KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA

ASSESSMENT OF THE POTENTIAL OF RECLAIMED MINED LAND FOR AGRICULTURAL PRODUCTION

A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL SCIENCE, COLLEGE OF SCIENCE, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL SCIENCE

BY

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JANUARY, 2012

DECLARATION

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

…… …….

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

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ACKNOWLEDGEMENTS

I would like to thank the Almighty God for how far He has brought me. I would also want to thank my supervisor, Professor B. W. L. Lawson and Lecturers of the College of Biological Sciences, for their guidance towards the successful completion of this project work.

I'm very much grateful for the support and encouragement of my family, most especially my wife Dora Pomaa, children: Adu Nyamekye Ransford and Adu Ferka Adelaide, my mum and sister, Mary Konama and Adu Asantewaa Florence respectively. I also want to thank the Management and Staff of the Environment and Social Responsibility Department of Newmont Ahafo for the opportunity and support extended to me.

To Mr. Napoleon Mensa (Laboratory Technician, Institute of Renewable Natural Resources - KNUST), Dr. Samuel Baidoo and all friends, I say '*merci*' in fact words cannot express my gratitude. Thank you.

ABSTRACT

One of the major negative impacts of mining is the damage caused to soil and surface vegetation. This includes loss of vegetation cover, fauna and their habitats, water bodies, landscape, disturbance to the existing soil structure, soil erosion, depletion of forest resources and threat to the rich biodiversity. This destruction culminates into reduced productive potential of the affected mined sites for both flora and fauna. To mitigate the impacts of environmental degradation, mining companies in Ghana are enjoined to reclaim their operational sites so that the ultimate land-use and morphology of these sites are compatible with either the current land-use in the surrounding area or with the pre-mining environment. This responsibility led to Newmont Ghana Gold Limited (NGGL), Ahafo to initiate an experimental concurrent reclamation exercise which commenced in 2009 at the Apensu South waste rock dump site. An area of 5.6 hectares was covered and divided into four treatment plots with different top and subsoil thickness at overall soil depth of one (1) meter. An un-mined farmland adjacent to the reclaimed area was used as control for the study. The study sought to assess the effectiveness of the reclamation exercise based on the various treatments and make appropriate recommendations for the best treatment in relation to soil physico-chemical parameters, in order to determine whether soil conditions meet the agricultural expectations of the inhabitants and its conformance to the predominant land-use within the area. The test of hypothesis was Ho:All treatment means would be equal whilst H_A: Some treatment means would be unequal. Composite soil samples from the four treatments and control were analyzed for chemical properties (N, P, K, Ca, Mg, Na, Cu, Zn, Fe, pH) and physical properties (bulk density, water holding capacity). Notwithstanding the exertions made by the company to embark on this reclamation exercises, there is no base line data on the nutrients status of the reclaimed soils which will go a long way to determine their suitability or otherwise for Agriculture. It is for this reason that this research was carried out. The results of the analyses showed a highly significant difference ($P<0.001$) in the concentration of all the parameters for the various treatments except bulk density which showed significant difference ($P<0.05$). In this respect, the H_O is rejected and H_A accepted. It is recommended that about 0.3m of well-maintained topsoil is used to top-dress all future reclamation plots to promote effective plant growth.

.**TABLE OF CONTENTS**

LIST OF TABLES

Tables

Page

LIST OF FIGURES

Figures **Page**

LIST OF PLATES

List of Abbreviations

GDP	Gross Domestic Product
UNEP	United Nations Environment Planning
EPA	Environmental Protection Agency
pH	Power of Hydrogen
CEC	Cation - Exchange Capacity
BS	Base Saturation
USDA	United States Department of Agriculture
FAO	Food and Agriculture Organization
CSIR	Council for Scientific and Industrial Research
RNA	Ribonucleic Acid
CAM	Crassulacean Acid Metabolism
AWHC	Available Water Holding Capacity
ANOVA	Analysis of Variance
CRD	Complete Randomized Design
AAS	Atomic Absorption Spectrometry
UV	Ultra Violet
H: V	Horizontal and vertical gradient ratio
WHC	Water Holding Capacity

C4 PlantsPlants which create a four carbon (C4) sugar as their basic sugar unitwhen performing photosynthesis, e.g. maize

$\alpha = 0.05$	Alpha was used in comparing treatment means to determine differences using Tukey HSD All-Pairwise Comparisons Test
$P < 0.001$ or 0.05	Level of significance at $P < 0.05$ or 0.001 were used in determining the level of significant differences among treatment values, using ANOVA
NGGL	Newmont Ghana Gold Limited

CHAPTER ONE

1.0 INTRODUCTION

In Ghana, where agriculture serves as one of the most important sectors of the economy, soils are the most important natural resources. Hence a sound knowledge of the soil quality and its management are absolutely essential if the country is to advance in her socio-economic development. Lack of knowledge of soil ecology in most mining areas in Ghana and their potential for agricultural production is one of the greatest problems impeding the ability of the country to feed its growing population (Greenland, 1981).

Environmental degradation is the deterioration of the environment through depletion of resources such as air, water and soil; the destruction of ecosystems and the extinction of wildlife. It is defined as any change or disturbance to the environment perceived to be deleterious or undesirable (Johnson 1997). For many years, shifting cultivation has been the dominant method of land management in Ghana. This system of management has become unsustainable due to socio-cultural and economic factors such as high population growth, high demand for land for agricultural and non-agricultural uses and the advancement of technology (Bonsu and Quansah, 1992). Mining activities such as Stone quarry, Salt mining, Manganese, Bauxite and mostly Gold mining have been noted to cause environmental degradation in Ghana, which in turn affect both the physical and chemical properties of the soil (Benneh and Agyapong, 1990). The life forms of plants either become rare or dominant as a result of mining activities. The life processes of plants may be affected due to the release of some dust into the vegetation which may settle on the leaves blocking the stomata and thereby may reduce photosynthetic activities of the plant and consequently affecting plant productivity. In Ghana, most productive lands are being stripped off their useful soil fertility as a result of poor soil management practices. Deforestation due to mining activities begins with total clearance of the natural vegetation and a move into a period of construction when land is stripped bare (Wolman, 1967).

In spite of the mining sector's socio-economic contribution to the country by increasing Gross Domestic Product (GDP) and also helping to reduce unemployment, etc., it has some negative consequences on the surrounding soil quality. All mining activities disturb the existing soil structure, resulting in poor infiltration, increased run off, soil loss, soil erosion,

depletion of forest resources and threat to the rich biodiversity (Troeh*et al*, 1980). The ever increasing numbers and activities of Mining Companies in Ghana have also come with its attendant problems such as pollution, poor sanitation and effluent discharges from mining industries.

The soil serves as a depository for vast quantities of pollutants. These pollutants affect the physical and chemical properties of soil as well as nutrient availability necessary for plant growth. In Ghana major sources of soil pollution include industrial activities such as mining, stone quarrying, manufacturing and use of agro-chemicals. Some examples of the pollutants include solid, liquid and gaseous wastes.

Improper mining activities are thus, a threat to public health and reduce the quality of life for both surrounding communities and the entire population. Moreover, the situation is likely to worsen due to continuous population growth and over exploitation by mining companies in the country. Most attempts to improve and manage the impact of mining activities on the soil by mining companies are the technical aspect of monitoring their activities to meet the standards and requirements. In Ghana, the mining sector is the major generator of hazardous wastes such as Lead, Mercury, Arsenic, etc. which can be very fatal (www.epa.org). The soil and water bodies become the recipients of all these kinds of hazards.

It is estimated that the natural process of creating one inch of soil takes about a thousand years (www.soil-science.info). It is clear therefore that it would take hundreds of years to regenerate the lost soil from the ground surface. Polluted soil takes a long time to be renewed as compared to polluted air or water. This condition is due to the bumper structure of soil. Cleaning of polluted soils is more difficult and complex than polluted water or air. These pollutants end up interfering with the physical and chemical compositions of the soil as well as nutrients available for plant growth. Soil pollutants result mainly from human activities such as energy production, agriculture, mining, etc. which introduce heavy metal effluents, etc. into the soil. The occurrence of these, lead to the presence of noxious and toxic substances in the soil. The discharge of mining waste can also lead to the obliteration of local fauna and flora, contamination and in extreme cases, soil sterilization.

The soil is one of the major receptacles for the intimate disposal of effluent. It provides a treatment for the biodegradable waste. However, its ability to absorb and assimilate added waste without causing serious environmental problem has limitations. These limitations come from the complicated nature or the physical, chemical and biological properties of the soil. It is therefore apparent that continuous stripping, extraction, excavation and soil compacting by heavy machines and discharges on the soil affect its inherent valuable properties and thus rendering it unsuitable for plant growth and establishment as well as for agricultural purpose (Bouwer, 1969).

Forest and land degradation are defined as the temporary or permanent lowering of the productive capacity of land (Young, 1989). In Ghana forest and land degradation have reached unprecedented levels in recent years. Statistics have shown that the national forest is diminishing at a rate faster than its natural regeneration. Between 1990 and 2000, Ghana lost an average of 135,000 hectares of forest per year. This amounts to an average annual deforestation rate of 1.8%. Between 2000 and 2005, the rate of forest degradation increased to 1.88% per annum. In total, between 1990 and 2005, Ghana lost 25.9% of its forest cover or around 1,931,000 hectares (F.A.O., 2005). Data from the Forestry Commission shows that at the beginning of the century, Ghana's forest cover stood at some 8.2 million hectares, but presently the nation can only boast of a forest cover of 1.63 million hectares. This means that Ghana has lost 6.57 million hectares forming approximately 80.12% of its natural forest mainly due to lumbering and logging, uncontrolled bushfires, surface mining and urban development. Currently, surface mining, according to Earth Watch (2001), has become a dominant factor accounting for land degradation. Land degradation has affected some 1900 million hectares of land worldwide. In Africa an estimated 500 million hectares of land have been affected by soil degradation, including 65% of the Continent's agricultural land. The rate at which arable land is being lost is increasing and is currently 30-35 times the historical rate. The loss of potential productivity due to soil erosion worldwide is estimated to be equivalent to some 20 million tons of grain per year; and this is happening worldwide, not just in Africa or Asia (UNEP, 1999).

The Environmental Protection Agency (EPA) of Ghana issued a directive to all mining companies to "clean up" the environment after their operations. This meant the lands that

were degraded through surface mining had to be restored. In an effort to comply with this directive, some mining firms employed a technique called the "backfill", where refuse were collected and spread on the degraded sites to induce rapid natural regeneration of vegetation. This was however not viable and time wasting, therefore reclamation forestry (establishment of forest plantations on reclamation plots) was employed to address the issue. This approach was seen as a step to, not only "repair" the soil, but put them to some economic use as well, while waiting for nutrient replenishment and general soil improvement.

Vegetation cover and consequently topsoil richness have been linked to both soil fertility and soil productivity as established by Young (1997). He established that trees have long been used to reclaim areas of degraded lands due to their capacity to grow under difficult climatic and soil conditions, coupled with their potential for soil conservation.

When planning the life of a mine, the above objectives are used as a broad basis for environmental and mine planning. The E.P.A. of Ghana has a responsibility to ensure that mine sites are left in a condition that reflects government and community expectations. In general, mine site should be reclaimed so that the ultimate land-use and morphology of the site are compatible with either the current land-use in the surrounding area, or with the pre-mining environment. The area could be maintained as an industrial or commercial site if it is appropriate (Mchaina, 2001). In British Columbia, diversity of post-mining land-uses has been chosen for mined lands: 53% of them were proposed for wildlife habitats, 22% for forestry, 9% for pasture and 16% for some other land-uses (Errington, 2001). Alexander (1996) hints that the activities found in the mined lands include the use of ponds for water supply, fish farms and recreation; brick and block making is also common and then adds: 'The major activity that can be found in mined areas is irrigated arable agriculture, which is centered around the flooded mining paddocks and the associated water courses'. In addition, reclaimed sites have a wide range of potential functions such as, hayland, recreational areas, wetlands and swimming pools (Cao, 2007). Although the initial impression in much of the landscape created by mining is one of desolation and dereliction, closer study shows that intensive use has been and is increasingly being, made of these areas (Alexander, 1996).

1.1 Problem Statement and Justification

Today it is accepted that mine closure requires the return of land to a viable post-mining use, such as agriculture. It is not even sufficient to simply physically reclaim mined lands as the ecological, physico-chemical, micro-biological and micro-climatic impacts of the closure must also be assessed and managed. With the Ahafo area being primarily agrarian, the inhabitants have high expectations of their lands been restored as nearly as possible to its original condition, with all environmental, heritage or conservation values intact to support sustainable agriculture in future.

Unfortunately, notwithstanding the physical land reclamation being carried-out by Newmont in its Ahafo Operational Area, no study has been carried out to assess the potential of the restored or reclaimed land in relation to soil physico-chemical properties which would be very critical in determining the agricultural potential of the reclaimed lands. By measuring the characteristics of the soil microbial community and determining the physico-chemical components, we can assess the status of the microbial ecosystem and in that sense the quality of the soil and the potential for agriculture after degradation. The present study therefore, seeks to assess the effectiveness of reclaimed mined land of Newmont in Ahafo area in relation to soil physico-chemical parameters, in order to determine whether or not the soil conditions would meet the agricultural ambitions of the inhabitants.

The Reclamation Section within the Environment Department of Newmont Ghana has nursed and transplanted a wide variety of indigenous and exotic tree species for the reclamation exercise. These include; 'Wawa' (*Triplochitonscleroxylon*), Mahogany- Savanna type (*Khayasenegalensis*), Mahogany - forest type (*Khayaanthotheca*), 'Kakapenpen' (*Rauvolfiavomitoria*), 'Enwo–ne –enkyene' (*Cleistopholis patens*), 'Akumabaa' (*Nesogordonia*papaverifera), Emire (*Terminaliaivoriensis*), etc.

Notwithstanding the exertions made by the company to embark on this reclamation exercises, there is no base line data on the nutrient status of the reclaimed soils which will go a long way to determine their suitability or otherwise for agriculture. It is for this reason that this research is being carried out.

1.2 Aim of the Study

The study sought to assess the potential of the reclaimed land for agricultural development in the mining area.

1.3 Specific Objectives of the Study

Thespecific objectives were to:

i. Determine the physico-chemical properties of the Apensu South reclaimed area.
ii. Determine the physico-chemical properties of unmined farm land adjacent to the Apensu South reclaimed area

1.4 Limitations

Inadequate funds did not permit the inclusion of all the essential elements such as Sulphur (S), Boron (B), Manganese (Mn), Molybdenum (Mo) and Chlorine (Cl) in this research. Coupled with funds, unavailability of time could not also allow for the inclusion of biological parameters as well as carrying out of field trials with crops.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Mining and Soil Degradation

After mining, the ecosystem may recover spontaneously if the resultant mineral substrate and the environmental conditions are adequate. However, in most cases, deficient physical, chemical and biological soil conditions such as imbalanced granulometry, low organic matter, soil biota shortage or isolation from colonization sources impede initiation of secondary succession or slow it down to a level incompatible with the social requirement for rapid solutions (Ash et al., 1994; Bradshaw, 1997)

2.2 Soil Relocation and Landscaping

The most obvious sign of landscape degradation is an alteration in the topography of the mined area. As a result of the huge scale of earth removal and relocation that occurs during surface mining, the first step in attempting to restore the area to its natural state is to landscape the topography so that it matches that of the surrounding areas. Whereas backfilling mining areas adds to the aesthetic value by blending it with the surrounding landscape; the correct topography is also necessary for the long-term stability of slopes as well as for the successful establishment of vegetation (Schor and Gray, 1995). The long term stability of a slope usually depends on its ability to reduce the impact of maximum water flow and for that matter erosion (Nicolau, 2003).

2.3 Important Factors to Consider in Moving Topsoil

The two most important aspects to consider in removing topsoil are the depth of soil to remove as topsoil and the conditions for storing topsoil. Studies indicate that the top 5 cm of soil contains 90% of the seed bank (de Villiers *et al*., 1994; de Villiers, 2000). However, there are difficulties in mechanically removing such shallow layers of soil. Moreover, the biologically active and nutrient enriched layer extends well beyond 5 cm. Since the soils in

semi-arid areas contain very little organic matter (Whitford, 1999); there is therefore little stratification in such nutrient poor soils. This means that delineating the topsoil layer with precision is not always easy (Lanz, 1997). There is a trade-off between losing too much of the nutrient enriched, biologically active soil, and diluting and irretrievably burying much of the seed bank. A solution that has been used with much initial success by some mining operators is to remove both a shallow seed bank topsoil layer and a deeper biologically active 'subsoil' layer separately and re-apply them in the corresponding order. This method has enhanced restoration success in the semi-arid regions of Australia (Anon, 1996).

2.4 Topsoil Management

Ideally, removed topsoil should be re-applied immediately (Sweeting and Clark, 2000). This requires careful planning and co-ordination from mining operators to ensure that sufficient surface mined areas are backfilled and prepared for the application of topsoil in advance of the removal of new topsoil and the opening up of new areas to mining. However, there are situations in which this is not possible. Storing topsoil for long period leads to seed bank depletion following germination during storage and anoxic conditions develop inside large storage heaps (Strohmayer, 1996). Even in small storage heaps, it is likely that a high proportion of the micro-organisms, fungi and soil biota are killed. Allied with the loss of biological communities is a significant depletion in soil nutrients. Both at inland and coastal lowland 'Namaqualand' sites, any relocation or stockpiling of topsoil reduced the concentrations of a range of nutrients (Schmidt, 2002; Mahood, 2003). These reductions appear to progress further over the first few months of stockpiling. They are reflected in the reduced productivity of bio-assay plants on these soils (Schmidt, 2002; Mahood, 2003).

2.5 Mined soils

Overburdened soils can be excavated from depths of 30 m or deeper and such soils comprise a sterile growth medium, devoid of nutrients, and depending on the clay content, are of high acidity and/or salinity and often phytotoxic (Desmet, 1996). Even shallow overburden soils are largely depleted of nutrients and all soils that have been through processing plants are

greatly depleted of nutrients and at least initially, are of a high salinity. All of these soils constitute unsuitable media for the establishment of plants, except in some cases for a few acid salt-tolerant species (de Villiers et al., 1994). These soils require either the re-application of suitable growth media, i.e. top soils or intensive and dramatic soil amelioration.

2.6 Soil pH

2.6.1 Soil pH effect on plant response

A soil pH of 5.2 to 8.0 provides optimum conditions for most agricultural plants however many plants have adapted to thrive at pH values outside this range (Lake, 2000). All plants are affected by the extremes of pH but there is wide variation in their tolerance of acidity and alkalinity. Some plants grow well over a wide pH range, whilst others are very sensitive to small variations in acidity or alkalinity. Microbial activity in the soil could also be affected by soil pH. Where the extremities of acidity or alkalinity occur, various species of earthworms and nitrifying bacteria disappear. Legume root colonising bacteria (Rhizobia) vary in their sensitivity to soil pH and have preferred ranges in which they are effective.

2.6.2 Soil pH effect on availability of soil nutrients

Soil pH affects the availability of nutrients and how the nutrients react with each other. At a low pH, beneficial elements such as molybdenum (Mo), phosphorus (P), magnesium (Mg) and calcium (Ca) become less available to plants. Other elements such as aluminium (Al), iron (Fe) and manganese (Mn) may become more available and Al and Mn may reach levels that are toxic to plants. The changes in the availability of nutrients cause the majority of effects on plant growth attributed to acid soils. Sensitive crops such as barley and lucerne can be affected by small amounts of exchangeable aluminium. Consequently, knowledge of the soil pH and associated aluminium toxicity is vital before planning to sow crops and pastures.In contrast, when the pH is greater than 7.5, calcium can tie up phosphorus, making it less available to plants (www.wikipedia.com). Additionally, alkaline soils cause zinc and cobalt deficiencies that lead to stunted plants, poor growth and reduced yields in some crops and pastures. Applying lime will help to increase soil pH and thus decrease the solubility of these elements in the soil. Liming has other benefits as well. It tends to produce

favourableconditions for microbial activity in soil, with such related benefits as enhanced nitrogen fixation and, in some cases, improved soil structure.

2.7 Soil nutrients essential for plant growth

Plant nutrition is a term that takes into account the interrelationships of mineral elements in the soil or soilless solution as well as their role in plant growth. In 1965, Epstein defined two criteria for an element to be essential for plant growth:

1. in its absence the plant is unable to complete a normal life cycle
2. that the element is part of some essential plant constituent or metabolite,

This is all in accordance with Liebig's law of the minimum. There are 17 essential plant nutrients. Carbon and oxygen are absorbed from the air, while other nutrients including water are obtained from the soil. Plants must obtain the following mineral nutrients from the growing media:

- the primary macronutrients: nitrogen (N), phosphorus (P), potassium (K)
- the three secondary macronutrients such as calcium (Ca), sulphur (S), magnesium (Mg).
- the macronutrient Silicon (Si)
- and micronutrients or trace minerals: boron (B), chlorine (Cl), manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), molybdenum (Mo), nickel (Ni), selenium (Se) and sodium (Na).

The macronutrients are consumed in larger quantities and are present in plant tissue in quantities from 0.2% to 4.0% (dry matter weight basis). Micronutrients are present in plant tissue in quantities measured in parts per million, ranging from 5 to 200 ppm, or less than 0.02% dry weight.

Most soil conditions across the world can provide plants with adequate nutrition and do not require fertilizer for a complete life cycle. However, man can artificially modify soil through the addition of fertilizer to promote vigorous growth and increase yield. The plants are able to obtain their required nutrients from the fertilizer added to the soil. A colloidal carbonaceous residue, known as humus, can serve as a nutrient reservoir. Besides lack of water and sunshine, nutrient deficiency is a major growth limiting factor.

Plant concentrations of essential elements may exceed the critical concentrations, the minimum concentrations required for growth, and may vary somewhat from species to species. Nevertheless, Table 2.0 below gives the general requirements of plants:

Table 2.0:The General Nutrient Requirements of Plants

Element	**Symbol**	**mg/kg**	**Percent**	**Relative number of atoms**
Nitrogen	N	15,000	1.5	1,000,000
Potassium	K	10,000	1.0	250,000
Calcium	Ca	5,000	0.5	125,000
Magnesium	Mg	2,000	0.2	80,000
Phosphorus	P	2,000	0.2	60,000
Sulfur	S	1,000	0.1	30,000
Chlorine	Cl	100	--	3,000
Iron	Fe	100	--	2,000
Boron	B	20	--	2,000
Manganese	Mn	50	--	1,000
Zinc	Zn	20	--	300
Copper	Cu	6	--	100
Nickel	Ni	0.1	--	1

Source: After Epstein (1965)

Ability of soils to supply secondary nutrients to plants indefinitely is subject to the law of conservation of matter and is therefore dependent upon nutrient cycling. Continued crop removal of Ca, Mg, and S requires replenishment just as surely as primary nutrients, but most

likely less frequently. Calcium and magnesium are often supplied by mineral weathering, either of natural soil materials or of agriculture lime; ground limestone added to correct soil acidity. Sulfur is often added to soil as either atmospheric deposition (associated with air pollution) or as impurities in fertilizers, particularly common P fertilizers.

Essential elements used by plants in relatively large amounts are called macro nutrients (N, P, K, S, Ca, Mg); those used by plants in smaller amounts are known as micro nutrients (Fe, B, Zn, Cu, Mo, Cl, Mn, Na). The rest are carbon (C), oxygen (O) and hydrogen (H) obtained from the gas CO_2 and water (H_2O). These three elements are required in large quantities for the production of plant constituents such as cellulose or starch. The other thirteen (13) elements are called mineral nutrients because they are taken up in mineral (inorganic) forms. They are traditionally divided into two groups; macronutrients and micronutrients, according to the amounts required. Regardless of the amount required, physiologically, all of them are equally important.

2.8 The role of soil nutrients in plant nutrition

Soil nutrients play many complex roles in plant nutrition. While most of them participate in the functioning of a number of enzymatic systems, there is considerable variation in the specific functions of the various nutrients in plant and microbial growth processes. For example, copper, iron and molybdenum are capable of acting as electron carriers in the enzyme systems that bring about oxidation-reduction reactions in plants. Such reactions are essential steps in photosynthesis and many other metabolic processes (Brady and Weil, 1999).

2.9 Some Essential Plant Nutrients under Study

2.9.1 Phosphorus (P)

Brady and Weil (1999) stated that phosphorus is a critical element in natural and agricultural ecosystems throughout the world. The natural supply of phosphorus in most soils is small and the availability of that which is present is very low. Inputs of phosphorus from the

atmosphere and rainfall are negligible. Fortunately, most undisturbed natural ecosystems loose little of this nutrient because phosphorus does not form gases that can escape into the atmosphere, nor does it readily leach out of the soil with drainage water.

Phosphorus, Brady and Weil (1999) argued is closely associated with animal and human activity. Bones and teeth contain large amounts of this element. Archaeologists study the phosphorus content of soil horizons, because they know that unusually high concentrations of this element often accumulate where humans have congregated and have discarded the bones of wild or domesticated animals. Phosphorus is so scarce in most soils that high concentrations are often an indication of past animal or human activity in the area. At the extreme, lack of adequate available phosphorus is contributing to land degradation mostly in the lesser developed countries of Tropical and Subtropical regions. Phosphorus deficiency often limits the growth of crops and may even cause crop failure. Without adequate phosphorus, regrowth of natural vegetation on disturbed forest and savannah sites is often too slow to prevent soil erosion and depletion of soil organic matter (Brady and Weil, 1999).

2.9.2 Potassium (K)

Of all the essential elements, potassium is the third most likely, after nitrogen and phosphorus to limit plant productivity. Low availability of soil potassium also commonly limits plant growth and reduces crop quality. Even though most soils have large total supplies of this nutrient, most of that present is tied up in the form of insoluble minerals and is unavailable for plant use. Also, plants require potassium in such large amounts that careful management practices are necessary in order to make this nutrient available rapidly enough to optimize plant growth.

Unlike phosphorus, potassium is present in the soil solution only as a positively charged cation, K^+. Like phosphorus, potassium does not form any gases that could be lost to the atmosphere. Its behavior in the soil is influenced primarily by soil cation exchange properties (Brady and Weil, 1999).

2.9.2.1 Role of potassium in plant nutrition

Potassium is known to activate over 80 different enzymes responsible for such plant processes as energy metabolism, starch synthesis, nitrate reduction, photosynthesis, and sugar degradation. As a component in plant cytoplasmic solution, potassium plays a critical role in lowering cellular osmotic potentials, thereby reducing the loss of water from leaf stomata and increasing the ability of root cell to take up water from the soil. As a result of the functions of potassium, a good supply of this element promotes the production of plump grains and large tubers.

Good potassium nutrition is linked to improved drought tolerance, improved winter hardiness, better resistance to certain fungal diseases, and greater tolerance of insect pests. Potassium also enhances the quality of flowers, fruits and vegetables by improving flavor and color and strengthening stems (Brady and Weil, 1999).

2.9.2.2 Potassium availability

In contrast to phosphorus, potassium is found in comparatively high levels in most mineral soils, except for those consisting mostly of quartz sand. In fact, the total quantity of this element is generally greater than that of any other major nutrient element. Amounts as great as 30,000 - 50,000 kg of potassium per hectare of soil, in the upper 15 cm of soil are not uncommon. Yet the quantity of potassium held in an easily exchangeable condition at any one time often is very small. Most of this element is held rigidly as part of the primary minerals or is fixed in forms that are, at best, only moderately available to plants (Brady and Weil, 1999). The preferred concentration of K in the soil for plant growth ranges between 100-400 mg/kg (Rai, 1977).

2.9.3 Nitrogen (N)

2.9.3.1 Nitrogen fixation

This is a process by which large amounts of atmospheric nitrogen are fixed through symbiotic andnon-symbiotic associations of plant roots and bacteria. Certain tree species

(mostly leguminous plants) have the ability to convert or more appropriately reduce the atmospheric N2. Fitzpatrick (1986) stated that there are a number of free living chemoheterotrophic bacteria including Azotobacter, Clostridium, Pastorianum and Beijerinckia species that are capable of utilizing atmospheric nitrogen to form their cell protein which upon the death of the organism is decomposed to ammonia to form part of the nitrogen available to plants or to take part in nitrification. Other microorganisms capable of fixing atmospheric nitrogen include some algae. Nitrogen is found primarily in organic forms in soils. It moves in soils and plants mostly in the anionic form.

2.9.3.2 Origin and distribution of Nitrogen.

Some 300,000 mg of nitrogen, according to Brady and Weil (1999), is found in the air above 1ha of soil. The atmosphere which is 78% gaseous nitrogen (N_2) in content appears to be a virtually limitless reservoir of this element. But the very strong triple bond between two nitrogen atoms makes this gas quite inert and not directly usable by plants or animals. Were it not for the ability of certain microorganisms to break this double bond and to form nitrogen compounds, vegetation in the terrestrial ecosystems around the world would be rather sparse, and little nitrogen would be found in soils.

Brady and Weil (1999) continued that the nitrogen content of surface mineral soils normally ranges from 0.02 to 0.5%, a value of about 0.15% being representative for cultivated soils. A hectare of such a soil would contain about 3.5 mg nitrogen in the A horizon and perhaps an additional 3.5mg in the deeper layers. In forest soils the litter layer might contain another 1 to 2 mg of nitrogen. While these figures are low compared to those for the atmosphere, the soil contains 10 - 20 times as much nitrogen as does the standing vegetation (including roots) of either forested or cultivated areas. Most of the nitrogen in terrestrial systems is found in the soil.

Most soil nitrogen occurs as part of organic molecules. Soil organic matter typically contains about 5% nitrogen; therefore, the distribution of soil nitrogen closely parallels that of soil organic matter because association with certain silicate clays or resistant humic acids helps protect the nitrogenous organic compounds from rapid microbial breakdown, typically only

about 2 to 3% of the nitrogen in soil organic matter is released annually as inorganic nitrogen. Unlike most of the inorganic nitrogen, the mineral forms of nitrogen are mostly quite soluble in water and may be easily lost from soils through leaching and volatilization. As it moves through the nitrogen cycle, an atom of nitrogen may appear in many different chemical forms, each with its own properties, behavior and consequences for the ecosystem. This cycle explains why vegetation (and indirectly animals) can continue to remove nitrogen from a soil for centuries without depleting the soil of this essential nutrient. The biosphere does not run out of nitrogen because it uses the same nitrogen over and over again (Brady and Weil, 1999).

2.9.4 Soil exchangeable calcium (Ca)

Levels of exchangeable calcium together with pH helps to determine which specific organisms thrive in a particular soil. Although in any chemical condition found in soils some bacterial species will thrive, high calcium and near- neutral pH generally result in the largest, most diverse bacterial populations. Low pH allows fungi to become dominant. The effect of pH and calcium helps explain why fungi tend to dominate in forested soils, while bacterial biomass generally exceeds fungal biomass in most sub-humid to semi-arid prairie and rangeland soils (Brady and Weil, 1999). The preferred concentration of Ca in the soil for plant growth ranges between 20-100 mg/kg (Rai, 1977).

Important ways by which calcium is removed from soil are through erosion, leaching and plant removal. The losses may be replaced by lime and fertilizer application. As the soluble calcium is removed from the soil by the growing plants or by leaching, the percentage base saturation and pH are gradually reduced (Brady and Weil, 1999). Three principal mechanisms by which nutrient ions dissolved in the soil solution come into contact with plant roots are diffusion, root interception and mass flow. All three mechanisms may operate simultaneously, but one mechanism or another may be most important for a particular nutrient, for example, in the case of calcium, which is generally plentiful in the soil solution, mass flow alone can usually bring sufficient amounts to the root surface (Brady and Weil, 1999).

2.9.5 Magnesium (Mg)

Brady and Weil (1999), stated that like calcium, important ways by which available magnesium are supplied to the soil are by lime and fertilizer applications and also by plant residues and manures. The losses are through erosion, leaching and plant removal. As the soluble magnesium compounds are removed from the soil by the growing plants, or by leaching, the percentage base saturation and pH are gradually reduced; eventually, another application of lime is necessary. This type of cyclic activity is typical of much of the magnesium added to arable soils in humid regions. The preferred concentration of Mg in the soil for plant growth ranges between 10-40 mg/kg (Rai, 1977).

2.9.6 The role of vegetation in improving soil chemical conditions

2.9.6.1 Reduction of soil acidity

Studies have shown that vegetation per se cannot reduce the acidity of strongly acidic soils. This is because the calcium which the trees supply via litter is insufficient to reduce acidity even by one (1) pH point (Young, 1989).

2.9.6.2 Increasing and sustaining levels of N, P, K, Ca and Mg availability.

According to Young (1989), a large quantity of nutrients is believed to circulate between plants and the soil annually in forest ecosystems. It is observed that this circulation provides a closed cycle thereby providing equilibrium in the whole system. The nutrient recycling hypothesis, which states that by the inclusion of trees, agroforestry systems can achieve a condition intermediate between losses and increasing plant uptake, has identified certain processes which can help in achieving this. These include gains made by the system, by way of atmospheric rain and dust fertilizers (rain-dissolved nutrients and nutrient containing dust particles), organic additions (litter fall, compost, nitrogen fixation, deep capture by tap roots, etc.). The pathways for losses were identified as erosion, leaching and harvesting.

2.9.7 Copper (Cu)

Copper (Cu) is taken up as Cu^{2+}. Its uptake appears to be a metabolically mediated process. However, Cu uptake is largely independent on competitive effects and relates primarily to the levels of available Cu in the soil. Cu is involved in chlorophyll formation and is a part of several enzymes such as cytochrome oxidase. As much as 70% of the Cu in plants may be present in the chlorophyll, largely bound to chloroplasts. It participates in lignin formation, protein and carbohydrate metabolism and is possibly required for symbiotic N fixation. Cu is a part of plastocyanin, which forms a link in the electron transport chain involved in photosynthesis. Cu is not readily mobile in the plant and its movement is strongly dependent on the Cu status of the plant. Negligible leaching of Cu occurs from all except very sandy soils (Blaylock, 1994).

Cu-deficiency symptoms are first visible in the form of narrow, twisted leaves and pale white shoot tips. At maturity, panicles/ears are poorly filled and even empty where the deficiency is severe. In fruit trees, dieback of the terminal growth can occur. In maize, yellowing between leaf veins takes place, while in citrus the leaves appear mottled and there is dieback of new twigs. The natural range for concentration of copper in soils is 7 – 80 mg/kg (Eddy *et al*., 2006) whilst the preferred concentration in the soil for plant growth ranges between 5-20 mg/kg (Rai, 1977). Cu-toxicity symptoms are more variable with species and less established than its deficiency symptoms. Excess Cu induces Fe deficiency and therefore, chlorosis is a common symptom.

2.9.8 Iron (Fe)

Fe is absorbed by plant roots as Fe^{2+} and to a lesser extent as Fe chelates. For efficient utilization of chelated Fe, separation between Fe and the organic ligand has to take place at the root surface, after the reduction of Fe^{3+} to Fe^{2+}. Fe is immobile in the phloem. Fe is generally the most abundant of the micro-nutrients with a dry-matter concentration of about 100 μg/g (ppm). According to Eddy *et al.* (2006), the natural range for Fe concentration in soils is 3000 – 5000 mg/kg whereas the preferred concentration in the soil for plant growth ranges between 20-100 mg/kg (Rai, 1977; Robinson, 1946). It plays a role in the synthesis of

chlorophyll, carbohydrate production, cell respiration, chemical reduction of nitrate and sulphate and in N assimilation. Fe deficiency begins to appear on younger leaves first. Otherwise, its deficiency symptoms are somewhat similar to those caused by Mn, as the deficiency of both Fe and Mn lead to failure in chlorophyll production. Yellowing of the interveinal areas of leaves (commonly referred to as iron chlorosis) occurs. In severe deficiency, leaves become almost pale white because of the loss of chlorophyll. In cereals, alternate yellow and greenstripes along the length of the leaf blade may be observed. Complete leaf fall can occur and shoots can die. Fe toxicity of rice is known as bronzing. In this disorder, the leaves are first covered by tiny brown spots that develop into a uniform brown colour. It can be a problem in highly weathered, lowland acid soils.

2.9.9 Zinc (Zn)

Zinc is taken up as the divalent cation Zn^{2+}. Early work suggested that Zn uptake was passive, but more recent work indicates that it is active (energy-dependent). Zn is required directly or indirectly by several enzyme systems, auxins and in protein synthesis, seed production and rate of maturity. Zn is believed to promote RNA synthesis, which in turn is needed for protein production. The mobility of Zn is low. The rate of Zn mobility to younger tissue is particularly depressed in Zn-deficient plants. Common symptoms of Zn deficiency are: stunted plant growth; poor tillering, development of light green, yellowish, bleached spots; chlorotic bands on either side of the midrib in monocots (particularly maize); brown rusty spots on leaves in some crops. In acute Zn deficiency as in rice, it may cover the lower leaves and in fruit trees the shoots may fail to extend and the small leaves may bunch together at the tip in a rosette-type cluster. Little-leaf condition is also a common symptom. Internodes are short. Flowering, fruiting and maturity can be delayed. Shoots may die off and leaves can fall prematurely. Deficiency symptoms are however, not the same in all plants.

The natural concentration range for zinc in soils is 10 - 300 mg/kg (Eddy et al., 2006) but the preferred concentration for plant growth ranges between 2.5-150 mg/kg (Rai, 1977). Zn toxicity can result in reduction in root growth and leaf expansion followed by chlorosis. It is generally associated with tissue concentrations > 200 μg/g of Zn.

2.9.10 Sodium (Na)

Sodium is involved in the regeneration of phosphoenolpyruvate in CAM and C4 plants. It can also substitute for potassium in some circumstances. It can stimulate the growth - increase leaf area and stomata, as well as improves the water balance of plants. Sodium also improves crop quality e.g. improves the taste of carrots by increasing sucrose. The preferred concentration of Na in the soil for plants growth ranges between 1-1000 mg/kg (Rai, 1977)

2.10 Bulk Density (BD)

Bulk density is more commonly used as an indicator of soil compaction. It (dry bulk density) is defined as the ratio of the mass, M, of dry soil to its volume, V (Wild, 1997). This volume includes both solid and pore spaces. The value of Bulk Density is of most relevance to the behavior of soil under field conditions, it is measured in the field. This is usually done by driving an open-ended cylinder into the soil. Soils with a high proportion of pore spaces to solids have lower bulk densities than those that are more compact and have less pore spaces. Consequently, any factor that influences pore spaces will affect bulk density (Dirk and Hagarty, 1984). Bulk density usually ranges from 1.0 - 2.0 g/cm^3 for mineral soils. A normal range of bulk densities for clay is 1.0 to 1.6 g/cm^3 and a normal range for sand is 1.2 to 1.8 g/cm^3 (Aubertin and Kardos, 1965) with potential root restriction occurring at 1.4 g/cm^3 for clay and 1.6 g/cm^3 for sand (Aubertin and Kardos 1965; Corley 1984). Many compacted urban soils have been shown to have a bulk density of 1.6 to 2.0 g/cm^3. Most trees grow best in well-aggregated, well-drained soils with bulk densities less than 1.5 g/cm3 (Craul, 1985).

During the compaction process, soil structure is destroyed and large soil pores collapse. Density is an indirect indicator of the adequacy of soil pore space. The bulk density of clay loam and silt loam surface soils normally ranges from 1.00mg/m^3 to as high as 1.60mg/m^3 depending on their condition (Brady and Weil, 1999). A lower bulk density together with improved soil structural stability and a balance between fine and coarse pores lead to ease of root penetration, which is a feature of fertile soils. Higher levels of organic matter on organic farms also lead to higher aggregate stability, lower bulk density and increased water holding capacity (Prasad and Power 1997).

2.11 Water Holding Capacity (WHC)

Available water holding capacity (AWHC) refers to the capacity of the soil to hold water that plants can use. It is controlled largely by soil texture. Silt loam and loam textures provide the greatest AWHC. Coarse textures (sand, sandy loam, etc.) have less microscopic surface area to hold the water for plants than do fine textured soils (silty clay loam, clay loam, clay, etc). Though these fine textured soils contain large surface areas for holding water, the clay particles bind much of the water so tightly that little of it is available to plants. The addition of organic matter to the soil usually increases the water holding capacity of the soil. This is because the addition of organic matter increases the number of micropores and macropores in the soil either by "gluing" soil particles together or by creating favourable living conditions for soil organisms. Certain types of soil organic matter can hold up to 20 times their weight in water (Reicosky, 2005). Hudson(1994) showed that for each 1% increase in soil organic matter, the available water holding capacity in the soil increased by 3.7%. Soil water is held by adhesive and cohesive forces within the soil and an increase in pore space will lead to an increase in water holding capacity of the soil. The time required to drain a field from flooded condition for a clay loam that begins at 43% water by weight to a field capacity of 21.5% is 6-days, whereas a sandy loam that is flooded to its maximum of 22% water will take 2-days to reach field capacity of 11.3% water. The available water for the clay loam might be 11.3% whereas for the sandy loam it might be only 7.9% by weight (Donahue et al. 1977).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

Asutifi District is one of the 22 districts in the BrongAhafo Region. It is located between latitudes 6°40' and 7°15' North and Longitudes 2°15' and 2°45' West. The district capital is Kenyasi, which is about 50km from Sunyani, the regional capital, through Atronie and Ntotroso. It shares boundaries with Sunyani Municipality in the North, Tano South District to the North East, Dormaa Municipality to the North West, Asunafo North District and Asunafo South District in the South West and AhafoAno South and North Districts (Ashanti Region) in the South East (www.asutifi.ghanadistricts.gov.gh). With a total land surface area of 1500 sq.km, the district is one of the smallest in the BrongAhafo Region. There are a total of 117 settlements in the district and four paramouncies, namely: Kenyasi No.1, Kenyasi No.2, Hwidiem and Acherensua. Some of the mine fringe communities and Newmont mine installations (NGGL, 2008) are shown in fig. 1.0 below:

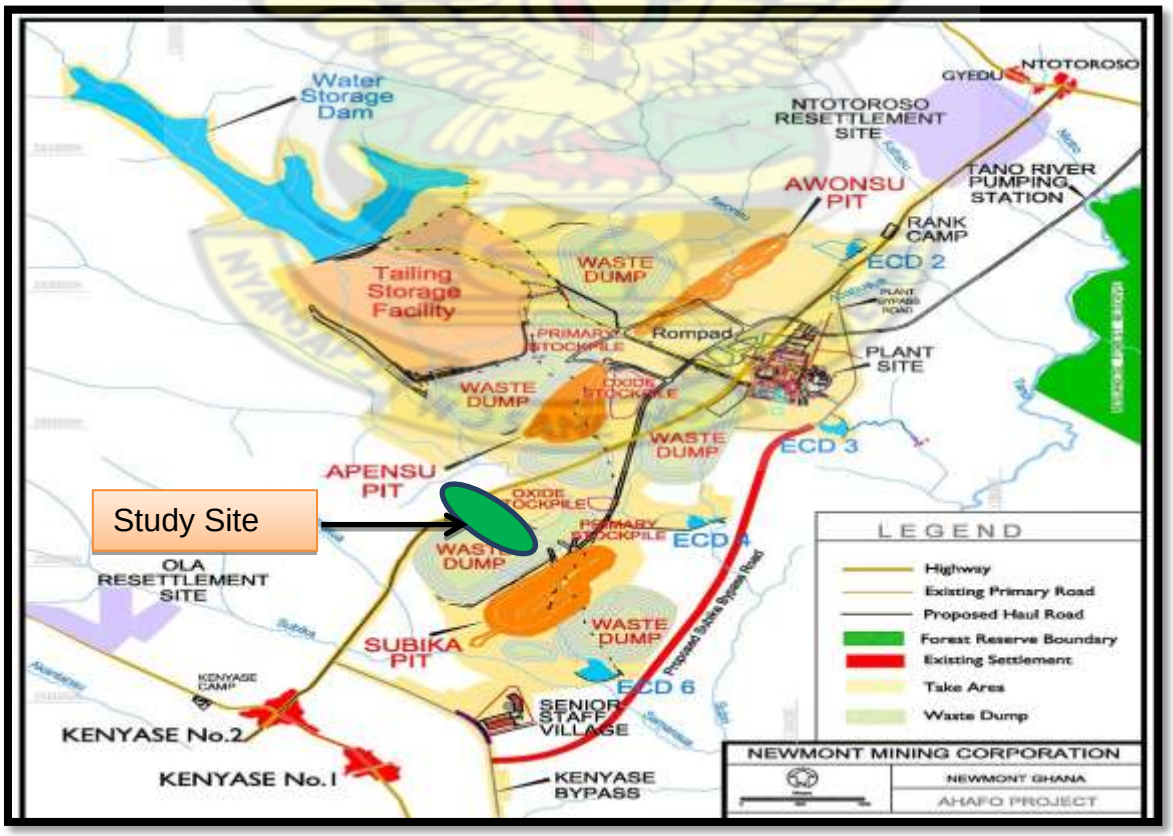

Figure 1.0: The map of the Asutifi District showing Newmont Ghana Gold Ltd installations

3.1.1 Topology and Drainage

The district lies within the forest dissected plateau physiographic region with average height of about 213 meters above sea level. The lowest part is about 198 meters above sea level found along the river basins whilst the highest point is found within a chain of mountains in the north east reaching a height of 426 meters above sea level. These mountains form water shed for the many tributaries of the Tano River and other streams. There are out crops of gigantic rocks found over Birimian rocks basement standing about 228 - 274 meters above the broad plateau surface. The district is drained by the Tano River and its many tributaries which include Nsubin, Goa and Ntotro rivers exhibiting a dendentric pattern. These youthful fast flowing rivers have cut up the plateau surface giving rise to the disserted nature of the plateau. Figure 3.2 shows the relief and drainage in the district (NGGL, 2008).

3.1.2 Climate and Vegetation

The district lies within the wet semi-equatorial zone marked by double rainfall maxima; June and October with a mean annual rainfall between 125cm and 200cm. The first rainy season is from May to July (major season) and the second rainy season is from September to October (minor season) when the district comes under the influence of the Wet Maritime Air-mass. The beginning of the rainy season is marked by heavy thunderstorms which sometimes cause the ripping off of building roofs and plant lodging. There is a sharp dry season between the two rainy seasons, coming between November and March when the tropical continental air-mass in the country sweeps over the area.

Relative humidity is generally high ranging between 75% to 80% during the two rainy seasons and 70% to 80% during the rest of the year. The district has a moist semi-deciduous forest. Human activities notably farming, lumbering and occasional bush fires have however disturbed this vegetation. This has changed some areas into a derived wooded savanna. Such transitional zones could be observed along the roads to Goamu-Koforidua, Kensere and Dadiesoaba. These developments call for immediate measures to protect this sensitive ecological zone (www.asutifi.ghanadistricts.gov.gh).

3.1.3a Geology and Soil

This physiographic region is underlain by Precambrian rocks of Birimian and Dahomeyan formations. The soils have developed over weathered products of lower birimianphyllite and alluvial sediments within river and stream valleys and the floodplains of the Tano River (Soil Research Institute, 2006). Two soil associations of Bekwai-Nzema-Oda and Birim-Awaham-Chichiwere can be encountered in the area (Adu, 1992).

The Birimian formations are known to be the gold bearing rocks. The Birimian rocks also have a high potential for Manganese and Bauxite. Currently gold is being mined in the area where these rocks are found by Newmont Ghana Gold Limited one of the largest mining companies in the world. These areas include Kenyasi No. 1 & 2, Ntotroso, Gyedu-Wamahinso and other smaller communities. However, other exploration activities are on-going in other communities within the District. Diamond is discovered at Wamahinso. There is also a widespread deposit of sand and clay in the district. The Sand deposits can be found at Kenyasi, Gambia No.2, Hwidiem and Acherensua whilst the clay deposits can be found at Nsunyameye and Dadiesoaba. There are rounded out crops of granite found over the Birimian rocks at KwadwoAddaekrom, Goa Asutifi, Georgekrom and Konkontreso which also have high potential of iron and bauxite (www.asutifi.ghanadistricts.gov.gh).

According to the Soil Research Institute (2006), soils in the area can be classified into the USDA Soil Taxonomy and the FAO World Reference Base for soil resource classification systems as mostly Ultisols (Acrisols and Nitisols) are on the uplands and mostly Fluvents (Fluvisols) and Inceptisols (Cambisols) are in the lowlands.

3.1.3b Baseline Soil Information from Ahafo Mining Area

The soils were found to have developed over weathered products of lower birimianphyllite and alluvial sediments within river and stream valleys and the floodplains of the Tano River. Two soil associations of Bekwai-Nzima-Oda and Birim-Awaham-Chichiwere were encountered (Adu, 1992). The component soil series members mapped were Bekwai, Oda, Temang, Birim, Awaham and Chichiwere series. Their major chemical properties are presented in the Table 1.0 below:

Table 1.0: Baseline Data Collection of the Soil Resources of Newmont Ahafo Project

Soil Series	Parameter	Topsoil	Subsoil
Bekwai	pH	6.0 – 6.5	4.8 – 6.5
Rhodi-Ferric	Org Matter %	3.2 – 4.2	0.47 – 1.9
Nitisol	Nitrogen %	0.12 – 0.39	0.04 – 0.09
	CEC (me/100g)	14.0 – 31.0	3.2 – 16.0
	BS%	99	46 – 99
Nzima	pH	5.5 – 6.5	4.7 – 7.0
Plinthic-Ferric	Org Matter %	4.2 – 5.4	0.28 – 1.4
Acrisol	Nitrogen %	0.15 – 0.26	0.02 – 0.08
	CEC (me/100g)	14 – 34	3 – 12
	BS%	99	91 – 98
Kokofu	pH	6.0 – 6.6	5.0 – 6.7
PlinthicAcrisol	Org Matter %	1.5 – 4.0	0.2 – 0.8
	Nitrogen %	0.08 – 0.28	0.02 – 0.06
	CEC (me/100g)	6.5 – 20.6	4.0 – 11.8
	BS%	99	57 – 99
Oda	pH	6.1 – 6.5	5.4 – 6.6
Gleyi-Clayic	Org Matter %	2.0 – 3.0	0.2 – 0.5
Fluvisol	Nitrogen %	0.08 – 0.12	0.03 – 0.04
	CEC (me/100g)	8.8 – 13.0	4.3 – 28.0
	BS%	98 – 99	97 – 99
Birim	pH	6.6	4.4
Hapli-Vertic	Org Matter %	1.8	0.17 – 0.38
Cambisol	Nitrogen %	0.12	0.-03 – 0.09
	CEC (me/100g)	6.4	8.1 – 18.2
	BS%	98	92 – 98

Credit: CSIR-Soil Research Institute of Ghana (2006)

On the uplands the soils were observed to be mostly Ultisols (Acrisols and Nitisols) while on the lowlands they were mostly Fluvents (Fluvisols) and Inceptisols (Cambisols).

In general, soil fertility is moderate to poor. Generally pH is high in surface horizons, ranging between 5.5 - 6.6 and decreases down the profile (Table 1.0). Surface horizons have moderate to high organic matter (1.5 - 5.4%). CEC varies considerably from moderate to high. The soils were evaluated by the Field Assessment Team of the CSIR - Soil Research Institute of Ghana (2006)as moderately suitable for the major plantation and food crops grown in the area namely cocoa, citrus, oil palm, plantain, cocoyam, cassava, maize, legumes and vegetables.

3.1.4 Study Site/Plots

The study took place at the Newmont AhafoApensu waste rock dump site. The plot (waste rock dump) which has an area of about 5.6 ha was re-sloped to a gradient of 3:1 and divided into four panels/zones. Subsoil (saprolite) and topsoil were placed at different depths on the panels (plots). This first concurrent reclamation was a trial to study and verify the effectiveness of topsoil-saprolite combinations at different thicknesses as a growth medium on waste rock re-contoured to a gradient of 3:1(H:V). This involved re-grading the waste rock dump, replacement of sub and topsoil, re-vegetation with grass and cover crops (for erosion control and nutrient fixation) and planting of native trees. The plots were all stabilized with erosion and sediment control structures and then seeded with grass and cover crop (*Pureraria).* The depth of soil placements for the various plots is as given below:

- Zone 1 had topsoil and subsoil mix of 0.4m and 0.6m respectively.
- Zone 2 had topsoil and subsoil mix of 0.3m and 0.7m respectively.
- Zone 3 had topsoil and subsoil mix of 0.2m and 0.8m respectively.
- Zone 4 had 1m depth (only subsoilwas placed on it).
- An un-mined farmland adjacent to the reclaimed area (T_1) was used as a control for the study.

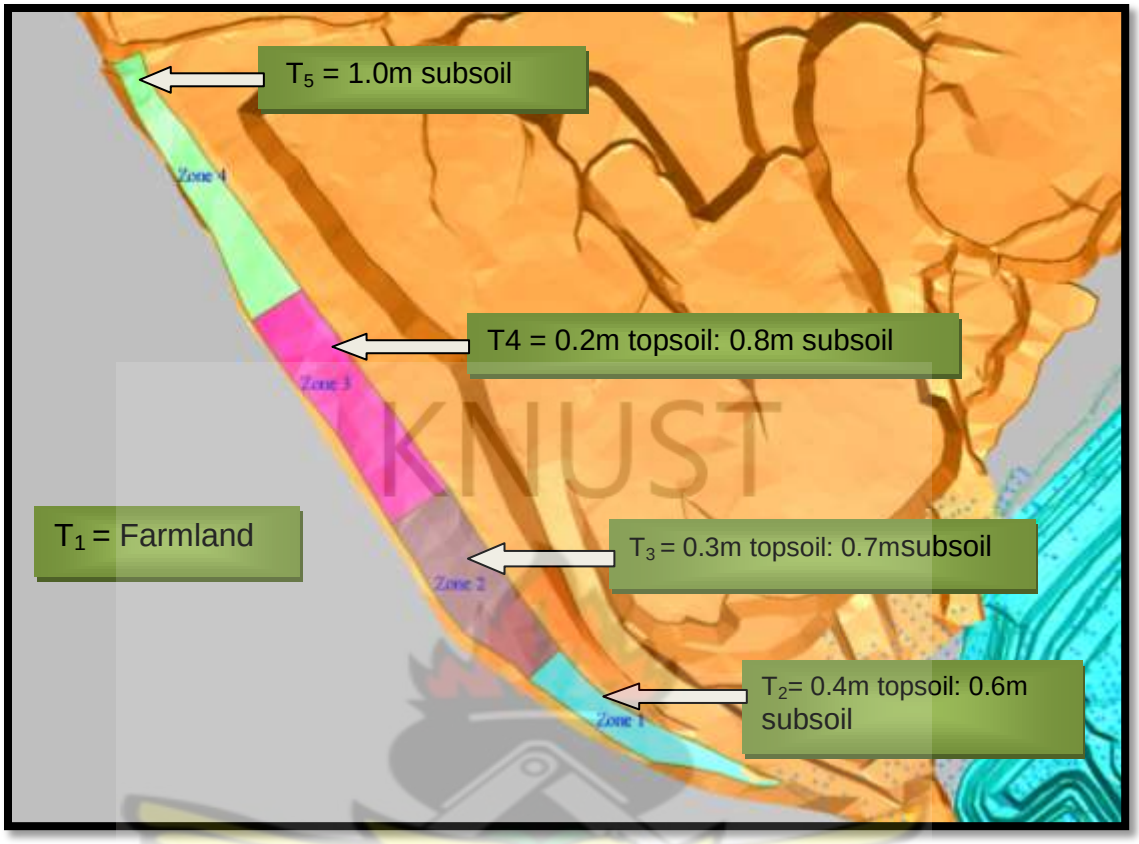

Figure 2.0: Map of the Study Site: NGGL Apensu South Waste Rock Dump

Source: Newmont Ghana Gold Limited (2008)

3.1.5 Sampling

1m X 1m quadrats were laid at each treatment site and replicated ten times. Soil samples of 0-20cm depth of profile (Plate A) were taken. Ten topsoil samples were then bulked and three subsamples were taken for laboratory analysis. Below were pictures taken during the sampling exercise.

Plate A: Soil sample collection using auger.to determine bulk density.

Plate B: Set up of soil sample collection

3.1.6 Statistical Analysis of Data

Soils were analyzed for the following chemicals (N, P, K, Ca, Mg, Na, Cu, Zn, Fe), pH, and physical properties (bulk density and water holding capacity-WHC). Data obtained from the analysis were subjected to Analysis of Variance (ANOVA) using a Complete Randomized Design (CRD) with five treatments and three (3) replications. Mean separation was then done where significant differences were found.

Tukey HSD All-Pairwise Comparisons Test of individual nutrients by treatment was done to determine which treatment means were not significantly different from one another. The treatments were as follows:

T_1 = Un-mined farmland

T_2 = Mix of 0.4m topsoil and 0.6m subsoil

T_3 = Mix of 0.3m topsoil and 0.7m subsoil

T_4 = Mix of 0.2m topsoil and 0.8m subsoil

T_5 = 1m depth of only subsoil

3.2 Soil Chemical Analysis

3.2.1 Sample preparation

Di-acid digestion was used for preparing samples for the determination of the following nutrients; N, P, K, Ca, Na, Mg, Fe, Zn and Cu.

Procedure:

The collected soil samples were air- dried, finely ground and sieved with 2mm sieve.2g of finely ground soil sample was weighed and placed into 300ml conical flask.20ml of di-acid mixture of HNO_3 & $HClO_4$ in the ratio 9: 4 was added to the sample.The contents were well mixed and placed on hotplate in a fume chamber.The mixture was gently heated until production of red NO_2 fumes ceased between the temperature of 90 and 150^oC.Heating continued till the volume of the content reached 3-4ml and became colourless. Content was cooled, filtered through an acid-washed filter paper into a 100ml volumetric flask and topped up to the mark with distilled water. This solution was used for nutrient estimation of P, K, Ca, Na, Mg, Fe, Zn and Cu with the aid of spectrophotometer, flame photometer and atomic absorption spectrophotometer.

3.3 Determination of Total Nitrogen

Total nitrogen was determined by the Kjeldahl Method (Bento, 1991).

3.3.1 Digestion

To 1.0g soil sample, 50ml distilled water and10ml conc. H_2SO_4 were added. One digestion tablet and boiling chips were also added before fitting in a digestion unit to boil until the solution was clear (or straw colour/yellow-like). A blank determination was included.

3.3.2 Distillation

After digestion, 300ml distilled water and 50ml NaOH-$Na_2S_2O_3$ were added. Solution was placed in the distillation unit. Distillate was collected in 50ml boric acid in Erlenmeyer flask till content of Erlenmeyer flask reached 200ml. Titration was done with 0.02N HC1. A blank was included.

Calculation

$$\% N = \frac{(\text{ml HC1 Sample} - \text{ml HC1 Blank})\ (NHC1)}{\text{Sample Weight}}$$

Operational Procedure for SpectrAA 220 Atomic Absorption Spectrometer

Below is a brief outline of the procedure for operating the AAS 220 to determine the following:

Copper and Zinc

The acetylene gas was fixed to the compressor. The Compressor was turned on. The liquid trap joined to compressed air pipe to rid-off any liquid trapped was blown. The Extractor was turned on. POWER switch on the AAS 220 Machine was also turned on. The capillary tube and the nebulizer block were cleaned with a cleansing wire. The opening of the burner was cleaned with an alignment card. The worksheet of the AAS software on the attached Computer was opened. The appropriate hollow cathode lamp in the selected lamp holder was inserted. The Lamp was turned on and the ray was aligned from the respective cathode lamp to hit the target area of the alignment card for optimal light throughput. The Lamp signals were optimized and the machine ignited. The capillary/aspirator tube was placed in a 10ml graduated cylinder containing deionized water; the aspiration rate was measured and was set to 4-6ml/minute, by adjusting the nebulizer. The recommended standard solutions and blanks were aspirated and a calibration curve was prepared. The machine AAS was then ready for the sample analysis.

Analytical Procedure for SpectrAA 220 Atomic Absorption Spectrometer:

Fundamentally, quantitative analysis by atomic absorption spectroscopy is a matter of converting samples and standards into solutions, comparing the instrumental responses of standards and samples, and using these comparative responses to establish accurate concentration values for the element of interest.

Convert the sample into solution, if it is not already in solution form. Make up a solution which contains no analyte element (the analytical blank). Make up a series of calibration solutions containing known amounts of analyte element (the standards). Atomize the blank and standard in turn and measure the response for each solution. Plot a calibration graph showing the response obtained for each solution as shown below. Atomize the sample solution and measure the response. Determine the concentration of the sample from the calibration, based on the absorbance obtained for the unknown.

Flame Spectrometer

A flame spectrometer heats the atoms of a sample to an excited state and then analyzes the resulting emitted spectra to determine the atomic makeup of the sample.

Atomic Absorption Spectroscopy (AAS)

Atomic absorption spectroscopy (AAS) determines the presence of metals in liquid samples. Metals include Fe, Cu, Al, Pb, Ca, Zn, Cd and many more. It also measures the concentrations of metals in the samples. Typical concentrations range in the low mg/L range. In their elemental form, metals will absorb ultraviolet light when they are excited by heat. Each metal has a characteristic wavelength that will be absorbed. The AAS instrument looks for a particular metal by focusing a beam of UV light at a specific wavelength through a flame and into a detector. The sample of interest is aspirated into the flame. If that metal is present in the sample, it will absorb some of the light, thus reducing its intensity. The instrument measures the change in intensity. A computer data system converts the change in intensity into an absorbance. As concentration goes up, absorbance goes up. The

researchercan construct a calibration curve by running standards of various concentrations on the AAS and observing the absorbance.

3.4 Soil pH

General procedure for soil pH (2.5:1 H_20) (Rhoades, 1982)

50ml deionized water was added to 20g soil. The mixture was stirred for 10 minutes, allowed to stand for 30 minutes and the mixture was then stirred again for 2 minutes. After calibrating the pH meter with a buffer of pH 7.00, the pH was read by immersing the electrode into the upper part of the soil solution and the pH value recorded.

3.5 Soil Physical Analysis

3.5 Bulk Density

The bulk density of soil is the mass per unit expressed as g cm^{-3}. Once the bulk density is known, measurement of soil mass, volume or percentage can be expressed interchangeably or in absolute terms. The procedure used in determining the bulk density of the research plots is based upon those described by Anderson and Ingram (1993).

2cm of surface soil was removed from the level area where samples were to be measured. A one open ended milk tin of 5cm diameter of known weight (WI) and volume (V) was inserted into the soil surface.Soil was excavated from around the tube and cut beneath the tube bottom.Excess soil was removed from the tube ends using a knife**,** the can and its content was dried at 105˚C for 2 days, and weighed (W2)

Calculation of Bulk Density

$$\text{Bulk Density} = \frac{(W2 - W1)\ g/cm^3}{V}$$

where: W1 = Weight of empty can

W2 = Weight of can and dry content

V= Volume of can

3.5.1 Soil Water Holding Capacity

Field capacity is defined as the maximum amount of water the freely drained soil can hold and is estimated after a saturated soil has been allowed to drain without allowing its moisture stores to be depleted by evaporation (Anderson and Ingram, 1993). The method is as follows:

An earth bund was built around a 1m X 1m area, and filled with water. Refilling with water was done as necessary so that approximately 50cm of water had soaked into the soil. The area was covered with a plastic sheet in order to prevent evaporation and left for 2 days. The soil samples were taken from the center of the plot and then dried at 105^{o}C for 48 hours. The dried soil was weighed again with the moisture can (W3). The weights were recorded as below:

Calculation

$$\% \text{ Soil moisture at field capacity} = \frac{(W2 - W3) \times 100}{(W3-W1)}$$

where:

W1 = Weight of empty can

W2 = Weight of moist soil + tin

W3= Weight of dried soil + tin

3.6 Quality control

Analysis of blanks: In order to assess contamination, a blank which was de-ionised water was analyzed along with the sample. Analysis of duplicate: For a batch of five samples, one was duplicated in order to assess the reproducibility of the machine. Method accuracy: Certified reference materials were run to check the accuracy of the equipment.

3.7 Precautions

The digestion of the soil samples was done in a fume chamber since Nitrogen (IV) Oxide fumes could cause choking. The digested samples before analysis with AAS were covered tightly to prevent contamination with pollutants or other gases in the atmosphere since these could affect the final results.

CHAPTER FOUR

4.0 RESULTS

Tables 3.0 – 5.0 presented below provide summarised information on the mean concentrations for the macro and micro-nutrients (N, P, K, Ca, Mg, Na, Cu, Fe and Zn), pH and the physical properties for all the five sample treatment plots. The means were obtained from the three replicates taken from the composite soil sample and subjected to laboratory analysis to determine the concentrations of the various parameters.

4.1 Soil Macro and Micro-Nutrients

Table 3.0: Mean Soil Chemical Properties (macro/micro-nutrients) for Treatment Plots

Treatment	Description	N (%)	P (g/kg)	K (g/kg)	Ca (g/kg)	Mg (g/kg)	Na (g/kg)	Cu (g/kg)	Fe (g/kg)	Zn (g/kg)
T_1	Un-mined farmland	0.291	259.3	1285.3	12479.5	42.3	419.0	16.5	8955.3	208.9
T_2	0.4m topsoil: 0.6m subsoil	0.129	152.3	789.0	6774.4	49.0	283.3	20.5	7108.7	90.4
T_3	0.3m topsoil: 0.7m subsoil	0.122	144.3	569.7	6965.3	35.7	378.0	13.7	5891.0	152.0
T_4	0.2m topsoil: 0.8m subsoil	0.113	142.4	436.9	7361.4	37.2	401.7	15.1	6375.3	145.5
T_5	100% subsoil	0.007	167.3	388.0	10366.2	44.7	296.0	43.8	7939.0	68.2

From Table 3.0 presented above, the following could be said about the mean treatment values which depict the concentration levels of the soil chemical elements in the various treatment plots:

N: The means of nitrogen from the different treatment plots indicate a higher amount of N as expected in the un-mined farmland (T_1) which was used as the control. The concentration of N in the various treatments decreased with decreasing amount of topsoil. Hence, the concentration of N decreased from an appreciable 0.129% in T_2 which contained 0.4m of topsoil to a negligible level of 0.007% in T_5 which contained no topsoil. The ANOVA test results depicted that the treatment means for Nitrogen for T_1 (0.291%),T_2 (0.129%), T3 (0.122%), T4 (0.113%) and T5 (0.007%) were highly significantly different from each other ($P<0.001$).

P: Again, the control sample, T1 yielded the highest amount of P of 259.3 mg/kg. T5 and T2 gave the next highest P concentrations of 167.3 and 152.3 mg/kg respectively. These were followed by concentrations of 144.3 and 142.4 mg/kg by T3 and T4 respectively. The mean values of Phosphorus for the treatments showed highly significant difference ($P<0.001$).

K: The farmland (T1) possesses the greatest amount of K of 1285.3 mg/kg, followed by T2 with 789.0 mg/kg through to T5 with the least concentration of 388.0 mg/kg which had the maximum and minimum amounts of topsoil among the reclamation plots. The concentration of K from the different treatments seem to follow a trend with respect to the depth of topsoil available on each plot which is very high on the farmland (T_1) and decreases across T_2 - T_5 with decreasing topsoil. These treatment mean values are highly significantly different from each other.

Ca: The treatment mean for Ca was highest for the un-mined farmland, T1 at 12,479.5 mg/kg with T5 following up with a concentration of 10366.2 mg/kg whilst the least concentration of 6,774.4 mg/kg was produced by T2. Mean values for Calcium also tended to show highly significant difference among all the treatments.

Mg: The highest Mg level of 49.0 mg/kg was produced by T2 followed by T5 with 44.7 mg/kg with the farmland, T1 giving 42.3 mg/kg. T4 and T3 gave the least concentrations of Mg at 37.3 and 35.7 mg/kg respectively. With $P<0.001$, Mg concentrations were highly significantly different among all the treatment plots.

Na: The levels of Na in the various samples did not produce any particular trend with farmland, T1 exhibiting the highest level of 419 mg/kg followed by T4 and T3 with 401.7 and 3378 mg/kg respectively. T5 and T2 produced the lowest Na of 296 and 283.3 mg/kg respectively. These treatment mean values for T1 – T5 showed highly significant difference when they were subjected to ANOVA test.

Cu: The level of Cu was greatest in T5 at 43.8 mg/kg which is composed entirely of subsoil materials followed by T_2 with 0.4m and 0.6m mixture of topsoil and subsoil at 20.5 mg/kg. The least amount of Cu was determined at T_3 at 15.7 mg/kg. The content of Cu among all the treatments were also highly significantly different from one another.

Fe: The highest Fe concentration was found in the un-mined farmland, T1 at 8,955.3 mg/kg followed by the treatment with subsoil only, T_5 at 7,939 mg/kg. T_2, T_4 and T_3 produced Fe concentration levels of 7,108.7, 6,375.5 and 5891 mg/kg respectively. The ANOVA test conducted on the mean values for Fe gave $P<0.001$, indicating a highly significant difference among the treatments.

Zn: The highest zinc concentration of 208.9 mg/kg was found in T1 with the least concentration of 68.2 mg/kg found in T5. T3 produced the second highest concentration of 152mg/kg followed by T4 and T2 with concentration of 142.2 and 90.4 mg/kg respectively. The mean values were also highly significantly different from one another.

The results produced a trend in the concentration of N and K with their concentration decreasing with decreasing depth of topsoil on the treatment plots. P levels also decreased along the decreasing depth of topsoil but increased sharply at the plot with no topsoil. The other nutrients did not produce any clear trend along or across the treatment plots but all their mean values when put to ANOVA test, showed highly significant differences among each treatment plot.

4.2 Soil pH

Table 4.0: Mean Soil pH from Treatment Plots

Treatment	Description	pH
T_1	Un-mined farmland	6.4
T_2	0.4m topsoil : 0.6m subsoil	6.2
T_3	0.3m topsoil : 0.7m subsoil	6.7
T_4	0.2m topsoil : 0.8m subsoil	7.3
T_5	100% subsoil	5.1

From Table 4.0 above, T_4 produced the highest pH of 7.3 which is slightly basic followed by T_3, T_2 and T_1 all of which produced slightly acidic conditions with pH values of 6.7, 6.4 and 6.2 respectively. T_5 showed the most acidic condition among the treatments with the least pH value of 5.1. The soil pH seemed to increase with decreasing topsoil depth among the treatment plots in the reclaimed area except the plot with no top soil. ANOVA test results on the mean pH values for T_1 – T_5 depicted highly significant differences among them all.

4.3 Soil Physical Properties (Bulk Density & Water Holding Capacity - WHC)

Table 5.0: Mean Soil Physical Properties from Treatment Plots

Treatment	Description	Bulk Density (g/cm^3)	Water Holding Capacity (%)
T_1	Un-mined farmland	1.2233	25.8767
T_2	0.4m topsoil : 0.6m subsoil	1.7640	28.5100
T_3	0.3m topsoil : 0.7m subsoil	1.5237	20.4867
T_4	0.2m topsoil : 0.8m subsoil	1.2412	18.5256
T_5	100% subsoil	1.5510	22.4667

As indicated in Table 5.0 shown above, the mean bulk densities of the various treatment plots indicate the least bulk density of 1.2 g/cm^3 at T_4 andT_1 and the highest of 1.8 g/cm^3 at T_2. ANOVA test showed that bulk densities among the treatments were only significantly different from each other with $P>0.001$ but $P<0.05$.

T2 had the highest WHC of 28.5% followed by T1, T5, T3 and T4 with decreasing WHC value of 25.9%, 22.5%, 20.5% and 18.5% respectively. These values for WHC showed highly significant difference among all treatment plots.

The bulk density decreases with decreasing topsoil depth among the treatment plots in the reclaimed area but increases on the plot with no top soil. A similar trend is also exhibited by treatment plots in the reclaimed area with their WHC decreasing with decreasing topsoil except on the plot without topsoil. So, whilst values were highly significantly different among treatments for WHC, they were however significantly different among treatments for their bulk densities.

4.4 Mean Comparisons

The mean comparison tables of soil chemical properties, pH and soil physical properties for the various treatments are presented in Tables 6.0 - 8.0 below. Treatment means were compared using $\alpha = 0.05$, whilst significant differences were determined at p value of 0.01 or 0.05. Values with different superscript alphabets in a row signify differences at $\alpha = 0.05$. The numbers in parenthesis represent standard errors of means.

Table 6.0: Comparison of Mean Soil Chemical Properties

Parameter	Treatments					Mean
	T_1	T_2	T_3	T_4	T_5	
N (%)	0.2909 [a]	0.1289 [b]	0.1219 [c]	0.1134 [d]	6.73E-03 [e]	0.1324 (1.414E-03)
P (g/kg)	259.3 [a]	152.3 [c]	144.3 [c]	141.3 [c]	167.3 [b]	172.9 (4.377E-03)
K (g/kg)	1285.3 [a]	789.0 [b]	569.7 [c]	370.0 [d]	388.0 [d]	680.4 (0.0104)
Ca (g/kg)	12480.0 [a]	6774.4 [d]	6965.4 [d]	7538.9 [c]	10366.0 [b]	8824.9 (0.0890)
Mg (g/kg)	42.3 [b]	49.0 [a]	35.7 [c]	37.3 [c]	44.7 [ab]	41.8 (1.333E-03)
Na (g/kg)	419.0 [a]	283.3 [c]	378.0 [b]	415.0 [ab]	296.0 [c]	358.3 (0.0124)
Cu (g/kg)	16.5 [c]	20.5 [b]	13.7 [e]	15.7 [d]	43.8 [a]	22.0 (9.545E-05)
Fe (g/kg)	8955.3 [a]	7108.7 [c]	5891.0 [e]	6606.0 [d]	7939.0 [b]	7300.0 (0.1006)
Zn (g/kg)	208.9 [a]	90.4 [d]	152.0 [b]	142.2 [c]	68.2 [e]	132.3 (1.509E-04)

Values with different superscript alphabets in a row signify differences at $\alpha = 0.05$.
Numbers in parenthesis represent standard errors of means.

From Table 6.0 presented above, the mean comparisons showed significant differences among all the treatment samples with respect to N at α=0.05. N produced a mean concentration of 0.1324%

Comparing the treatment means of P indicated that there was no significant difference among three of the treatment samples which were T2, T3 and T4 at $\alpha = 0.05$. T1 and T5 had exhibited some significant differences between them.

Comparisons of the mean at $\alpha = 0.05$ for K signified differences among four treatments which were T1, T2, T3 and T4 or T5 whereas T4 and T5 had no significant difference between them.

Comparisons of the mean for calcium among the treatments showed there were no significant differences among T2 and T3 which contained 0.4m and 0.3m of topsoil respectively. There was however, significant difference between T1 and T4 and T5.

With respect to Mg, there was no difference between T2 and T5 as well as T5 and T1 at $\alpha = 0.05$. In the same vein, T4 and T3 which gave the least amounts of Mg at 37.3 and 35.7 mg/kg also did not show any difference at $\alpha = 0.05$. There was however significant differences between the means of T1, T2 and T3

Comparisons of the mean for Na showed significant differences among three treatments $\alpha = 0.05$ which were among T1, T2 and T3 but T2 and T5 showed no significant difference.

The comparison of means for Cu at $\alpha = 0.05$ depicted significant differences among all the treatment means of the samples.

Comparisons of the means for Fe at $\alpha = 0.05$ showed significant differences among all the treatment samples.

Comparison of the means for Zn also produced significant difference between each of the treatments at $\alpha = 0.05$.

Table 7.0: Mean Soil pH of the Different Treatments

Parameter	Treatments					Mean
	T_1	T_2	T^3	T_4	T_5	
pH	6.4033 [c]	6.1733 [d]	6.7467 [b]	7.5133 [a]	5.1367 [e]	6.3947 (6.992E-03)

Values with different superscript alphabets in a row signify difference at $\alpha = 0.05$.

From Table 7.0 above, the mean pH values showed significant differences at $\alpha = 0.05$ among the treatments.

Table 8.0: Comparison of Soil Physical Properties

Parameter	Treatments					Mean
	T_1	T_2	T^3	T_4	T_5	
Bulk Density (g/cm^3)	1.2233 [bc]	1.7640 [a]	1.5237 [abc]	1.1537 [c]	1.5510 [ab]	1.4431 (0.1128)
WHC (%)	25.877 [b]	28.510 [a]	20.487 [d]	17.723 [e]	22.467 [c]	23.013 (0.3827)

Values with different superscript alphabets in a row signify differences at $\alpha = 0.05$.
Numbers in parenthesis represent standard errors of means.

As shown in Table 8.0 above, there was a significant difference between only the means of T_4 and T_2 at $\alpha = 0.05$ in terms of the mean comparisons for bulk density but the treatments WHC produced significant differences among all the treatment means at $\alpha = 0.05$.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Soil Chemical Properties

5.1.1 Nitrogen

The ANOVA test results revealed a highly significant difference among the five treatment plots. This is an indication of wide variation in the soil nitrogen within the reclaimed sites as well as between them and the un-mined farmland.

The mean comparisons at $\alpha = 0.05$ showed significant difference among all the treatment samples with respect to N. The level of nitrogen from the different treatment plots indicates a higher amount of N in the un-mined farmland. This could be attributed to leaf litter fall, higher decomposition and higher incidence of free, chemo-heterotrophic bacteria which promotes decomposition. The amount of N in plots $T_1 - T_2$ which contained some amounts of topsoil could be described as being within normal value. The values obtained are supported by the work of Brady and Weil (1999), who asserted that the nitrogen content of surface mineral soil normally ranges from 0.02 – 0.5%, a value of about 0.15% being representative of cultivated soils.

Though the levels of N in T2 – T4 were appreciable, the wide difference between them and that of the un-mined farmland could be attributed to amount of top soils used in the reclamation as well as deterioration in soil nutrients during the period of top soil stockpiling. This confirms the works by Schmidt (2002) and Mahood (2003), that any relocation or stockpiling of topsoil reduced the concentrations of a range of nutrients. The porous nature of reclaimed sites could be sited for a possible higher rate of leaching of ammonia and nitrate from the top soil.

The insignificant amount of N in T5 which had no topsoil underscores the importance of top soil in soil nutrient management. The overburdened soils used in reclaiming T5 had been excavated from depths of 30m or deeper and as such comprised a sterile growth medium, devoid of nutrients.

Generally, the N content of 1.13%, 1.12% and 1.22% for treatments T_1, T_2 and T_3 respectively which contained some amounts of topsoil, depicts a similar or even higher N levels than in most of the component soil series mapped out in the mining area.

5.1.2 Phosphorus

The treatment plots exhibited highly significant difference with respect to the amount of P. As in the case of N, the un-mined farmland had the greatest amount of P. This situation has some relation to the findings by Brady and Weil (1999), that an undisturbed natural ecosystem loses little of this nutrient because phosphorus does not form gases that can escape into the atmosphere, nor does it readily leach out of the soil with drainage water.

T5 which comprises mainly of overburdened soil materials provided higher amount of P than T2 – T4 which had no difference in their treatment means. The higher levels of P in T5 may be attributable to an increased amount of Phosphorus in the waste rocks (due to high P-sorption in the Nitisols and Acrisols of the soil geology) used as base material for the reclamation as well as its proximity to the sampling depth.

The lower levels of P in T2 – T4 may be a result of deterioration of stockpiling topsoil which is in line with the findings of Schmidt (2002) and Manhood (2003) that any relocation or stockpiling of topsoil reduced the concentration of a range of nutrients. Comparing the treatment means indicated that there were significant differences among only three of the treatment samples at $\alpha = 0.05$. T_1 and T_5 had differences but there was none among T_2, T_3 and T_4

5.1.3 Potassium

There were highly significant differences in the levels of potassium between the soils of the various sites. The farmland possessed the greatest amount of K, followed by treatment plot 1 (T_1) which had the highest amount of topsoil among the reclamation plots. The concentrations for K produced a trend where their level decreased with decreasing levels of top soils. Comparison of treatment means at $\alpha = 0.05$ showed significant differences among

all the treatments except between T4 and T5 where there was either little or no topsoil.The trend which appears to be created with respect to the means of K from the different treatments could be attributed to the depth of topsoil available on each plot which is very high on the farmland (T_1) and decreases as with the amount to topsoil from T_2 through to T_5 which has no topsoil. The K concentration range of 1285.3 - 388.0 mg/kg for the area is in line with the preferred concentration ranges of K in the soil for plant growth of between 100-400 mg/kg (Rai, 1977).

Nevertheless too much potassium in the soil can adversely affect plants including killing seeds and seedlings, as well as reducing calcium and magnesium uptake from the soil. (www.soilminerals.com)

5.1.4 Calcium

The ANOVA test run on the levels of calcium from the five treatments plots indicates highly significant differences among all the treatments. The treatment mean was highest for the un-mined farmland, T_1 at 12,479.5 mg/kg and the least, T_2 at 6,774.4 mg/kg which had a mixture of 0.4m and 0.6m top and subsoil respectively. The mean comparisons for calcium among the treatments showed there were no significant differences among T_2 and T_3 which contained 0.4m and 0.3m of topsoil respectively. There was, however, significant difference between T2 and T3 relative to T4 and T5 with T5 at 10,366 mg/kg exhibiting the highest level after the farmland followed by T4 at 7,538.9 mg/kg.

According to Brady and Weil (1999), the important ways by which calcium is removed from the soil are through erosion, leaching and crop removal. It could therefore be inferred that increasing levels of calcium in T_4 and T_5 could be as a result of bringing subsoil materials containing leached Ca nutrients to the soil surface during the reclamation process. Again, the generally high levels of Ca among treatment plots could be attributed to natural supply by mineral weathering.

The general calcium requirements for plants average about 5,000 mg/kg. (Brady and Weil, 1999) With the calcium levels in the treatments ranging between 10,366 – 6,744.4 mg/kg, it

could be said that the reclaimed plots possess adequate calcium that can meet the general requirement of plants. The study area's Ca concentration range of 12479.5 - 6774.4 mg/kg is far in excess of the preferred concentration in the soil for plant growth ranging between 20-100 mg/kg (Rai, 1977). Calcium, for all practical purposes, is not considered to have a directly toxic effect on plants. Most of the problems caused by excess soil Ca are the result of secondary effects of high soil pH. Another problem from excess Ca may be the reduced uptake of other cation nutrients. Before toxic levels are approached in the plant, crops will often suffer deficiencies of other nutrients, such as phosphorus, potassium, magnesium, boron, copper, iron or zinc (www.spectrumanalytic.com).

5.1.5 Magnesium

The ANOVA test indicated that the level of magnesium differed highly significantly among the treatment samples. Mean comparison information shows T_2 had the Mg highest level of 49.0 mg/kg followed by T_5 with 44.7 mg/kg with the farmland, T_1 containing 42.3 mg/kg. There was however no difference between T_2 and T_5 as well as T_5 and T_1 at $\alpha = 0.05$. In the same vein, T4 and T3 which gave the least amounts of Mg at 37.3 and 35.7 mg/kg also did not show any difference at $\alpha = 0.05$.

Again, the Mg concentration of 49 – 35.7 mg/kg is as good as the preferred concentration range of Mg in the soil for plant growth of 10-40 mg/kg (Rai, 1977) but may be insignificant compared to the general plant requirement of about 200 mg/kg proposed by Brady and Weil (1999). Some of the reclamation plots (T2 and T5) exhibited higher concentration of Mg than the control area (T1).

As was indicated by Brady and Weil (1999), Magnesium may have to be added to the soil through liming, fertilizer application, plant residues and manures in order to augment the Mg content to levels that can support productive plant growth.

5.1.6 Sodium

The levels of sodium according to the ANOVA test conducted significantly differed among the treatment plots. The levels of Na in the various samples did not produce any particular trend with farmland, T_1 exhibiting the highest level of 419 mg/kg followed by T_4 and T_3 with 415.0 and 378.0 mg/kg respectively. T_5 and T_2 produced the lowest Na of 296 and 283.3 mg/kg respectively. The mean comparison showed significant differences among three treatments $\alpha = 0.05$ which were among T1, T2 and T3 but T2 and T5 as well as T1 and T4 or T3 and T4 showed no significant difference.

As stated by Blaylock (1994), up to 50% of the soil Na is present in the soil solution. It is more susceptible to leaching than any other cation. For this reason, it is not possible to build up soil Na levels over a period of years. This could account for the general low levels of Na in the soils of the study area. This notwithstanding, the Na levels among the treatments very much agree with the work done by Rai (1977), who put the preferred concentration of Na in the soil for plant growth between 1-1000 mg/kg

5.1.7 Copper

The ANOVA analysis gave a probability value of less than 0.001 indicating a highly significant difference among the treatment plots. The level of Cu was greatest in T_5 at 43.8 mg/kg which is composed entirely of subsoil materials followed by T_2 with 0.4m and 0.6m mixture of topsoil and subsoil of 20.5 mg/kg. The least amount of Cu was determined at T_3 at 15.7 mg/kg. The comparison of means at $\alpha = 0.05$ depicted significant differences among all the treatment samples.

With the mean Cu level for the treatments ranging between 15.7- 43.8 mg/kg, the area could be said to have adequate levels of Cu for utilization by crops. This is based on the assertion made by Epstein (1965) that the general nutrient requirement of plants with respect to Cu is about 6.0 mg/kg. The elevated level of Cu in the area could be attributed to the mining operation in the area and conforms to a study done by Boamponsem et al. (2009) about heavy metal concentration in the mining areas of Tarkwa.

Again, as stated by Archer (1985), negligible leaching of Cu occurs from all except very sandy soils. With the various soil series in the area except the Temang and Chichimere series being clayey loam, it could be said that continuous accumulation over a period has also contributed to the elevated levels of Cu. The range of Cu concentration among the treatments however agrees with the work done by Eddy *et al*. (2006), which puts the natural range for concentration of Cu in soil at 7 – 80 mg/kg. However, only the Cu concentrations for control as well as T2-T4 would be good according to the preferred concentration in the soil for plant growth which is put in the range 5-20 mg/kg (Rai, 1977). Unless preventive actions are taken, Cu level in T5 would become toxic.

5.1.8 Iron

The results for iron showed significant differences among the treatment samples. The highest Fe concentration was found in un-mined farmland, T1 at 8,955.3 mg/kg followed by the treatment with subsoil only, T_5 at 7939 mg/kg. T_2, T_4 and T_3 produced Fe concentration levels of 7,108.7, 6,375.5 and 5891 mg/kg respectively.

According to Brady and Weil (1999), the general Fe nutrient requirement of plants is about 100 mg/ kg. By this assertion, it can conveniently be assumed that all the treatments would have sufficient amounts of Fe available for use by plants that would be cultivated on them.

With the mean Fe concentration range of 5891.0 – 8955.0 mg/kg produced by this study, the levels exceed the natural iron (Fe) concentration range of 3000 – 5000 mg/kg according to Eddy *et al.,* (2006), as well as the 20-100 mg/kg preferred concentration in the soil for plant growth (Rai, 1977). The elevated Fe concentration in the area could be attributed to composition of the parent rocks as well as prevailing local activities since both the reclaimed and control areas exhibited similar concentration

5.1.9 Zinc

The study depicted highly significant differences among the treatment samples with a P-value of less than 0.001. The mean comparison also produced a significant difference

between each of the treatments relative to the other at $\alpha = 0.05$. The highest zinc concentration of 208.9 mg/kg was found in T1 with the least concentration of 68.2 mg/kg found in T5. T3 produced the second highest concentration of 152mg/kg followed by T4 and T2 with concentration of 142.2 and 90.4 mg/kg respectively.

The Zn concentration range of 68.2 – 208.9 mg/kg for the study area agrees with the natural zinc concentration range of 10 – 300 mg/kg in soils reported by Eddy *et al.* (2006). The control area (T1) has excess amount of Zn whilst the reclamation plots (T2-T5) have optimum concentrations according to the 2.5-150 mg/kg range preferred concentration for plant growth proposed by Rai (1977) and Robinson (1946). Again, if the general Zinc nutrient requirement of plants is 20 mg/kg as stated by Epstein (1965), then the soil in the study area has adequate store of zinc to meet the requirements of plants.

5.1.10. Soil pH

The results of the pH of the various treatments indicated highly significant differences among all the treatment means. The mean comparison also showed significant differences among the treatment means at $\alpha = 0.05$. T_4 produced the highest pH of 7.5 which is slightly basic followed by T_3, T_2 and T_1 all of which produced slightly acidic conditions with pH values of 6.7, 6.4 and 6.1 respectively. T5 gave the most acidic condition among the treatments with a pH of 5.1.

It could generally be said that T4 and T3 have near neutral conditions whilst T1 and T2 have slightly acidic condition with T5 having acidic conditions.

These pH values agree with the baseline data collection of soil resources of the Ahafo Project Area in 2006 which indicated a pH range of 5.5- 6.6 with decreases down the profile. Thus, the decreased pH of T_5 which comprises only subsoil was to be expected.
The pH range of 5.1- 7.5 for the study area is very much in tune with the soil pH of 5.2- 8.0 which according to Lake (2000), provides optimum conditions for most agricultural plants.

The prevailing pH range would also not adversely affect the availability of beneficial nutrients such as Mo, P, Mg and Ca.

5.1.11 Bulk Density

The bulk densities of soil from the treatment plots were significantly different at $p < 0.05$. Comparing the mean bulk densities of the various treatment plots indicates the least bulk density of 1.2 at T_4 and a highest of 1.8 at T_2. There was significant difference between the means of T4 and T2 only at $\alpha = 0.05$.

The bulk densities for the Treatments ranged between 1.2 - 1.8g/cm^3 and are within the range of bulk densities for clay which is 1.0 - 1.6g/cm^3 as well as for sand which is 1.2- 1.8g/cm^3 as stated by Aubertin and Kardos (1965).
It can therefore be said that the reclamation plot suffered minimal compaction during leveling-up of the soil.

5.1.12 Water Holding Capacity (WHC)

The ANOVA Test gave a highly significant difference in terms of WHC among the treatment means, at $p<0.001$.

The mean comparison for the same parameter among the treatments produced significant differences among all the treatment means at $\alpha = 0.05$. T_2 had the highest WHC of 28.5% followed by T_1, T_5, T_3 and T_4 with decreasing WHC value of 25.9%, 22.5%, 20.5% and 17.7% respectively. The turning of the soil leading to change in soil structure may have caused an increase in pore spaces leading to an increase in water holding capacity of the soils for the treatment plot in line with the work of Donahue et al. (1977). This is witnessed from the high levels of WHC attained from the study.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Based on the findings of the study, it can be concluded that all the four treatment plots under the reclamation exercise had suitable nutrient content and conditions in terms of the concentration of plant macro and micro nutrients, pH, bulk density and WHC. The control plot (T_1) as well as T_2 and T3 which had between 3-4m topsoil, exhibited nutrient concentration levels which can support agricultural activities. This assertion is also supported by the optimal pH, bulk density and WHC exhibited by T1, T2 and T3.

T4 and T5 in their current state would require quite a considerable length of time to undergo further weathering and decomposition in order to promote optimum conditions for agriculture.

Finally, the various treatments provide significant differences. As there was significant difference among the various treatments, it was observed that treatments with appreciable amounts of topsoil (about 3m or more) showed a generally improved condition for agriculture in terms of plant nutrients, pH, bulk density and WHC.

The improved physico-chemical performance displayed by N, P, K, Ca and Fe in the treatment plots could be attributed to the incorporation of legumes into the rehabilitation process. The plots were all stabilized with erosion and sediment control structures and then seeded with grass and cover crop (*Pureraria*). These have been left on the soil surface to decay in order to improve the soil quality.

6.2 Recommendations

It is recommended that;

1. Topsoil of high fertility status must be removed and kept during the mining operations and used again to spread over degraded site for quick establishment of plants.

2. Effective soil fertility enhancement programs must be developed for rehabilitation of mined land

3. Soil materials with high gravel and stone contents (over 60%) must be avoided as sole materials for the rehabilitation exercise.

4. Fast growing legumes such as mucuna (*Mucunapruriens*) should be incorporated as cover crop and for nitrogen fixation. Legumes with some economic value such as cowpea, soybean, groundnuts, canavalia or jack bean *(Canavaliaensiformis)* etc. could also be used and community members used in the rehabilitation exercise could be made to sell them for additional income or donated to schools. This could provide physical evidence about the reclamation successes to the communities.

5. The gradient of the leap of waste dump and for that matter the reclamation plots should be reduced, as the current gradient of 3:1 (H: V) appears steep. This will reduce erosion as well as provide easy access to enable people to work in such areas after reclamation

6. Further studies be undertaken to confirm the findings of the present study and to determine other nutrients not covered by the study.

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APPENDICES

APPENDIX A

Statistix 8.0

Completely Randomized ANOVA for Nitrogen (N)

Source	DF	SS	MS	F	P
Treatment	4	0.12419	0.03105	10342	0.0000
Error	10	0.00003	3.002E-06		
Total	14	0.12422			

Grand Mean 0.1324 CV 1.31

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	2.44	4	0.6558
Cochran's Q	0.5223		
Largest Var / Smallest Var	10.453		

Component of variance for between groups 0.01035
Effective cell size 3.0

Treatment	Mean
T1	0.2909
T2	0.1289
T3	0.1219
T4	0.1134
T5	0.0067

Observations per Mean 3
Standard Error of a Mean 1.000E-03
Std Error (Diff of 2 Means) 1.414E-03

Completely Randomized ANOVA for Phosphorus (P)

Source	DF	SS	MS	F	P
Treatment	4	0.02921	0.00730	254	0.0000
Error	10	0.00029	0.00003		
Total	14	0.02950			

Grand Mean 0.1729 CV 3.10

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	15.4	4	0.0040
Cochran's Q	0.9211		
Largest Var / Smallest Var	397.00		

Component of variance for between groups 0.00242
Effective cell size 3.0

Treatment	Mean
T1	0.2593
T2	0.1523
T3	0.1443
T4	0.1413
T5	0.1673

Observations per Mean 3
Standard Error of a Mean 3.095E-03
Std Error (Diff of 2 Means) 4.377E-03

Completely Randomized ANOVA for Potassium (K)

Source	DF	SS	MS	F	P
Treatment	4	1.71554	0.42888	2655	0.0000
Error	10	0.00162	0.00016		
Total	14	1.71715			

Grand Mean 0.6804 CV 1.87

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	11.6	4	0.0204
Cochran's Q	0.8135		
Largest Var / Smallest Var	103.74		

Component of variance for between groups 0.14291
Effective cell size 3.0

Treatment	Mean
T1	1.2853
T2	0.7890
T3	0.5697
T4	0.3700
T5	0.3880

Observations per Mean 3
Standard Error of a Mean 7.338E-03
Std Error (Diff of 2 Means) 0.0104

Completely Randomized ANOVA for Calcium (Ca)

Source	DF	SS	MS	F	P
Treatment	4	75.1443	18.7861	1582	0.0000
Error	10	0.1187	0.0119		
Total	14	75.2631			

Grand Mean 8.8249 CV 1.23

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	1.11	4	0.8927
Cochran's Q	0.3254		
Largest Var / Smallest Var	4.2013		

Component of variance for between groups 6.25807
Effective cell size 3.0

Treatment	Mean
T1	12.480
T2	6.774
T3	6.965
T4	7.539
T5	10.366

Observations per Mean 3
Standard Error of a Mean 0.0629
Std Error (Diff of 2 Means) 0.0890

Completely Randomized ANOVA for Magnesium (Mg)

Source	DF	SS	MS	F	P
Treatment	4	3.537E-04	8.843E-05	33.2	0.0000
Error	10	2.667E-05	2.667E-06		
Total	14	3.804E-04			

Grand Mean 0.0418 CV 3.91

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	1.39	4	0.8452
Cochran's Q	0.3250		
Largest Var / Smallest Var	4.3333		

Component of variance for between groups 2.859E-05
Effective cell size 3.0

Treatment	Mean
T1	0.0423
T2	0.0490
T3	0.0357
T4	0.0373
T5	0.0447

Observations per Mean 3
Standard Error of a Mean 9.428E-04
Std Error (Diff of 2 Means) 1.333E-03

Completely Randomized ANOVA for Sodium (Na)

Source	DF	SS	MS	F	P
Treatment	4	0.05037	0.01259	55.0	0.0000
Error	10	0.00229	0.00023		
Total	14	0.05265			

Grand Mean 0.3583 CV 4.22

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	3.12	4	0.5385
Cochran's Q	0.4885		
Largest Var / Smallest Var	11.408		

Component of variance for between groups 0.00412
Effective cell size 3.0

Treatment	Mean
T1	0.4190
T2	0.2833
T3	0.3780
T4	0.4150
T5	0.2960

Observations per Mean 3
Standard Error of a Mean 8.734E-03
Std Error (Diff of 2 Means) 0.0124

Completely Randomized ANOVA for Copper (Cu)

Source	DF	SS	MS	F	P
Treatment	4	0.00185	4.624E-04	33836	0.0000
Error	10	1.367E-07	1.366E-08		
Total	14	0.00185			

Grand Mean 0.0220 CV 0.53

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	8.41	4	0.0777
Cochran's Q	0.6341		
Largest Var / Smallest Var	52.000		

Component of variance for between groups 1.541E-04
Effective cell size 3.0

Treatment	Mean
T1	0.0165
T2	0.0205
T3	0.0137
T4	0.0157
T5	0.0438

Observations per Mean 3
Standard Error of a Mean 6.749E-05
Std Error (Diff of 2 Means) 9.545E-05

Completely Randomized ANOVA for Iron (Fe)

Source	DF	SS	MS	F	P
Treatment	4	16.9559	4.23898	279	0.0000
Error	10	0.1519	0.01519		
Total	14	17.1078			

Grand Mean 7.3000 CV 1.69

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	8.75	4	0.0675
Cochran's Q	0.7450		
Largest Var / Smallest Var	164.99		

Component of variance for between groups 1.40793
Effective cell size 3.0

Treatment	Mean
T1	8.9553
T2	7.1087
T3	5.8910
T4	6.6060
T5	7.9390

Observations per Mean 3
Standard Error of a Mean 0.0712
Std Error (Diff of 2 Means) 0.1006

Completely Randomized ANOVA for Zinc (Zn)

Source	DF	SS	MS	F	P
Treatment	4	0.03667	0.00917	268306	0.0000
Error	10	3.417E-07	3.417E-08		
Total	14	0.03667			

Grand Mean 0.1323 CV 0.14

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	6.16	4	0.1877
Cochran's Q	0.4878		
Largest Var / Smallest Var	14.286		

Component of variance for between groups 0.00306
Effective cell size 3.0

Treatment	Mean
T1	0.2089
T2	0.0904
T3	0.1520
T4	0.1422
T5	0.0682

Observations per Mean 3
Standard Error of a Mean 1.067E-04
Std Error (Diff of 2 Means) 1.509E-04

Completely Randomized AOV for Soil pH

Source	DF	SS	MS	F	P
Treatment	4	9.02084	2.25521	30753	0.0000
Error	10	0.00073	0.00007		
Total	14	9.02157			

Grand Mean 6.3947 CV 0.13

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	1.95	4	0.7450
Cochran's Q	0.3636		
Largest Var / Smallest Var	4.0000		

Component of variance for between groups 0.75171
Effective cell size 3.0

Treatment	Mean
T1	6.4033
T2	6.1733
T3	6.7467
T4	7.5133
T5	5.1367

Observations per Mean 3
Standard Error of a Mean 4.944E-03
Std Error (Diff of 2 Means) 6.992E-03

Completely Randomized ANOVA for Bulk Density

Source	DF	SS	MS	F	P
Treatment	4	0.75954	0.18988	9.95	0.0016
Error	10	0.19083	0.01908		
Total	14	0.95037			

Grand Mean 1.4431 CV 9.57

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	1.22	4	0.8755
Cochran's Q	0.4284		
Largest Var / Smallest Var	4.5595		

Component of variance for between groups 0.05693
Effective cell size 3.0

Treatment	Mean
T1	1.2233
T2	1.7640
T3	1.5237
T4	1.1537
T5	1.5510

Observations per Mean 3
Standard Error of a Mean 0.0798
Std Error (Diff of 2 Means) 0.1128

Completely Randomized AOV for WHC

Source	DF	SS	MS	F	P
Treatment	4	219.237	54.8093	250	0.0000
Error	10	2.196	0.2196		
Total	14	221.433			

Grand Mean 23.013 CV 2.04

	Chi-Sq	DF	P
Bartlett's Test of Equal Variances	3.52	4	0.4743
Cochran's Q	0.5253		
Largest Var / Smallest Var	19.404		

Component of variance for between groups 18.1965
Effective cell size 3.0

Treatment	Mean
T1	25.877
T2	28.510
T3	20.487
T4	17.723
T5	22.467

Observations per Mean 3
Standard Error of a Mean 0.2706
Std Error (Diff of 2 Means) 0.3827

APPENDIX B

Statistix 8.0

Tukey HSD All-Pairwise Comparisons Test of N by Treatment

Treatment	Mean	Homogeneous Groups
T1	0.2909	A
T2	0.1289	B
T3	0.1219	C
T4	0.1134	D
T5	6.73E-03	E

Alpha 0.05 Standard Error for Comparison 1.414E-03
Critical Q Value 4.655 Critical Value for Comparison 4.656E-03
All 5 means are significantly different from one another.

Tukey HSD All-Pairwise Comparisons Test of P by Treatment

Treatment	Mean	Homogeneous Groups
T1	0.2593	A
T5	0.1673	B
T2	0.1523	C
T3	0.1443	C
T4	0.1413	C

Alpha 0.05 Standard Error for Comparison 4.377E-03
Critical Q Value 4.655 Critical Value for Comparison 0.0144
There are 3 groups (A, B, etc.) in which the means
are not significantly different from one another.

Tukey HSD All-Pairwise Comparisons Test of K by Treatment

Treatment	Mean	Homogeneous Groups
T1	1.2853	A
T2	0.7890	B
T3	0.5697	C
T5	0.3880	D
T4	0.3700	D

Alpha 0.05 Standard Error for Comparison 0.0104
Critical Q Value 4.655 Critical Value for Comparison 0.0342
There are 4 groups (A, B, etc.) in which the means
are not significantly different from one another.

Tukey HSD All-Pairwise Comparisons Test of Ca by Treatment

Treatment	Mean	Homogeneous Groups
T1	12.480	A
T5	10.366	B
T4	7.5389	C
T3	6.9654	D
T2	6.7744	D

Alpha 0.05 Standard Error for Comparison 0.0890
Critical Q Value 4.655 Critical Value for Comparison 0.2928
There are 4 groups (A, B, etc.) in which the means
are not significantly different from one another.

Tukey HSD All-Pairwise Comparisons Test of Mg by Treatment

Treatment	Mean	Homogeneous Groups
T2	0.0490	A
T5	0.0447	AB
T1	0.0423	B
T4	0.0373	C
T3	0.0357	C

Alpha 0.05 Standard Error for Comparison 1.333E-03
Critical Q Value 4.655 Critical Value for Comparison 4.388E-03
There are 3 groups (A, B, etc.) in which the means
are not significantly different from one another.

Tukey HSD All-Pairwise Comparisons Test of Na by Treatment

Treatment	Mean	Homogeneous Groups
T1	0.4190	A
T4	0.4150	AB
T3	0.3780	B
T5	0.2960	C
T2	0.2833	C

Alpha 0.05 Standard Error for Comparison 0.0124
Critical Q Value 4.655 Critical Value for Comparison 0.0407
There are 3 groups (A, B, etc.) in which the means
are not significantly different from one another.

Tukey HSD All-Pairwise Comparisons Test of Cu by Treatment

Treatment	Mean	Homogeneous Groups
T5	0.0438	A
T2	0.0205	B
T1	0.0165	C
T4	0.0157	D
T3	0.0137	E

Alpha 0.05 Standard Error for Comparison 9.545E-05
Critical Q Value 4.655 Critical Value for Comparison 3.142E-04
All 5 means are significantly different from one another.

Tukey HSD All-Pairwise Comparisons Test of Fe by Treatment

Treatment	Mean	Homogeneous Groups
T1	8.9553	A
T5	7.9390	B
T2	7.1087	C
T4	6.6060	D
T3	5.8910	E

Alpha 0.05 Standard Error for Comparison 0.1006
Critical Q Value 4.655 Critical Value for Comparison 0.3312
All 5 means are significantly different from one another.

Tukey HSD All-Pairwise Comparisons Test of Zn by Treatment

Treatment	Mean	Homogeneous Groups
T1	0.2089	A
T3	0.1520	B
T4	0.1422	C
T2	0.0904	D
T5	0.0682	E

Alpha 0.05 Standard Error for Comparison 1.509E-04
Critical Q Value 4.655 Critical Value for Comparison 4.967E-04
All 5 means are significantly different from one another.

Tukey HSD All-Pairwise Comparisons Test of pH by Treatment

Treatment	Mean	Homogeneous Groups
T4	7.5133	A
T3	6.7467	B
T1	6.4033	C
T2	6.1733	D
T5	5.1367	E

Alpha 0.05 Standard Error for Comparison 6.992E-03
Critical Q Value 4.655 Critical Value for Comparison 0.0230
All 5 means are significantly different from one another.

Tukey HSD All-Pairwise Comparisons Test of Bulk Deensity by Treatment

Treatment	Mean	Homogeneous Groups
T2	1.7640	A
T5	1.5510	AB
T3	1.5237	ABC
T1	1.2233	BC
T4	1.1537	C

Alpha 0.05 Standard Error for Comparison 0.1128
Critical Q Value 4.655 Critical Value for Comparison 0.3712
There are 3 groups (A, B, etc.) in which the means
are not significantly different from one another.

Tukey HSD All-Pairwise Comparisons Test of WHC by Treatment

Treatment	Mean	Homogeneous Groups
T2	28.510	A
T1	25.877	B
T5	22.467	C
T3	20.487	D
T4	17.723	E

Alpha 0.05 Standard Error for Comparison 0.3827
Critical Q Value 4.655 Critical Value for Comparison 1.2595
All 5 means are significantly different from one another.