KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF ENVIRONMENTAL SCIENCE

COLLEGE OF SCIENCE

THE EFFECTIVENESS OF *BROUSSONETIA* MAT IN SLOPE STABILIZATION AND SOIL FERTILITY IMPROVEMENT

BY

MUHAMMED BIN ABUBAKAR

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BY

MUHAMMED BIN ABUBAKAR

FEBRUARY, 2013

DECLARATION

I certify that this thesis does not contain any material previously submitted for a degree or diploma in any university, and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

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MUHAMMED BIN ABUBAKAR **Date**

Certified by:

………………………… ……………………

ERIC A. AGYAPONG **Date**

(Supervisor)

……………………………. ……………………

REV. S. AKYEAMPONG **Date**

(Head of Department)

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God abundantly exalt you all.

ABSTRACT

In order to control soil erosion, different types of erosion control materials are used. This study investigated the effectiveness of using mats made from the bark of the York plant (*Broussonetia papyrifera*) in controlling soil erosion. The efficiency of the mats were also compared with that of Vetivar grass *(Vetiveria zizanioides)* and Bahama grass (*Cynodon dactylon)* as erosion control methods on two types of slope gradients (2.5:1 and 3:1). Vetevra grass and Bahama grass were planted on trial plots, and York jute mats were also laid, and the plots were monitored for the number of channels that developed after rainfall events, the depth of the channels, weight of eroded material, major nutrient content (N, P, K) as well as organic matter, for a period of three months. The results of the study showed that all the erosion control materials used were effective in controlling soil erosion. The Vetevar grass was able to reduce sedimentation, while the Bahama grass was able to reduce the number of channels and to a lesser extent the amount of erodible materials (sediments). The York jute mat was effective in controlling the amount of erodible materials and completely eliminated the creation of erosion channels, and thus performed better as an erosion control material than the Bahama and the Vetivar grasses. The erosion control materials also helped to improve the nutrient status of the soils. The major plant nutrients (N, P, K) and organic matter content of the soils all appreciated considerably for all three materials. The plots treated with York jute mat saw the initial nitrogen concentration increased by nearly 3-folds. Similarly, nitrogen levels in the soils on the plots planted with Bahama grass saw the nitrogen content increasing by 2.5-folds while the nitrogen levels more than doubled on plots treated with Vetevar grass. Generally, the plots treated with York jute mat had the overall highest increments in N, P, K and organic matter followed by the Bahama and Vetivar grasses, in that order.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
BMPs	Best management practices
CBD	Convention on Biological Diversity
FAO	Food and Agriculture Organization
FORIG	Forestry Research Institute of Ghana
FOSA	Forestry Outlook Study for Africa
IAS	Institute for Advanced Study
ISCO	International Soil Conservation Organization
ISSER	Institute of Statistical, Social and Economic Research
NGGL	Newmont Ghana Gold Limited
NPK	Nitrogen, Phosphorus and Potassium
ppm	Parts per million
Reps	Replicates
ROA	Roles of Agriculture
TSF	Tailings Storage Facility
UNU	United Nations University
WSF	Water Storage Facility

CHAPTER ONE

1.0 INTRODUCTION

Many construction companies in Ghana excavate and degrade Ghanaian fertile lands thereby exposing the surface of such lands to ravages of erosion and compaction (Folly, 2007). Increased soil erosion means loss of land, reduced soil fertility, lower groundwater recharge, more sediment flows into rivers, higher contaminants in diminishing water supplies, lowered quality of drinking water, increased flooding, and diminished economic benefits and increased hardships to both rural and urban populations especially in developing countries (Pimentel, 2006).

Soil erosion by water is a serious problem in tropical countries, particularly on steep lands and in areas devoid of vegetative cover. Runoff increases appreciably with increase of slope i.e. soil losses can be expected to increase with slope steepness as a result of respective increase in volume of surface runoff (Mohd, 2000). Senayah *et al*. (2009), also stated that sandy granitic soils on steep slopes are very susceptible to erosion. Wind and water erosion as well as leachate, often cause offsite pollutions which are particularly acute in the rapidly growing economies of developing countries, where resources are not adequate to provide a satisfactory solution to the problem. It is therefore important to research into various forms of soil erosion control practices and their effectiveness in reducing, if not completely, controlling soil nutrient loss (Whitford, 2002).

Several methods have been proposed to address soil erosion. Slope protection techniques are composed of living organic materials, such as grasses, live stakes and inert materials such as jute mats; and coir fiber rolls which support sustainable environment (Van Beek, 2008).

In many cases, the control methods will not only prevent the soil from washing away, but will enhance the landscape by holding back valuable soil nutrients (Blanco and Rattan, 2010). The different types of effective methods for erosion prevention includes soil surface cover. This decreases the deteriorating capabilities of the impact from rain, or any other type of eroding agent. This preventive measure helps eliminate the transportation of eroded particles elsewhere, thus slowing the process of erosion as a whole (Sands, 2005).

Erosion control mats for covering the soil surface are usually woven from straw, coconut fiber, aspen fiber, jute, and polypropylene (plastic), and are with lots of ridges and obstructions meant to slow down the speed at which water moves across the soil surface (http://www.ehow.com/how_2103282_install-erosion-control-fabric.html). Appreciation of these two biodegradable erosion control mats in erosion control has resulted from the fact that they decompose over time and the organic matter from them is released into the soil encouraging the growth of vegetation (www.permathene.com/documents/catalogue/single/erosion/eeek.pdf).

When erosion-control blankets made of biodegradable material are used, they eventually decay leaving the emerging plants to control the problem of erosion (Nan, 2008).

The bark of Paper mulberry (*Broussonetia papyrifera*) is composed of very strong fibers, and is used for making Japanese type of cloth, called Tapa (Arthur and Craig, 2006; http://en.wikipedia.org/wiki/Paper Mulbrry). The bark of Paper mulberry therefore can be compared to the jute (*Corchorusolitorius),*which is used as soil erosion control mat due to its strong fiber. A casual examination of the ground floor of Paper mulberry grove reveals complete decay of the litter. This characteristic can be relied upon to be used in soil erosion control, because eco-friendly erosion control blankets are biodegradable (Williamson *et al*., 2007).

The decomposition of Paper mulberry is likely to release the essential plant nutrients (NPK) to the soil because it is rich in minerals; for example, it contains 17% calcium carbonate. The flower and young leaf of the Paper mulberry has a protein content of 16-21%, together with nutrient minerals such as P, K, Ca and Mg and is suitable for human consumption

(www.rarefruit.org/PDF_files/Broussonetia_papyrifer.pdf).

The name, paper mulberry consists of the genus name Broussonetia, dedicated to the French botanist Pierre Marie Auguste Broussonet (1761-1807), who introduced this species in France in the 18th century and the Latin term *papyrifera*, "one that makes paper", alluding the Eastern use of the bark to make paper (http://mediambient.itineraris.bcn.cat/en/node/317/367).

Paper mulberry, known in Ghana as 'York', was named after the Technical Officer who worked on the plots during the experimental trials in the 1970s at Forest Research Institute of Ghana (FORIG), to find out how the plant could be used to produce paper in Ghana (Bosu and Apetorgbor, 2006). Both fertile male and female plants of the plant were introduced into Ghana by (FORIG). However, the plant has now become invasive at alarming proportion in the closed forest zone of Ghana second only to *Chromolaena odorata* the most important invasive plant in Ghana (Bosu and Apetorgbor, 2006).

The ability of Paper mulberry to colonize degraded lands makes it suitable for reforestation programmes in some situations, although it can become invasive when both male and female trees are present, followed by pollination and seed set (Hawthorne, 1990).

1.1 STATEMENT OF THE PROBLEM

Many methods have been used to control soil erosion and / or restore soil fertility. Methods based on the use of inorganic materials such as geotextiles have negative effects on the environment. The use of organic materials (plant parts), however, has several advantages. The materials decompose over time and the organic matter from them is released into the soil to improve the soil fertility.

Paper mulberry is a plant that has the ability to colonize degraded lands which makes it suitable for reforestation programmes in some situations (Hawthorne, 1990). However, the plant has now become invasive at alarming proportion in the closed forest zone of Ghana second only to *Chromolaena odorata* the most important invasive plant in Ghana (Bosu and Apetorgbor, 2006).

The plant is rich in minerals such as calcium carbonate. Its decomposition is therefore likely to release the essential plant nutrients (NPK) to the soil. In this study, the effectiveness of the bark of the York plant (*Broussonetia papyrifera*) as an erosion control and/or soil fertility improvement material is assessed.

1.2 JUSTIFICATION OF THE PROJECT

The bark of Paper mulberry is composed of very strong fibers similar to that of Jute plant (*Corchorusolitorius*) which is used as erosion control fabric in developed countries. It is hoped that the findings will encourage companies which excavate the soil resulting in soil erosion, to use it in their rehabilitation programmes. It would also help to stop the use of non-biodegradable geo-fabrics which contribute to soil degradation in Ghana by mining companies and other construction companies.

1.3 OBJECTIVES

The main objective of the project was to produce a soil erosion control mat from the bark of the York plant (*Broussonetia papyrifera*), while the specific objectives were to:

- make a soil erosion control material using the bark of York plant;
- measure the number of holes developed and the amount of erodible materials produced after application of the York jut mats;
- compare the performance of the York jut mats with Vetivar grass *(Vetiveria zizanioides)* and Bahama grass (*Cynodon dactylon*);
- determine the effects of slope gradients 3:1 and 2.5:1 on soil erosion using the three materials; and
- determine nutrient and organic matter status of soils under each of the erosion control materials.

CHAPTER TWO

LITERATURE REVIEW

2.1 SOIL EROSION

Soil erosion is a process and several researchers have defined it in different ways. According to Mohd (2000), soil erosion is the process by which materials are removed from the soil surface and transported to another location. Soil erosion is the process by which soil and rock are removed from the Earth's surface by natural processes such as wind or water flow, and then transported and deposited in other locations (Toy, 2002). It is a process of both particle detachment and transport by wind, water and ice. Soil erosion is the detachment of a portion of the soil profile or soil surface.

Soil erosion is basically a two-fold process that involves particles detachment and particles transportation. Soil particles can be transported a short distance like the splash from a raindrop impact, or may be transported a longer distance to the bottom of the slope, or into a water body where they are deposited. Soil erosion is initiated by drag impact or tractive forces acting on individual particles of soil at the surface. If the soil surface is covered by vegetation such as grasses or cover crops as well as erosion control blankets or, if the soil surface is deliberately scarified, the rate of erosion may be very small or absent.

There are three primary types of erosion that occur as a direct result of rainfall and these are; sheet erosion, rill erosion, and gully erosion. Sheet erosion is generally seen as the first and least severe stage in the soil erosion process, which is followed by rill erosion, and finally gully erosion, which is the most severe of the three (Borah, 2008).

Sheet erosion is the transport of loosened soil particles by surface runoff that is flowing downhill in thin sheets. Rill erosion refers to the development of small, ephemeral concentrated flow paths, which function as both sediment source and sediment delivery systems for erosion on hill slopes. Gully erosion occurs when runoff water accumulates, and then rapidly flows in narrow channels during or immediately after heavy rains or melting snow, removing soil to a considerable depth (Poeson, 2002).

Investigations done by the Soil Research Institute of Ghana into soil erosion caused by water in Ghana revealed that, at least 23% of the country is subject to very severe sheet and gully erosion 43.3% to severe sheet and gully erosion and 29.5% to slight to moderate sheet erosion (Folly, 2007).

The rate of soil erosion depends on climatic factors such as the amount and intensity of rainfall and the wind speed as well as storm frequency (Barry, 1995).

2.2 THE CAUSES OF SOIL EROSION

Land clearing, wild fires and new home constructions are typical causes of soil erosion. Severe wild fires can lead to significant soil erosion if they are followed by heavy rainfall (Goudie, 2000). Deforestation causes increased erosion rates due to exposure of mineral soil by removing the humus and litter layers from the soil surface, removing the vegetative cover that binds soil together, and causing heavy soil compaction.

Human activities frequently intensify the rates of soil erosion, particularly if they entail stripping or removal of vegetation thereby disturbing the soil (Blanco and Rattan, 2010).

Increasing needs of the human population have resulted in farming, road construction and surface mining, where large acres of forests are cleared exposing steep lands, to the ravages of erosion which results in siltation of water bodies (Stuart and Edwards, 2006).

In Ghana, the rapid population growth since independence, coupled with internal migration, accounts for the high rate of forest degradation and soil erosion because the population density has increased and land has become scarcer. The poor and landless peasant farmers tend to be pushed onto ecologically sensitive areas with low agricultural potential such as, erosion-prone hills where as a result of repeated farming the land has been subjected to serious soil erosion (FOSA, 2000)

Erosion is a natural process but in the absence of site disturbance by construction or farming, the rate of soil loss is very small. Accelerated soil erosion degrades soil quality and agricultural sustainability (Bogumil, 2012). In the Northern part of Ghana, erosion problems have resulted in poor crop yield and increased cost of crop production due to the purchase and use of commercial fertilizers. The underlying causes are due to a combination of factors of both physical and socioeconomic character such as population pressures, poor farming practices and high erodibility of the soil (Folly, 2007).

2.2.1 Man-induced Erosion

Some natural erosion may become problematic when people begin excavating the land, because each time the soil is dug, it is exposed to erosion and may not be able to support any kind of plant life. Disturbance of the soil surface, including activities like construction, farming, or logging, greatly increases the amount of sediment loss from the site due to erosion(John and Robert, 2002).

Two of the most critical examples of man-induced erosions are associated with construction due to urbanization and farming (Goudie, 2000). According to Gray and Sotir (1995), greater percentage of man-induced erosion is from agriculture and mining activities. It is worth knowing that under poor management, the area affected by surface mining could be several times more than the area actually exploited for the ore. The potential problems which may arise include wind and water erosion which could reduce the productivity of soils and create sedimentation of water bodies and dust nuisance.

According to Randhir (2007), when large hectares of vegetation are cleared, surface run-offs carry sediments to rivers and streams. Depending upon their physical and chemical properties, these sediments can suppress the growth of aquatic life.

2.2.2 Agricultural activities

Agricultural lands in Ghana are susceptible to severe erosion because the soil on these lands is repeatedly tilled and left without a protective cover of vegetation (Enu-Kwesi, 2006). The rotational bush fallow system characterized by clearing and burning of the vegetative cover has negative environmental externality expressed in soil erosion, serious deforestation and rural landscape degradation (Botchie *et al*., 2003).

Da Cunha (1991), also stated that soil erosion especially from agricultural activity is considered to be the leading global cause of diffuse water pollution, due to the effects of the excess sediments flowing into the world's waterways. The sediments themselves act as pollutants, as well as being carriers for other pollutants, such as attached pesticide molecules or heavy metals. In agricultural production, when soil sediments that include pesticides are eroded into rivers, lakes, and reservoirs, fish production is adversely affected (Nowell, 1999).

Millions of hectares of forests are cleared worldwide for agricultural activities causing soil erosion, salinization, and water logging leading to irretrievable loss of million hectares of fertile lands each year (Lobb, 2009). Although erosion is a natural process, human land use policies also have had an effect on erosion, especially industrial agriculture, deforestation, and urban development (Cooke *et al.*, 1999).

In Ghana, soil erosion continues to decrease the soil moisture capacity and plant nutrient content, especially of shallow soils. Farmers are aware of the problem, but because it is a long–term process it is overshadowed by the immediate food production needs.

2.2.3 Illegal logging

Forest clearing either for farming purpose or for timber harvesting exposes the forest floor to the mercy of rain splashes that leads to sheet erosion. Many forests have been devastated by illegal logging. Once the canopy of the forest is broken the soil which hitherto was protected now becomes subjected to erosion. Forest removal reduces fuel wood supplies and forces the poor in developing countries to rely more heavily on crop residues and manure for fuel instead of allowing them to decompose to fertilize the soil. The diversion of crop residues and manure further intensifies soil erosion and water runoff and consumes valuable nutrients. If crop residues are left on the land, nutrients are added and soil quality and productivity will remain high and sustainable (Pimentel, 2006*)*.

2.2.4 Soil water repellency

On sloping sites soil water repellency can trigger off surface water runoff causing loss of nutrients and sediments, which may end up in surface streams and water ways with the potential to cause significant pollution (Rachel, 2003). Water repellency (hydrophobicity) of soils is a property with major repercussions for soil erosion because it can promote rain splash detachment and soil loss not only by water, but also by wind (Doerr *et al*., 2000). Water repellent behaviour in soil is caused by dry coatings of hydrophobic material on soil particles or aggregates, as well as hydrophobic organic matter, such as fungal strands and particles of decomposing plant material **(**Blackwell, 1996).

2.3 EFFECTS OF SOIL EROSION

Soil erosion has caused the silting-up of rivers, lakes and reservoirs. In Ghana, silting-up and blockade of water ways have led to serious inundation being experienced any time there is a heavy down pour. Serious soil erosion has led to the emergence of infertile lands to support plant growth, because the entire rich top soil has been stripped due to soil erosion.

But in some severely eroded savanna lands, as much as 120 cm of soil has been lost. The problem has therefore aggravated drought in areas with severe problems (Sjef, 1995)**.**

In the Upper East Region of Ghana soil loss by sheet and rill erosion leaving only sandy loam and grave1above the parent materials. The loss of organic matter and plant nutrients in available form due to soil erosion is having devastating effects on agricultural production (Folly, 2007).

According to Pimentel (2006), soil erosion has caused the decrease of cultivated land and serious desertification because arable land is finite and the population continues to increase. Environmental impacts on land resources can be substantial with removal of vegetation resulting in soil erosion which can lead to sedimentation, turbidity in water supplies and salinization (ISCO, 2004).

Soil erosion is an important environmental problem in many developing countries and may represent a considerable drag on economic development. Slow, insidious soil erosion threatens human health and welfare as well as the environment (Donald, 2003)).

The degradation of soil by erosion is of particular concern because soil re-formation is extremely slow. Soil erosion is second to population growth as the biggest environmental problem the world faces (Pimentel *et al*., 2001).

Mbagwu *et al*. (1983), stated that, in terms of crop yield, once the fertile top soil is removed as a result of soil erosion, no amount of fertilizer combinations applied to the soil can equal the top soil loss. Soil erosion and soil mining are important environmental problems in many developing countries. It is widely believed that the per capita food supply in developing countries has been reduced because of erosion-associated loss of productivity and population growth. In Ghana, soil erosion may represent a considerable drag on economic development. The cost of soil degradation through erosion depends, however, not only on the productivity effects it has on agricultural growth, but also on how the agricultural sectors are linked to the rest of the economy (Folly, 2007).

With the introduction of the new mining and mineral law, P.N.D.C law 153 in 1986, which aims at encouraging new mining investment in the country, mining activities have intensified. Environmentally, some mining methods are believed to be destructive because a very large area of vegetation together with topsoil is removed before the rock being mined is reached. If such open areas are not immediately revegetated, soil erosion could set in (Enu-Kwesi, 2006). In Ghana an estimated 69 per cent of the total land surface has been degraded due to soil erosion (Asiamah, 1987; EPA, 2002).

About 77 % of Africa is affected by soil erosion and that the most serious erosion prone areas

can be found in Ghana and 15 other countries (Bogumil, 2012). Degradation of arable land through soil erosion may depress world food production leading to severe famine in less developed countries.

Soil erosion adversely affects crop productivity by reducing the availability of water, nutrients and organic matter, as the topsoil thins by restricting rooting depth (Mirsal, 2008).

Soil erosion has devastating effects on crops and water bodies, as water that would have entered the soil matrix flows off and deposit eroded soil in flood plains, river channels, lakes and reservoirs causing reduction in the useful life of reservoirs (Pimentel *et al*., 2001). Large tracts of land have been destroyed by water erosion leading to soil and nutrient losses as well as flooding and siltation of river bodies (Quansah, 2001)

The effect of increased sediments loads from soil erosion on aquatic ecosystems can be catastrophic. Silt can smother the spawning beds of fish, by filling in the space between gravel on the stream bed. It also reduces their food supply, and causes major respiratory issues for them as sediment enters their gills. The biodiversity of aquatic plant and algal life is reduced, and invertebrates are also unable to survive and reproduce. While the sedimentation event itself might be relatively short-lived, the ecological disruption caused by the mass die off often persists long into the future (Merrington, 2002). When erosion occurs, the amount of water runoff increases, so that less water enters the soil matrix to become available for the crop. The most harmful effect of erosion on plant is that less water enters the soil for plants to survive (Connor, 2011). Soil erosion can remove organic matter from soil and that the material removed may be several times richer in organic material than the soil left behind.

Organic matter is important to water retention, soil structure, and cation exchange capacity and is also the source of a large portion of the nutrients needed by plants. Water and wind erosion reduce the water-holding capacity of soil by selectively removing organic matter and finer soil particles (Allison, 1973).

2.4 EROSION CONTROL

Human beings have over the years tried to control erosion. These attempts have been deliberate or otherwise. However, prevention and control of erosion depend on understanding the mechanics of the erosion process. According to Wischmeier and Smith (1958), before soil mass is removed by runoff or wind, the forces binding the soil particles together must be overcome by the drag force of the runoff or wind. Again, soil particles should be fine, loosely packed or sandy so that they could be easily carried away by the erosion agent. Erosion control consists of decreasing drag or tractive force, by directing water flowing over the surface into a defined channel or, increasing resistance to erosion by protecting the surface with a suitable cover like mulches or jute mats (Toy, 2002).

In many cases the control methods will not only prevent the soil from washing away, but will enhance the landscape by holding back valuable soil nutrients. The type of erosion control technique to use at a particular site depends on many factors among which include; type of soil, the terrain, frequency and amount of rainfall, anticipated peak flows and run-off direction (Wischmeier and Smith,1958). Stone ditch constructed with stones or boulders could be erected across a channel or water way in a U-shape to reduce the velocity of flow. Terracing may not be suitable for the control of soil erosion on sandy soils while silt fences are suitable wherever the flow of runoff becomes concentrated and has the potential to impact downstream resources.

Erosion control techniques are complementary in their actions and according to Van Beek (2008), many soil conservation technologies can be combined to reduce erosion rates.

Management of soil for water and wind erosion control is based on soil conservation practices which recognize the need to protect the soil surface with adequate crop and residue cover, and use of erosion control structures where necessary (Julien, 2010). In many cases, the control methods will not only prevent the soil from washing away, but will enhance the landscape by holding back valuable soil nutrients.

Erosion control structures offer technical assistance to reduce slope erosion. Erosion control structures are used in natural areas, agricultural settings or urban environments. The controls often involve the creation of a physical barrier, such as vegetation or rock, to absorb some of the energy of the wind or water that is causing the erosion. On construction sites, they are often implemented in conjunction with sediment controls such as sediment basins and silt fences (Blanco and Rattan, 2010). Implementing soil and water conservation technologies would benefit both farmers and society as a whole. For individual farmers, reducing soil erosion would help preserve the productivity of the land, reduce the need for fertilizers and other energy inputs, and decrease water stress on crop production (Montgomery, 2007).

2.5 FORMS OF SOIL EROSION CONTROL TECHNOLOGIES

The principal method of controlling soil erosion and its accompanying rapid water runoff is maintenance of adequate vegetative cover. Plants intercept and dissipate the energy in raindrops, enabling the water to reach the soil without damage (Zuazo and Pleguezuelo, 2009).

Plant stems, roots, and organic matter left on cropped land after harvest help to control runoff and encourage water percolation into the soil. Cover crops used as surface mulch not only reduces soil erosion, but also slows evaporation of soil moisture, increases infiltration of rainfall, increases soil organic matter and aids in control of weeds (Denise, 2001). Crimped straw mulch, combined with revegetation, has been identified as an effective means to control erosion.

Living and dead plant biomass left on fields reduce soil erosion and water runoff by intercepting and dissipating rain drop and wind energy. The simple practice of straw-mulching may increase biota threefold (Pimentel *et al*., 1995).

Vegetation acts as an interface between the atmosphere and the soil. It increases the permeability of the soil to rainwater, thus decreasing runoff. The roots of the plants bind the soil together, and interweave with other roots, forming a more solid mass that is less susceptible to both water and wind erosion. The removal of vegetation increases the rate of surface erosion (Joyce *et al*., 2002).

Various methods of soil erosion control include the conjunctive use of plants and earth-retaining structures. Other farming techniques like farming along the contours have been practiced by man to reduce soil erosion (Donald and Sotir, 1996).

The application of livestock manure, jute netting and planting of cover crops combined with minimum passage of machinery can substantially reduce soil erosion (Barry, 1995). Land clearing and new home construction are typical causes of erosion. In many cases the control methods will not only prevent the soil from washing away, but will enhance the landscape by holding back valuable soil nutrients (Neil and Robert, 1996).

2.5.1 Mats and Screens

Properly installed erosion control mats are effective at trapping sediment. During rain storms, the mats intercept surface runoff and reduce the velocity of flow. Water passes through the tiny spaces in the mats while leaving behind the sediment on the uphill side of the mats, thereby reducing sediment erosion (Minnesota Pollution Control Agency, 2000).

Seed-impregnated fiber mats are laid on steep slopes. Wooden stakes are used to hold these mats in place during germination of the seeds. These mats can be laid immediately after the conclusion of any earth work that has disturbed the topsoil. Once installed, the mats must be kept watered, and the impregnated seeds begin to sprout within a matter of days (Basu *et al*., 2005).

Erosion control and revegetation mats are flexible three-dimensional mats or nets of natural or synthetic material that protect soil and seeds against water erosion prior to establishment of vegetation. They permit vegetation growth through the web of the mat material and have been used as temporary channel linings where ordinary seeding and mulching techniques will not withstand erosive flow velocities (www.dot.ca.gov/hq/oppd/hdm/pdf/chp0870.pdf).

2.5.2 Contoured Earth

Soil can be contoured on gentle slopes to slow or control the flow of water. Over time, silt and soil will gradually fill in these contours to provide a level surface to the flow of water in heavy rains (Borah, 2008). Graded soil bunds can bring about significant reduction in runoff, reduce losses of soil nutrients and organic carbon (Adimassu *et al*., 2009).

2.5.3 Reliable and proven soil conservation technologies

The technologies to reduce or eliminate soil erosion include ridge-planting, no-till cultivation, grass strips, mulches, living mulches, terracing, contour planting and cover crops (Styczen and Morgan, 1995). No-till production reduces soil erosion and conserves soil moisture (Ditsch *et al*., 2002). Terracing, planting on contours, cover cropping and spreading of pruned palm fronds could check soil erosion (Asamoah and Nuertey, 1970). Permanent agriculture such as the tree, food crops and animal husbandry encourage soil conservation and soil erosion prevention (Botchie *et al*., 2003).

To determine the best combination of appropriate technologies, the soil, slope, locale, and available water must all be considered. Although many effective erosion control technologies are available, soil erosion persists at levels greatly in excess of soil formation rates in most major agricultural regions (Pimentel *et al*., 2001).

2.5.4 Roughening the soil surface

A more cost effective method of erosion control is roughening the soil surface with horizontal depression created by a tiller or other equipment on the contour or by leaving the area in a roughened condition. Mulch also roughens the soil surface and provides immediate protection to exposed soils. To corroborate the above claim, Williamson *et al.*, (2007) stated that it enhances plant establishment by conserving moisture and moderating soil temperatures.

The amount of soil erosion that occurs in an area depends upon two factors: the speed with which water and wind travel across it, and the abundance of plant life that is growing there. Since one has no control over the speed of the wind, how heavily it rains, or the currents of the river, one needs to concentrate on the plant life (Sands, 2005). Whisenant (2008), also reported that protective ground cover minimizes soil erosion. It also increases the soil content of organic matter lowers the soil temperature and improves the water holding capacity of soil. Cover crops increase water infiltration and the potential for soil water storage thereby recharging aquifers (Styczen and Morgan, 1995).

2.5.5 Plastic covering

If erosion problems arise which cannot be dealt with by straightforward establishment of vegetation, then assistance of physical stabilization can be sought (Williamson *et al*., 2007). This involves the covering of the surface of exposed soils with materials that can prevent or retard erosion by wind or water.

2.5.6 Alternative erosion control blankets

Most erosion control blankets are biodegradable materials that can be used to protect disturbed slopes and channels from wind and water erosion. The blanket materials are natural materials such as straw, wood excelsior and coconut. Erosion control blankets provide excellent short and long term erosion control when properly installed and maintained (U.S. Natural Resources Conservation Service, 2009).

Some alternatives to erosion control blankets are hydro mulch, temporary silt fence or using real logs and rocks to create locations for water to settle out. Hydro mulching consists of organic mulch such as wood fiber or paper cellulose that is mixed with water and sprayed on the slope (Patrick, 2004).

Silt fences are made of woven wire and a fabric filter cloth which trap sediment from runoff. They should be used in areas where runoff is more dispersed over a broad flat area. Silt fences are not suitable for concentrated flows occurring in small rills or gullies (Van Beek, 2008).

Menlo (2003), also claims that, silt fences are usually meant to catch any runoff from the construction of the project, but they can be used until the slope re-establishes itself enough to stop any runoff. Once this is accomplished, removal of the fences is required.

Coir logs are also used to protect a stream-bank from erosion in areas with a low-velocity current. The logs provide growing media for newly installed vegetation. They are secured at the toe of the slope using wooden stakes. Seeds or cuttings are installed into the logs. As the coir logs begin to biodegrade, the plants establish their root system into the bank helping to stabilize the stream-bank against erosion (http://www.ehow.com/how_2103282_install-erosion-control-fabric.html).

CHAPTER THREE

MATERIALS AND METHODS

3.1 THE STUDY AREA

The study area was the premises of Newmont Ghana Gold (NGGL) at Ahafo Kenyase in the Asutifi North District of the Brong Ahafo Region of Ghana. NGGL is located between latitudes 640 degrees and 715 degrees North and longitudes 215 and 245 degrees West. It lies within the wet semi-equatorial zone and it is marked by a bimodal rainfall regime with an annual mean rainfall of between 1250 and 2000 mm.

The area is mainly occupied by abandoned cocoa farms which have been invaded by the paper mulberry. Two areas with low depression that have received a placement of a layer of top soil with gradients (2.5:1 and 3:1) lying between the TSF and WSF were selected for the field trials (Figure 1). The TSF and WSF, located at one-and-a half kilometres north-west of NGGL plant site are separated by a haul road and a community access road. The choice of the area was therefore influenced by its proximity to the mine site where the land has been degraded as a result of mining and the abundance of York trees.

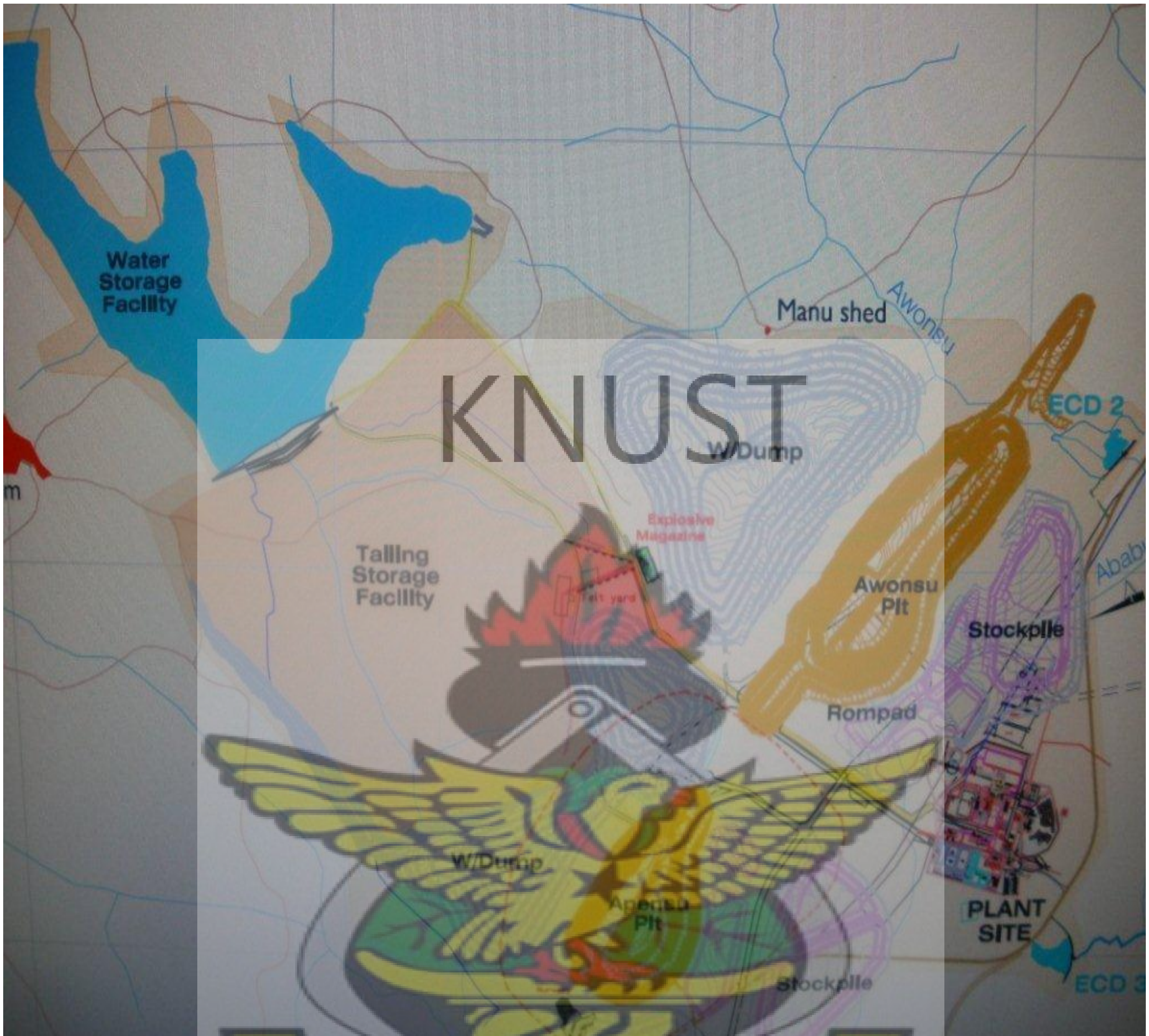


Figure 1: Map of the study area showing the NGGL concession area

3.2 THE PROCESSING OF THE BARK OF YORK PLANT

The outer skins or bark of mature York plants were removed leaving only the soft, white inner bark. Stripping was done about one meter from the base of the plant up to where the branching starts. An incision was made on the tree bark and with the aid of a wedged stick the bark was stripped off. The stripped bark was put on a hard wooden surface of a log and beaten with wooden mallet into a fine mesh. After being beaten, it was woven into chicken mesh-like mats and trimmed with a pair of scissors, as can be seen in plate 1. A piece of pointed metal which had been fabricated for this purpose and given the name “pin” was used to weave the mats manually by hand. Each mat measured (1×1) m^2. The purpose of weaving was to create open spaces in the material which served as sediment traps or tiny check dams, when the mat is laid in erosion prone areas. Five of the mats were joined together to form rolls of (1×5) m^2 and they were called “York jute mats".

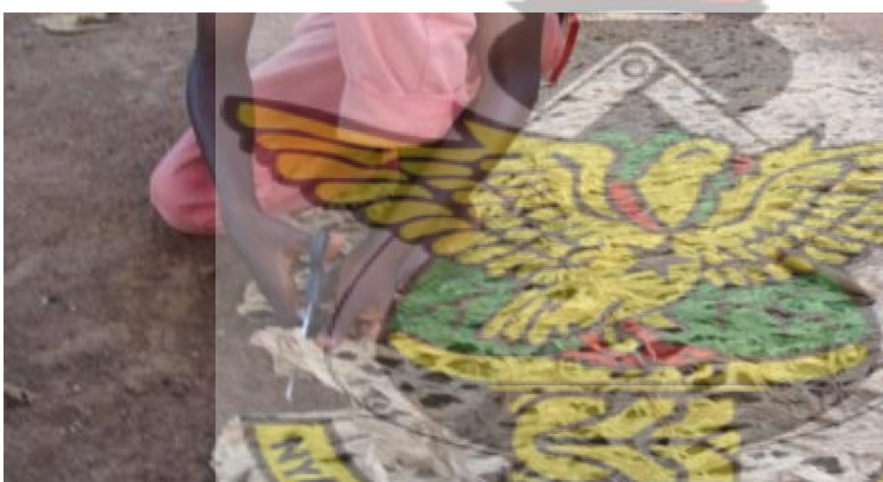
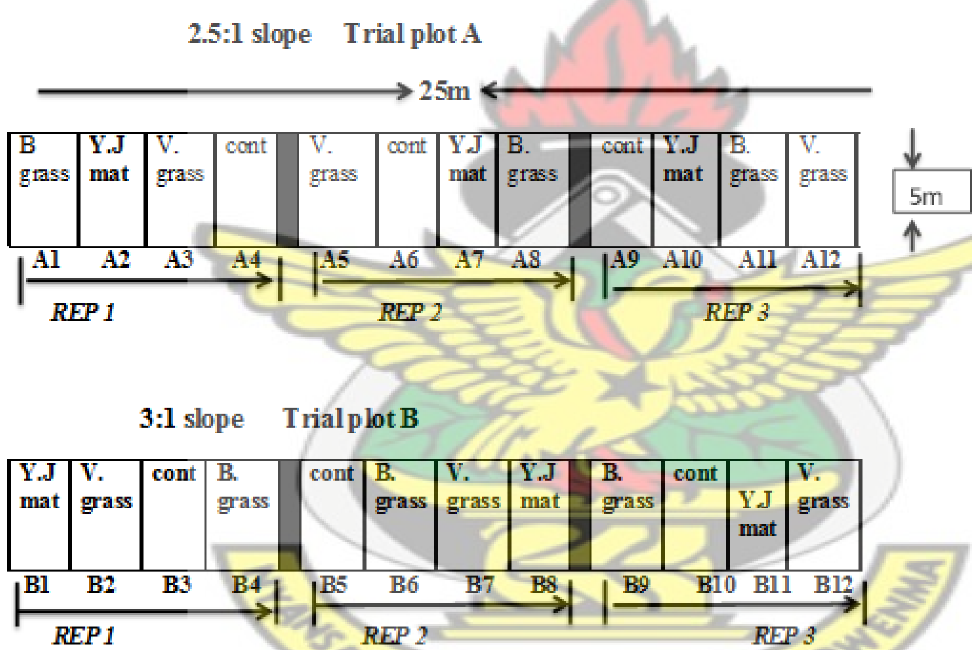


Plate 1: Processing the stripped bark into chicken mesh-like mats

3.3 THE EXPERIMENTAL PLOTS

Two sites on the fill slopes were cleared and 24 trial plots measuring 25 m by 5 m each were made. The three erosion control materials namely, Vetevar grass, Bahama grass and the York jute mat were laid on these plots as shown in Figure 2. Each trial plot had twelve sub-plots and each sub-plot measured 2 m by 5 m. An open area acted as a control plot. In all, there were three replications. The distance between replicated plots was 0.1 m (Figure 3). The identities of the sub-plots were boldly written on labels and placed in front of each of the sub-plots, as shown in Plates 2 and 3. Grubbing of weeds on the trial plots was done periodically. The sub-plots were separated from each other by berms constructed with compacted soil. The berms prevented the run-off from one sub-plot from entering another sub-plot.



Key: - Y.J mat = York jute mat; V. Grass = Vetevar grass; B. Grass = Bahama grass; Cont. = Control; REP = Replicated plots

Figure 2: The schematic arrangement of the mats on the experimental plots

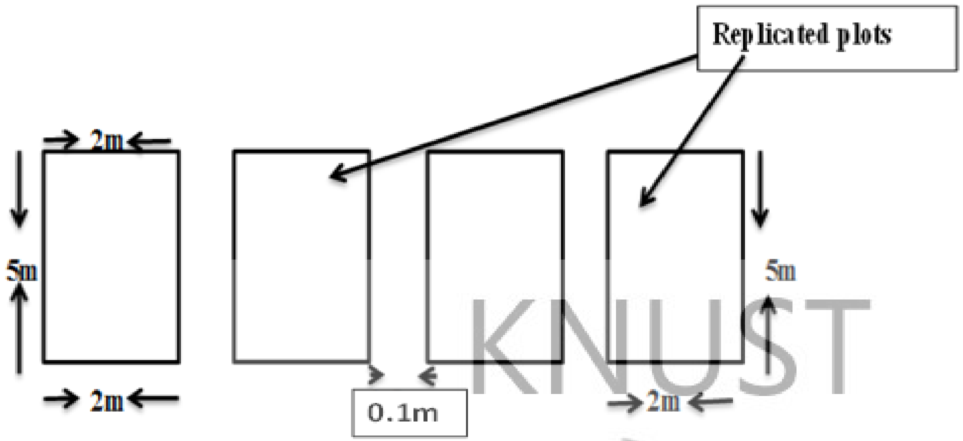


Figure 3: The arrangements of replicated plots

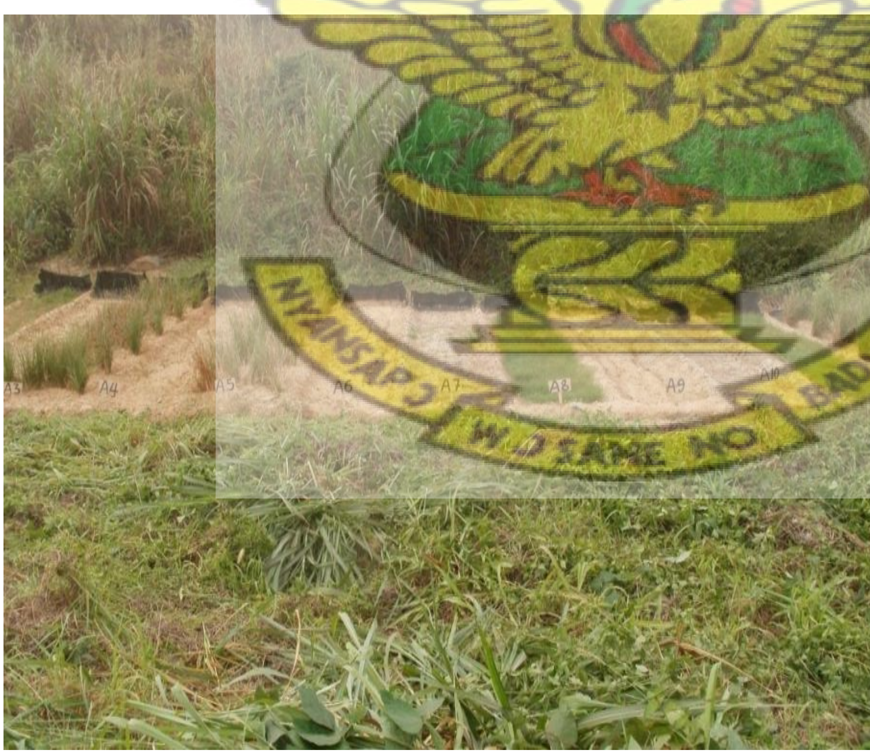


Plate 2: The trial plot A on the 2.5: 1 slope

Plate 3: The trial plot B on the 3: 1 slope

At the lower end of the sub-plots, shallow trenches 15 cm deep and 30 cm wide were constructed across the slope from one berm to another in which the eroded materials settled as seen in Plate 4. The trenches were lined with silt fence. Pieces of silt fence were also erected to serve as barriers to the flow of run-offs as shown in plate 4.

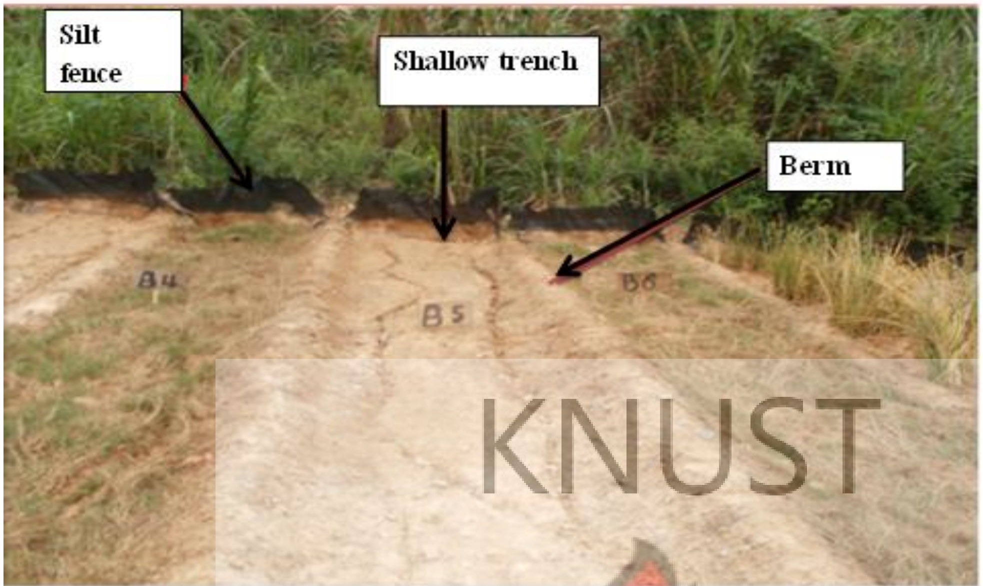


Plate 4: Sub-plots separated by berms

3.3.1 Spreading the York jute mats

The York jute mats were laid on sub-plots A2, A7, A10, B1, B8 and B11 as shown in Figure 3. A small trench was dug on the top of the slope of the particular sub-plot meant for York jute mat. In this trench the top end of the York jute mat was placed. The mats were laid out evenly but loosely on the soil surface in the direction of flow without stretching. The mats overlapped. In order to let the mats overlap, the upstream sections were placed on top. The laid mats were consolidated with small bamboo pegs which were notched. The purpose of using the pegs was to hold the mats firmly in the soil and to protect them from being removed by wind or run-off.

3.3.2 Planting the Vetevar grass

Single slips of Vetevar grass were trimmed and planted on sub-plots A3, A5, A12, B2, B7 and B12 from upper end of the slope to the bottom end of the slope at a spacing of 1 cm within rows and 1 m between rows across the slope as shown in Figures 2 and 3. The rows of Vetevar grass were planted in a “U” form to mimic the flow of water on a relatively smooth sloping surface. The Vetevar grass was watered soon after planting and every other day.

3.3.3 Planting of Bahama grass

The vegetative parts of Bahama grass were planted randomly on sub-plots A1, A8, A11, B4, B6 and B9 very close to each other and watered soon after planting as shown in Figures 2 and 3. The Bahama grass was also watered every other day.

3.4 DATA COLLECTION

Recording of data was done each day after rainfall at mid-day. However, the last thee records (2nd, 5th and 7th December) were taken after hydroseeder watering at mid-day. In all, a total of 10 rainy days’ records were taken (i.e. from 24th October to 7th December, 2011). On each sub-plot, the amount of eroded materials was collected and the depth of channels measured with a tape measure while the number of channels was counted. The essence of collection of eroded materials at mid-day was to make sure that the materials were dry.

3.4.1 Measuring the Depths of Erosion Channels

The depths of channels were measured with a 30-meter ruler at three different points on each sub-plot. The first point was at the upper portion of the sub-plot and the second point was at the middle portion of the sub-plot, while the third point was at the lower portion of the sub-plot.

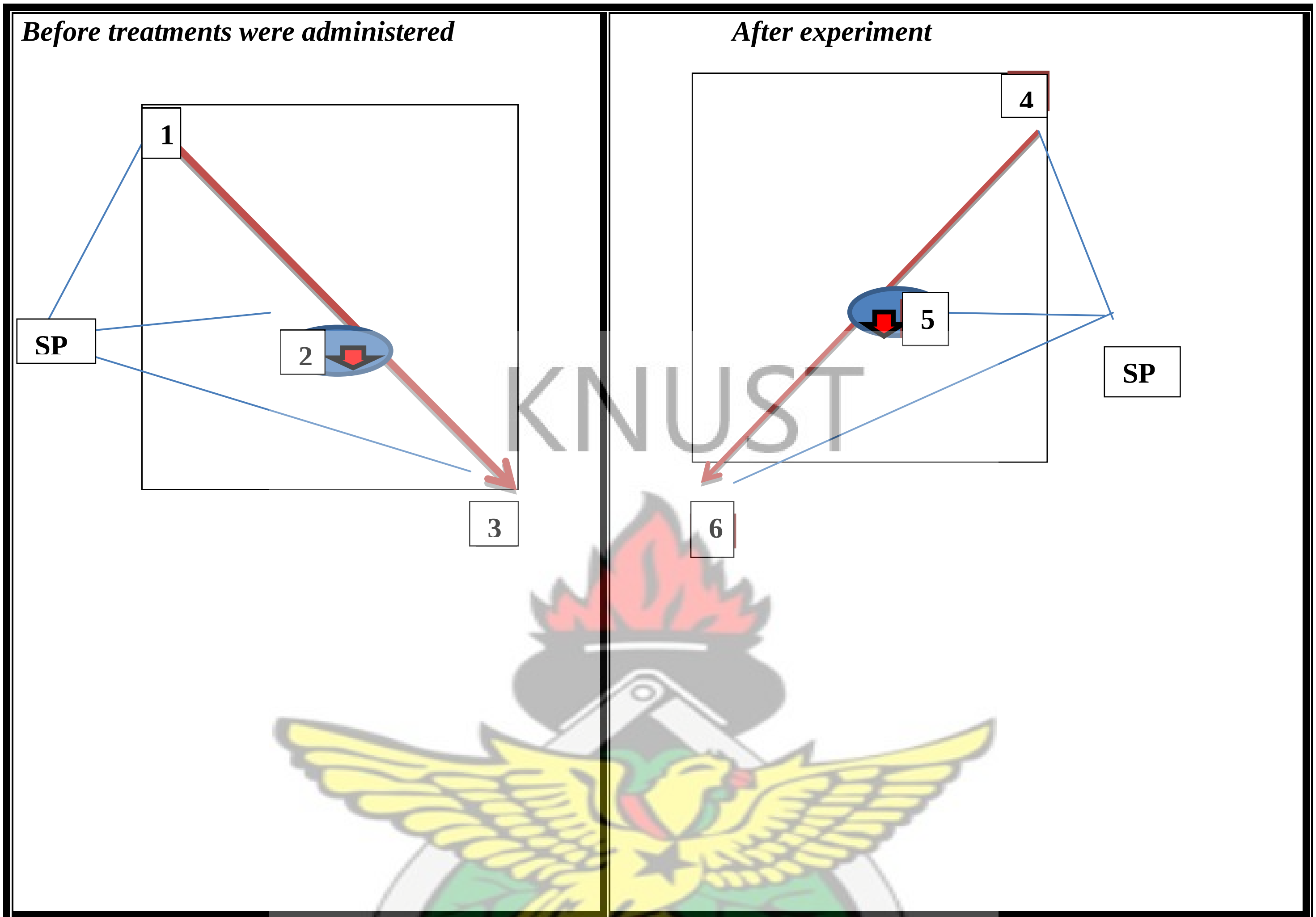
3.4.2 The collection of eroded materials

The eroded materials which had settled on the pieces of silt fence which was lined in the trenches, were collected and sent to the assay laboratory for drying at 15^{o}C for two days to make sure the materials were completely dry after which, the weight was taken.

3.4.3 Determination of the nutrient status of the soil

On each sub-plot, soil samples were taken at three points as indicated in Figure 4 before and after the experiment to determine the nutrient status of the soils at the site. Nitrogen, phosphorus and potassium as well as organic matter content were determined.

Before the installation of the treatments, soil samples were taken diagonally at points denoted by 1, 2 and 3 on each sub-plot as seen in Figure 4. A bamboo peg was fixed at the area denoted by "2" to make sure that after the experiment, soil samples would not be taken from the same spot again.



Key: SP= sampling points

Figure 4 Schematic presentation of soil sampling points

Sample holes measuring 30 cm wide by 30 cm deep were dug at three points on each sub-plot and soil samples weighing 5 kg were taken with a hand trowel at 30 cm deep and air-dried for 24 hours. The soil samples from each sub-plot were mixed together twice and heaped in conical shapes on a piece of polythene sheet. This was to make sure that the soil was completely mixed together. Each heap was then divided into four equal parts and two parts were separated from the other two. One-and-a half kilogram of this quantity of soil which has been separated were put in paper bags. The bags were closed, folded and tied with tapes and sent to the Soil Research Institute laboratory at Kwadaso for nutrient status analysis.

3.6 Statistical analysis

All statistical analysis of the results were done using the Microsoft Excel and one-way Randomized Analysis of Variance (ANOVA). Statistical tests were done at 95% confidence level.

CHAPTER FOUR

RESULTS

4.1 NUMBER OF CHANNELS

The mean numbers of channels created during the three months period of recording are shown in Figure 5. The mean number of channels ranged from zero to 6.67 on the 2.5:1 slope and 0.33 to 7.33 on the 3:1 slope. The plots without erosion control material on the 3:1 slope had more channels than the 2.5:1 slope. Similarly, for all the other plots with or without erosion control material, the 3:1 slope had more number of erosion channels than the 2.5:1 slope.

Generally, the plots without soil erosion control material had the highest number of channels, followed by the plots treated with Vetivar grass, Bahama grass and York jute mat, respectively. The plots treated with York jute mats had virtually no channels created during the three months of the experimental trial.

On the 3:1 slope, the sub-plot without any soil control material recorded the highest mean number of 7.33 channels. Similarly, the highest number of channels recorded on the sub-plot without any soil control material on the 2.5:1 slope was 6.67 channels compared with the other soil erosion control materials.

The sub-plot which was treated with Bahama grass recorded a highest mean of 6.3 channels on the 3:1 slope and 4.0 channels on the 2.5:1 slope whiles the plots treated with Vetevar grass recorded the respective highest mean values of 6.0 and 5.3 channels on the 3:1 and 2.5:1 slopes.

The sub-plots treated with the York jute mat recorded the highest mean numbers of 0.33 channel on the 3:1 slope and no channel on the 2.5:1 slope. These values were the lowest of all the treatments.

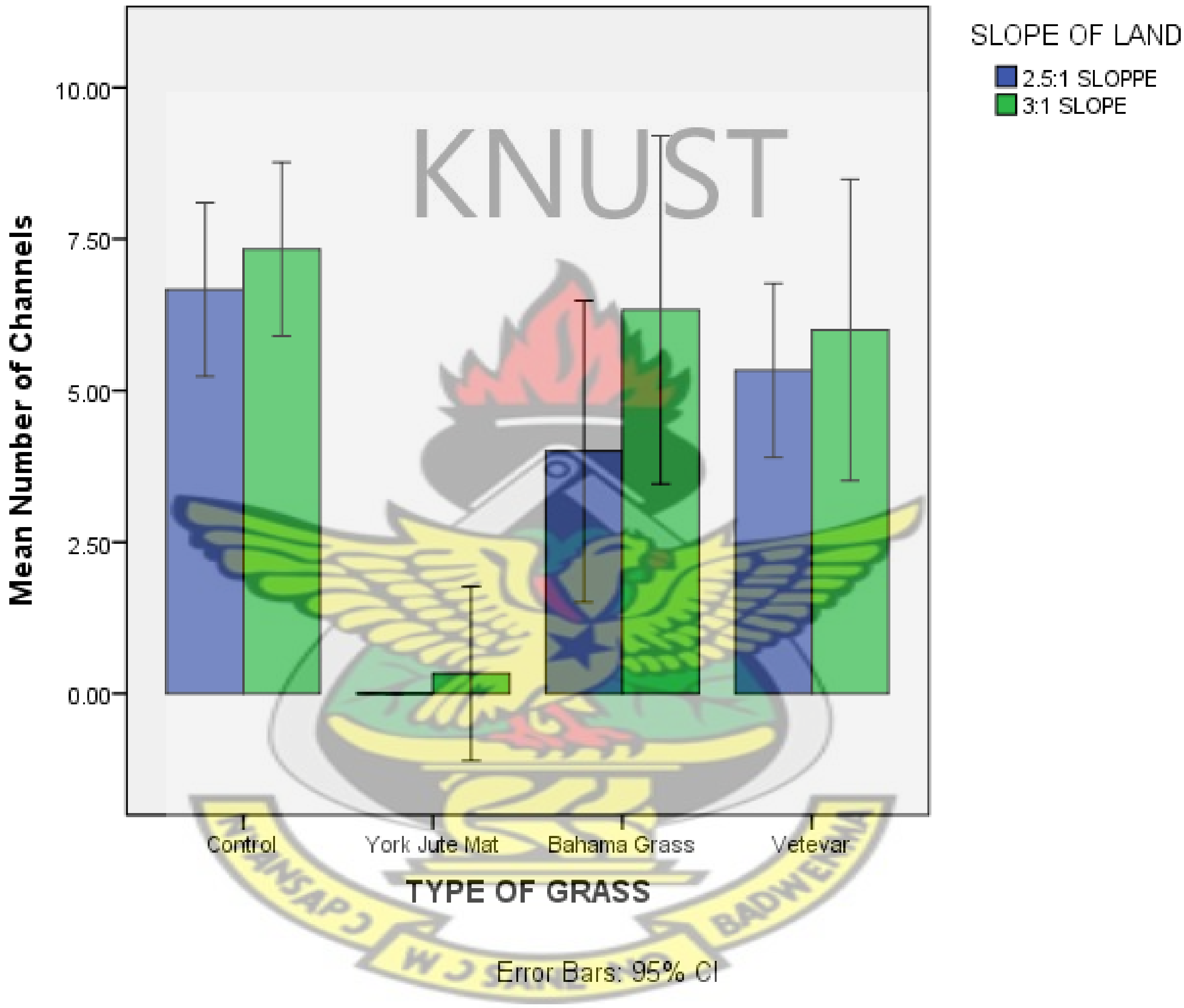


Figure 5 The mean number of erosion channels recorded on the experimental plots

4.2 DEPTH OF CHANNELS

During the three months period of recording, the highest mean depths of channels was 3.8 cm, and was recorded on the sub-plot without any soil control material on the 3:1 slope, while the lowest mean depth of channels (0 cm) was recorded on the sub-plots treated with York jute mat on the 2.5:1 slope (Figure 6).

The sub-plots without any soil control material recorded the highest mean depth of 3.80 cm, while a value of 3.10 cm was recorded on the 2.5:1 slope (Figure 6). The sub-plots treated with Vetevar grass recorded a mean depth of 2.37 cm and 2.33 cm on the 2.5:1 slope.

The highest values recorded on the plots treated with Bahama grass were 2.23 cm and 2.0 cm, respectively, for the 3:1 and 2.5:1 slopes.

All the sub-plots treated with York jute mat recorded the lowest mean depths. On the 3.1 slope it was 0.07 cm while on the 2.5:1 slope, it was zero.

There was another interesting results from the sub-plots treated with Bahama grass and Vetevar grass in respect of the mean depths of channels recorded. Both Bahama and Vetevar sub-plots recorded almost the same mean depths of channels on the 3:1 slope. Bahama sub-plot recorded mean depth of 2.33 cm while Vetevar sub-plot recorded mean depth of 2.37 cm.

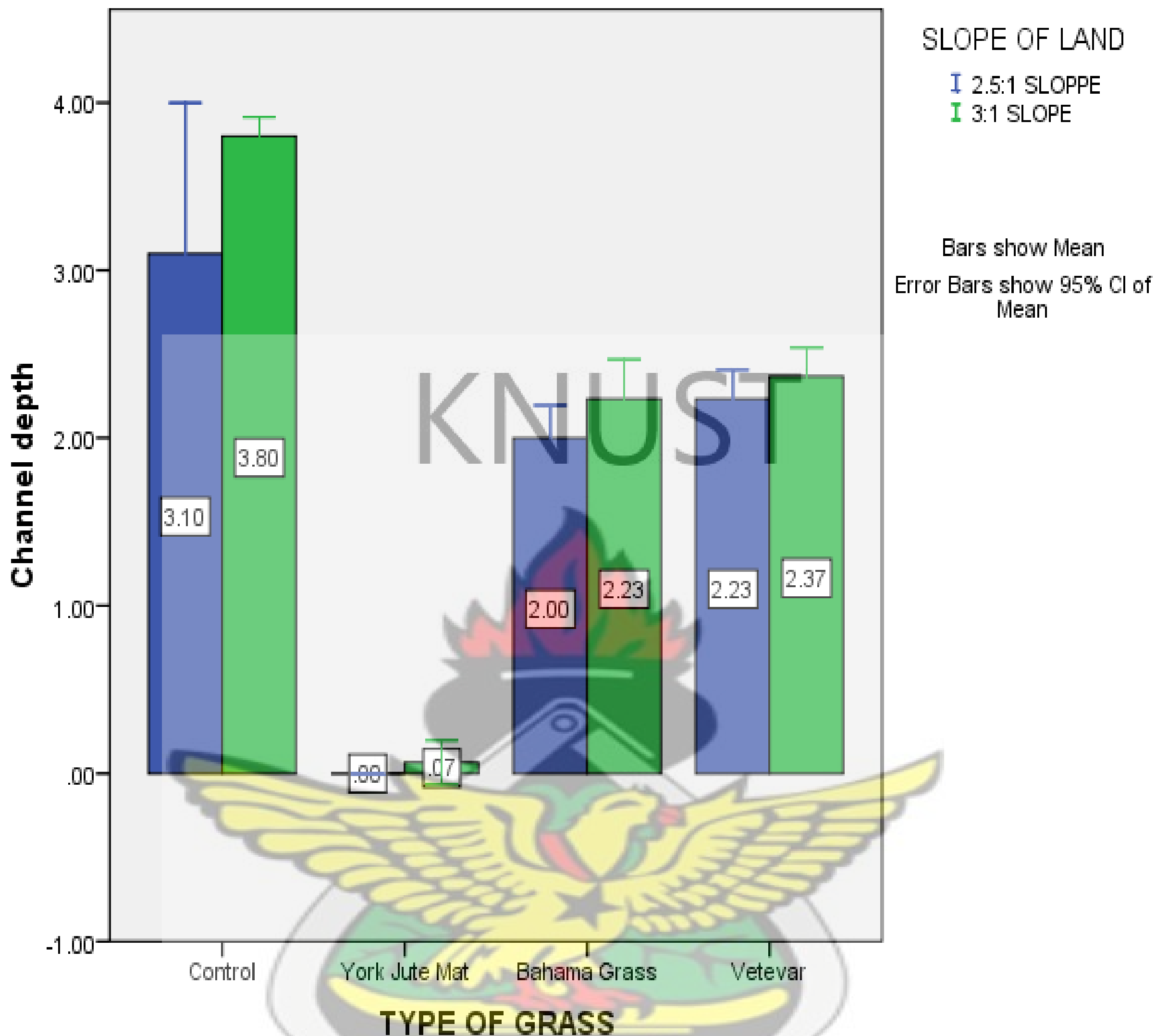


Figure 6 The mean depth of erosion channels recorded on the experimental plots

4.3 ERODIBLE MATERIAL

The mean weight of eroded materials recorded in the study ranged between zero on the 2.5:1 slope and 6.67 kg on the 3:1 slope (Figure 7).

On the 3:1 slope, the sub-plots without any treatment recorded the highest mean weight of erodible materials of 6.67 kg, followed by Bahama grass (5.33 kg), Vetevar grass (4.95 kg) and York jute mat (0.19 kg).

On the 2.5:1 slope, the sub-plots without any treatment, again, recorded the highest mean weight of erodible materials of 5.90 kg followed by Vetevar grass (4.33 kg), Bahama grass (3.52 kg) and York jute mat (0 kg).

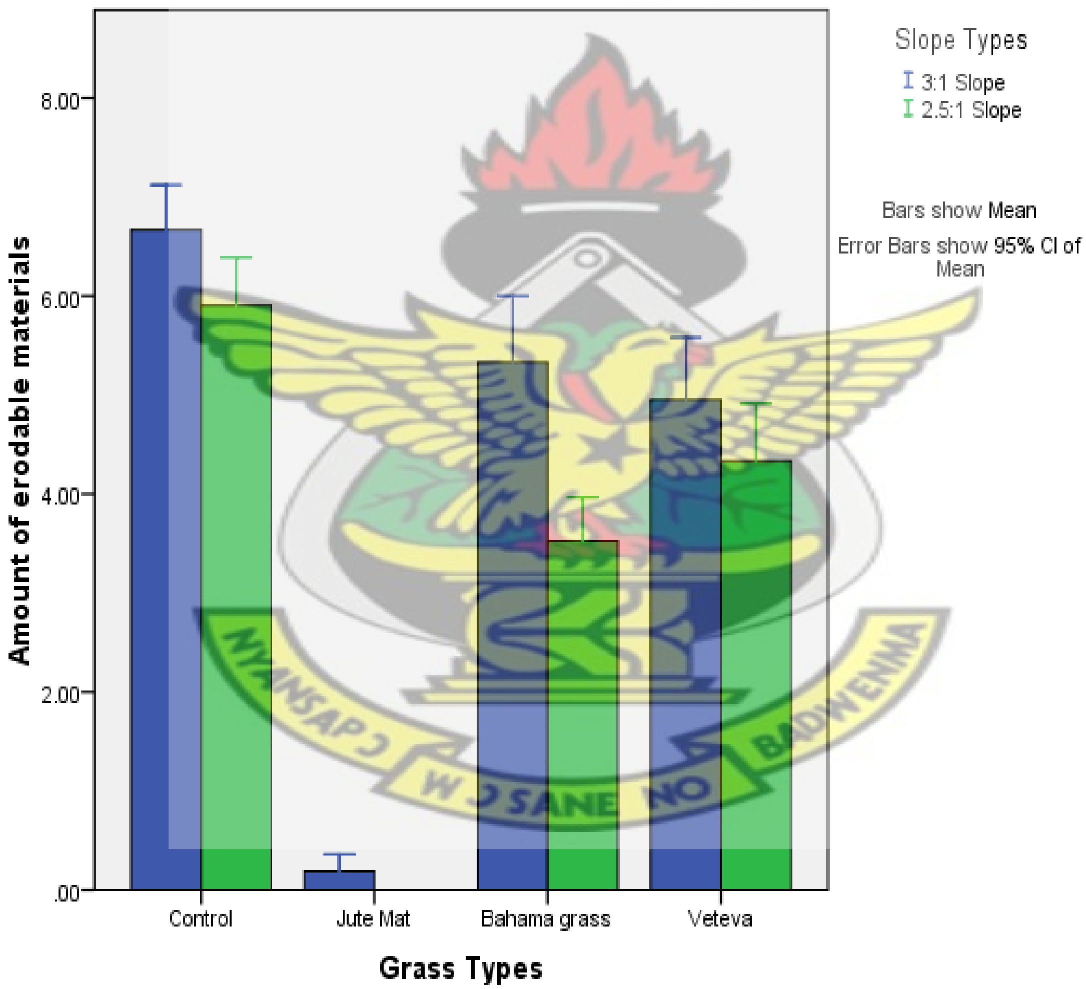


Figure 7 The mean weight of erodible materials recorded on the experimental plots

4.4 NUTRIENT ANALYSIS

The soil laboratory results were transformed for normality using MINITAB statistical software. After normalization, the data were subjected to one-way analysis of variance (ANOVA).

4.4.1 Nitrogen Concentration

The initial nitrogen concentration in the soil was 0.10%. After the trial, the sub-plots treated with York jute mat recorded the highest mean concentration of 0.28% Nitrogen, followed by the sub-plots treated with Bahama grass with a mean concentration of 0.25%, and 0.22% for the sub-plot treated with Vetevar grass. The least of 0.1% Nitrogen was recorded on the plots without soil erosion control material (Table 1).

Table 1 Mean nitrogen concentration in topsoil before and after the experimental trials

Erosion control material	**Nitrogen concentration (%)**	
	Before Treatment	**After Treatment**
York jute mat	0.10	0.28±0.01
Bahama grass	0.10	0.25±0.01
Vetevar grass	0.10	0.22±0.006
Control	0.10	0.10±0.01

4.4.2 Phosphorus Concentration

The mean Phosphorus concentrations (ppm) recorded before and after the study are shown in Table 2. The sub-plots treated with York jute mat recorded the highest mean concentration of 17.85 ppm of Phosphorus, followed by the sub-plots treated with Bahama grass with a mean concentration of 15.39 ppm. The third highest mean of 12.43 ppm of phosphorus was recorded on the sub-plot planted with Vetivar grass, while the least of 2.55 ppm of Phosphorus was recorded on the plot without soil erosion control material. The initial mean phosphorus concentration in the topsoil was 2.33 ppm.

Table 2 Mean phosphorus concentration in topsoil before and after the experimental trials

Erosion control material	Phosphorus concentration (ppm)	
	Before Treatment	After Treatment
York jute mat	2.33	17.85±1.00
Bahama grass	2.33	15.39±2.01
Vetevar grass	2.33	12.43±1.00
Control	2.33	2.55±0.01

4.4.3 Potassium Concentration

The mean Potassium concentrations (ppm) recorded after the three month period of study ranged from 87.04 ppm to 180.78 ppm (Table 3). The sub-plots treated with York jute mat recorded the highest mean potassium concentration of 180.78 ppm, from an initial mean value of 84.06 ppm. This was followed by the sub-plots treated with Bahama grass which increased from an initial K concnetration of 84.38 ppm to 150.65 pmm. On the plots treated with Vetivar grass, the mean K concentration increased from 84.70 ppm to 120.52 ppm after the trial. However, on the plots without any erosion control control material, the initial K concentration of 83.73 ppm increased only slightly to 87.04 ppm at the end of the study.

Table 3 Mean potassium concentration in topsoil before and after the experimental trials

Erosion control material	Potassium concentration (ppm)	
	Before Treatment	**After Treatment**
York jute mat	84.06	180.78±2.01
Bahama grass	84.38	150.65±2.00
Vetevar grass	84.73	120.52±2.00
Control	83.73	87.04±2.00

4.4.4 The Mean Organic matter concentration (%)

The mean organic matter contents recorded ranged from 1.83% on the control plot to 3.75% on the plots treated with jute mat (Table 4). Mean organic matter contents of 3.47% and 3.16% were recorded on the sub-plots planted with Bahama and Vetevar grasses, respectively. The initial organic matter content of all the soils was 1.80%.

Table 4 Mean organic matter content in topsoil before and after the experimental trials

Erosion control material	Organic matter content (%)	
	Before Treatment	**After Treatment**
York jute mat	0.10	3.75±0.03
Bahama grass	0.10	3.47±0.02
Vetevar grass	0.10	3.16±0.02
Control	0.10	1.83±0.02

CHAPTER FIVE

DISCUSSION

5.1 Performance of the Soil Erosion Control Materials

The Vetevar grass was able to reduce sedimentation, while the Bahama grass was also able to reduce the number of channels and to a lesser extent the amount of erodible materials (sediments). The York jute mat reduced the amount of erodible materials and eliminated the creation of erosion channels. The performance of the erosion control materials with respect to loss of soil, showed that there was serious soil erosion on the plots without soil erosion control materials, whereas there was very little soil erosion on the plots covered with soil erosion control materials. Under similar rainstorm intensities, open soil surface experiences more soil loss than roughened soil surfaces.

The presence or absence of soil erosion could also be attributed to the fact that during the three months period, some of the plant materials used to check soil erosion might have decomposed and added some organic matter to the soil. Soil organic matter allows water infiltration so that much of the topsoil could not be carried away by runoff water. The incorporation of cover crops into the soil is immediately followed by an increase in abundance of soil microorganisms that aid in the decomposition of this fresh material. The additional decomposition of organic matter allows for the re-incorporation of nutrients such as nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), and sulfur (S) into the soil (Ditsch *et al*., 2002). Soils rich in organic matter has better structure and is therefore less susceptible to being washed or blown away. This assertion is supported by Cooke *et al*. (1999). The fertility of the eroded materials was higher than the initial fertility of the soil (Quansah and Baffoe-Bonnie,1981).

Maintaining good residue cover provides good resistance to water erosion (Torri, 1996). The Bahama grass plots had fewer erosion channels and eroded materials than the Vetevar grass plots. This may be attributed to the fact that, the roots and stems of the Bahama grass covered the entire soil surface thereby increasing the roughness of the ground surface and the permeability of the soil, leading to increased infiltration capacity of the soil. This result might also be due to the fact that the dense nature of Bahama grass reduced the erosive force of runoff on the steeper slope. Dense cover crop physically slows down the velocity of rainfall before it contacts the soil surface, preventing soil splashing and erosive surface.

5.2 The Effect of Slope on Soil Erosion

The study revealed that, soil erosion was much slower on the 2.5:1 slopes than on the 3:1 slope. For example, the Bahama grass recorded mean number of channels of 6.3 and 4, respectively on the 3:1 and 2.5:1 slopes, while in terms of eroded materials, the respective values were 5.33 and 3.52 kg. Similarly, the Vetevar grass plots recorded mean numbers of 6 and 5.33 channels on the 3:1 and 2.5:1 respectively. Values for eroded materials were 4.95 and 4.33 kg for 3:1 and 2.5:1 respectively. The plots without soil erosion control material on the other hand, recorded 7.33 channels and 6.67 on the 3:1 and 2.5:1, respectively. The recordings for erodible materials, were 6.67 and 5.90 kg on the3.1 and 2.5:1 slopes, respectively. The York jute mat plots, recorded almost zero for all the parameters on both types of slopes.

The amount of eroded materials differed significantly among the treatment types ($p < 0.05$) except the Bahama grass and the vetevar grass ($p > 0.05$), on both slope gradients. Again, there were significant differences in the depth of channels among the different types of erosion control materials, except the Bahama grass and the vetevar grass where insignificant difference existed among their mean values on both slope gradients. Similar association existed among the mean values of the number of channels.

In a similar experiment performed by Higaki *et al*. (2004) on four types of erosion sites located on degraded sloping lands in Nepal, they reported that surface erosion was very little on gentle slopes. Several researchers have made claims to explain why steep bare slopes are prone to soil erosion. According to Wainwright and Brazier (2011), soil erosion increases with slopes on bare soils. Bare soil erodes much more easily than soil covered with mulch or plants (Cobourn *et al*., 2010). Soil surface exposure also compacts the soil, impedes drainage through the 2–6 in. layer and makes the soil erode more easily (Cunningham,1963).

Farmers use several methods to limit soil erosion, among which includes the leafing of a band of grass on the area to be protected so that the soil stays within the boundaries. The roots also hold the soil in place, so it is not washed away easily (Blanco and Rattan, 2010). Soil losses can be expected to increase with slope steepness as a result of respective increases in volume and velocities of surface runoff (Mohd, 2000). In the Sudan Savanah zone of Ghana, the soils developed from Birrimian phylite are sandy and as such highly susceptible to erosion, especially on steep slopes (Senayah *et al*., 2009). Water runoff tends to accelerate as gravity pulls it down the slope and decelerates on more gentle slopes especially where frictional forces exerted by surface debris that dissipate energy can overcome the driving forces. In an undisturbed forest, the mineral soil is protected by a layer of leaf litter and humus that cover the forest floor. These two layers form a protective mat over the soil that absorbs the impact of rain drops (Styczen and Morgan,1995).

5.3 The Nutrient Status of the Soils

5.3.1 Nitrogen levels in the soils

At the end of the study, the plots treated with York jute mat had the initial nitrogen concentration increased by nearly 3-folds to 0.28% from the initial 0.10%. The York jute plant is known to be rich in crude protein (Sangkhom and Somphanh, 2009). The higher percentage of nitrogen recorded could be attributed to the breakdown of the protein in the plant material upon the decomposition of the jute mat. The plots planted with Bahama grass had the nitrogen content increased by 2.5-folds to 0.25% from the initial value of 0.10%. Similarly, the nitrogen content in the soil on the plots treated with Vetevar grass had the nitrogen content more than doubled to 0.22% from the initial. The nitrogen tied up in the crop biomass is released back into the soil once the crop begins to decompose (Ditsch *et al*., 2002). When plant residues are returned to the soil, various organic compounds undergo decomposition and contributes nitrogen, phosphorus and other nutrients to the soil (Juma, 1998).

Repeated litter application increases buildup of soil nitrogen and soil phosphorus with long-term trends in N and P runoff (Harmel *et al*., 2009). The plots without erosion control materials had nothing added to the soil.

Statistically, no significant differences existed among the nitrogen levels in the soils of the different treatments ($p > 0.05$).

5.3.2 Phosphorus levels in the Soil

The plots treated with York jute mat had approximately 660% phosphorus added to the soil. The plots planted with Bahama grass saw phosphorus concentration increasing by approximately

560% while those treated with Vetevar grass saw phosphorus concentration increasing by approximately 430%. The plots without erosion control materials had approximately 9% phosphorus added to the soil. The litter or plant materials might have contributed to the increase in the plant nutrients such as phosphorus and nitrogen. Litter fall is the dominant pathway for nutrient return to the soil, especially for nitrogen and phosphorus (http://en.wikipedia.org/wiki/Litterfall).

More phosphate is lost to water running over the soil surface or leaching through the soil, that might be the reason why the plot without soil erosion control material had very little amount of phosphorus in the soils. When soil erosion occurs, more fine particles are removed than coarse particles, causing sediments leaving the soil to carry P along (Lowell *et al*., 2009).

There was significant difference ($p < 0.05$) in mean phosphorus concentrations between the soils treated with Bahama and Vetevar grassses, and also between the Bahama grass and the control plots. Similarly, differences in mean phosphorus values were significant between the Vetevar grass and the jute mat plots, as well as between the Vetevar and the control plots. However, no statistical difference existed between the Bahama grass and the jute mat plots ($p > 0.05$).

5.3.3 Potassium Levels in the soil

All the plots treated with the erosion control materials saw increments in the potassium concentrations after the 3 month period of application. While the highest increment was in the soils treated with the York jute mat at approximately 115%, the plots planted with Bahama grass and Vetevar grass saw increments of 79% and 42%, respectively. The plots without erosion control materials had approximately 4% Potassium added to the soil.

Organic materials usually have a large cation exchange capacity, enabling them to retain potassium ions effectively (Hue and Silva, 2000).

The plots without erosion control material were virtually open, i.e. without vegetation. This might have accounted for the small quantity of Potassium present in the soil. It is probable that majority of the potassium in the soil might have leached away. According to Hue and Silva (2000), Potassium is present in ionic form (K^{+}) in the soil solution and it is quite mobile. Therefore, potassium which is not taken up by plants may be lost by leaching. They again stated that Potassium deficiency occurs more often, in highly eroded soils than in soils protected from erosion. Therefore the severe erosion which occurred on the plots without erosion control materials might have accounted for the low amount of potassium in the soil. Significant losses of potassium can occur under adverse conditions i.e. when soil is water-logged, frozen or very dry and deeply cracked.

Mean potassium concentrations differed significantly among the different treatments ($p < 0.05$).

5.4 Organic Matter (OM) Status of the soil

At the end of the study, the plots treated with York jute mat had approximately 108% OM added to the soil. The organic matter content in the soils from the plots planted with Bahama grass increased by approximately 93% while the increment was about 76% for those planted with Vetevar grass. Only 2% of organic matter was added to the plots without erosion control materials. The higher concentrations of organic matter added to the soils with erosion control materials might have come about as a result of the partial or complete decay of the erosion control materials on the plots. Soil organic matter contributes to the fertility of soils. It binds the soil aggregates together and is a storehouse of major and minor plant nutrients (Alexandra and

Benites, 2005). A variety of materials such as grass clippings, leaves, hay, straw, kitchen scraps, shredded bark, used as mulch act as a direct composting system which add plant nutrients to the soil (Cobourn *et al.*, 2010). Crop residues left on the field add plant nutrients to the soil and, in addition, form small dams that help retain runoff water, thereby reducing erosion (Ecogardening, 1993). The reason for smaller amount of organic matter increase on the plot without erosion control material could be attributed to the relatively no vegetation on the plot. Where the soil is exploited for crop production without restoring the organic matter, the nutrient cycle is broken and soil fertility declines (Alexandra and Benites, 2005). Erosion occurs when wind and rain dislodge topsoil which contains many essential nutrients, from fields and hillsides. Stripped of its valuable top layer, the soil left behind is often too poor to sustain good plant growth (Pimentel *et al.*, 1987).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The study has shown that the erosion control materials used were effective in controlling soil erosion. The Vetevar grass was able to reduce sedimentation, while the Bahama grass was also able to reduce the number of channels and to lesser extent the amount of erodible materials (sediments). The York jute mat reduced the amount of erodible materials (sediments) and eliminated the creation of erosion channels, and thus performed better as an erosion control material than the Bahama and the Vetivar grasses.

The erosion control materials also helped to improve both the stability and nutrient status of the soil. The nutrient status, especially for the major plant nutrients (N, P, K) and organic matter content of the soil also appreciated considerably for all three materials. The plots treated with York jute mat had the overall highest increments in N, P, K and organic matter followed by the Bahama and Vetivar grasses, in that order.

Thus, it can be concluded from the study that mats made from the bark of York jut plant offers a very good alternative for controlling soil erosion.

6.2 RECOMMENDATIONS

In order to combat soil erosion and reclaim degraded lands, especially from mining activities, the following Best Management Practices (BMPs) are recommended based on the results of this study:

1. Combination of Vetevar grass and York jute mat,
2. Combination of Bahama grass and York jute mat.
3. Combination of Vetevar grass, Bahama grass and York jute mat.

To protect areas of brisk activities at construction and excavation sites where vast stretch of land is stripped of vegetation, then the third listed BMP is the preferred choice. The tiny holes in York jute mat are generally designed to act as tiny sediment basins to trap sediments flowing over it. The York jute mat naturally biodegrades to promote vegetation establishment. The establishment of a permanent vegetative cover for long term erosion protection is of priority for such lands. This is because such lands are subjected to rapid soil erosion, sedimentation and loss of fertile top soil as well as soil compaction and need immediate attention. The planting of stoloniferous grass varieties such as Bahama grass which spread rather than grow upright over bare soil to reduce soil erosion is the best.

The Vetiver grass could be an important tool to reduce sedimentation and increase ground water recharge. Best erosion control material allows for the re-incorporation of major plant nutrients that are found in the soil such as Nitrogen (N),Potassium(K),Phosphorus(P) as well as Organic matter.

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APPENDICES

Appendix A: Number of channels

A1 Mean number of channels developed on the plots with 3:1 slope gradient after rainfall events and hydroseeding.

Amount of Rainfall (mm)	7.6	13.6	0.4	9.0	10.0	3.2	0.3	Hyd. seeder	Hyd. seeder	Hyd. seeder
Treatments	**Mean number of channels**									
York Jute mat	0	0	0	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Bahama grass	2. 7	4.7	4.7	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Vetevar grass	3.00	3.5	4.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Control	4. 7	6.3	6.3	7.3	7.3	6.3	7.3	7.3	7.3	7.3

A2 Mean number of channels developed on the plots with 2.5:1 slope gradient after rainfall events and hydroseeding.

Amount of Rainfall (mm)	7.6	13.6	0.4	9.0	10.0	3.2	0.3	Hyd. seeder	Hyd. seeder	Hyd. seeder
Treatments	**Mean number of channels**									
York Jute mat	0	0	0	0	0	0	0	0	0	0
Bahama grass	2.0	3.3	3.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Vetevar grass	2.3	3.3	3.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
Control	4.0	5.3	5.3	6.7	6.7	6.7	6.7	6.7	6.7	6.7

APPENDIX B: Depth of channels

B1 Mean depth of channels developed on the plots with 3:1 slope gradient after rainfall events and hydroseeding.

Amount of Rainfall (mm)	7.6	13.6	0.4	9.0	10.0	3.2	0.3	Hyd. seeder	Hyd. seeder	Hyd. seeder
Treatments	**Mean depth of channels (cm)**									
York Jute mat	0	0	0	0.07	0.07	0.07	0.07	0.07	0.17	0.17
Bahama grass	0.63	1.27	1.27	1.47	1.77	2.03	2.23	2.43	2.60	3.03
Vetevar grass	0.83	1.56	1.57	1.73	1.90	2.17	2.37	2.57	2.70	3.00
Control	1.78	2.40	2.50	3.27	3.43	2.63	3.80	3.97	4.13	4.27

B2 Mean depth of channels developed on the plots with 2.5:1 slope gradient after rainfall events and hydroseeding.

Amount of Rainfall (mm)	7.6	13.6	0.4	9.0	10.0	3.2	0.3	Hyd. seeder	Hyd. seeder	Hyd. seeder
Treatments	**Mean depth of channels (cm)**									
York Jute mat	0	0	0	0	0	0	0	0	0	0
Bahama grass	0.37	1.13	1.23	1.37	1.53	1.78	1.67	2.13	2.43	2.43
Vetevar grass	1.03	1.33	1.37	1.63	1.77	2.03	2.23	2.40	2.60	2.73
Control	1.03	2.33	2.43	2.67	2.70	3.06	3.17	3.30	3.63	3.73

Appendix C: Mass of Erodible Materials

C1 Mean weight of eroded materials after rainfall events and hydroseeding on the plots with slope gradient 3:1

Amount of Rainfall (mm)	7.6	13.6	0.4	9.0	10.0	3.2	0.3	Hyd. seeder	Hyd. seeder	Hyd. seeder
Treatments	Mean mass of eroded materials (kg)									
York Jute mat	0.50	0.60	0.67	0.97	1.13	0.97	0.13	0.2	0.23	0.10
Bahama grass	1.70	7.23	7.37	8.27	9.2	9.03	2.27	2.3	1.03	0.13
Vetevar grass	3.26	5.90	6.07	6.93	7.3	6.90	2.93	2.30	0.90	0.43
Control	11.00	13.87	14.00	15.17	15.63	15.47	6.33	8.60	3.20	0.47

C2 Mean mass of eroded materials after rainfall events and hydroseeding on the plots with slope gradient 2.5:1

Amount of Rainfall (mm)	7.6	13.6	0.4	9.0	10.0	3.2	0.3	Hyd. seeder	Hyd. seeder	Hyd. seeder
Treatments	Mean mass of eroded materials (kg)									
York Jute mat	0.27	0.37	0.53	0.67	0.83	0.36	0.17	0.17	0.17	0.07
Bahama grass	2.30	5.00	5.10	5.70	5.97	5.67	2.13	1.00	0.53	0.13
Vetevar grass	1.13	4.57	4.77	5.97	6.5	6.30	2.43	1.60	0.47	0.23
Control	7.77	11.20	11.40	9.17	12.93	12.50	5.30	5.63	2.33	0.37

APPENDIX D: Analysis of Variance

D1 Analysis of variance for number of channels for slope gradient 3:1

Variate: Number of channels

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	252.3050	84.1017	89.33	<.001
Residual	36	33.8940	0.9415		
Total	39	286.1990			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

units 11	-2.92	s.e.	0.92
units 21	-2.25	s.e.	0.92
units 31	-2.04	s.e.	0.92

Tables of means

Variate: Number_of_channels

Grand mean 4.46

Treatment	Bahama grass	Control	Jute mat	Vetevar grass
	5.62	6.74	0.21	5.25

Standard errors of differences of means

Table	Treatment
rep.	10
d.f.	36
s.e.d.	0.434

Least significant differences of means (5% level)

Table	Treatment
rep.	10
d.f.	36
l.s.d.	0.880

D2 Analysis of variance for number of channels for slope gradient 2.5:1

Variate: Number of channels

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	204.6608	68.2203	101.87	<.001
Residual	36	24.1090	0.6697		
Total	39	228.7697			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

units 21	-2.30	s.e.	0.78
units 31	-2.15	s.e.	0.78

Tables of means

Variate: Number_of_channels_on_2_5_slope

Grand mean 3.60

Treatment	Bahama grass	Control	Jute mat	Vetevar grass
	3.66	6.15	0.00	4.60

Standard errors of differences of means

Table	Treatment
rep.	10
d.f.	36
s.e.d.	0.366

Least significant differences of means (5% level)

Table	Treatment
rep.	10
d.f.	36
l.s.d.	0.742

D3 Analysis of variance for depth of channels on slope gradient 3:1

Variate: Mean depth of channels

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	50.7001	16.9000	40.31	<.001
Residual	36	15.0931	0.4193		
Total	39	65.7932			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

units 31	-1.44	s.e.	0.61

Tables of means

Variate: Mean_depth_of_channels

Grand mean 1.80

Treatment	Bahama grass	Control	Jute mat	Vetevar grass
	1.87	3.22	0.07	2.04

Standard errors of differences of means

Table	Treatment
rep.	10
d.f.	36
s.e.d.	0.290

Least significant differences of means (5% level)

Table	Treatment
rep.	10
d.f.	36
l.s.d.	0.587

D4 Analysis of variance for depth of channels on slope gradient 2.5:1

Variate: Mean_depth_of_channels

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	41.0797	13.6932	40.55	<.001
Residual	36	12.1554	0.3377		
Total	39	53.2352			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

units 11	-1.237	s.e.	0.551
units 31	-1.775	s.e.	0.551

Tables of means

Variate: Mean_depth_of_channels

Grand mean 1.581

Treatment	Bahama grass	Control	Jute mat	Vetevar grass
	1.607	2.805	0.000	1.912

Standard errors of differences of means

Table	Treatment
rep.	10
d.f.	36
s.e.d.	0.2599

Least significant differences of means (5% level)

Table	Treatment
rep.	10
d.f.	36
l.s.d.	0.5270

D5 Analysis of variance for weight of eroded materials on slope gradient 3:1

Variate: Eroded materials

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	492.04	164.01	12.99	<.001
Residual	36	454.65	12.63		
Total	39	946.69			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

units 40	-9.90	s.e.	3.37

Tables of means

Variate: Eroded materials

Grand mean 5.02

Treatment	Bahama grass	Control	Jute mat	Vetevar grass
	4.85	10.37	0.55	4.29

Standard errors of differences of means

Table	Treatment
rep.	10
d.f.	36
s.e.d.	1.589

Least significant differences of means (5% level)

Table	Treatment
rep.	10
d.f.	36
l.s.d.	3.223

D6 Analysis of variance for weight of eroded materials on slope gradient 2.5:1

Variate: Eroded_materials_2_5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	286.594	95.531	12.41	<.001
Residual	36	277.227	7.701		
Total	39	563.821			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

units 40	-7.49	s.e.	2.63

Tables of means

Variate: Eroded_materials_2_5

Grand mean 3.74

Treatment	Bahama grass	Control	Jute mat	Vetevar grass
	3.35	7.86	0.36	3.40

Standard errors of differences of means

Table	Treatment
rep.	10
d.f.	36
s.e.d.	1.241

Least significant differences of means (5% level)

Table	Treatment
rep.	10
d.f.	36
l.s.d.	2.517

D7 Analysis of variance for potassium content in soils after the trials

Variate: K_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	14550.924	4850.308	1212.55	<.001
Residual	8	32.001	4.000		
Total	11	14582.924			

Information summary

All terms orthogonal, none aliased.

Tables of means

Variate: K_%

Grand mean 134.75

Treatment	Bahama	Control	Vetevar	York
	150.65	87.04	120.52	180.78

Standard errors of differences of means

Table	Treatment
rep.	3
d.f.	8
s.e.d.	1.633

Least significant differences of means (5% level)

Table	Treatment
rep.	3
d.f.	8
l.s.d.	3.766

D8 Analysis of variance for nitrogen content in soils after the trials

Variate: N_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	0.03662	0.01221	0.23	0.872
Residual	8	0.42187	0.05273		
Total	11	0.45849			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

units 10 0.530 s.e. 0.187

Tables of means

Variate: N_%

Grand mean 0.281

Treatment	Bahama	Control	Vetevar	York
	0.250	0.370	0.223	0.280

Standard errors of differences of means

Table	Treatment
rep.	3
d.f.	8
s.e.d.	0.1875

Least significant differences of means (5% level)

Table	Treatment
rep.	3
d.f.	8
l.s.d.	0.4324

Analysis of variance for phosphorus content in soils after the trials

Variate: P_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	394.230	131.410	97.82	<.001
Residual	8	10.747	1.343		
Total	11	404.977			

Information summary

All terms orthogonal, none aliased.

Message: the following units have large residuals.

units 5	-2.00	s.e.	0.95
units 6	2.01	s.e.	0.95

Tables of means

Variate: P_%

Grand mean 11.97

Treatment	Bahama	Control	Vetevar	York
	15.39	2.55	12.43	17.52

Standard errors of differences of means

Table	Treatment
rep.	3
d.f.	8
s.e.d.	0.946

Least significant differences of means (5% level)

Table	Treatment
rep.	3
d.f.	8
l.s.d.	2.182

D10 Analysis of variance for organic matter content in soils after the trials

Variate: OM_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	3	6.5006250	2.1668750	4127.38	<.001
Residual	8	0.0042000	0.0005250		
Total	11	6.5048250			

Information summary

All terms orthogonal, none aliased.

Tables of means

Variate: OM_%

Grand mean 3.0525

Treatment	Bahama	Control	Vetevar	York
	3.4700	1.8300	3.1600	3.7500

Standard errors of differences of means

Table	Treatment
rep.	3
d.f.	8
s.e.d.	0.01871

Least significant differences of means (5% level)

Table	Treatment
rep.	3
d.f.	8
l.s.d.	0.04314