and restoration. It shows soil properties under the canopy of individual trees and those in the surrounding areas without tree cover. It could be seen that soils under vegetation had accumulated higher N, P and K than those under open field. This is due to the increased supply of litter provided by the vegetation which contributes organic matter, which in turn decomposes to release nutrients and that are responsible for improvement in soil fertility on degraded mined lands. This conforms to the research by Ingram (1990) and Troeh et al. (1980) who reported that the increased supply of litter (above and below ground residue) under natural fallow is considered to be responsible for the maintenance of soil organic matter and improvement in soil productivity of degraded lands. For instance, for *Acacia albida*, cases of 50 to 100% increases in organic matter and nitrogen under the canopy are known, together with increased water-holding capacity (Felker, 1978). Young (1989) also comments that in semi-arid climates, it is common to find higher soil organic matter and nutrient content under tree canopies than in adjacent open land.

Role of revegetation in improving soil biological properties

Maintenance and increment in soil organic matter

Organic matter is defined as the portion of soil that includes animal and plant remains at various stages of

decay. There are three components of soil organic matter: living biota (the roots, microbes and other organisms that occupy the soil); fragments of plants and animal remains in various stages of decay such as fallen leaves, dead organisms, animal excreta, or crop residues; and residues of active decay, organic compounds remaining on the soil which is called humus (Plaster, 2009).

Ingram (1990) and Troeh et al. (1980) point out that, the increased supply of litter (above and below ground residue) under natural fallow is considered to be responsible for the maintenance of soil organic matter and improvement in soil productivity on degraded lands. Of all the effects of trees, that of maintaining soil organic matter levels through the supply of litter and root residues is the major cause of soil fertility improvements. It is the prime mover of nutrients, from which stems many of the other soil improving processes (Young, 1997). According to Barber (1995), the chemical composition of soil organic matter is approximately 50% carbon, 5% nitrogen, 0.5% phosphorus, 39% oxygen and 3% hydrogen. However, he noted that these values fluctuate from soil to soil. The organic matter of a typically well-drained mineral soil is small, varying from 1 to 6% by weight in the topsoil and even less in the subsoil. The main effects of soil organic matter are on soil physical properties and nutrient supply (chemical effects) (Young, 1989).

Physically, organic matter improves conditions of all mineral soils for many reasons. Organic matter helps sandy soils by increasing their water-and nutrient-holding capacity. It also improves clay soils by loosening them and improving their tilth (Plaster, 2009).

The major chemical effect is with nutrient supply. The supply is balanced across the range of primary, secondary and micronutrients so long as it remains in the form of organic molecules, it is protected from leaching (other than in the case of podzols) and it is a slow release of nutrients in available forms through mineralization (Young, 1989).

Other merits of organic matter upon nutrient supply are the blocking of phosphorus-fixation sites, which improves the availability of phosphorus; and the complexing of

improved availability of micronutrients. It has been suggested that a good organic matter status provides favourable soil environment for fixation. A further chemical effect is the remarkable enhancement of CEC by the clay-humus complex; this is particularly important where CEC of a clay mineral is low, as in soils dominated by kaolinitic clay minerals and free iron oxides such as ferralsols and acrisols (Young, 1989). Raising the CEC improves nutrient retention both of naturally recycled elements and those added in fertilizer.

In a 2005 study, consistent applications of organic matter increased production nutritional status of crops on sandy soils, improved soil quality and reduced the need for fertilization (Plaster, 2009).

Russell (1973) also reported that the principal source of nitrogen which is a very essential nutrient for crops growing on land not receiving any nitrogenous fertilizer is that which is released by the soil population decomposing the organic matter. This organic matter, according to Young (1997), is supplied largely by tree residues. Soil organic matter is therefore, said to be central to soil management.

Production of a range of qualities of plant litter

This has the effect of distributing, over time, the release of nutrients mineralized by litter decay. Where the vegetation species are trees, they provide both woody and herbaceous residues, and thus a range in quality both of above – ground litter and root residues (Young, 1989).

Timing of nutrient release

Given the range in quality of tree residues, their different rate of decay will cause the release of nutrients to be spread over time. In managed systems this release can be partly controlled, through selection of tree species on the basis of rates of leaf decay and timing of pruning (Young, 1989).

Effects upon soil fauna

Trees greatly modify the kinds and amounts of soil fauna, generally in order to favor fertility (Young, 1989). A specific indirect effect has been suggested that shade trees in plantations, through reduction of weeds by shading, result in less need to use chemical herbicides which adversely affect soil fauna.

According to Dutta (1999), litter fall acts as a critical regulating component to enrich the microbial biomass on mine spoil. Root biomass and above ground plant biomass are considered to be the main source of soil organic

matter and the latter is highly correlated with microbial biomass (Schnurer et al., 1985; Dutta and Agrawal, 2002).

Role of revegetation in checking soil erosion

Agronomic measures of erosion control use the protective effect of vegetation covers to reduce erosion. According to Kohnke and Bertrand (1959), the only effective method of erosion control and the logical way of bringing strip-mined lands back into usefulness is to revegetate them.

The main purpose of erosion control on land previously used for mining is to create a stable environment for vegetation establishment and growth, in order to promote reclamation of land for agriculture or recreation, and to minimize off-site drainage. Since mine spoil banks are generally areas where erosion starts very quickly and because of the infertile and toxic nature of the material, vegetation grows very slowly (Morgan, 2005).

Vegetation plays a major role in the process of erosion control on gullied areas, construction sites, road embankments, landslides, sandstones, mine – spoils, and pipe-line corridors (Morgan, 2005). Vegetation also acts as a protective layer or buffer between the atmosphere and the soil (Morgan, 2005).

The above ground components such as leaves and stems, absorb some of the energy of falling raindrops, running water and wind, so that less is directed at the soil, whilst the below ground components, comprising the root system, contribute to mechanical strength of the soil (Morgan, 2005). This mechanical strength of the soil helps to reduce runoff and conserves the soil moisture and therefore, aid to increase the soil moisture availability content of the soil.

Also, crops and vegetation which give good ground cover and have an extensive root system help to reduce water erosion (Biswas and Mukherjee, 1994). Dense sods produced by grass and several leguminous plants are outstanding examples in this respect (Biswas and Mukherjee, 1994). As a method of increasing infiltration and reducing runoff, revegetation is carried out in gully erosion control where the area around the gullies is treated with grasses, legumes, shrubs, trees, or a combination of these aided in the early stages by mulching in some cases (Morgan, 2005).

Tree planting (in afforestation) is recognized as a suitable method of reducing run-off and erosion, especially if applied to head water catchment as a means of regulating floods (Morgan, 2005).

Experiments have shown that afforestation can reduce runoff in gullied areas by 65 to 80% and soil loss by 75 to 90% (Morgan, 2005). Again, Gong and Jiang (1977) reports that the use of grass in revegetating gullied areas can also reduce run off by 50 to 60 and soil loss by 60 to

80%.

SUMMARY AND CONCLUSION

This review was conducted to assess the contribution of revegetation to improvement of soil fertility of degraded mined lands. The following summary and conclusions were made:

Mining results in soil degradation through destruction of soil structure, accelerated soil erosion, excessive leaching, compaction, reduced soil pH, accumulation of heavy metals in soils, depletion of organic matter, decreased plant available nutrients, reduced cation exchange capacity and decreased microbial activity.

The results obtained in this study indicate that revegetation through forest vegetation is one of the efficient means of restoring lost soil fertility through improvement in soil organic matter content, available nutrients, cation exchange capacity, increased biological activities as well as improvement in physical conditions of the soil.

From the review, it can be concluded that revegetation can improve fertility of degraded mined lands but it will require longer period to restore the fertility close to the original level. Some of the promising tree species that can be used for revegetation are *Acacia*, *Leucaena* and other legume trees that are acid-tolerant and can add substantial amount of organic matter to the soil.

Conflict of interest

The author has not declared any conflict of interest.

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APPENDIX 1

Revegetation of degraded mined lands by AngloGold Ashanti Company Limited, Obuasi, Ghana (Said, 2009) (Figures 2 and 4)

In days past the top soil excavated prior to mining was kept for reclamation or re-vegetation. The mine spoil comprising the waste rock and tailings were used for the re-vegetation of the study area. Presently, the top soil will be heaped and kept where it can easily be accessed and used during reclamation or revegetation. Nitrogen-fixing plants such as *Acacia mangium*, *Senna siamea* and *Leucaena leucocephala* are used for the revegetation exercise. Analysis of the soil samples under a 10 year revegetation found the soil moisture content at 9.1, 8.2 and 14.1% and for areas under *A. mangium*, *S. siamea*

and mixed plantation of *A. mangium* and *S. siamea* respectively, as compared to the area under natural forest (under *Tectona grandis*) with 14.5% moisture content. The moisture content of the "Dokyiwa" reclaimed site (area under the mixed plantation) was similar to that of the un-mined area under natural vegetation (*T. grandis*). Other soil physical and chemical parameters such as texture, bulk density, soil pH, total nitrogen, available phosphorus, soil total carbon and exchangeable cations also showed encouraging results. These show the improvement in the soil fertility as a result of revegetation.