STRENGTH PROPERTIES OF LOCALLY CONSTRUCTED RICE BUNDS IN THE ADANSI NORTH DISTRICT OF GHANA

By

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DECLARATION

I hereby declare that this project is my own work towards obtaining an MPhil and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

The rice industry in Ghana faces challenges of low productivity, low yield and poor grain quality, resulting in overwhelming import dependence. Rice can be cultivated all year round with bund and irrigation. Also, land originally not suitable for rice cultivation can be used when bund is considered. Successive Governments over the years launch series of flagship programs which are aimed at reducing rice imports, poverty alleviation and employment creation which many have failed. Though bunds are widely used in many countries and other parts of Ghana, the system is relatively new in the Adansi North District of the Ashanti region of Ghana.

The purpose of this study is to examine the durability and soil strength properties of rice bund constructed by local farmers. Three farmer's fields KB, FB and PB were studied to ascertain their strength properties and their durability. Four bunds were constructed on a research plot labeled RB1, RB2, RB3 and RB4. RB1 and RB4 where compacted while RB2 and RB3 where uncompacted. Laboratory test indicates that soils of RB1, RB2 and KB where classified as clay of intermediate plasticity which proved stronger than RB3, RB4, FB and PB which were clay of low plasticity. After 40 days of bund measurements, farmer field bunds reduced in height between 36 to 42 %. Research field measured that uncompacted bunds reduced in height by 34 and 40 % while compacted bunds reduced by 6 % or less.

Bund compaction increases operational cost and reduces profit in the first season however, increases profit drastically in the second season. It is therefore concluded that uncompacted bunds erode faster than compacted bunds, compaction increases soil strength and bund strength is determined by soil type and level of compaction.

TABLE OF CONTENT

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

FB- Fumso Bund

JICA- Japan International Cooperation Agency

JIRCAS- Japan International Research Center for Agricultural Sciences

KB- Kusa Bund

KNUST- Kwame Nkrumah University of science and Technology

LL- Liquid Limit

MDD- Maximum Dry Density

MoFA- Ministry of Food and Agriculture

OMC- Optimum Moisture Content

PB- Pipiiso Bund

PI- Plasticity Index

PL- Plastic Limit

RB1- Research Bund 1

RB2- Research Bund 2

RB3- Research Bund 3

RB4- Research Bund 4

SRID- Statistics, Research and Information Directorate

USCS- Unified Soil Classification System

USDA- United State Department of Agriculture

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Before the 20th century cassava, plantain, yam, cocoyam, millet, maize and sorghum were the staple food crops eaten in Ghana with rice dishes enjoyed occasionally, especially on festive seasons. Today rice is virtually consumed on daily bases and has become one of the most important food commodity in the Ghanaian diet and cuisine, only second to maize. The interest for rice increases every year. From 1999 to 2008 alone, the consumption of rice per capita in Ghana increased from 17 kg to 38 kg and was estimated to increase to 63 kg by 2018 due to rapid population growth and urbanization (MoFA, 2009); huge prospects therefore exist in the rice production industry.

The rice industry faces low production, low yield and poor grain quality, resulting in overwhelming import dependence. It is therefore expected that rice imports are to be between 6.5 and 10.1 million tonnes in 2020 (lançon and erenstein, 2002). Rice production in Ghana can possibly take care of local and some global demands if good strategy is implemented.

Paddy rice cultivation success is heavily dependent on water availability during the entire growth period. Bunds are constructed by rice farmers to maintain the required quantity of water needed for production; these bunds trap water and retain them for rice production. Bunding has increased production in many countries and is believed to be the way to reducing high importation of the commodity in the country. Rice can be cultivated all year round with bunds and irrigation. Also, land originally not suitable for rice cultivation can be used when bunds are utilized. Bund construction however, is laborious, initial cost of construction and maintenance is high and could be unattractive to poor subsistent rice farmers. The bund technique itself is an imported knowledge and therefore needs special skills to construct and maintain well.

Rice bund's ability to retain enough water during production, have minimal leakage through the bund walls, limit overflow and runoff, and withstand failure is critical considerations in construction. Bunds should be solid enough to avoid recurrent costs from reconstruction and maintenance but affordable enough for local farmers.

1.2 PROBLEM STATEMENT

Bund construction for rice cultivation is a technique introduced by Japan International Cooperation Agency (JICA) in the Adansi North district with technical support from the Ministry of Food and Agriculture (MoFA). This technique is new and never seen in the district before. It takes extra effort and cost to construct them. Before implementation of the rice bund system, farmers had challenges with the traditional way of rice cultivation where land is prepared and seed rice either planted in rows or broadcasted. The challenges in this system is enormous including difficulty in weed control, low germination rate, pest and disease infestation, water shortage at critical times of the growth cycle and yield loss due to these challenges and more.

Bunds were said to be the solution to many of these challenges and that yield could greatly increase when the rice bund system was adopted. In the 2017 cropping season, three demonstration fields were established by MoFA and JICA at Kusa, Pipiiso and Fumso to demonstrate the new technology. After the first year of production yield indeed increased; however, there were many challenges that caused farmers not to adopt the technology. Some major concerns included; high cost of construction, its labour-intensiveness, technical assistance needed before construction and land ownership and tenure system limitations. In addition to these challenges, farmers were bedeviled with the fact that bunds needed to be reconstructed only a season after construction since most of the bunds have been heavily eroded. This study seeks to examine why most of these bunds failed and suggest a possible solution to the problem.

1.3 JUSTIFICATION OF THE STUDY

Successive Governments over the years launch series of flagship programs which are aimed at reducing rice import rates, poverty alleviation and employment creation which many have failed. Failure of such flagship programs may also be attributed to low investment in technological knowledge and research.

“Planting for Food and Jobs” is the latest of such flagship programmes, launched in 2017 to reduce the influx of imported food into the Ghanaian market while tackling youth unemployment. The government provides inputs in the form of seed rice and fertilizer to farmers at subsidized rates. However, the success of the rice production sector by providing fertilizer and seeds only may not provide the entire solution in achieving self-sufficiency in rice production. Irrigation and mechanized agriculture is the surest way to attaining greater heights in food security. However, uncertainty in the weather conditions poses a serious challenge in the agricultural sector in Ghana.

Bund and irrigation is the insurance package to weather uncertainty and failure. Though bunds are widely used in many countries and other parts of Ghana, the system is relatively new in the Adansi North District. There has not been any research done on the strength properties of bunds constructed by local farmers in the Adansi North District. This research will help rice farmers make informed decisions on how to improve the strength properties of bund material which will eventually lead to longevity of bund thereby saving cost of continues reconstruction.

1.4 OBJECTIVES OF THE STUDY

The purpose of this study is to examine the durability and soil strength properties of rice bund constructed by local farmers.

Specifically, the study seeks;

- To determine the strength properties of rice bunds constructed by local farmers

- To estimate the rate of erosion of constructed bunds
- To determine the durability of suitable constructed bunds using local materials
- To evaluate the cost implications of the various bund construction types.

1.5 RESEARCH QUESTIONS

The research will be looking to solve the following questions

1. What are the strength properties of bunds construction by local farmers?
2. What is the rate of erosion on bunds constructed by farmers?
3. How durable are the bunds constructed from local materials?
4. What are the cost implications of the different types of bund construction?

1.6 ORGANIZATION OF THE TEXT

Chapter one: provides the introduction of a study background, problem statement, justification and significance of the study, objectives, research questions and text organization of text.

Chapter two: examines relevant literature related to the subject. These are the views of various authors related to the construction of rice bunds and its strength properties. The areas considered shall include; land clearing, bund construction, leveling, land puddling, bund compaction, strength properties of bunds materials, advantages and disadvantages of bund construction and compaction.

Chapter three: entails the research methodology used in the study. It includes the research design, data collection and analysis.

Chapter four: presents the results, analysis and discussions.

Chapter five: gives conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 RICE AS A CROP PLANT

Rice (*Oryza sativa*) is a plant belonging to the family of grasses, Gramineae (Poaceae). It is a major food crop of the world and features regularly in the food the menu of about half the world's population. Rice grows well on a wide range of soils and water systems: irrigated, lowland rainfed, upland and flood prone. Different rice varieties grow under specific conditions and areas ranging from deeply flooded to flat or hilly or non-terraced slopes. Hence, rice can be defined as semi-aquatic, annual grass plant. Rice provides 20 % of the per capita energy, and 13 % of the protein consumed worldwide (Juliano, 1994).

Depending on variety and environmental conditions, rice crop may take approximately 3 to 6 months to attain full maturity. Rice undergoes three phases of growth generally: vegetative, reproductive and ripening. Rice varieties may as well be grouped into two groups: short - lived varieties that mature in 105–120 days and long-lived varieties that mature within 150 days. A 120 day variety spends about 60 days in the vegetative phase, 30 days in the reproductive phase and 30 days in the ripening phase when planted in a tropical environment, (Chiang et al, 2017)

2.2 GLOBAL RICE SUPPLY AND DEMAND ESTIMATIONS

Rice production is predicted to grow worldwide by 1.4 % in 2018 to 511.4 million tonnes. The expansion is estimated to be area-driven and concentrated in Asia, where more stable weather and attractive returns of producers could lift output further. Production is also expected to recover in Africa and the USA, while tight producer margins are likely to depress output elsewhere in the world (FAO, 2018).

World rice trade is anticipated to fall marginally (0.8 %) beneath the 2017 record to 47.8 million tonnes, obviously import cuts by countries in Africa and Latin America and the Caribbean are to a great extent deliveries to other regions. Asia's import demands look set to stay solid in 2018, in the midst of endeavors by nations as Indonesia and the Philippines to shore up reserves and contain increment in local prices (FAO, 2018).

As food consumption continues to increase, world rice production will rise by 1 % in 2018/19 to 509.5 million tons. This level would miss the mark concerning the forecast volume figure for 2018, involving a likely 1.5 % expansion in worldwide rice remainders in 2018/19 to 173.7 million tons. China would again contribute much to this stocks development, in spite of the fact that reserves are likewise observed ascending in India, Indonesia, the Philippines and the United States. The strong demand for indica rice in Asia, combined with stronger Japonica and fragrant stocks, has prolonged the upward trend in international rice prices that began in late 2016 (FAO, 2018).

2.3 RICE CULTIVATION: THE GHANA SITUATION

Rice producers in Ghana are classified based on their agro ecologies to be specific: rainfed lowland rice production covering 78 % of the arable area, irrigated land covering 16 %, and 6 % of production covering rain fed upland system. 118,000 ha of land are cropped to rice per year averagely (JICA, 2007). Ghana's average yield is 2790 kg per hectare (Factfish, 2017). In 2016, annual rice area planted was 236,000 ha, representing a growth rate of 4.70 % and annual production of 688,000 Mt (MOFA- SRID, 2017). Below is a summary of food balance sheet for milled rice production.

Table 2. 1: Food balance sheet of 2016/17 production season for milled rice

Gross Biological Production	**474,499**	**Mt**
Available Total Domestic Production Available For Human Consumption	412,814	Mt
Total Import	697,391	Mt
Carry Over Stock	100,812	Mt
Total Export	1,428	Mt
Total Supply Of Commodity	1,123,975	Mt
Per Capita Consumption	35	kg/annum
Estimated Net Consumption	1,003,346	Mt
Closing Stock	112,398	Mt
Total Needs	1,115,743	Mt
Net Deficit/ Surplus	8,232	Mt

Source: (MoFA-SRID, 2017).

According to the Directorate of the Crop Services Division of MoFA, the country produced 443,000 Mt of rice in 2015, which fell short of the local consumption by 300,000 Mt. National rice consumption stands at 700,000 Mt a year. At the same time 2014, the country spent $290 million importing 414,000 Mt of rice to meet local consumption needs (Ghanaweb, 2017). According to the Food Fortification Initiative, rice and wheat are Ghana's two top imported food commodities; in 2016 imports reached 0.6 million Mt.

2.4 CHALLENGES IN RICE CULTIVATION

In a research conducted by Muhammad et al. (2013), on the challenges in rice cultivation, the following challenges were highlighted as problems faced by rice growers;

i. Production related problems faced by rice growers include: high price of fertilizer and counterfeiting issues, inadequate water supply, high input cost, high rent cost over borrowed agricultural machinery, inadequate extension services and personnel and lack of credit facilities.

ii. Crop protection related challenges faced by rice growers include; costly pesticide/herbicides/weedicides and ineffective fungicide

iii. Marketing related problems faced by rice growers include; poor transportation, storage difficulties, low price produce pricing and inadequate market knowledge and demands.

Many of these challenges are similar to those in the Ghanaian context. There are different perceptions showing that persistent development of irrigated rice, where the soil is kept up in anaerobic conditions for delayed periods, results in clutters which restricts yield (Pulver and Nguyen 1999).

Other challenges in rice production are; low returns from rice production and declining yield growth as a result of pressure from abiotic stresses for example salinity, high temperature and law soil water content.

2.5 LAND PREPARATION FOR RICE FARMING

Appropriate land preparation for rice farming is very vital determinant of rice yield in inland-valley and marshy rice production systems in Ghana. Timely land preparation is very necessary to avoid further delays in crop establishment and to enable decomposition of organic materials. Land preparation for rice farming has many processes which include; clearing, Ploughing, bund construction, Puddling and leveling. These processes help the rice farmer to ensure the land is appropriately worked on before rice is cultivated. (Defoer et al., 2009)

2.5.1 Clearing and Weeding the Field

Clearing and weeding involves cutting the weed and stacking them on the bunds, or spreading them out over the field (Wopereis et al., 2009). All weeds and unwanted plants should be gotten rid of with the help of a cutlass or a hoe before embarking on the other land preparation processes. If possible, all weeded weeds and other plants should be burnt to ensure the land is fully cleared.

2.5.2 Ploughing

Ploughing is a very important factor to consider when preparing a rice field for rice farming. This helps to till the land and also control weed growth. In the Adansi North District of the Ashanti Region, most farmers do not consider ploughing before cultivating rice. This is as result of the lack of machines necessary for land preparation and labour cost. Proper land preparation facilitates water, nutrient, and pest management. Soil is ploughed in a saturated or flooded condition using a hand tractor or mini tractor during wetland ploughing, and in dryland ploughing, soil is ploughed in a dry condition mostly with a large four-wheel tractor mounted with rotary or multiple disc plough, disc harrow and other implements (Brouwer et al., 1988).

Most farmers in the Adansi North District of the Ashanti Region lack these machines and therefore, the few who plough their land use man power. Tools like shovels and hoes are used in these areas during ploughing and making farmers incur much cost during land preparation.

2.6 BUND CONSTRUCTION

Bunds are generally applied to sloping fields in order to reduce water runoff and erosion and may likewise be useful for seriously degraded soils (Ruffino, 2009). Bunds are small earth embankments used to retain and manage irrigated water within a basin. They are sometimes called ridges, dykes or levees. The height of the bund is determined by the irrigation depth and the freeboard. The width of the bunds should be such that leakage will be minimal. Contour bunds must be developed on even ground, though semi-round bunds can likewise be connected to uneven territory. Design and construction are simple and should be possible without much particular information. Stone bunds are by and large more safe and need less upkeep. Building stone bunds can be expensive if stone resources are limited. It is therefore advisable to build earthen bunds in such areas.

For the purposes of this study the cross section of all bunds was approximated to a trapezoidal section. The base width of a rice bund constructed is approximately 60 to 80 cm with a height of 60 to 90 cm. Brouwer, et al. (1988) recommends that the "settled height of a constructed bund should be 40 to 50 cm". Shape and size of rice bunds vary and may be determined by the land slope, and soil type. The bund may be enclosed to a size ranging from 10 to 10,000 m^2 forming rectangular, square or irregular shape.

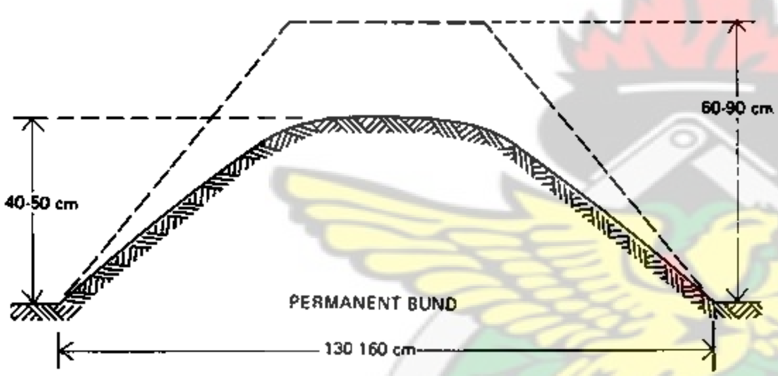


Figure 2. 1: Shape and dimensions of permanent bunds

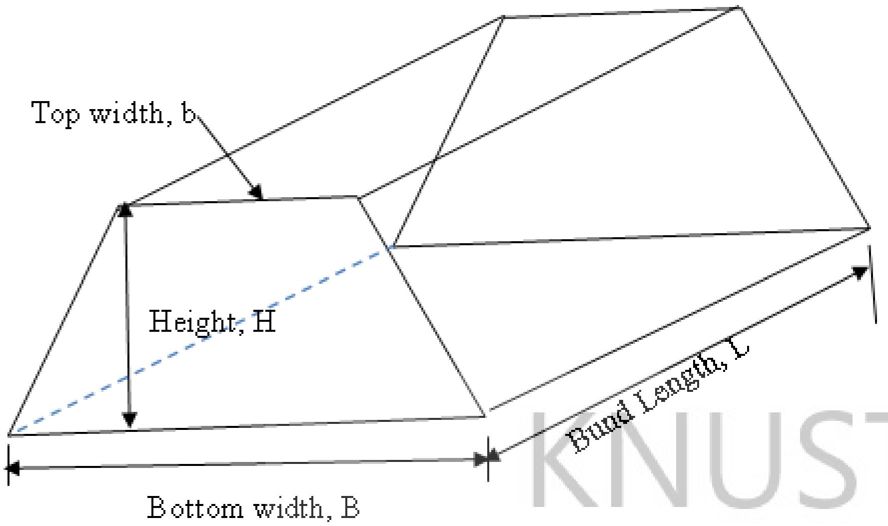


Figure 2. 2: Typical trapezoidal bund section

- Height of the bund is H, cm
- Base width of the bund is B, cm
- Top width of the bund is b, cm
- Length of bund is L, cm
- Area of the bund A, cm^2
- Volume of bund V, cm^3

Cross sectional area (A) of the Trapezoidal, bund is given as:

$$A = \left(\frac{B+b}{2}\right) \times H \quad \text{......} 2.1$$

Volume of bund material (V) is given as

$$V = A \times L \quad \text{......} 2.2$$

2.6.1 Causes of Bund Failures

1. Cracking as a result of movements like the natural settling of a bund (ASDSO, 2018): Bunds made with soils with high clay content are likely to develop cracks when compacted. This is because clay expands when introduced to heat and contracts when cooled. Weathering as a result of the heat of the sun causes expansion in bunds and forces out air trapped in the bunds and as a result may aid in the development of cracks on the bunds. This is a natural occurrence and therefore adequate maintenance is very necessary to keep the bunds in shape
2. Inadequate maintenance and upkeep: Farmers who do not maintain their bunds regularly by patching up worn off parts and repairing cracks end up destroying their bunds after a short while. (ASDSO, 2018)
3. Piping: Piping is when leakage through a bund is not legitimately sifted and soil particles proceed to advance and shape sinking openings in the bund. Seepage often occurs as a result of cracks in bunds constructed, bund appurtenances, and bund foundations (ASDSO, 2018).

2.7 SOIL PUDDLING

Puddling of some heavy-textured soils prompts an expansion in absolute soil volume and a reduction in mass thickness. Those soils, in which the mud portion scatters when the soil is worked wet, form an arbitrary gel-like structure of the soil particles.

As water becomes scarce, the delicate puddle soil will have a tendency to 'solidify'. Puddling causes fractional scattering of mud particles, which discharges adequate clay to fill a large number of the pores between the structural units (Indrajit, n.d.).

The soil surface layer is made thick and compact. In the long run, the porosity of this surface layer is diminished by the penetration of muddy surface materials. At that point the essential passageway channels to deep soil are shut. The soil profile material can never again ingest air freely (Indrajit, n.d.).

According to an Article shared by Indrajit (n.d.); wet system of rice cultivation needs puddled condition, which involves ploughing of land in moist condition. The lands are ploughed and re-ploughed, with planking after each ploughing, to bring the soil to a fine ‘puddle’ condition. The whole of the upper layer of the soil should be in this smooth soft muddy condition, permitting the roots to ramify freely in the medium without being obstructed by hard layers.

In the puddled soil, water is held in the field. For rice crop, it is imperative to keep up standing water in the field as rice is a semi-aquatic crop. Puddling helps in the maintenance of water, so that rice can be developed effectively on (Indrajit, n.d.)

2.7.1 Advantages of Puddling

Some advantages of puddling include:

1. Easy in transplanting rice due to soft mud. Plants are pushed into the mud with thumb and forefinger.
2. Increase in availability of nutrients, especially phosphorus, iron and manganese.
3. Weeds are controlled by puddling. Buried weeds in the mud do not come out easily.
4. Less power required in tillage.
5. Loss of water by percolation is reduced because of structure less soil and the formation of tillage pan (Indrajit, n.d.)

2.7.2 Disadvantages of Puddling:

Some disadvantages of puddling are as follows:

1. Soil structure is destroyed.
2. In paddy field, other upland crops may not grow well due to structure less soil and presence of tillage pan.
3. Root development is poor.
4. A large quantity of water is required for puddling the soil.
5. Because of absence of air in the paddy field, toxic substances like hydrogen sulphide, ferrous oxide etc., are formed.
6. Loss of nitrogen (de-nitrification) is also occurred in water- logged paddy field (Indrajit, n.d.)

2.8 LAND LEVELING

Land leveling is another important factor to consider when preparing a field for rice production. Land leveling enhances water preservation on dryland.

According to FAO (1989), land leveling is used in surface irrigation, such as basin and furrow irrigation. Which requires:

- preparing the irrigation plot in a way that no high or potentially low spots restrict the smooth circulation of irrigated water on the plot, and
- ensure the optimal slope for water movement over a field when irrigated.

Leveling results in more efficient irrigation and, if fertigation and chemigation are applied, in more proficient utilization of fertilizers and pesticides. In fields of uneven grounds, high areas may not be covered by irrigation water, and the dissolved nutrients and/or pesticides might percolate unused deep into the soil away from the reach of roots. In case of low areas, water and the dissolved nutrients and chemicals may accumulate and create zones of water logging and nutrient or pesticide accumulation. This may aggravate soil air circulation and water uptake by crops. In either case, the uniformity of the crop cover is disturbed and yields might decrease (FAO, 1989)

2.8.1 Effects and Benefits of Land Levelling

Effective land leveling lessens the work in crop establishment and management, and builds the yield and quality. Research has shown a large increase in rice yield due to good field leveling (IRRI, 2013).

The fundamental advantages of leveling includes; even irrigation water coverage on the field, better crop establishment, even crop stand and maturation, reduction in weeds and decrease in labour requirement for weeding, farming area increase, reduction in farm operation times, the possibility of changing from planting and transplanting to direct seeding which results in reduced labour, and average yield increase (IRRI, 2013).

2.9 WATER MANAGEMENT

Lowland rice cultivation requires a considerable amount of water availability. It takes about 1,432 liters of water to create 1 kg of rice in a flooded swamp production system. Total seasonal water contribution to rice fields differs from as little as 400 mm in heavy clay soils with shallow groundwater tables to in excess of 2000 mm in coarse-finished (sandy or loamy) soils with profound groundwater tables (Bouman et al, 2004).

Also 1300 to 1500 mm of water is required for flooded rice in Asia (Bouman et al, 2004). Irrigated rice needs approximately 34 to 43 % of the total world's irrigation water, or about 24 to30 % of the developed fresh water resources of the entire world.

2.10 SOIL STRENGTH PROPERTIES

In determining soil strength properties, standard classification test should be performed on all soil samples in the laboratory. These tests may include bulk density, moisture content and Atterberg limits. The above tests give information to determine the usability of the soil for earthwork on the project. Strength parameters including cohesion and frictional angle for undrained soil are necessary.

2.10.1 Soil Compaction

Soil compaction is defined as the volume change produced by momentary load application caused by rolling, tamping or vibration (Huang et al., 2011). There is a significant removal of air without any major change in mass of water in the entire soil mass. Soil compaction results in the following advantages:

- Reducing or preventing harmful soil settlement
- Control of unwanted volume changes caused by frost, swelling and shrinkage.

In measuring soil compaction, the following can give an indication of the level of soil compaction

- Dry bulk density
- Shear strength
- Penetration resistance
- Reduction in soil permeability (Huang et al., 2011)

Soil compaction can be measured in the laboratory using; uniaxial confined compression test in an oedometer, triaxial compression cell or direct shear test.

2.10.2 Triaxial Test

Triaxial test is one of the most versatile and widely performed geotechnical laboratory tests to determine the shear strength and stiffness of soil and rock for geotechnical use. It has many advantages over simpler procedures of testing such as direct shear tests, advantages include the ability to control specimen drainage and take pore water pressure measurements. Primary parameters obtained from the triaxial test may include the angle of internal soil friction φ, cohesion c, and undrained shear strength cu, although other parameters such as the shear stiffness G, compression index Cc, and permeability k may also be determined (GDS, 2013). There are three primary triaxial tests are performed in the laboratory, these are: Unconsolidated Undrained test (UU), Consolidated Undrained test (CU) and Consolidated drained test (CD) (GDS, 2013).

2.10.2.1 The Unconsolidated Undrained (UU) Test

This test is completed on a soil sample which has just been consolidated to some stress in the field and laboratory. The strategy in this test includes the utilization of a limiting weight (σ_3 or σ_c) under undrained conditions taken after by the shearing of the soil under undrained conditions (Strength of Soils and Rocks, n.d.).

The stress-strain curve of soil materials is generated out of the triaxial test and the Mohr coulomb for the soil material determined to find the cohesion and friction angle. Frictional angle or angle of internal soil friction is a proportion of the capacity of a unit of rock or soil to withstand a shear pressure. It is the angle (φ), estimated between the normal force (N) and resultant force (R), that is achieved when failure just happens in light of a shearing stress (S). Its tangent (S/N) is the coefficient of sliding friction. Its values are determined experimentally (Encyclopedia, n.d.).

2.10.3 Atterberg Limits

In the mid twentieth century, Atterberg proposed the cutoff points of consistency for agricultural purposes to get a reasonable idea of the scope of water substance of a soil in the plastic state (Atterberg, 1911). These points of confinement of consistency, in particular plastic cutoff and liquid limit, are outstanding as soil Atterberg limits. Plastic limit is the limit between semi-strong and plastic state, and fluid farthest point isolates plastic state from fluid state (Campbell, 2001).

2.10.4 Bulk Density

Soil bulk density is the weight of dry soil divided by the total soil volume. It can be said to be the heaviness of soil in a given volume. Soils with bulk density of 1.6 g/cm3 have a tendency to limit root development and mass thickness increments with compaction. Bulk density increases with compaction and tends to increase with depth. Sandy soils are more inclined to high bulk density. Therefore, bulk density can be utilized to figure soil properties per unit area (Brown k. and Wherrett A., 2002.).

Using the Core-cutter method, bulk density (γ_b) is then computed as follows:

$$\gamma_b = \frac{W_S - W_c}{V_c} \qquad \text{2.3}$$

Where,

W_s $is\ the\ weight\ of\ the\ core - cutter\ plus\ wet\ soil, g$

W_c $is\ the\ weight\ of\ the\ core - cutter, g$

V_c $is\ the\ volume\ of\ the\ core - cutter, cm^3$

γ_b $is\ bulk\ density -\ g/cm^3$

2.10.5 Particle Size Analysis

Features of particle size analysis are the destruction or dispersion of soil aggregates into discrete units by chemical, mechanical or ultrasonic means and the separation of particles according to size limits by such means as sieving and separation, as well as other methods (Gee et al., 2002).

2.11 EROSION

Surface erosion and subsurface piping are common in sand, nonplastic silt and dispersive clays. The measure of disintegration that happens along a slope is a factor of soil type, precipitation power, slope angle, length of slope, and vegetation cover. Soil erosion is widely noticeable form of soil degradation. Water erosion globally affected 1094 million ha land area, of which 751 million ha is heavily affected and 549 million ha by wind erosion, of which 296 million ha is heavily affected (Lal, 2003). Erosion rate is determined by the weight of eroded material per unit amount of percolation over the period. Computation of erosion was done as below:

$$Erosion\ rate = \frac{Weight\ of\ eroded\ bund\ material\ in\ the\ period, (M)}{Total\ rainfall\ in\ the\ same\ period, (P)} \qquad \text{.......................... 2.4}$$

If,

- Cross sectional area of the bund at the beginning of a period is A_1, cm^2
- Cross sectional area of the bund at the end of the period is A_2, cm^2
- Length of bund is L, cm
- The bulk density of bund material is $\gamma_b,\ g/cm^3$
- Total rainfall within the period (P) is measured in mm

Volume (V) of the bund is given as:

- $V = cross\ sectional\ area\ \times Length = A \times L$ ……………………………………..2.5

Volume of bund material at the beginning of a period V_1 (cm^3) is

- $V_1 = A_1 \times L$………………………………………………………………………..2.6

Volume of bund material at the end of a period V_2 (cm^3) is

- $V_2 = A_2 \times L$…………………………………………..………………………2.7

Volume of bund material eroded V_{erod} (cm^3)

- $V_{erod} = V_1 - V_2$……………………………………………………………..………2.8

Weight of eroded bund material at the end of the period is M, g

- $M = \gamma_b \times$
  V_{erod}………………………………………………………………………………........2.9

(MOFA, KNUST, JIRCAS, 2017)

2.12 ECONOMIC ANALYSIS OF RICE CULTIVATION

The customary land tenure system determines the size of land available for rice cultivation in Ghana. Land for cultivation is acquired through inheritance, gift, purchase or rent. It is extremely difficult for farmers to increase the size of their farm holding due to hindrances by the existing land tenure arrangements in the country.

2.12.1 Source of Inputs (Seeds and Fertilizer)

Rice farmers today are privileged to purchase seeds and fertilizer from the Ministry of Food and Agriculture under the government’s flagship program “planting for food and jobs”. However, many farmers process their own seeds from their previous harvest. Asare (2000) in a study conducted in the northern region of Ghana, states that 62 % of farmers process their seeds from the previous harvest as 10

% purchase from market, extension agents and MOFA. The remaning 28 % get their seeds from different sources to be specific; irrigation schemes and close-by nations. Once more, majority of farmers who used fertilizer bought them from the open market; a couple also obtained fertilizer from neighboring farmer (Asare, 2000).

2.12.2 Types of Labour

In the northern region as reported by Asare (2000), 56 % of farmers who utilize family labour, 24% utilize commercial labour and 20 % utilized hired labour. Other farmers utilized family labour ordinarily for activities ivcluding, planting, weed control, harvesting and processing (Asare, 2000). hired labour is generally utilized in land preparations while commercial labour is utilized in collecting rice from field to the storage facility.

2.12.3 Types of Rice Varieties Cultivated

In 2017, six new rice varieties were released in Ghana. The locally-developed rice varies are AGRA-CRI-LOL-2-27, AGRA-CRI-LOL-1-7, CRI-1-11-15-5 and CRI-1-11-15-21. Their release names are; CRI-Dartey, CRI-Emopa, CRI-Mpuntuo, CRI-Kantinka, CRI-Aunty Jane and CRI-Oboafo. This brings the aggregate number of rice varieties developed and released in Ghana with help from AGRA to thirteen (AGRA, 2017).

2.12.4 Source of Credit

Agriculture financing is vital part in expanding the total overall yield. There are no credit facilities known currently supporting rice farming in the Adansi North District apart from the PFJ programme which provides some level of support in terms of subsidy on inputs.

2.12.5 Marketing of Products

Demand for rice is high in Ghana, as the country imports 70 % of the entire rice consumed locally. There should be available market for locally produced rice. However, patronage of domestic rice is relatively low compared with imported rice. Attributable to poor quality of produce among other factors accounting to the shortfall (JAKF, 2015).

2.12.6 Profitability of Rice Farming

According to Asare (2000), only 46 % of indigenous rice varieties rice farmers made profits as 54 % incurred loss. These farmers made profits ranging from 364,500 to 9,000 Cedis, comparatively those who made losses also had their ranging from 343,000 to 63,500 Cedis. Severe weather conditions could be linked to the high percentage of losses which intern reduced the available water for the plant's growth and development. Nearly 78 % of farmers cultivating improved rice varieties made gains against 22 % who incurred losses. They also made gains significantly ranging between 1,888,000 to 6,500 Cedis, while the loser lost between 4,000 to 587,600 Cedis. Many farmers who plant improved rice variety made significant gains due to high investments made in cultivation in the season as compared to farmers who cultivated indigenous rice varieties. However, the other losers who made a population of nearly 22 % were mainly attributed to improper management, poor soil type and lack of technical assistance. The cost of production averagely per hectare of cultivated land was 612,000 cedis for improved variety and 280,400 Cedis for indigenous variety per growing season (Asare, 2000).

Averagely yield was estimated at twenty bags for improved variety and ten bags for indigenous variety per hectare. Averagely a bag of rice cost 40,000 Cedis for all variety types since there is no price variations for the various rice varieties (Asare, 2000). Average returns and net income for the improved variety was between 800,000 and 187,500 Cedis while that of the indigenous variety was between

360,000 and 79,600 Cedis. Relatively, from the studies made by Asare (2000) indicates that, of cost and returns, improved rice variety cultivation is more profitable as 78 % of farmers made profit. Indigenous rice varieties were considered to be relatively less profitable, showing 54 % loss and 46 % profit (Asare, 2000).

2.13 DEFINITION OF TERMS

Bund: a raised area of land around a rice field or a reservoir that is designed to keep water in

Clay: A natural earthy material that is plastic when wet, consisting essentially of hydrated aluminum silicates: used for the production of bricks, pottery etc.

Compacted bund: applied stress on a raised area of land around a rice field to cause densification as air in order to make it strong

Compaction: soil compaction is the process in which a stress applied to a soil causes densification as air is displaced from the pores between the soil grains

Consolidation: the action or process of making something stronger or more solid

Erosion: the process of eroding or being eroded by wind, water, or other natural agents

Sand: the more or less fine debris of rocks, consisting of small, loose grains, often of quartz

Shear strength: Shear stresses are forces that are applied tangentially along a face of the soil. It is measured in Newton per meter squared

Silt: earthy matter, fine sand, or the like carried by moving or running water and deposited as a sediment

Trapezoidal: a quadrilateral plane figure having two parallel and two nonparallel sides

Uncompacted bund: bunds that are not closely or firmly packed together.

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY AREA

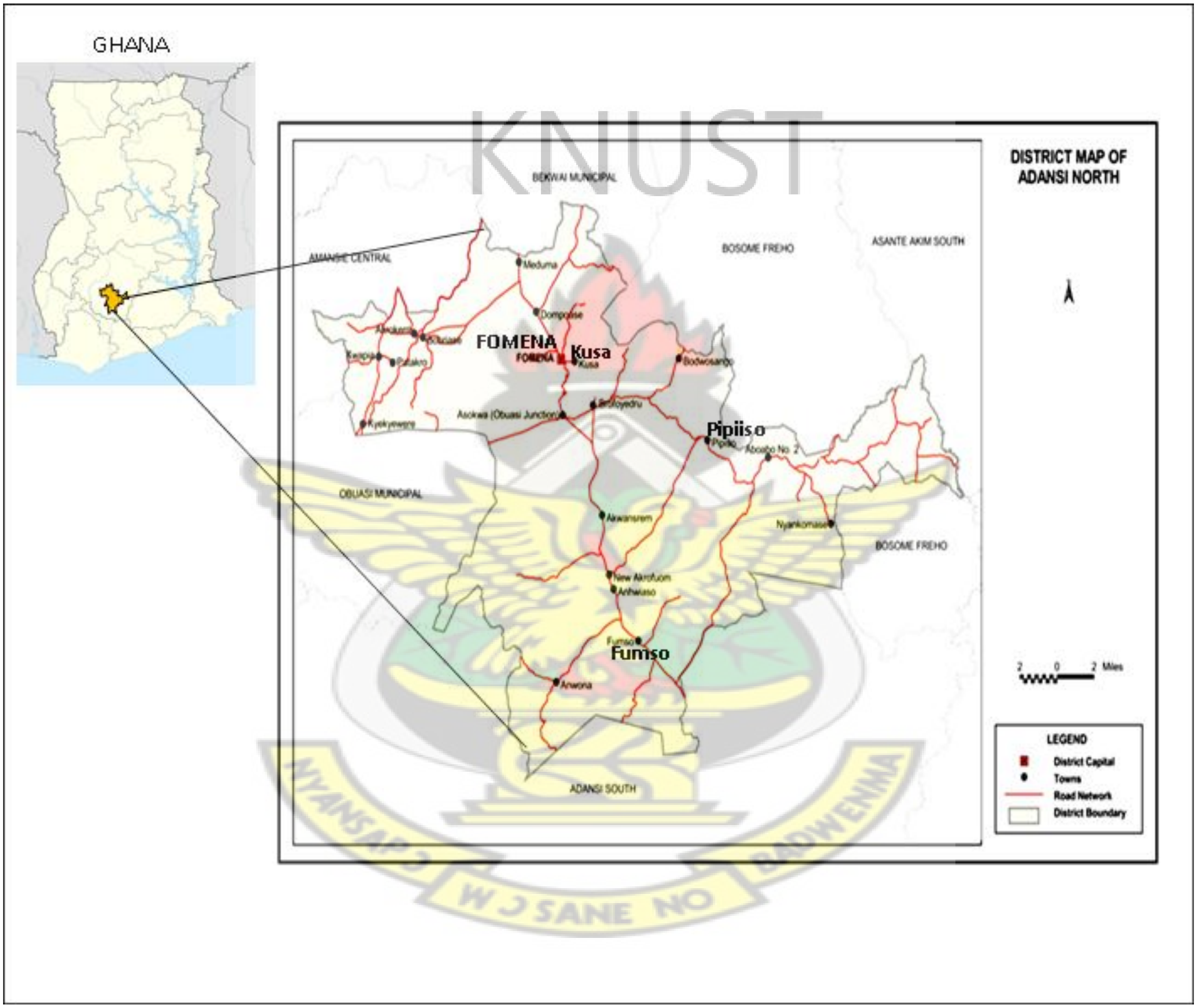


Figure 3. 1: Map of Adansi North District showing communities where research was conducted

The Adansi North District (AND) is found between Longitude 1.5^0 W, latitude 1.4^0 N and Longitude 1.5^0 W latitude 6.3^0 N. The District falls among a typical Semi-Equatorial Climatic Region of Africa that characteristically experiences high temperatures and high precipitation throughout the year. The land covers a district of roughly 853.63 sq. km representing about 4.7 % of the total land area of Ashanti Region. The District is shares boundaries the South –West with Obuasi District, in the South by Adansi South District, in the South-East by Bosome Freho District, in the North-East by Bekwai District and by West Amansie Central District (GSS, 2014).

The AND has an undulating terrain with over half the total land area rising to an average height of 300 meters above sea level. It has many streams portraying a typical dendritic pattern. Major streams within the district are: Bemin, Fum, Gyimi, Kyeabo, Ankafo, Adiembra, Asabri, Subine, Konwia, Kyekye, Atraime, etc. Most of these rivers are used for domestic and industrial purposes and are perennial. As a result of this, farmers cultivate vegetables during the dry season, and this helps several farmers to be in business throughout the year (GSS, 2014).

Temperatures are usually high throughout the year with mean monthly temperatures ranging between 26 ^{0}C and 30 ^{0}C with February and March being the hottest period within the year. The mean annual temperature is 27 ^{0}C. The annual total peculation ranges between 1,250 mm and 1,750 mm. The major rains occur between April and July whilst the minor rains occur between September and December. Relative humidity is high, about 80 % in the rainy season and 20 % in the dry season. The temperature and rainfall pattern enhance the cultivation of many food and cash crops such as cocoa, oil palm, citrus, vegetables, yams, cassava, cocoyam, cereals etc. As a result of the double maxima rainfall pattern, there are two cropping seasons in a year: the major cropping season and the minor cropping season. The climate also supports forest vegetation which supports the growth of timber like odum, wawa, sapele etc. These are harvested for export to earn foreign exchange. Some are also used locally to create jobs for the people (GSS, 2014).

3.2 STUDY METHODS

3.2.1 Selection of Rice Farmers

Rice bund construction is new to farmers in AND. There are three rice bund fields in the district which were all constructed by groups of rice farmers in their location with technical support from MOFA and funding from JICA. The group size ranges from ten to fifteen. A total of twenty-five (25) rice farmers were interviewed on the technique they use in constructing their rice bunds. Rice farmers were selected from Pipiiso, Fumso and Kusa all in the Adansi North District of the Ashanti Region of Ghana. The respondents were asked to review the past growing season with the bunds and contribute their views on them.

3.2.2 Assessment of Bunds Constructed by Farmers

To validate the work of the farmers, bunds were also constructed on a controlled field to test for their strength properties. The controlled field was sited at Fomena where experimental bunds were constructed and labeled in the research as Research Bund 1 (RB1), Research Bund 2 (RB2), Research Bund 3 (RB3) and Research Bund 4 (RB4). The strength properties of the bunds constructed by the farmers were compared with the ones constructed by the researcher. Soil samples from farmer's fields were tested for their strength properties as detailed in Appendix 1 to Appendix 5.

3.2.3 Soil Tests

Soil core sampler was used to collect undisturbed soil core samples for soil profiling. In the process, spade was used to prepare an undisturbed flat horizontal surface to drive the sampler through. Then a hammer was used to push the core sampler gently into the soil. The soil sample was then poured into a plastic bag and sealed making date and location where the sample was taken. Five samples were taken from each bund type and averaged to show the various soil properties. Undisturbed soil samples were taken to the laboratory to determine moisture content, bulk density, Atterberg limits, particle size distribution, compaction test and triaxial test.

Plate 3. 1: **Soil test in the laboratory**

3.2.4 Construction and Assessment of New Bunds

Four bunds were constructed on the research field, two of the bunds were compacted and the other two were not compacted. The compacted bunds were labeled RB1 and RB4 with the uncompacted bunds labeled RB2 and RB3. The following were used to aid the construction of the rice bunds: wheel barrow, wooden pegs, pick axe, mall hammer, spade, shovel, head pan, rope, water pump, GPS, tape measure and hand level. The land development process for rice bund constructions was done systematically as; site selection, ploughing, bund construction, land levelling and puddling and water management and harvesting.

3.2.4.1 Site Selection and Land Preparations

Site selection was based on proximity to the rice farmers' field and use of bunds. Clearing of the land is a very essential process in the development of land for rice farming. Weeds and other unwanted plants on the land are cleared before ploughing begins. In some areas, ploughing is done without clearing the land. This turns some of the weeds into the soil and facilitates easy growing of the weeds again. For the purpose of this research, it was therefore very important to clear the land before ploughing was done to ensure weeds do not grow very fast on the ploughed land (plate 3.1).

Plate 3. 2: Land clearing

3.2.4.2 Bund Construction

For the purposes of this study, the cross sectional area of all bunds was approximated to trapezoidal shape. Four bunds were constructed. Soil for the construction of RB1 and RB2 were from a hill which is common on many rice fields. Many local rice farmers mainly sit on these hills to scare off birds. RB3 and RB4 were constructed using soil on the field itself as recommended by MoFA which is the practice of all farmers. Soil is collected from each side of the bund and heaped using a hoe.

Additionally, three rice farmers' fields in the study area were assessed; these fields are PB, FB and KB.

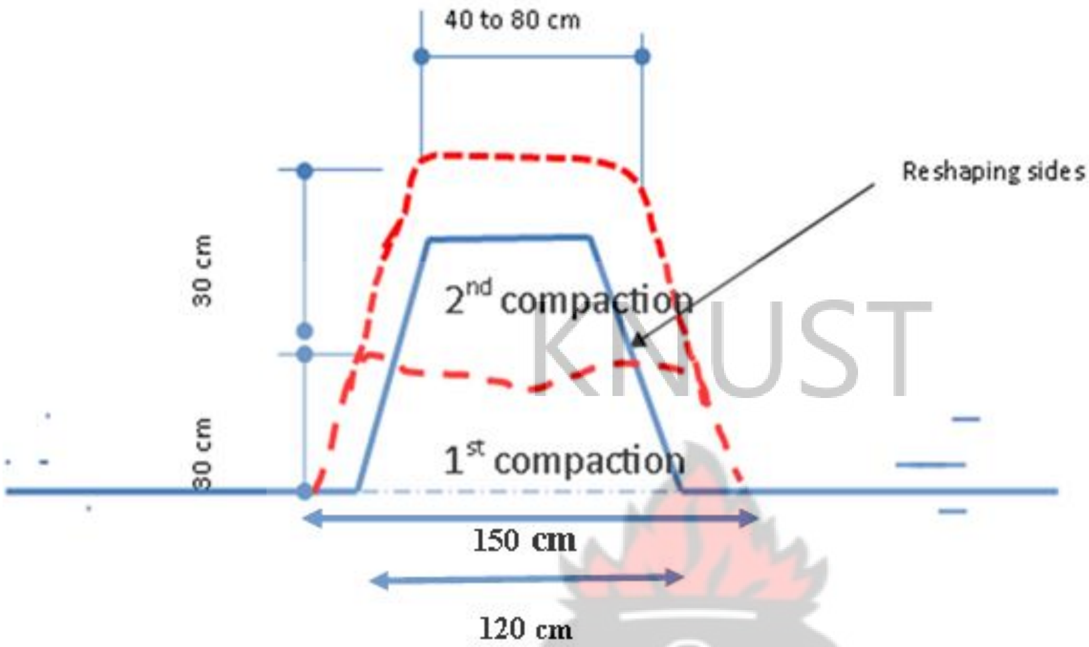


Figure 3. 2: Shape and dimension of permanent bunds

Figure 3. 3: A three dimensional rendition of a rice bund

The bund was set out using tape measure, line and peg. Shallow trench of width 130 cm (Plate 3.3A) was dug. It was filled with soil (Plate 3.3B) and compacted to required height. Compaction was done in two layers first compaction was done to a height of 30 cm and topped with soil then compacted to 50 cm (Figure 3.2). The soil was well compacted to make sure the bund becomes very strong enough.

Construction of the bund required 3 men for 21 man days to be able to construct and compact the four bunds to the required strength. Below is picture illustration of the various field activities;

3.2.4.3 Ploughing

As indicated in Plate 3.3F, ploughing was done manually with hole. The primary purpose of ploughing is to turn over the upper layer of the soil, bringing fresh nutrients to the surface while burying weeds and allowing them to decay. Ploughing is very necessary because it softens the soil for easy transplanting of seedling. Ploughing also prepares soil medium for root development and growth.

3.2.4.4 Bund Height Measurement

An instrument was designed and constructed for measuring bund height and shape (Plate 3.9). This bund measuring tool consists of the vertical part with stand and a spirit level. The spirit level ensures that the instrument was set vertically. The vertical part is 130 cm and had holes created at 10 cm interval which allows the horizontal part to fit in well for reading.

Figure 3. 4: Bund measuring tool

A - Digging of shallow trench

B - Filling of the dug trench with soil

C- The dug trench after filling with soil

D - Bund Compaction

E - Removal of weeds

F - Ploughing of the land

Plate 3. 3: **Bund construction procedure**

The horizontal part of the measuring instrument is calibrated from the base in centimeters for easy reading. Plate 3.5A shows how the instrument is used on the field.

Readings were taken five times per bund type. Research field bund was four in total, each of these bunds where 6 meters long. Point where these readings were taken was pegged at an interval of 1 meter for easy location during reading.

3.2.4.5 Land Leveling and Puddling

Leveling and puddling were done to enhance water use by the plant. Puddling was done by foot (Plate 3.5B). Walking through the field breaks the soil, this helps soften soil by mixing it with water in the bund. Afterwards, the field is leveled by pushing a rake through field.

The rice seeds were nursed to be planted into the bunds. Nursery beds were made and seeds were nursed on the 7th of June 2018.

3.2.4.5 Water Management and Harvesting

Rice is normally grown in bunded fields that are persistently flooded between 7 to 10 days before harvest. Consistent flooding guarantees adequate water levels and reduces weeds interference.

To productively utilize water and improve rice yields, the accompanying water management practices were:

1. Construction of field channels to control the flow of water in and out of the field.
2. Ploughing and levelling of land to limit water loss and create a hard pan.
3. Leveling the field.

4. Maintaining bunds and repair any cracks or opening.

Regular flooding of the field generally gives the best condition for rice growth. In the light of transplanting, water levels ought to be 3 cm, and gradually increased to 5−10 cm (with increasing plant height) and remain there until the point that the moment that the field is drained 7−10 days before harvest. For wet seeded rice, the field should be flooded once the plants are adequately strong to withstand shallow flooding.

3.2.4.6 Transplanting, Weed Control, Fertilizer Application, Protection from Birds and Harvesting

Transplanting was done on June 28, 2018 (Plate 3.5D). Selective herbicides were also used to control weeds while broad spectrum herbicides were used for weed control on bund surface. Push weeder was used in controlling weeds on the field (Plate 3.5E). As per recommendation application of fertilizer was done twice. For one acreage rice field, two bags of NPK 15:15:15 and two bags Ammonium or urea fertilizer is applied. NPK is used as the base application at a rate of 30 kg/ha. Apply ammonium sulfate or urea 30days before heading (30 kg per ha). Fungicide was applied from five days after transplant to zero days of heading to prevent brown spot or blast disease in the ripening. To protect field from birds, nets was used to cover field (Plate 3.5F).

Plate 3. 4: **Some field activities**

3.2.5 ECONOMIC ANALYSIS OF RICE BUNDS

Three main rice production systems were considered in finalizing the cost implication of rice production using bunds. They are; rice production without bunds, rice production with uncompacted bunds and rice production with compacted bunds. Cost of production from land clearing to harvesting, threshing and winnowing was estimated for each system. Then yield for an acreage production also estimated. These three systems of rice cultivation were further economically analyzed in a seasons to ascertain their profit margins after two seasons.

3.2.5.1 Marginal Costing Principle

Marginal costing principles were used to assess the profit on rice cultivation. In marginal costing, fixed production overheads are not ingested into cost units and stock are valued at marginal or variable cost and fixed production overheads are treated as period cost and charged to profit and loss account for the period which the overhead is incurred. Contribution margin is given by:

$$CM = TR - TOC \quad \text{……3.1}$$

Where CM: contribution margin, TR: total revenue and TOC: total operating cost. CM is the margin that is adding to fixed cost and profit. (Hagan et al., 2016).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 CHARACTERISTICS OF RICE BUNDS CONSTRUCTED BY FARMERS

Height and volume variations determine the longevity of bunds with time. For a bund to serve its intended purpose, it needs to maintain its height and volume. Figure 4.1 and 4.2 illustrates how height and volume vary on various rice bunds with time.

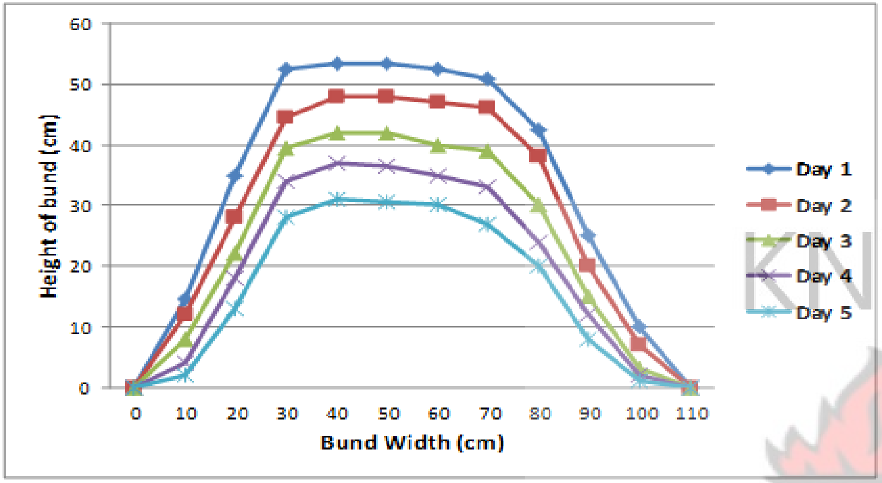
4.1.1. Cross Section of Rice Bunds Constructed by Farmers

The KB as indicated in Figure 4.1A initially had a mean height of 53.5 cm from Day 1 reduced to 48, 42, 37 and 31 in the day 2, 3, 4 and 5 respectively. Base width of the bund remained constant throughout the entire 5 days period at 110 cm. The top width was recorded as 40 cm, 37 cm, 35 cm, 30 cm and 30 cm for day 1, 2, 3, 4 and 5 respectively.

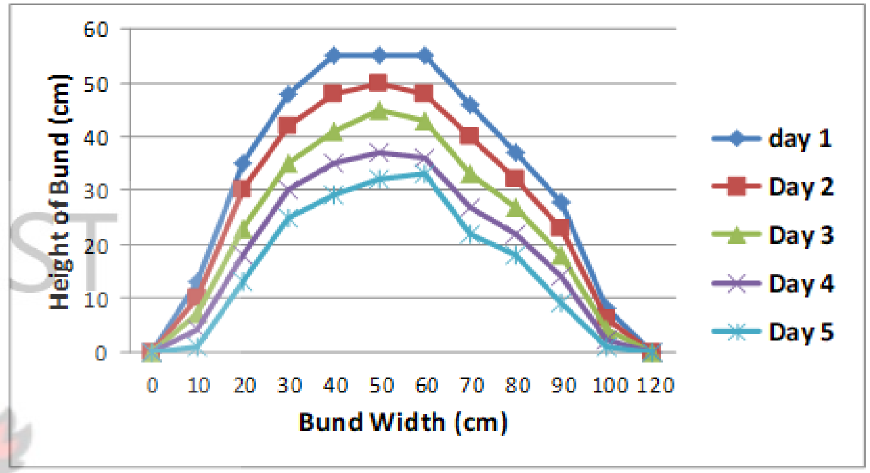
On day 1 the bund height was 55 cm for FB as illustrated in Figure 4.1B. Subsequent readings were 50, 45, 37, and 32 cm for day 2, 3, 4 and 5 respectively. Base width remained at 110 cm for the entire five days while top width was 20, 18, 12, 10 and 8 cm respectively for day 1, 2, 3, 4, and 5 respectively.

The PB was constructed taller than all the others with an initial height of 70 cm on day 1. Day 2 height stood at 66 cm, while day 3, 4 and 5 were 59, 56 and 45 cm. The base width remained constant at 90 cm. the top width for day 1, 2, 3, 4, and 5 were 30, 27.7, 26, 20 and 18 cm respectively as in Figure 4.1C.

A - The cross-sectional changes of KB



B - The cross-sectional changes of FB



C - The cross-sectional changes of PB

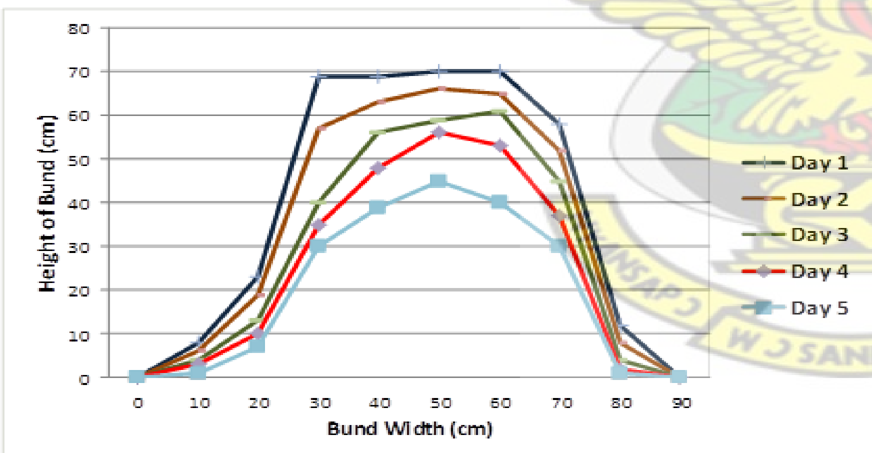


Figure 4. 1: The cross-sectional changes of KB, FB and PB

4.1.2. Cross Section of Rice Bunds Constructed on Research Field

As illustrated in Figure 4.2A, mean height for day 1, 2, 3, 4 and 5 were 53.5, 52.5, 51.5, 51 and 50.5 cm respectively while base width stood at 100 cm for all the days for RB1. Top width for day 1, 2, 3, 4 and 5 were 30, 28, 28, 27.8 and 27.5 cm respectively.

Base width of RB2 at the research field was 110 cm and it remained constant throughout the reading days. The top width for day 1, 2, 3, 4 and 5 however varied at 20, 17, 13, 10 and 9 cm respectively. Height of bund was 52, 49, 48, 45 and 35 cm for day 1, 2, 3, 4 and 5 respectively as presented in Figure 4.2 B.

Heights of RB3 were 47, 41, 36, 34 and 31 cm for day 1, 2, 3, 4, and 5 respectively. The base width remained at 90 cm at the entire reading days with top width 10, 9.5, 6, 6 and 5 cm respectively for day 1, 2, 3, 4, and 5.

Height of RB4 were 50, 49, 48, 47 and 46 cm respectively while bottom width remain at 90 cm and top width varied from 12, 11, 10, 10 and 10 cm respectively as illustrated in Figure 4.2 D.

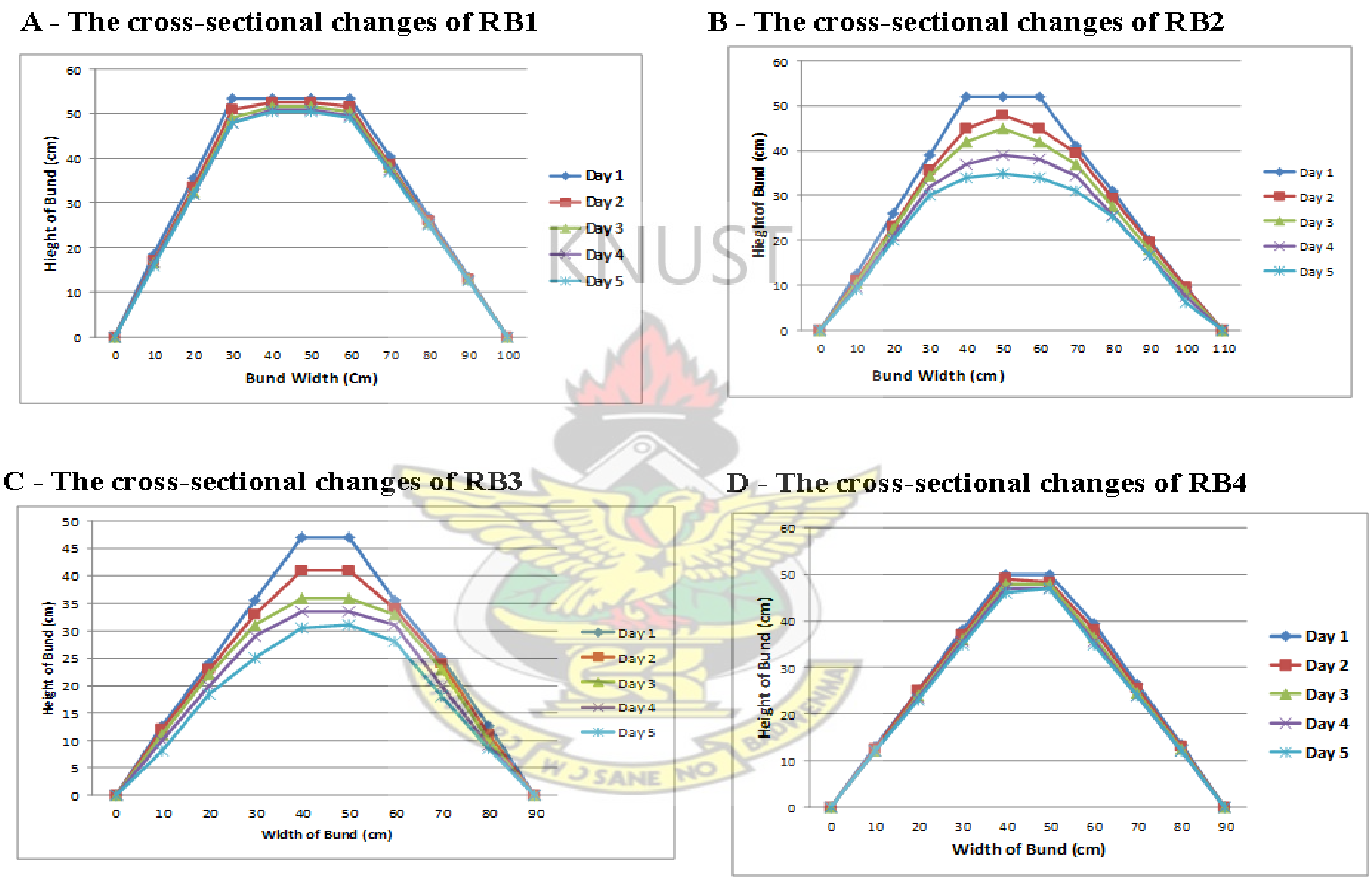


Figure 4. 2: **The cross-sectional changes of research field bunds**

4.1.2 Mean Bund Height Variations with Time

Soil heap over time will consolidate, reducing pore space, increase bulk density as well as reduce height. Looking at the variation of bund height with respect to time on the various fields, the Figure 4.3 below compares the various heights variations;

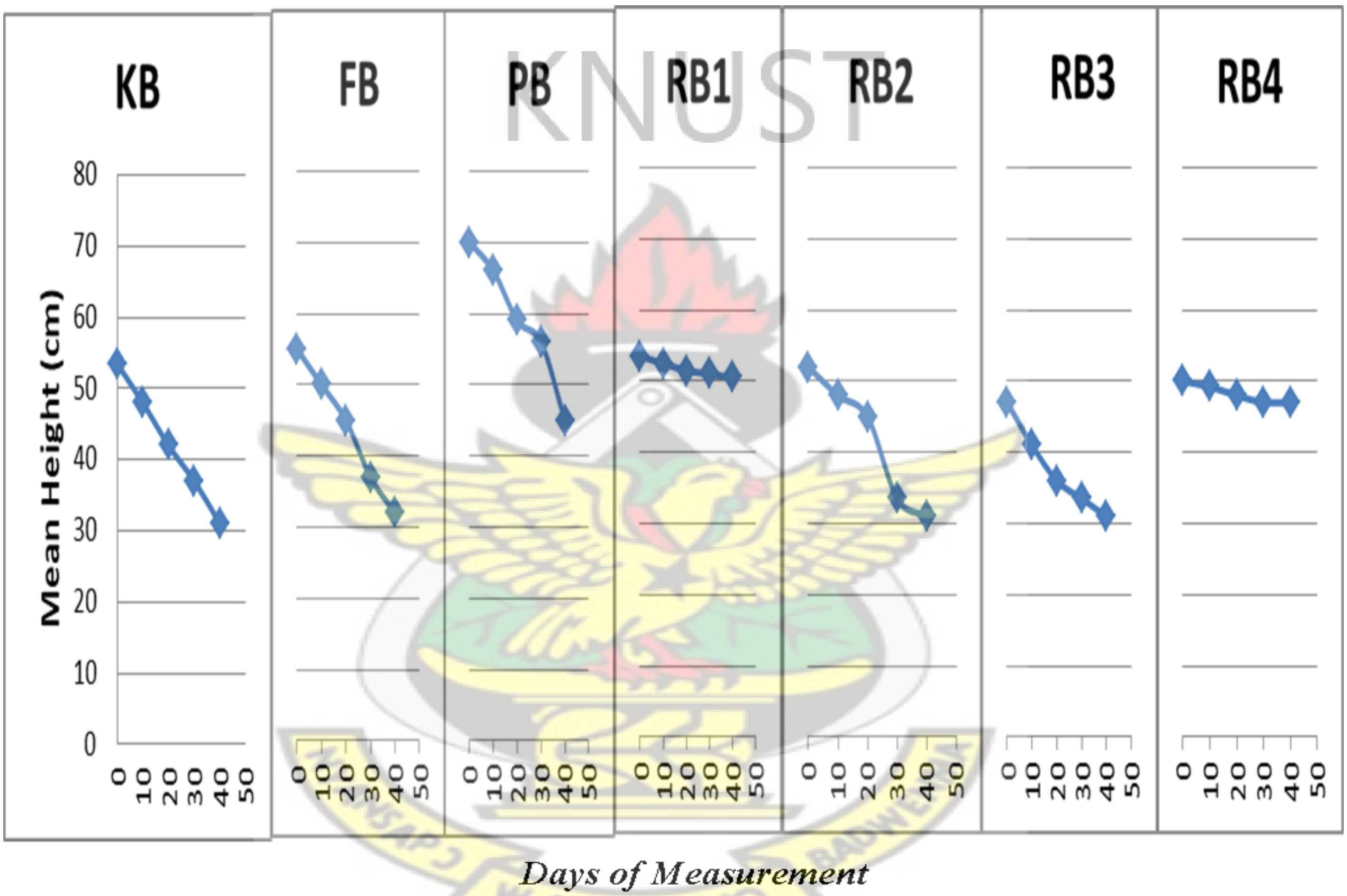


Figure 4. 3: Mean bund height variations with time

Figure 4.3 depicts mean height variation with respect to time for all the bund types under research. KB height varied from 54 cm to 31cm which is approximately 42 % reduction. FB varied from 55 to 32 cm approximately 42 % reduction. PB varied from 70 to 45 cm approximately 36 % reduction. RB1 varied from 54 to 51 cm approximately 6 % while RB2 varied from 52 to 31 cm approximately 40 %. RB3 changed from 47 to 31 cm approximately 34 % reduction RB4 varied from 50 to 47 approximately 6 % reduction.

4.1.3 Mean Bund Volume Variation with Time

Figure 4.4 presents analysis of the various bunds with respect to changes in their volume variations with time. Readings taken in 10 days intervals have been represented below;

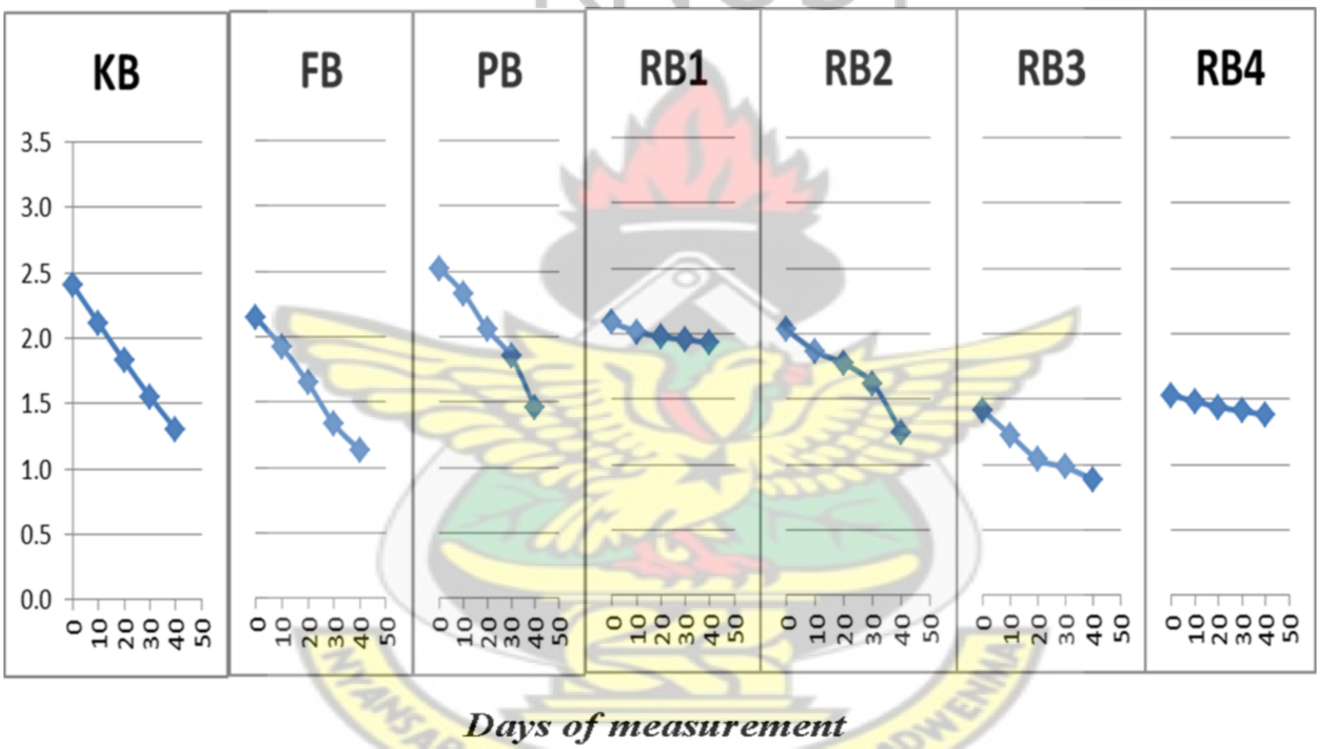


Figure 4. 4: Mean bund volume variations with time

KB reduced in volume from 2.4 to 1.30 m^3 that is 46 % change in volume. FB reduced in volume from 2.15 to 1.13 m^3 that is 47 % change in volume. PB reduced in volume from 2.52 to 1.46 m^3 that is 42 % change in volume. RB1 reduced in volume from 2.09 to 1.93 m^3 that is 7 % change in volume. RB2 reduced in 2.03 to 1.25 m^3 38 % change in volume. RB3 reduced in volume from 1.41 to 0.88 m^3 that is 37 % change in volume. RB4 reduced from 1.53 to 1.38 m^3 representing 10 % volume change.

4.1.4: Effects of Compaction on Bund Volume Change

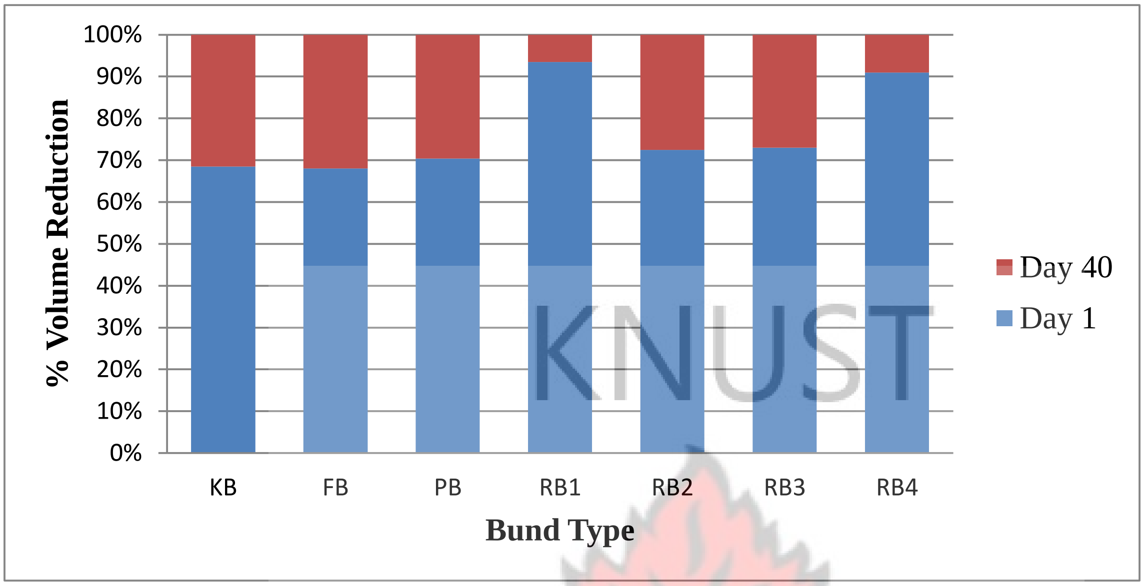


Figure 4. 5: Bund on rice field volume variation comparison

From Figure 4.5, all the farmer fields: KB, FB and PB lost 46, 47 and 42 % respectively of their volume after 40 days of reading. At the research site, RB1 reduced in volume by 7 %, RB2 reduced by 38 %, RB3 37 % and RB4 10 % volume reduction.

4.2 RATE OF EROSION ON BUNDS CONSTRUCTED BY FARMER

Figure 4.6 is a representation on the effects of erosion on bunds constructed at various farmer fields and that construct on research field.

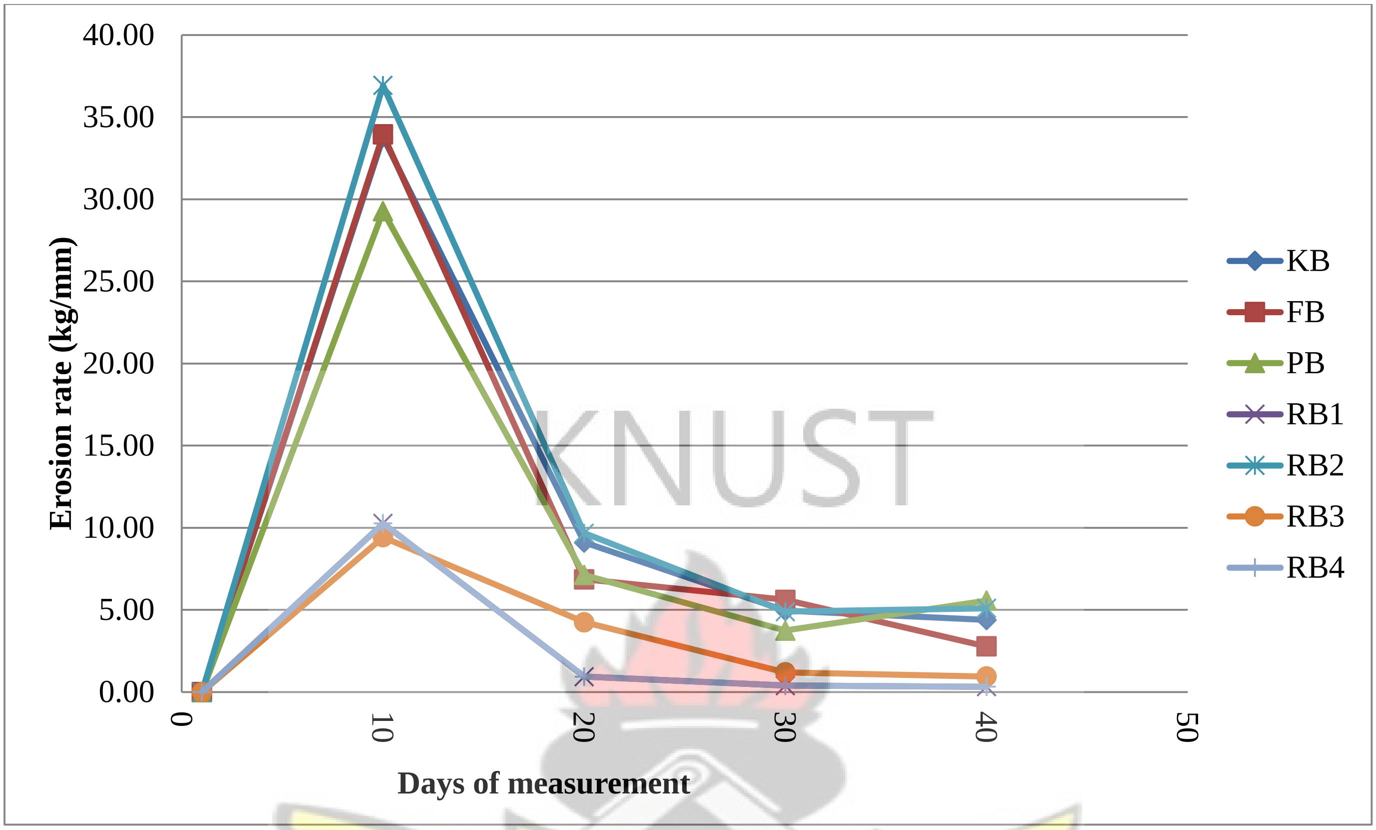


Figure 4. 6: Mean bund erosion rate with time

The erosion rate on all the bunds looks similar in nature. Erosion is low on RB1 and RB2 while erosion is highest on FB.

4.3 STRENGTH PROPERTIES OF BUNDS CONSTRUCTION BY FARMERS

Results of the strength test conducted on the various bunds are presented below.

4.3.1 Bulk Density and Moisture Content Test for Soil Samples

After taking soil samples from the Pipiiso, Kusa, Fumso, RB1, RB2 and RB3 rice bunds, samples were taken to the KNUST Geotechnical Engineering Laboratory for analysis;

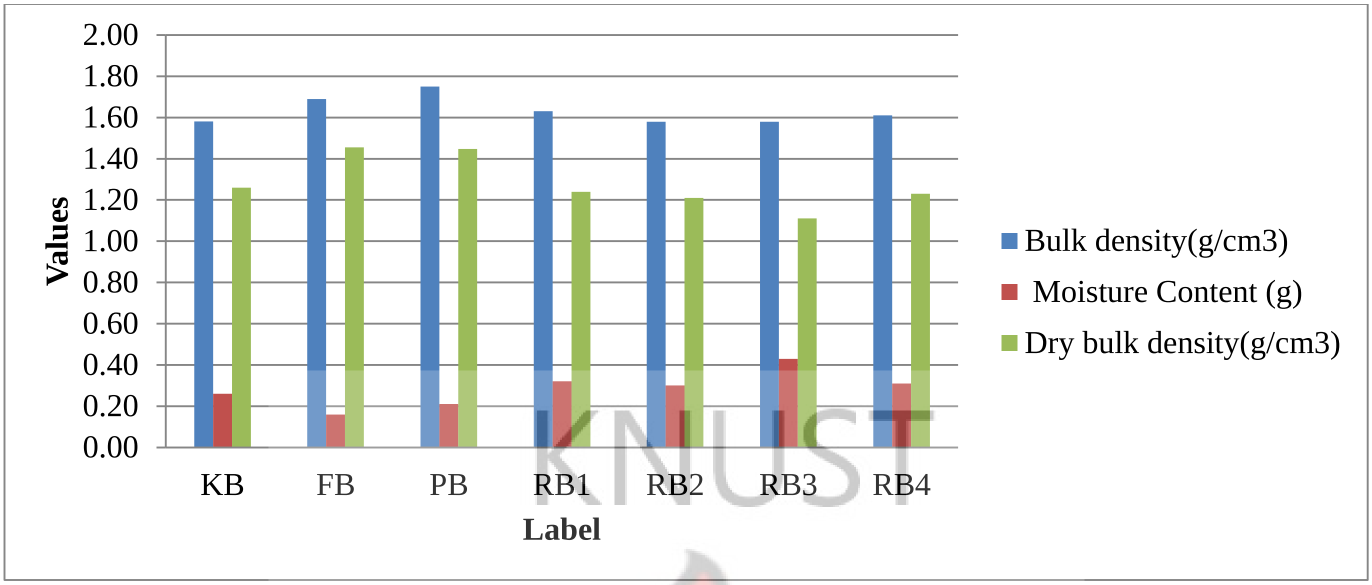


Figure 4. 7: Bulk density, moisture content and dry bulk density

The average bulk density for KB is 1.58 g/cm^3, with percentage moisture content of 25.63 % and Dry bulk density of 1.26 g/cm^3. FB has an average bulk density of 1.69 g/cm^3, percentage moisture content of 16 % and dry bulk density of 1.45 g/cm3. The PB soil sample has an average Bulk density of 1.75 g/cm^3 with percentage Moisture content of 21.03 % and a Dry bulk density of 1.45 g/cm^3. Soil sample from RB 1 has an average bulk density of 1.63 g/cm^3, with a percentage moisture content of 32.17 % and a dry bulk density of 1.24 g/cm^3, RB2 has an average bulk density of 1.58 g/cm^3, moisture content of 30.97 % and a dry bulk density of 1.21 g/cm^3. The RB 3 has an average bulk density of 1.58 g/cm^3 with percentage moisture content of 43.32 % and dry bulk density of 1.11 g/cm^3 and RB 4 has an average bulk density of 1.61 g/cm^3 with percentage moisture content of 31 % and dry bulk density of 1.23 g/cm^3.

4.3.2 Classification and Index Tests

Table 4. 1: Classification and index tests

Test	Atterberg		Particle Size Distribution		Compaction		USCS
			Test Results Summary				
RB 1&2	LL	49.28	Sand	0	OMC	19.82	CI- clay of intermediate plasticity
	PL	28.15	Silt	72	MDD	1.59	
	PI	21.13	Clay	28			
RB 3&4	LL	51.62	Sand	23.3	OMC	23.61	CH-clay of high plasticity
	PL	32.14	Silt	60.7	MDD	1.46	
	PI	19.48	Clay	16			
KB	LL	46.12	Sand	59.4	OMC	14.08	CI- clay of intermediate plasticity
	PL	27.41	Silt	37.3	MDD	1.54	
	PI	18.71	Clay	3			
FB	LL	32.2	Sand	80.6	OMC	14.05	CL- clay of low plasticity
	PL	17.27	Silt	12.8	MDD	1.85	
	PI	14.95	Clay	6.2			
PB	LL	26.88	Sand	64.8	OMC	13	ML- Silt of low plasticity
	PL	18.24	Silt	29.8	MDD	0.98	
	PI	8.64	Clay	5.4			

LL - Liquid Limit; PL - Plastic Limit; PI – Plasticity Index; OMC – Optimum moisture content; MDD - Maximum Dry Density

From the results in Table 4.1 shows the presence of clay mineral likely to be kaolinite for RB 1 and 2, RB 3 and 4, and KB whereas the clay mineral present in FB and PB is montmorillonite using the Cassagrande PI-LL chart. The presence of this mineral caused the soil samples to have clay content varying from 5 % to 28 % of its total quantity with silt content between 12 % and 72 % and 0 % to 80% being sand with varying OMC of 13 % to 24 %.

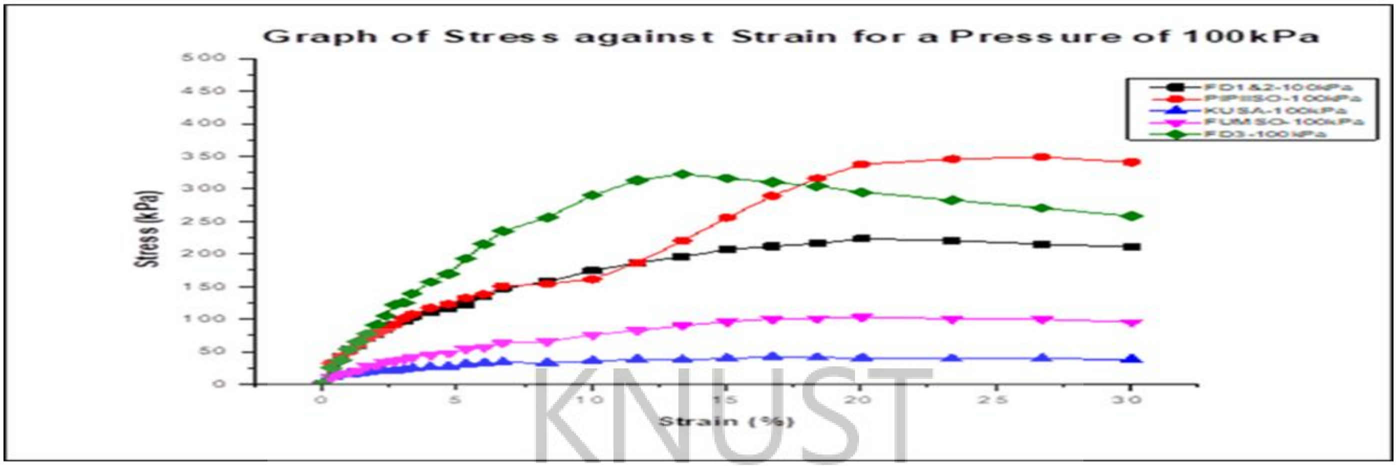
Table 4. 2: **Triaxial test summary**

Triaxial Test Result Summary		
Test	**Cohesion (kPa)**	**Friction Angle (Ø)**
RB 1&2	103.152	4.23
RB 3&4	87.92	17.969
FB	52.661	3.469
KB	6.864	4.266
PB	95.183	15.3

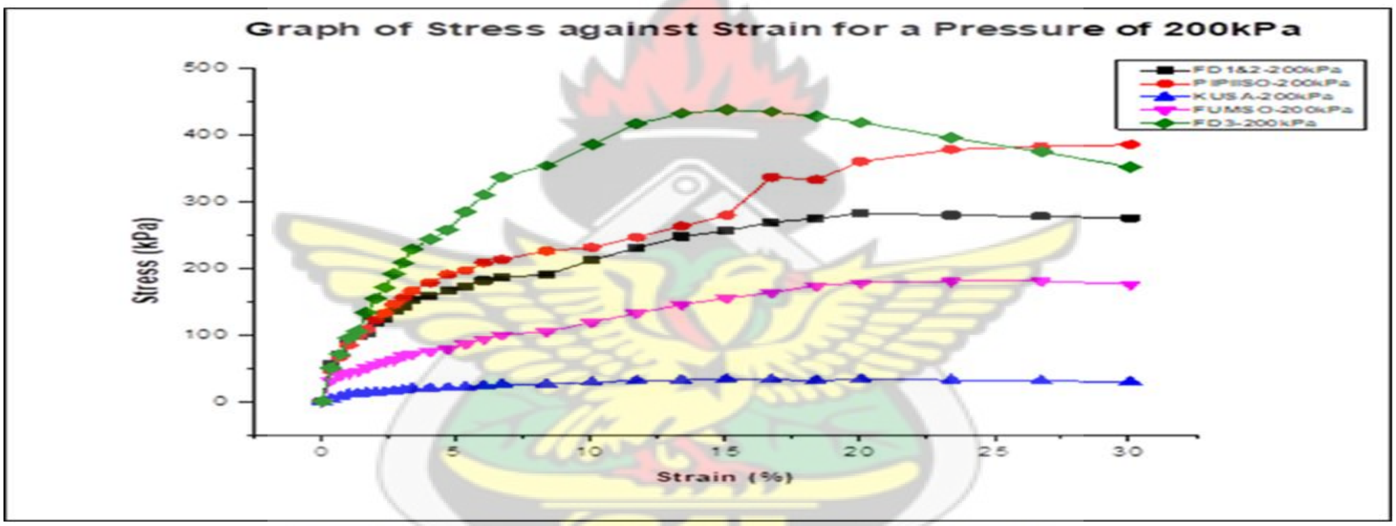
From the summary Table 4.2, the angle of friction reduces as the clay content increases because the pressures applied are higher than the pre-compacted strength leading to the rearrangement of particles whiles cohesion kept increasing with increase in clay content. This is because both factors are dependent on the clay content of the soil taking into consideration the size and shape of the particles. At low pressures, high cohesion and friction angles are induced by higher number of contact points between aggregates.

From the stress against strain graphs (Figure 4.8), the increase in strain causes an increase in stress with an increase in pore pressure until it peaked and drops. The stress strain graphs show a non-linear and elastic character.

A—100KPa



B—200KPa



C—300KPa

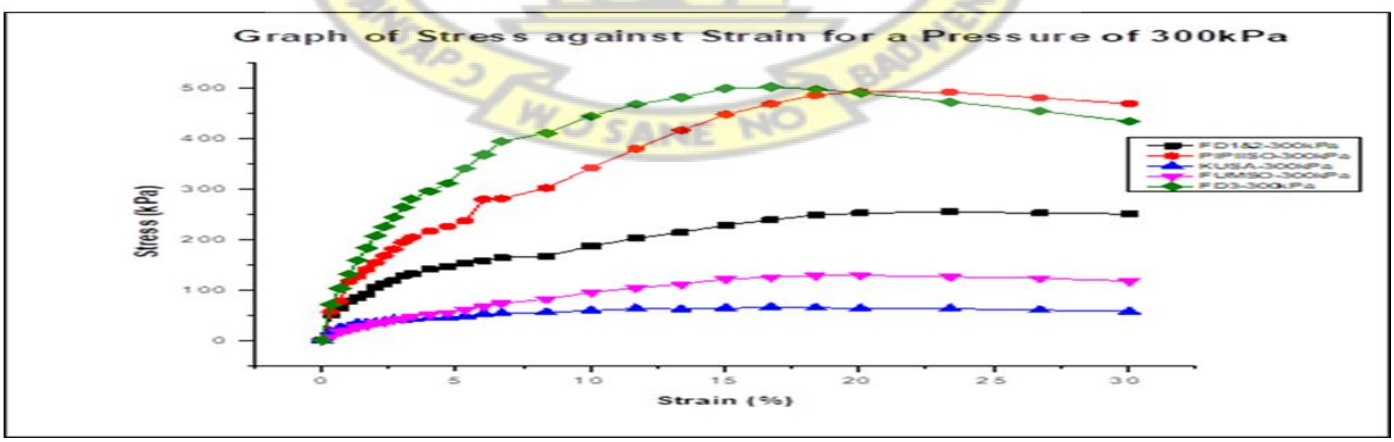


Figure 4. 8: Stress against strain

4.4 DURABILITY OF BUNDS CONSTRUCTED BY LOCAL FARMERS

Rate of volume reduction on bunds can help determine if bunds will need to be reconstructed after a certain period of time or not. Data on bunds were taken at 10 days interval to determine the rate of volume change which will aid in our analysis on whether the bund will need to be reconstructed. Actual readings were taken for the first 40 days as indicated in Figure 4.5, looks clear that after 40 days of reading, rate of volume loss from farmers' fields are high nearly half of their volume is lost.

Assuming all conditions remain constant, in 80 days bunds in the various fields are graphically presented in Figure 4.9.

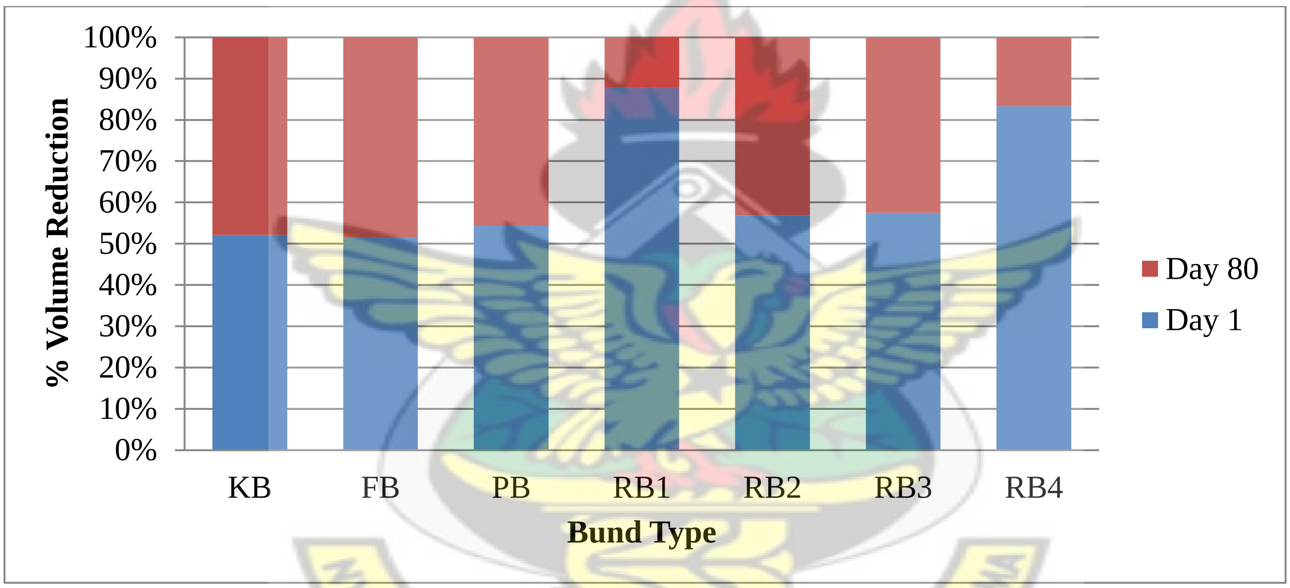


Figure 4. 9: The difference in volume of constructed bunds after 80 days

Figure 4.9 clearly shows that compacted fields will be stronger than uncompacted fields after 80 days as RB1 and RB4 shows small reduction compared with the other uncompacted bunds. This is presented more visibly in Figure 4.10 and 4.11;

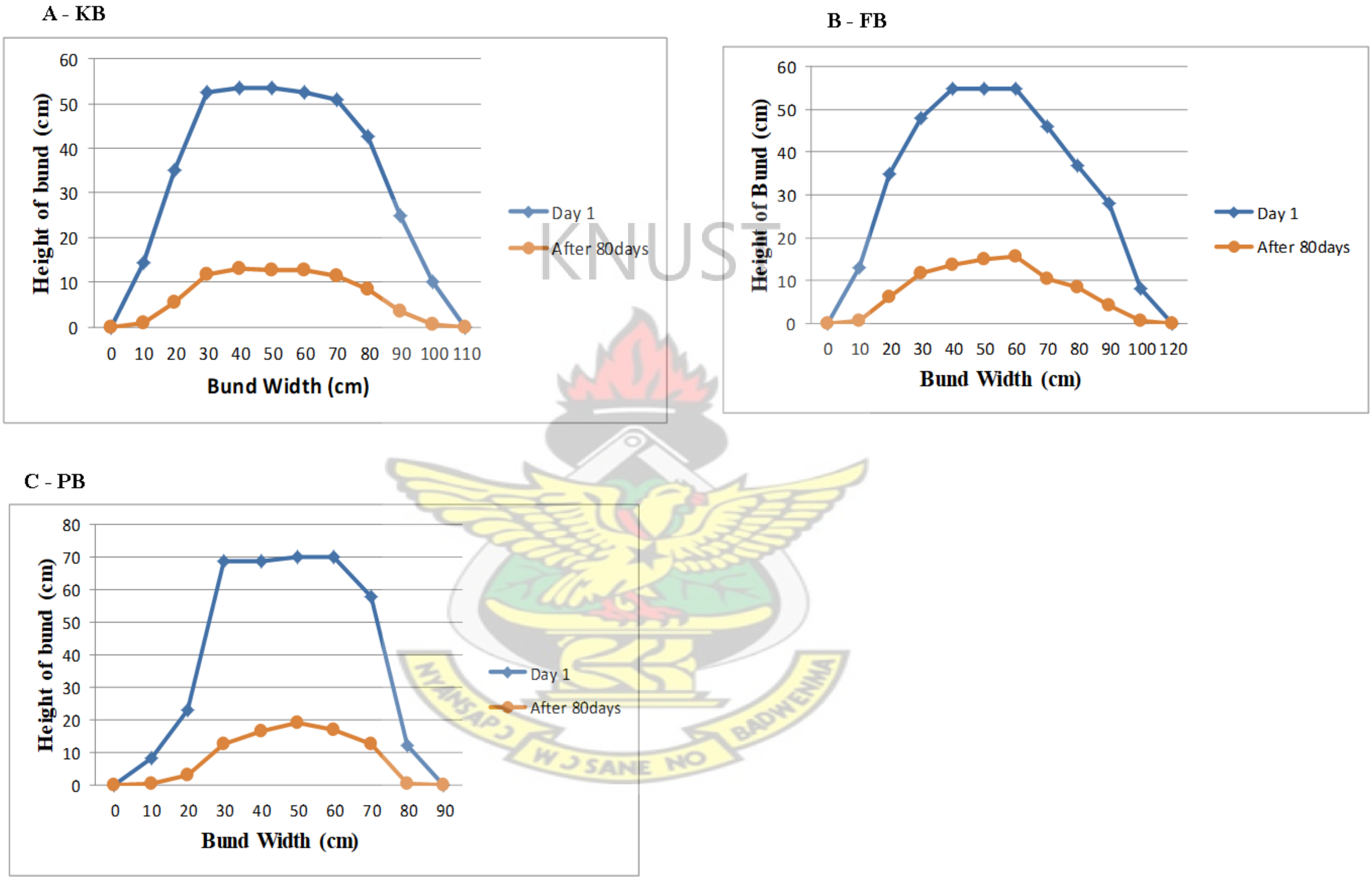


Figure 4. 10: **The cross-sectional changes of farmer bunds after 80 days**

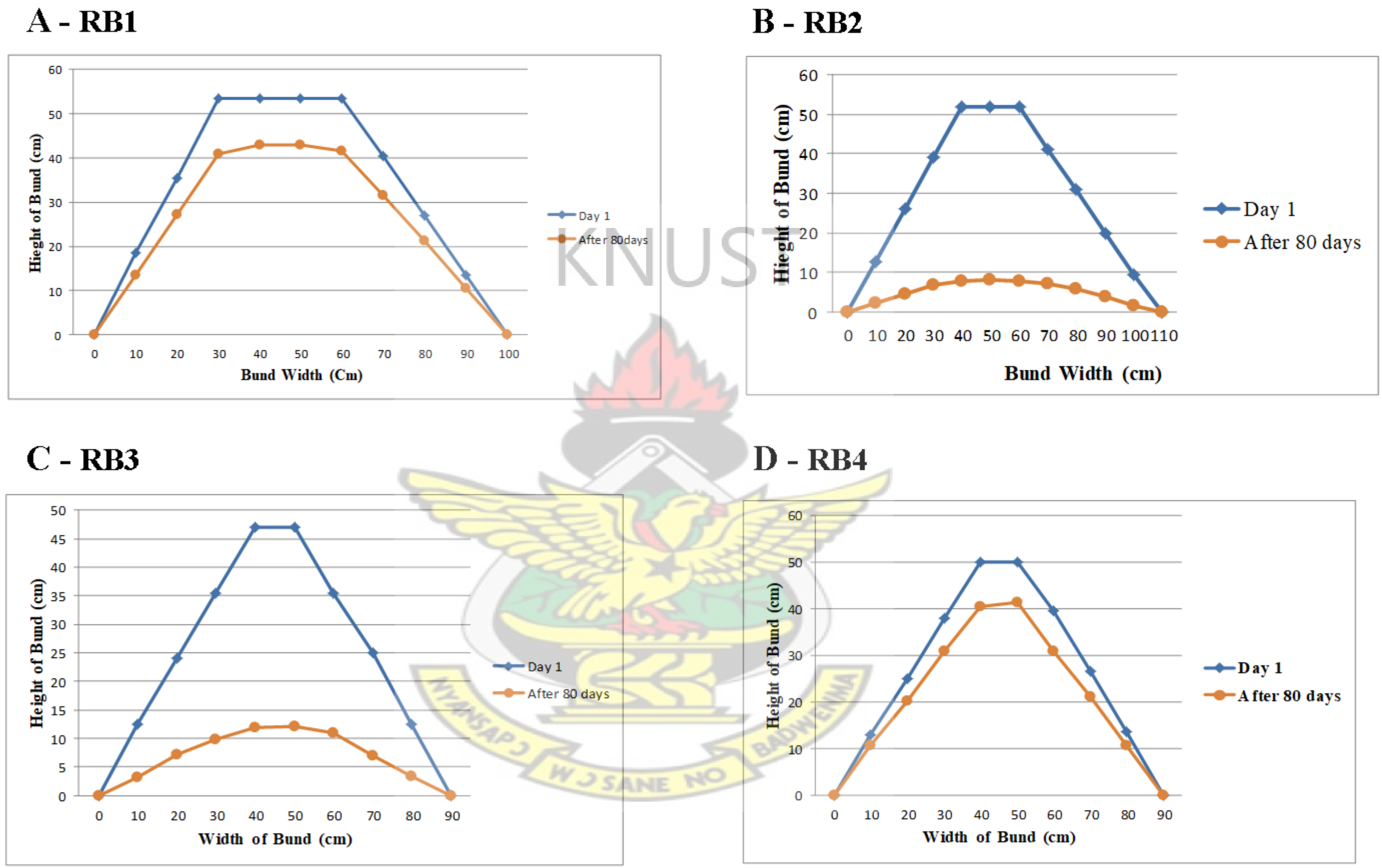


Figure 4. 11:The cross-sectional changes of research bunds after 80 days

Figure 4.10 shows that bunds constructed by farmers reduced to nearly the ground level and therefore will need to be reconstructed after the first cropping season.

Looking at the cross section of the research bunds after 80 days (Figure 4:11), RB1 does not need to be reconstructed after one cropping season. RB2 is low in height and volume making it necessary for reconstruction. RB3 will need to be reconstructed as it losses most of its volume. RB4 looks very strong and will not need to be reconstructed after 80 days.

As per the results from various tests indicates that bunds become firmer and stronger when compacted. After 80 days of construction, KB reduced by 92 %, FB by 94 %, PB by 84 %, RB2 by 76 % and RB3 74 %. All these fields were not compacted hence the massive reduction in their volume and height. Yet costs of construction of these bunds are the same.

RB1 and RB4 recorded low volume and height reduction compared with all the other fields, RB1 recorded 14 % reduction in bund volume while RB4 recorded 20 %. Both fields were well compacted.

There will therefore be a need to reconstruct all of the uncompacted bunds before the new cropping season.

4.5 COST IMPLICATIONS OF THE DIFFERENT TYPES OF BUND CONSTRUCTION

From Table 4.3, bunds constructed on rice field (uncompacted) increases the Total Operational cost from USD 345.33 to USD 661.39 nearly twice the initial cost. These excess costs drive most farmers away from the technology. However, yield on the other hand on the same plot of land increased from 750 kg to 1250 kg per acreage with the need for reconstruction every year.

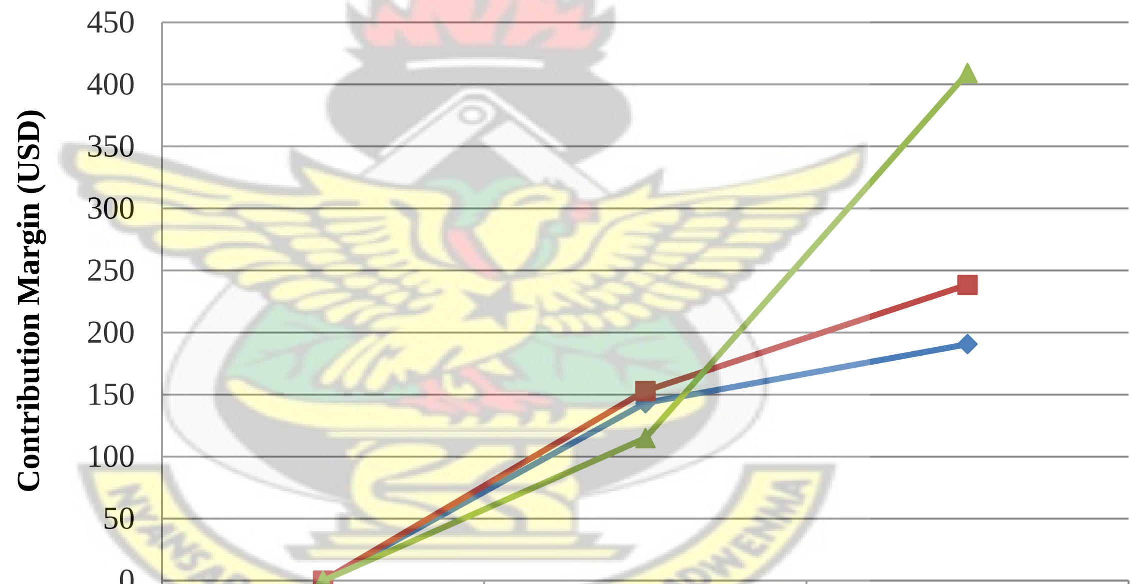
Table 4. 3: Cost analysis of bund construction

Item	Season 1 Without bund	Season 1 With bund uncompacted	Season 1 With bund compacted	Season 2 Without bund	Season 2 With bund uncompacted	Season 2 With bund compacted
Harvested rice (kg) for 1 acre rice	750	1250	1250	750	1250	1250
Number of bags (50kg)	15	25	25	15	25	25
Total revenue (TR) (USD 34.19 per bag)	**512.85**	**854.75**	**854.75**	**512.85**	**854.75**	**854.75**
Operating Cost						
Land clearing	38	38	38	24.7	24.7	24.7
Bund construction	0	228	228	0	190	19
Bund compaction	0	0	38	0	0	0
Ploughing and leveling	0	76	76	0	76	76
Direct planting	76	0	0	76	0	0
Seeds (30kg direct 16kg nursery)	12.825	6.84	6.84	12.825	6.84	6.84
Nursery	0	4.75	4.75	0	4.75	4.75
Transplanting	0	114	114	0	114	114
Weed control	49.4	24.7	24.7	49.4	24.7	24.7
Fertilizer and application	68.4	68.4	68.4	68.4	68.4	68.4
Net for bird scaring	53.2	53.2	53.2	19	19	19
Harvesting	19	19	19	19	19	19
Threshing and winnowing	28.5	28.5	28.5	28.5	28.5	28.5
Total operating cost (TOC)	**345.33**	**661.39**	**699.39**	**297.83**	**575.89**	**404.89**
Contribution margin (TR-TOC)	**167.53**	**193.36**	**155.36**	**215.03**	**278.86**	**449.86**

*****All cost in United States Dollar (USD)**

Compacted bunds on rice fields according to Table 4.3, raises the operational cost further to USD 699.39 which is USD 38 more than uncompacted bunds. However, yield between compacted and uncompacted bund fields remains the same at 1250 kg/acreage with all conditions remaining constant.

However, profits on compacted bunds are realized in subsequent cropping seasons (Figure 4.12). Contribution margin for compacted bunds greatly increases in subsequent seasons to USD 449.86 as against USD 278.86 of uncompacted bunds. "The higher the contribution margin the larger the amount of funds available to defray the fixed cost. The rule is that the contribution margin needs to be positive and the higher it is the better" (Hagan et. al., 2016).



		Season 1	Season 2
Without Bund	0	143.17	190.67
Uncompacted Bund	0	152.95	238.45
Compacted Bund	0	114.95	409.45

Figure 4. 12: Contribution margin variations with rice cultivation types

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

The following conclusions have been drawn based on the results of the study conducted:

Bunds constructed by farmers are loosely heaped and erodes very fast. Farmer's bunds losses between 40 to 47 % of its total volume after 40 days of construction.

- Uncompacted bunds erode faster than compacted bunds.
- The soil used in bund construction is strengthened when compacted.
- Bund construction and compaction increases Total Operational Cost (TOC) by 50 % thereby reducing Contribution Margin (CM) by 7% thereby reducing profit in the first season. In the second season, compacted bunds reduce TOC from 50 % to 26 % increasing CM by 52 %. Comparatively, compacted bunds are more profitable than uncompacted bunds.
- Bund strength is dependent on soil type and level compaction. Clay of intermediate plasticity soil type is stronger than clay of high plasticity.

5.2. RECOMMENDATIONS

Based on the discussion and conclusions above, the following is recommended:

5.2.1 Recommendations for Policy

- Bunds constructed on rice field should be compacted adequately to reduce their rate of erosion thereby increasing their longevity.
- All rice farmers, Agriculture Extension Agents and all other stakeholders in rice cultivation should be trained on the importance of bund construction and how to construct strong bunds for better results.

- Bund construction is very expensive and labour intensive, therefore support from stakeholders in terms of funding maybe necessary in making rice cultivation successful.

5.2.2 Recommendations for Further Research

- Further studies should be conducted on the soil type and best material for bund construction.

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APPENDIXES

APPENDIX 1: SOIL ANALYSIS OF PIPIISO BUND

Field location: Pipiiso

GPS location N06*13.541' W001*23.523'

Area of field 443.94m^2

Table 1.1: Bulk density and moisture content test results for Pipiiso bund

Bulk Density And Moisture Content Determination								
Sample id	**J6**	**C18**	**I7**	**D4**	**B2**	**XX2**	**J4**	**X9**
Mass of soil (g)	675	720	622	711	622	705	652	681
volume (cm^3)	384.65	384.65	384.65	384.65	384.65	384.65	384.65	384.65
BULK DENSITY(g/cm^3)	**1.75**	**1.87**	**1.62**	**1.85**	**1.62**	**1.83**	**1.70**	**1.77**
moisture content								
mass of container (g)	17.9	18.82	18.26	18.26	17.92	18.26	17.92	17.93
mass of container & wet soil (g)	153.53	178.57	149.96	169.6	177.75	169.55	145.76	171.23
mass of container and dry soil	126.02	148.12	125.71	145.84	153.65	146.46	120.31	148.5
mass of wet soil	135.63	159.75	131.7	151.34	159.83	151.29	127.84	153.3
mass of dry soil	108.12	129.3	107.45	127.58	135.73	128.2	102.39	130.57
mass of water	27.51	30.45	24.25	23.76	24.1	23.09	25.45	22.73
Moisture content	0.25	0.24	0.23	0.19	0.18	0.18	0.25	0.17
% Moisture Content	25	24	23	19	18	18	25	17
DENSITY OF DRY SOIL(g/cm^3)	**1.40**	**1.52**	**1.32**	**1.56**	**1.37**	**1.55**	**1.36**	**1.51**

Table 1.2: Atterberg limits test results on Pipiiso soil sample

container no.	B22	A18	B40	B19	B18	B9	B15
Mass of container	3.7	3.7	3.73	3.8	3.78	3.66	3.76
Mass of wet sample and container	25.15	32.45	38.37	36.93	50.41	22.81	22.86
Mass of container and dry sample	21.35	26.37	30.81	29.48	39.59	19.83	19.94
Penetration (mm)	6.8	19.2	24.2	25.4	27.1		
Mass of water	3.8	6.08	7.56	7.45	10.82	2.98	2.92
Mass of dry sample	17.65	22.67	27.08	25.68	35.81	16.17	16.18
Percentage moisture content	21.53	26.82	27.92	29.01	30.22	18.43	18.05

Liquid limit	26.88
Plastic limit	18.24
Plasticity index	8.64

Table 1.3: Soil compaction test result for Pipiiso bund

Mass of Container + Wet Sample (gm)	**5842**		**5916**		**6019**		**6137**		**6227**		**6167**	
Mass of Cylinder (gm)	4247		4247		4247		4247		4247		4247	
Mass of Wet Sample	1595		1669		1772		1890		1980		1920	
Container ID	ZL	G10	m4	9Z	4Z	BK	Q3	A61	H14	P2	V1	q1
Mass of Container + Wet Soil (gm)	118	119.9	105.27	106.5	98.4	82.2	110	104	130.7	113.2	98.63	106.03
Mass of Container + Dry Soil (gm)	117	119	102.18	103.7	93.7	79.1	103	96.32	118.5	102.5	88.55	94.61
Mass of Container (gm)	25.4	25.17	25.87	25.73	25.5	25.4	25	24.67	25.44	25.36	25.33	26
Mass of Water	0.88	0.88	3.09	2.79	4.71	3.08	7.4	7.72	12.14	10.67	10.08	11.42
Mass of Dry Sample	91.7	93.82	76.31	77.99	68.2	53.7	77	71.65	93.08	77.13	63.22	68.61
Percentage Moisture Content	0.96	0.94	4.05	3.58	6.91	5.73	9.63	10.77	13.04	13.83	15.94	16.64
Average Moisture Content	0.95		3.81		6.32		10.20		13.44		16.29	
Bulk Density	1.77		1.85		1.96		2.09		2.19		2.13	
Dry Density	1.75		1.78		1.85		1.90		1.93		1.83	
Height of mould	11.5											
Diameter of mould	10											
Volume of mould	903											

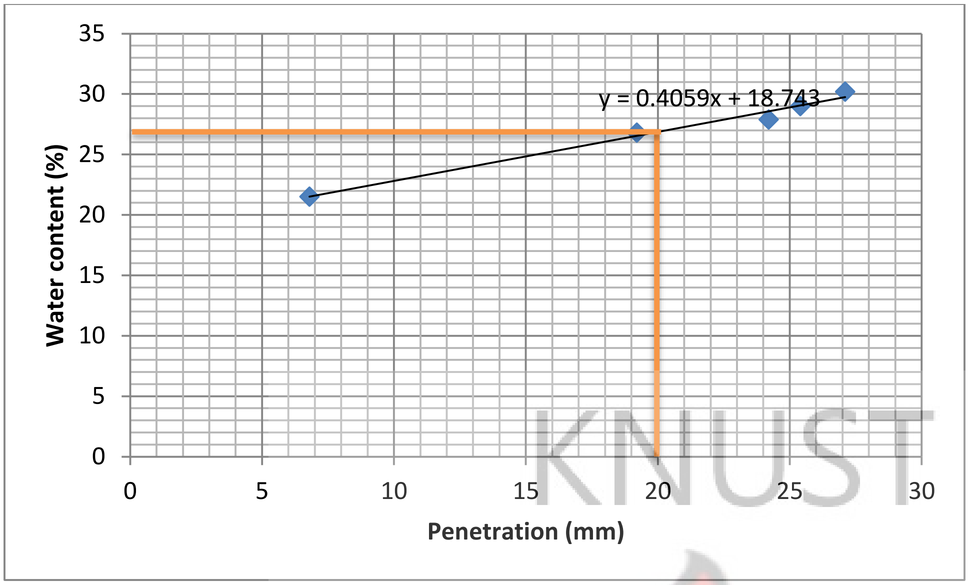

Figure 1.1: Atterberg Limits Test Results on Pipiiso Soil Sample

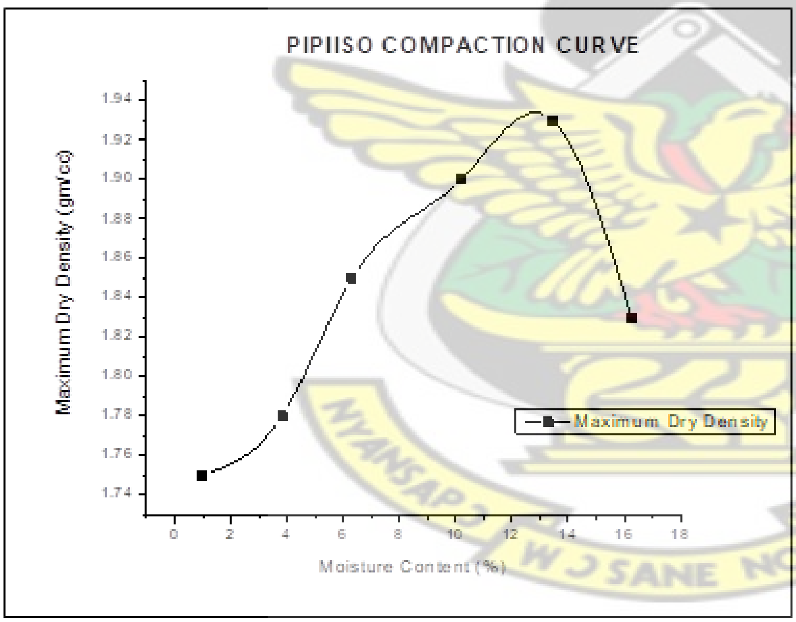

Figure 1.2: Dry density vs optimum moisture content curve on Pipiiso Bund soil sample

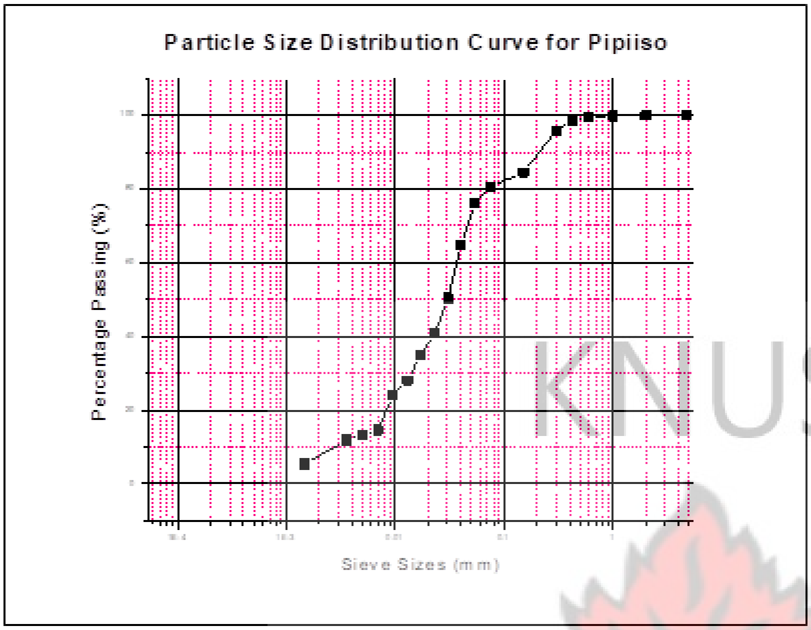

Figure 1.3: soil grading test analysis for Pipiiso field

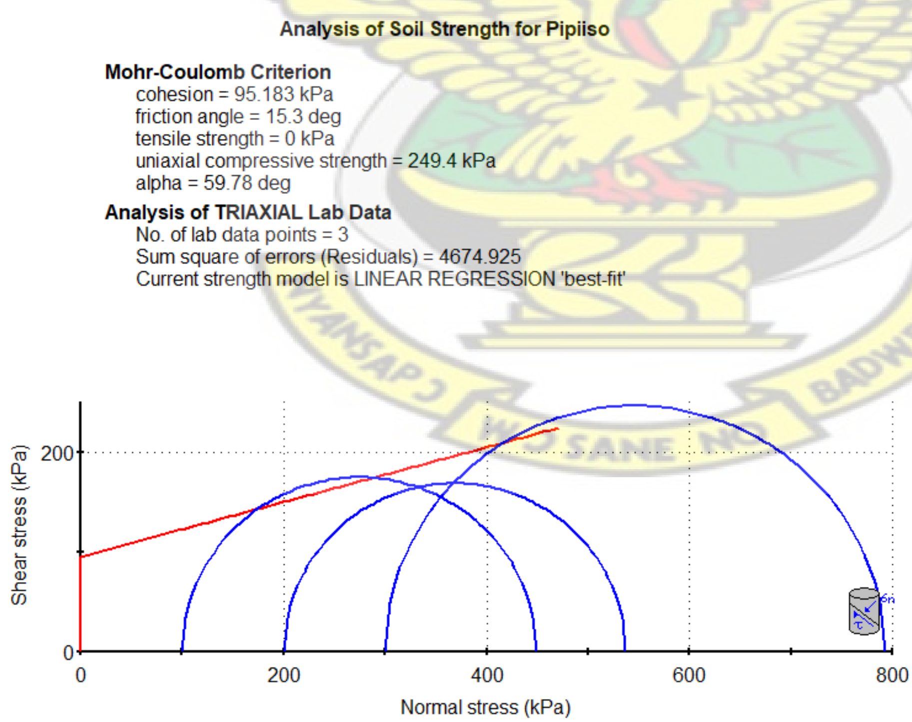

Figure 1.4: Analysis of soil strength for Pipiiso

APPENDIX 2: SOIL ANALYSIS FOR KUSA

FARMERS FIELD 2

LOCATION: Kusa

AREA OF FIELD 296.13m2

GPS N06*16.926' W001*30.209'

Table 2.1: Bulk density and moisture content test results for Kusa Bund

Sample Id	H4	X7	G6	H3	X5	H7	Q11	H16
Mass of soil (g)	619	638	591	556	586	661	626	589
volume (cm^3)	384.65	384.65	384.65	384.65	384.65	384.65	384.65	384.65
BULK DENSITY(g/cm^3)	**1.61**	**1.68**	**1.54**	**1.45**	**1.52**	**1.72**	**1.63**	**1.53**
moisture content								
mass of container (g)	25.7	25.6	25.39	25.64	25.29	25.31	25.24	25.42
mass of container & wet soil (g)	195.98	202.93	160.23	194.38	175.77	185.57	226.48	203.61
mass of container and dry soil	161.24	164.78	125.08	170.35	143.67	154.09	189.67	166.61
mass of wet soil	170.28	177.33	134.84	168.74	150.48	160.26	201.24	178.19
mass of dry soil	135.54	139.18	99.69	144.71	118.38	128.78	164.43	141.19
mass of water	34.74	38.15	35.15	24.03	32.1	31.48	36.81	37
Moisture content	0.26	0.27	0.35	0.17	0.27	0.24	0.22	0.26
% Moisture Content	26	27	35	17	27	24	22	26
DENSITY OF DRY SOIL(g/cm^3)	**1.28**	**1.30**	**1.14**	**1.24**	**1.20**	**1.38**	**1.33**	**1.21**

Table 2.2: Atterberg Limit Test Results on Kusa Soil Sample

Container no.	B24	A29	X11	C11	A25	C18	X3
Mass of container	3.68	3.58	3.76	3.62	3.77	3.75	3.75
mass of wet sample and container	19.12	31.01	26.67	32.41	26.1	18.44	19.83
mass of container and dry sample	14.59	22.48	19.43	22.87	18.58	15.28	16.37
penetration (mm)	10.7	18.4	21.8	25.9	27.9		
mass of water	4.53	8.53	7.24	9.54	7.52	3.16	3.46
mass of dry sample	10.91	18.9	15.67	19.25	14.81	11.53	12.62
percentage moisture content	41.52	45.13	46.20	49.56	50.78	27.41	27.42

liquid limit	46.12
plastic limit	27.41
plasticity index	18.71

Table 2.3: Soil compaction test results for Kusa Bund

Mass of container + wet sample (gm)	**5482**		**5591**		**5639**		**5744**		**5831**		**5897**		**5943**		**5958**		**5906**	
Mass of cylinder (gm)	4247		4247		4247		4247		4247		4247		4247		4247		4247	
Mass of wet sample	1235		1344		1392		1497		1584		1650		1696		1711		1659	
container ID	UB40	SSB	KC	C2	H17	AT	C1	KW	Q11	K20	G7	H7	B16	A	AYZ	BC	5Z	TX1
Mass of container + wet soil (gm)	79	105	108	97	87	88	80	114	115	101	116	136	125	117	108	129	121	104
Mass of container + Dry soil (gm)	78	103	104	94	82	83	75	105	105	92	102	119	106	100	91	107	97	85
Mass of container (gm)	25.7	25.9	24.5	25.5	24.5	25.4	25.5	26.0	25.2	25.4	25.1	25.3	25.2	24.8	26.3	25.7	25.7	25.6
Mass of water	1.0	1.3	3.9	2.8	4.6	4.5	5.4	9.1	10.7	9.8	14.2	17.2	18.8	17.1	17.3	22.0	23.3	18.7
Mass of dry sample	52.4	77.4	79.8	69.0	58.0	57.8	49.4	78.7	79.5	66.3	76.5	93.8	80.9	75.5	64.5	81.3	71.7	59.3
Percentage moisture content	1.9	1.7	4.9	4.0	7.9	7.7	10.9	11.5	13.4	14.7	18.6	18.3	23.2	22.6	26.7	27.0	32.4	31.5
Average moisture content	1.8		4.4		7.8		11.2		14.1		18.5		22.9		26.9		31.9	
Bulk density	1.4		1.5		1.5		1.7		1.8		1.8		1.9		1.9		1.8	
Dry density	1.3		1.4		1.4		1.5		1.5		1.5		1.5		1.5		1.4	
Height of mould	11.5																	
Diameter of mould	10																	
Volume of mould	903																	

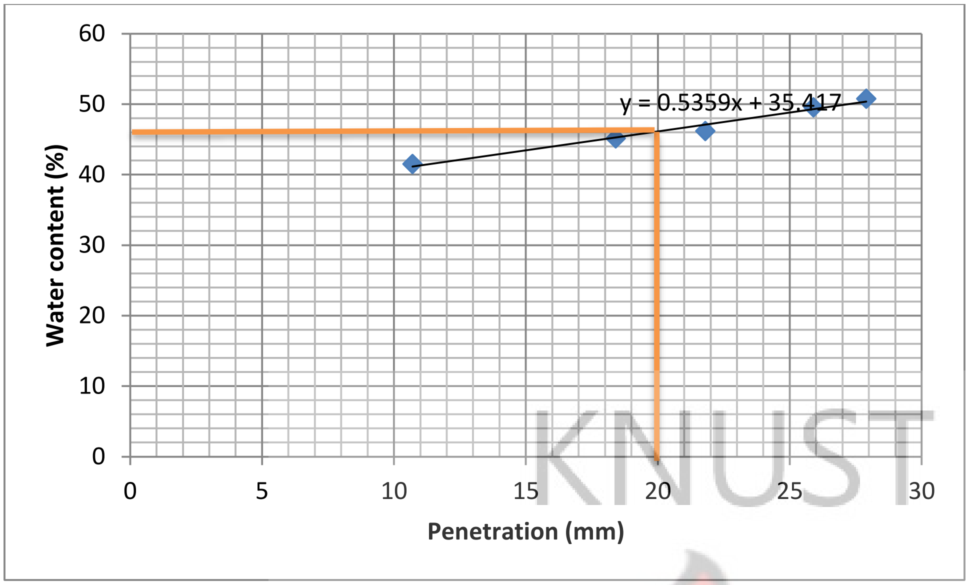

Figure 2.1: Atterberg limits test results on Kusa

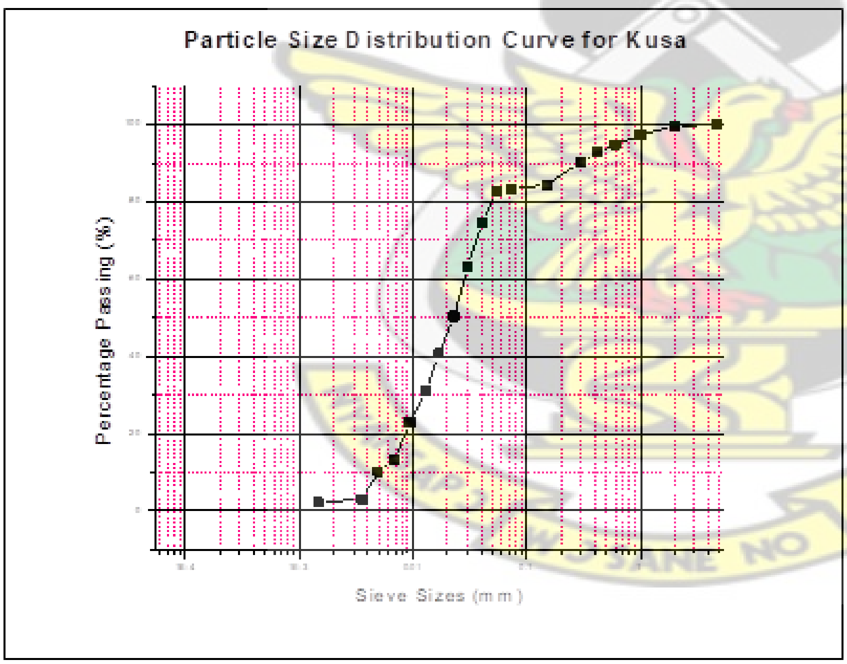

Figure 2.2: Soil grading test analysis for Kusa field

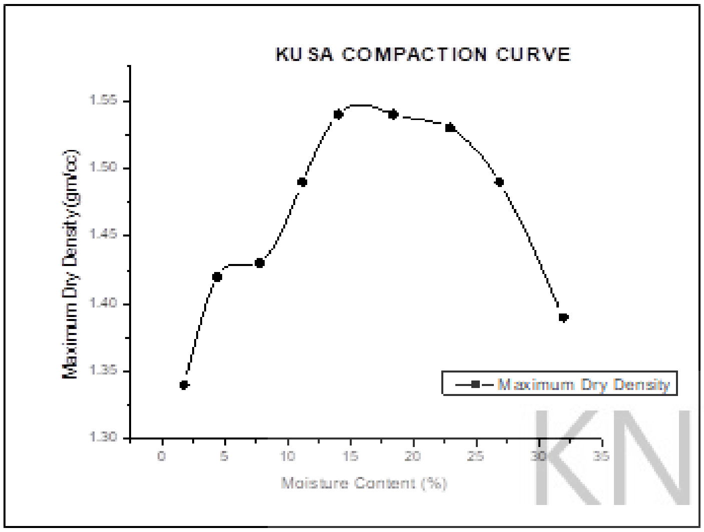

Figure 2.3: Soil compaction test results for Kusa Bund

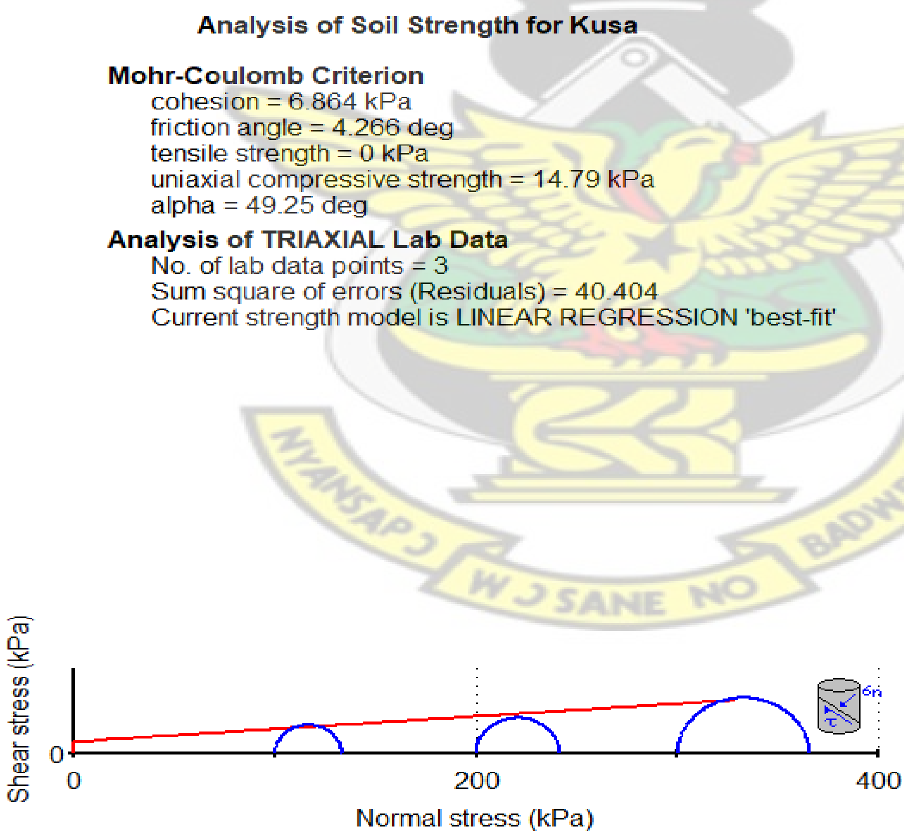

Figure 2.4: Analysis of soil strength for Kusa

APPENDIX 3: SOIL ANALYSIS FOR FUMSO BUND

FARMERS FIELD 3
LOCATION FUMSO
GPS N06*05.815' W0001*26.240'
AREA OF FIELD 505.15m²

Table 3.1: Bulk density and moisture content test result for Fumso Bund

Bulk density and moisture content						
Sample id	Q3	F9	AF	M2	q1	Q2
Mass of soil (g)	497	575	731	715	688	692
Volume (cm^3)	384.65	384.65	384.65	384.65	384.65	384.65
BULK DENSITY (g/cm^3)	**1.29**	**1.49**	**1.90**	**1.86**	**1.79**	**1.80**
Moisture content						
Mass of container (g)	25.45	25.81	26.11	25.86	26.07	25.54
Mass of container & wet soil (g)	221.66	224.06	205.64	214.6	226.28	190.83
Mass of container and dry soil	170.06	198.74	163.92	176.79	187.18	160.82
Mass of wet soil	196.21	198.25	179.53	188.74	200.21	165.29
Mass of dry soil	170.76	172.44	153.42	162.88	174.14	139.75
Mass of water	25.45	25.81	26.11	25.86	26.07	25.54
Moisture content	0.15	0.15	0.17	0.16	0.15	0.18
% Moisture Content	14.90	14.98	17.02	15.88	14.97	18.28
DENSITY OF DRY SOIL(g/cm^3)	**1.12**	**1.30**	**1.62**	**1.60**	**1.56**	**1.52**

Table 3.2: Atterberg limit test results on Fumso soil sample

Atterberg limit test							
Container no.	A4	X17	B38	K7	A37	A39	C6
Mass of container	3.73	3.53	3.86	3.76	3.72	3.72	3.63
Mass of wet sample and container	27.53	30.63	45.52	37.39	33.95	14.22	13.6
Mass of container and dry sample	22.33	24.3	35.52	29.13	26.33	12.7	12.11
Penetration (mm)	12.7	18.5	24	26.2	29.5		
Mass of water	5.2	6.33	10	8.26	7.62	1.52	1.49
Mass of dry sample	18.6	20.77	31.66	25.37	22.61	8.98	8.48
Percentage moisture content	27.96	30.48	31.59	32.56	33.70	16.93	17.57

Liquid limit	32.20
Plastic limit	17.25
Plasticity index	14.95

Table 3.3: Soil Compaction test result for Fumso Bund

Compaction Test Results												
Mass of container + wet sample (gm)	5735		5831		5954		6062		6155		6107	
Mass of cylinder (gm)	4247		4248		4249		4250		4251		4252	
Mass of wet sample	1488		1583		1705		1812		1904		1855	
Container ID	KW	SSB	G10	G7	Qz	K20	BK1	BC	H17	Q11	TX1	7Z
Mass of container + wet soil (gm)	90.5	107.7	91.8	99.3	90.5	87.0	102.3	90.8	104.6	99.8	124.3	133.0
Mass of container + Dry soil (gm)	90.1	107.1	89.7	96.9	86.3	83.1	95.4	84.7	94.8	90.6	109.2	116.6
Mass of container (gm)	26.0	26.0	25.3	25.1	25.8	25.4	25.4	25.7	24.6	25.6	25.6	25.4
Mass of water	0.4	0.6	2.1	2.4	4.1	3.9	6.9	6.1	9.8	9.2	15.1	16.5
Mass of dry sample	64.2	81.2	64.4	71.9	60.6	57.7	70.0	59.0	70.3	65.0	83.6	91.2
Percentage moisture content	0.6	0.7	3.3	3.3	6.9	6.7	9.9	10.3	13.9	14.2	18.1	18.0
Average moisture content	0.7		3.3		6.8		10.1		14.0		18.1	
Bulk density	1.6		1.8		1.9		2.0		2.1		2.1	
Dry density	1.6		1.7		1.8		1.8		1.8		1.7	
Height of mould	11.5											
Diameter of mould	10											
Volume of mould	903											

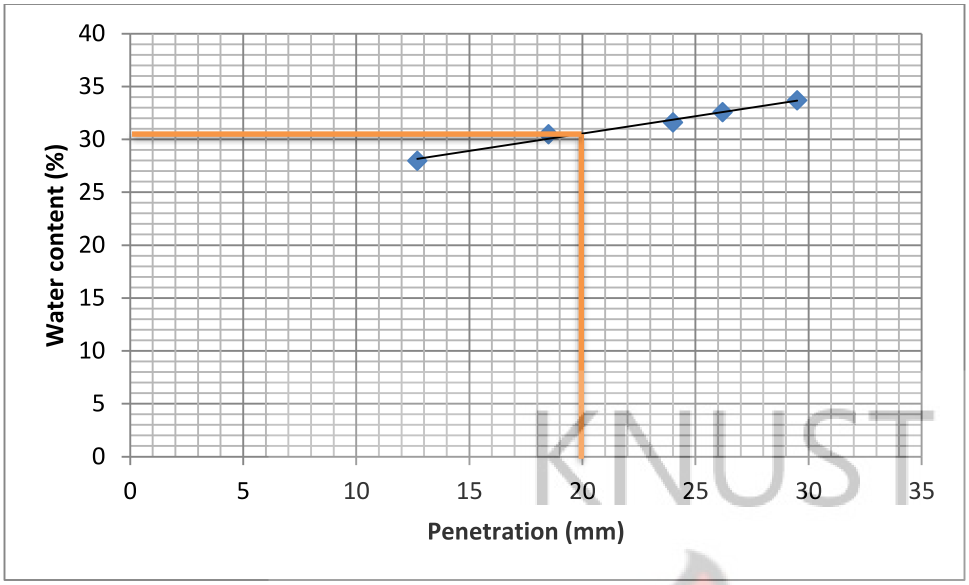

Figure 3.1: Atterberg Limits Test results on Fumso

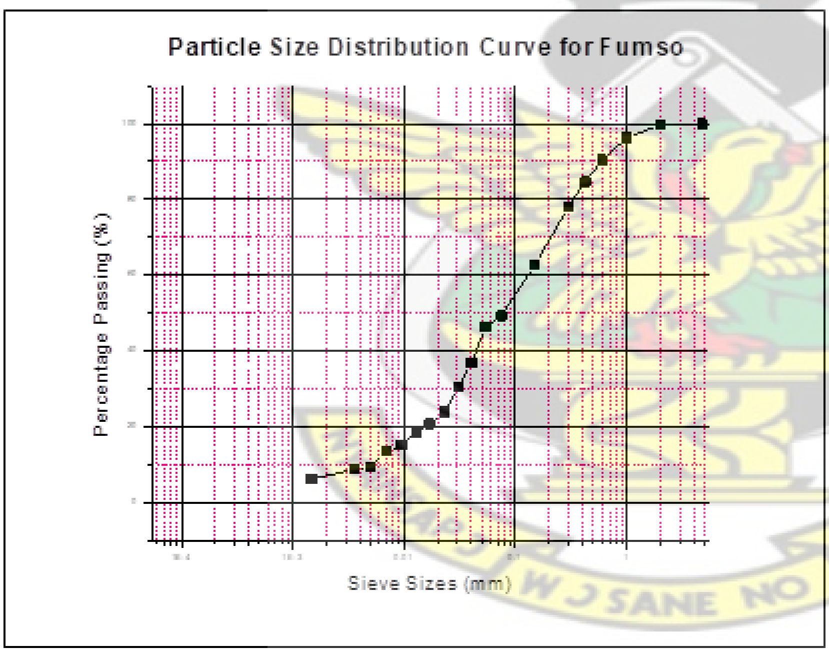

Figure 3.2: Soil grading test analysis on Fumso field

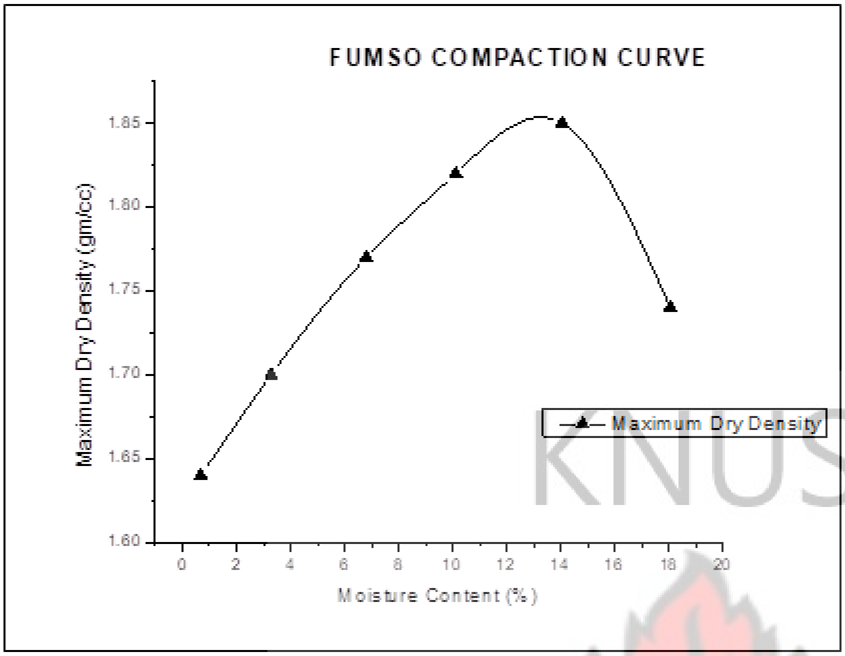

Figure 3.3: Soil compaction test result on Fumso Bund

Analysis of Soil Strength for Fumso

Mohr-Coulomb Criterion
cohesion = 52.661 kPa
friction angle = 3.469 deg
tensile strength = 0 kPa
uniaxial compressive strength = 111.9 kPa
alpha = 48.46 deg

Analysis of TRIAXIAL Lab Data
No. of lab data points = 3
Sum square of errors (Residuals) = 2827.945
Current strength model is LINEAR REGRESSION 'best-fit'

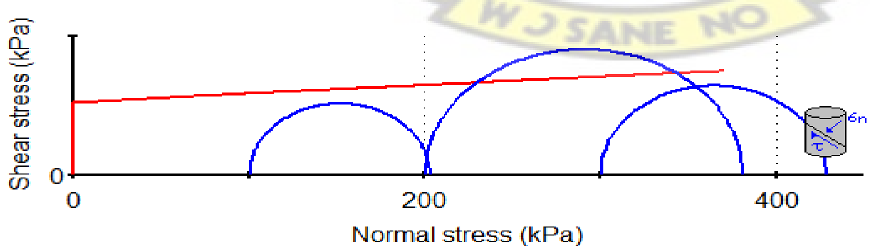

Figure 3.4: Analysis of soil strength for Fumso

APPENDIX 4: SOIL ANALYSIS OF RESEARCH FIELD 1 AND 2

Table 4.1: Bulk density and moisture content test result for Research Field 1

Bulk Density And Moisture Content Determination					
sample id	**sample1**	**sample2**	**sample3**	**sample4**	**sample5**
Mass of soil (g)	642	619	616	623	556
Volume (cm^3)	384.65	384.65	384.65	384.65	384.65
BULK DENSITY(g/cm^3)	**1.669**	**1.609**	**1.601**	**1.620**	**1.445**
Moisture content					
Container ID	ED	I4	J2	C18	XB2
Mass of container (g)	19.4	18.15	18.16	17.97	20.44
Mass of container & wet soil (g)	115.73	111.03	122.4	118.26	101.32
Mass of container and dry soil	93.49	84.89	93.54	95.56	84.36
Mass of wet soil	96.33	92.88	104.24	100.29	80.88
Mass of dry soil	74.09	66.74	75.38	77.59	63.92
Mass of water	22.24	26.14	28.86	22.7	16.96
Moisture content	0.30	0.39	0.38	0.29	0.27
% Moisture Content	30.02	39.17	38.29	29.26	26.53
DENSITY OF DRY SOIL(g/cm^3)	**1.28**	**1.16**	**1.16**	**1.25**	**1.14**

Table 4.2: Bulk density and moisture content test result for Research Bund 2

Sample Id	Sample1	Sample2	Sample3
Mass of soil (g)	614	633	690
Volume (cm3)	384.65	384.65	384.65
BULK DENSITY(g/cm3)	**1.596**	**1.646**	**1.794**
Moisture content			
Container ID	J6	NZ	D4
Mass of container (g)	17.9	18.23	18.27
Mass of container & wet soil (g)	81.92	98.57	108.96
Mass of container and dry soil	68.6	77.31	88.43
Mass of wet soil	64.02	80.34	90.69
Mass of dry soil	50.7	59.08	70.16
Mass of water	13.32	21.26	20.53
Moisture content	0.26	0.36	0.29
% Moisture Content	26.27	35.99	29.26
DENSITY OF DRY SOIL(g/cm3)	**1.26**	**1.21**	**1.39**

Table 4.3: Atterberg limit tests on soil samples for Research Field 1 and 2

Liquid Limit						
Container no.		A31	K3	N3	C10	A32
Mass of container	gm	3.51	3.62	3.76	3.74	3.73
Penetration	mm	10.1	15.1	20.1	25.2	28.4
Mass of container & wet sample	gm	20.97	21.24	23.65	23.15	26.09
Mass of container & dry sample	gm	15.74	15.73	17.05	16.5	18.1
Mass of water	gm	5.23	5.51	6.6	6.65	7.99
Mass of dry sample	gm	12.23	12.11	13.29	12.76	14.37
Water content	**%**	42.76	45.5	49.66	52.12	55.6

Plastic Limit					
Container no.	gm	G2	B9	LL	49.28
Mass of container	gm	3.79	3.58	PL	28.15
Mass of container & wet sample	gm	6.44	6.71	PI	21.13
Mass of container & dry sample	gm	5.86	6.02		
Mass of water	gm	0.58	0.69		
Mass of dry sample	gm	2.07	2.44		
Water content	%	28.02	28.28		
Average water content	**%**	28.15			

Table 4.4: Compaction Test result for Research field 1 and 2

Compaction test														
Mass of container + wet sample (gm)	5510		5598		5778		5910		5979		5982		5877	
Mass of cylinder (gm)	4255		4256		4257		4258		4259		4260		4261	
mass of wet sample	1255		1342		1521		1652		1720		1722		1616	
container ID	MK	AYZ	EB	H4	E2	F5	Q12	E3	TX1	H6	E10	X5	F1	P2
Mass of container + wet soil (gm)	121.01	127	122.68	92.1	109.41	106.9	116.89	112.7	152.1	142.42	141.37	118.12	128.73	138.43
Mass of container + Dry soil (gm)	115.54	121	113.32	86.16	99.18	95.93	102.83	99.19	134.09	120.5	114.06	96.63	101.77	108.81
Mass of container (gm)	25.7	26.1	26.37	25.6	25.17	25.82	26.18	25.32	25.58	25.37	25.95	25.31	25.73	25.36
Mass of water	5.47	5.86	9.36	5.94	10.23	10.95	14.06	13.53	18.01	21.92	27.31	21.49	26.96	29.62
Mass of dry sample	89.84	94.6	86.95	60.56	74.01	70.11	76.65	73.87	108.51	95.13	88.11	71.32	76.04	83.45
Percentage moisture content	6.09	6.20	10.76	9.81	13.82	15.62	18.34	18.32	16.60	23.04	31.00	30.13	35.46	35.49
Average moisture content	6.14		10.29		14.72		18.33		19.82		30.56	32.79	35.47	35.49
Bulk density	1.39		1.49		1.68		1.83		1.90		1.91		1.79	
Dry density	1.31		1.35		1.47		1.55		1.59		1.46		1.32	
Height of mould	11.5													
Diameter of mould	10													
Volume of mould	903.21													

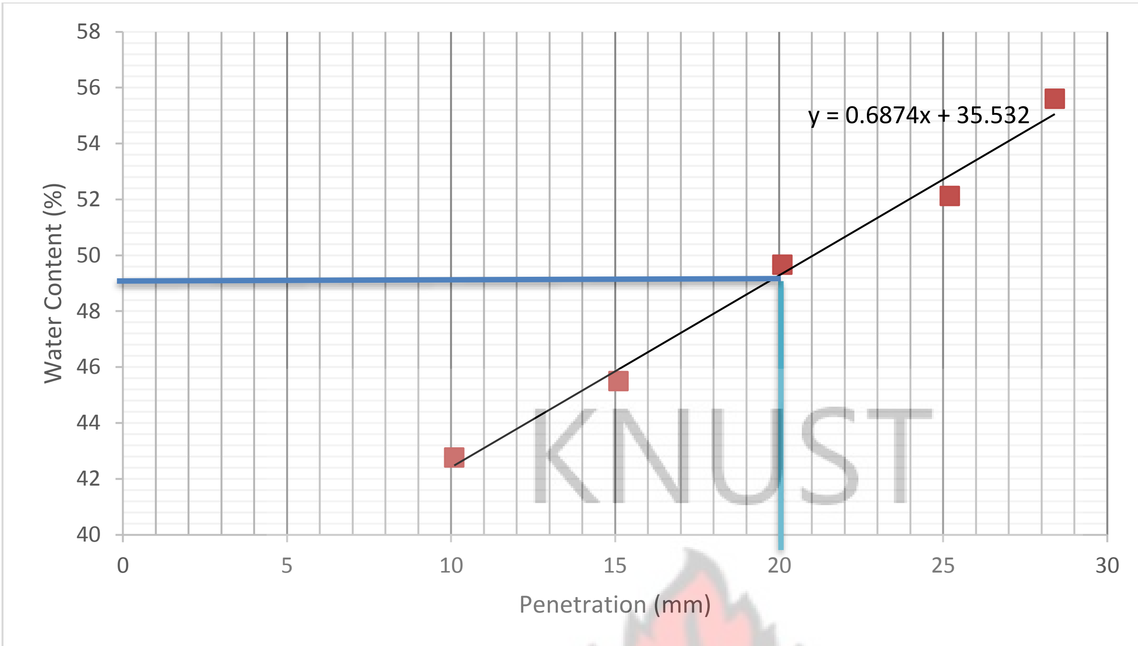

Figure 4.1: Atterberg Limits test results on Research Fields 1 and 2

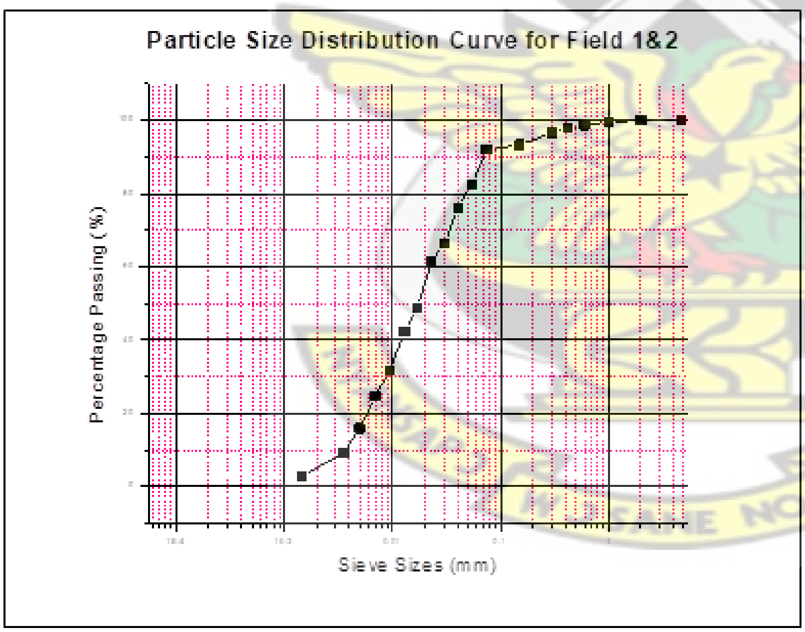

Figure 4.2: Soil grading test analysis for researcher field 1 and 2

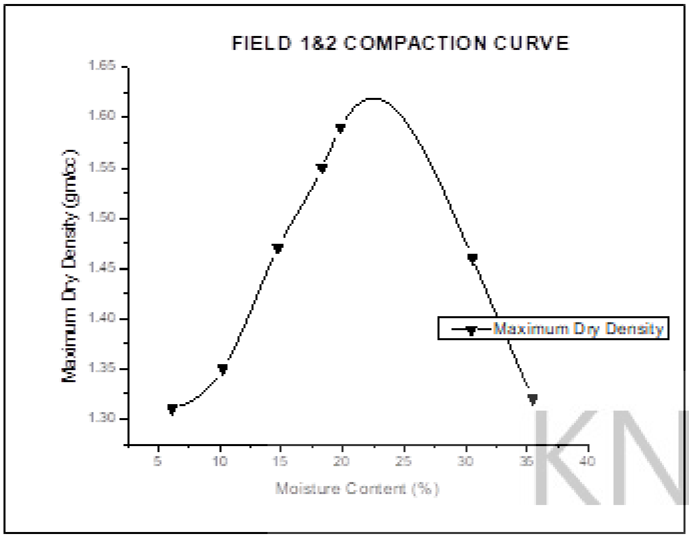

Figure 4.3: Soil compaction test result on Research field 1 and 2

Analysis of Soil Strength for Field 1 and 2

Mohr-Coulomb Criterion

cohesion = 103.152 kPa
friction angle = 4.23 deg
tensile strength = 0 kPa
uniaxial compressive strength = 222.1 kPa
alpha = 49.22 deg

Analysis of TRIAXIAL Lab Data

No. of lab data points = 3
Sum square of errors (Residuals) = 1303.311
Current strength model is LINEAR REGRESSION 'best-fit'

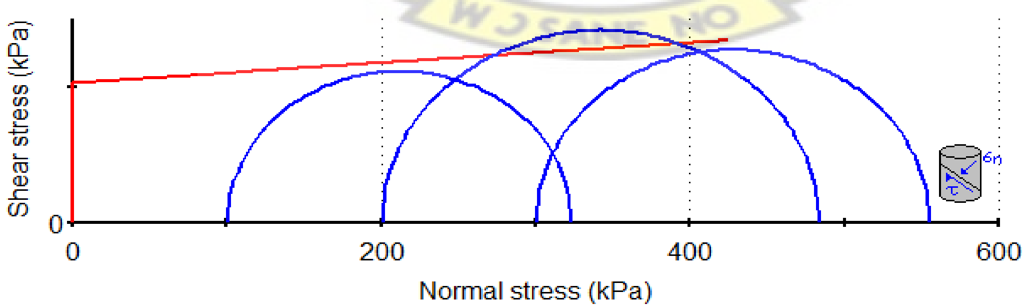

Figure 4.4: Analysis of soil strength for research field 1 and 2

APPENDIX 5: SOIL ANALYSIS OF RESEARCH FIELD 3 AND 4

Table 5.1: Bulk density and moisture content determination for Research field 3

Bulk density determination					
sample id	sample1	sample2	sample3	sample4	sample5
Mass of soil (g)	618	620	617	593	597
Volume (cm^3)	384.65	384.65	384.65	384.65	384.65
BULK DENSITY(g/cm^3)	**1.61**	**1.61**	**1.60**	**1.54**	**1.55**
Moisture content					
Container ID	73	NZ	ED	X4	I4
Mass of container (g)	18.21	18.3	19.38	18.36	18.17
Mass of container & wet soil (g)	141.05	137.61	114.63	145.92	113.14
Mass of container and dry soil	113.56	107.74	81.49	103.69	80.84
Mass of wet soil	122.84	119.31	95.25	127.56	94.97
Mass of dry soil	95.35	89.44	62.11	85.33	62.67
Mass of water	27.49	29.87	33.14	42.23	32.3
Moisture content	0.29	0.33	0.53	0.49	0.52
% Moisture Content	28.83	33.40	53.36	49.49	51.54
DENSITY OF DRY SOIL(g/cm^3)	**1.25**	**1.21**	**1.05**	**1.03**	**1.02**

Table 5.2: Bulk density and moisture content determination of Research field 4

Sample Id	Sample1	Sample2	Sample3
Mass of soil (g)	614	631	613
Volume (cm^3)	384.65	384.65	384.65
BULK DENSITY(g/cm^3)	**1.596**	**1.640**	**1.594**
Moisture content			
container ID	J6	NZ	D4
Mass of container (g)	17.9	18.23	18.27
Mass of container & wet soil (g)	81.92	98.57	108.96
Mass of container and dry soil	68.6	77.31	88.43
Mass of wet soil	64.02	80.34	90.69
Mass of dry soil	50.7	59.08	70.16
Mass of water	13.32	21.26	20.53
Moisture content	0.26	0.36	0.29
% Moisture Content	26.27	35.99	29.26
DENSITY OF DRY SOIL(g/cm^3)	**1.26**	**1.21**	**1.23**

Table 5.3: Atterberg limit tests on soil samples for research field 3 and 4

Liquid Limit							
Container No		A7	X3	K2	B17	X25	
Mass of container	gm	3.69	3.76	3.68	3.72	3.62	
Penetration	mm	12.2	17	21.4	26.5	29	
Mass of container & wet sample	gm	28.65	28.99	29	27.76	26.35	
Mass of container & dry sample	gm	20.72	20.65	20.17	19.14	18.15	
Mass of water	gm	7.93	8.34	8.83	8.62	8.2	
Mass of dry sample	gm	17.03	16.89	16.49	15.42	14.53	
Water content	%	46.56	49.38	53.55	55.9	56.43	

Plastic limit							
Container no		B37	A14			LL	51.62
Mass of container	gm	3.73	3.78			PL	32.14
Mass of container & wet sample	gm	8.6	8.11			PI	19.48
Mass of container & dry sample	gm	7.39	7.08				
Mass of water	gm	1.21	1.03				
Mass of dry sample	gm	3.66	3.3				
Water content	%	33.06	31.21				
Average water content	**%**	**32.14**					

Table 5.4: Compaction test results for Researcher field 3 and 4

Compaction test														
Mass of container + wet sample (gm)	5511		5646		5693		5791		5893		5917		5889	
Mass of cylinder (gm)	4255		4256		4257		4258		4259		4260		4261	
Mass of wet sample	1256		1390		1436		1533		1634		1657		1628	
Container ID	G4	G2	X7	G6	E8	E6	PB0002	E9	F4	q2	G9	G5	SD3	K4
Mass of container + wet soil (gm)	96.67	106	99.15	109.5	120.77	125	122.68	121.3	114.51	115.51	126.51	115.45	115.86	113.55
Mass of container + Dry soil (gm)	90.26	98.3	90.75	99.46	106.45	111.2	107.02	105.1	97.39	98.5	104.02	94.93	92.3	90.49
Mass of container (gm)	26.3	25.7	25.59	25.9	25.47	25.36	25.54	26.27	26.21	25.09	25.67	25.57	25.52	25.97
Mass of water	6.41	7.35	8.4	10.01	14.32	13.83	15.66	16.12	17.12	17.01	22.49	20.52	23.56	23.06
Mass of dry sample	63.96	72.6	65.16	73.56	80.98	85.81	81.48	78.86	71.18	73.41	78.35	69.36	66.78	64.52
Percentage moisture content	10.022	10.1	12.891	13.61	17.683	16.12	19.219	20.44	24.052	23.171	28.705	29.585	35.28	35.741
Average moisture content	10.07		13.25		16.90		19.83		23.61		29.14		35.51	
Bulk density	1.39		1.54		1.59		1.70		1.81		1.83		1.80	
Dry density	1.26		1.36		1.36		1.42		1.46		1.42		1.33	
Height of mould	11.5													
Diameter of mould	10													
Volume of mould	903.21													

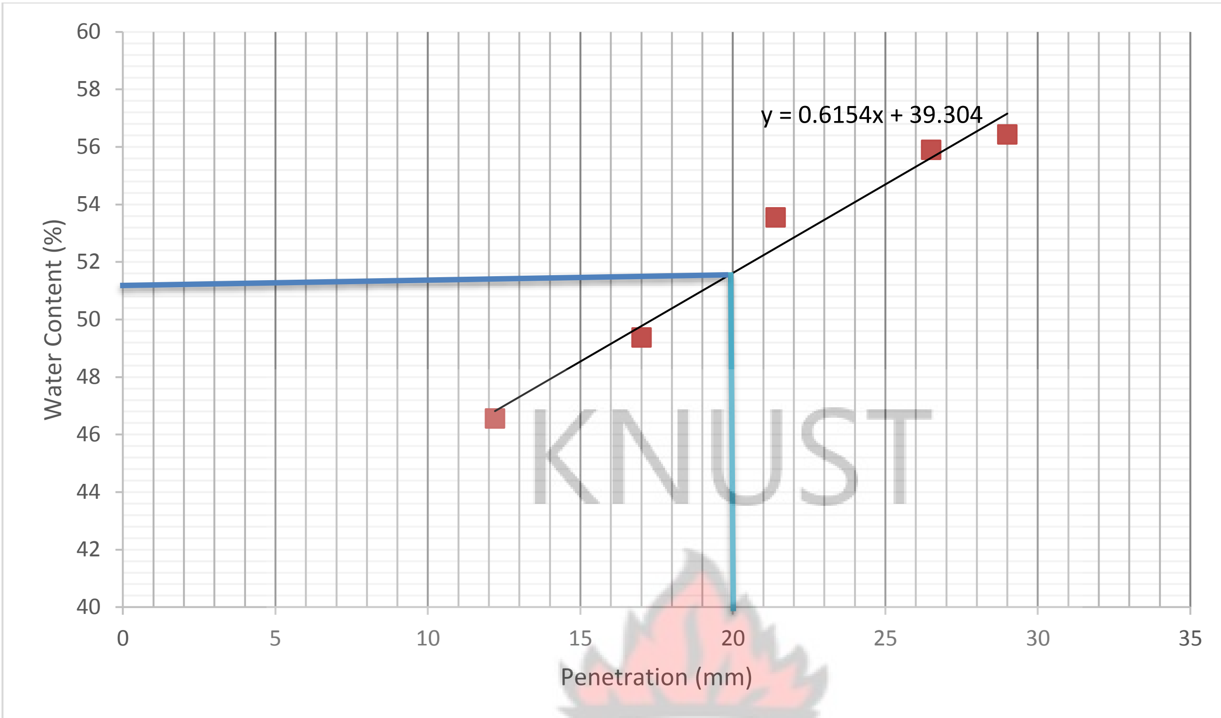

Figure 5.1: Atterberg Limits Test results on Research Fields 3 and 4

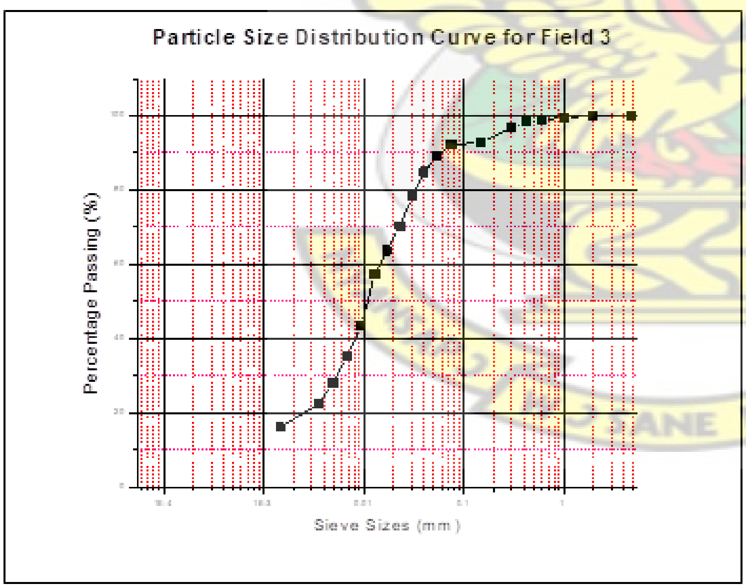

Figure 5.2: Soil grading test analysis on Research field 3and 4

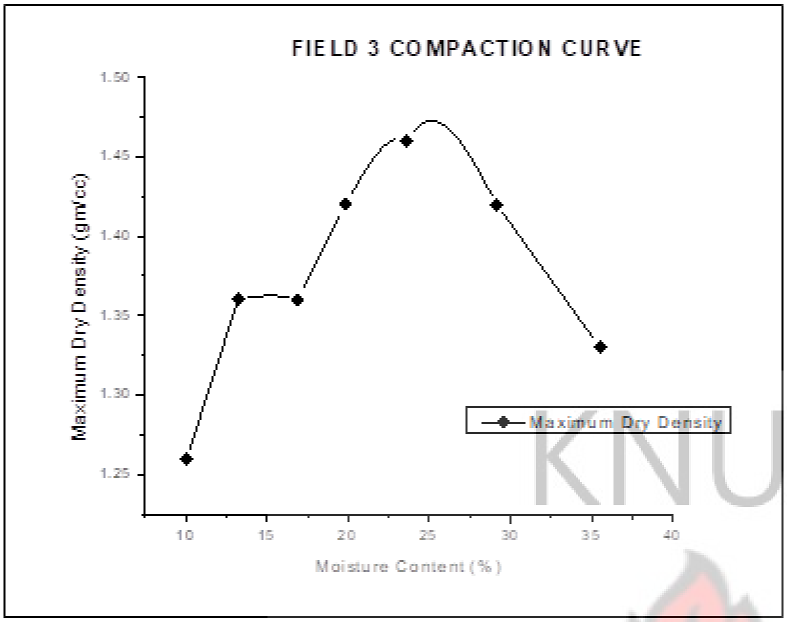

Figure 5.3: Soil compaction test results on research field 3 and 4

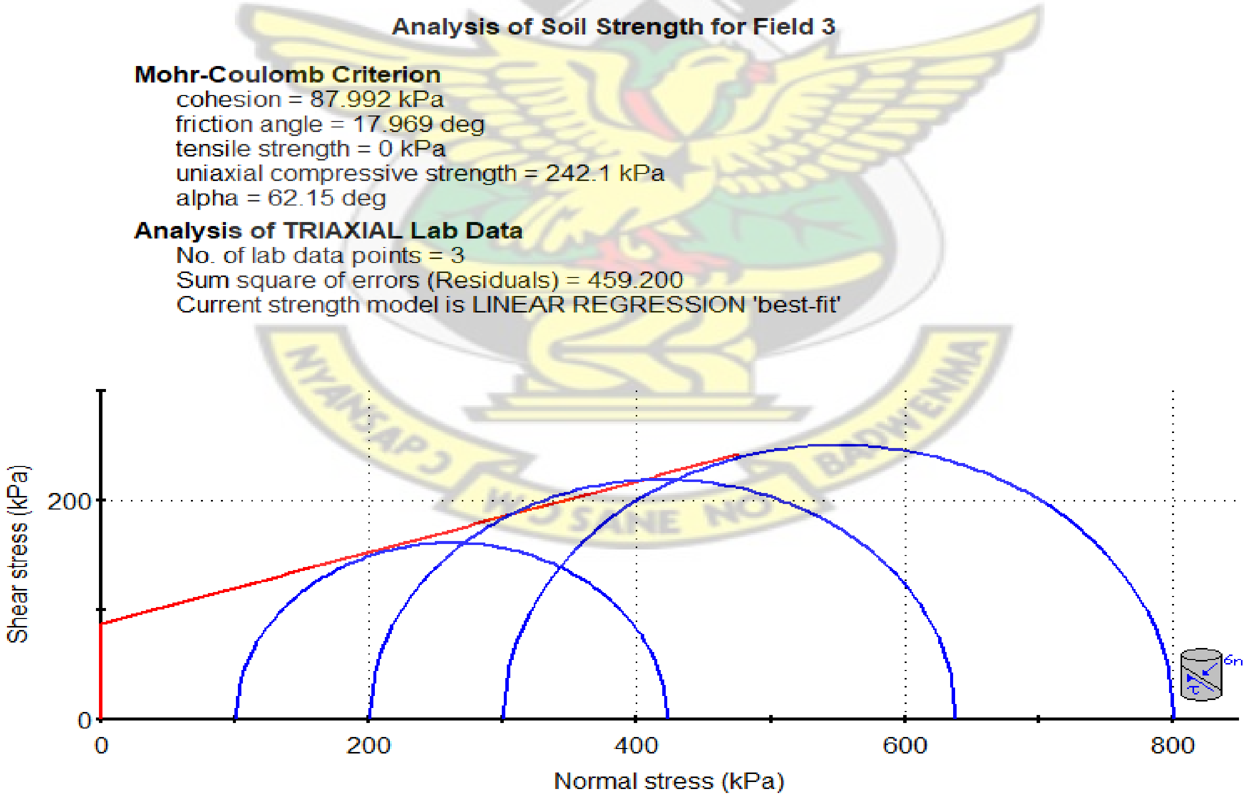

Figure 5.4: Analysis of strength for field 3 and 4