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SOIL DISPLACEMENT USING DISC PLOUGH IN A CLAYEY LOAM SOIL

BY

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DECLARATION

I, EUNICE DAZUGO, do hereby declare that this work, SOIL DISPLACEMENT USING DISC PLOUGH IN CLAYEY LOAM SOIL, with the exception of the cited references, was written and submitted by me in the University of Ghana from AUGUST 2015 to MAY 2016, under the supervision of Dr. Aliu. A. Mahama and Dr. Malcolm Josiah.

I further declare that this work has not been submitted to University of Ghana or any other university.

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ABSTRACT

Soil displacement by tillage is a major contributor to the redistribution of soil particles within the soil profile. The extent of soil redistribution eventually has an effect on the performance of crop production. It is, therefore, valuable to investigate soil displacement by disc plough since it is known to be the widely used primary tillage implement in Ghana. Consequently, a study was conducted at the Livestock and Poultry Research Centre of the University of Ghana (LIPREC) with a tractor - disc plough aggregate. Using three ploughing speeds (5km/hr, 7km/hr and 9km/hr) and three ploughing depths (12cm, 15cm and 18cm), a 3^2 factorial experiment was designed for this study. The essential soil and tracer characteristics were verified. The movement of tracers inserted into the soil measure soil displacement in the x-y-z coordinate directions. The data was statistically analysed to establish the effects of ploughing speed and depth on soil displacement.

Results from our experimental study showed that on the average the disc plough tillage moved soil particles through a distance of 59.8 ± 12.5cm. Ploughing speed and depth had significant effects ($p \leq 0.05$) on soil displacement by the disc plough. Increasing ploughing speed generally led to increase in soil displacement with a wider mix. The study also showed that most of the tracers were spread within the region of 12cm above to 6cm below the original surface of the field. The disc plough mixes majority of the transported soil particles within this region of the tilled layer. At higher speed of 9km/hr the displaced soil particles were highly mixed within this region whiles at 5km/hr the displaced soil particles were concentrated within the upper 6cm.

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DEDICATION

I dedicate this thesis to the Almighty God who has been my pillar throughout this journey.

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I would like to reflect on the people who have supported and helped me so much throughout the course of my research.

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LIST OF SYMBOLS

D – Calculated displacement distance (cm)

$H_{1,2,3}$ – Depth of cut (cm)

M_b – Mass of bead (g)

W_s – Moisture content of soil sample (%)

M_c – Mass of empty moisture can (g)

M_d – Mass of oven dried soil sample and moisture can (g)

M_s – Mass of moisture can and sieved soil sample (g)

M_w – Mass of wet soil sample and moisture can (g)

$S_{1,2,3}$ – Ploughing Speed (km/hr)

ρ_s – Bulk Density of Soil (kg/cm^3)

ρ_b – Density of Bead (kg/cm^3)

V_b – Volume of Bead (cm^3)

h – Height of cylindrical soil core sampler (cm)

r – Radius of cylindrical soil core sampler (cm)

x – Tracer coordinate perpendicular to line of draft in the horizontal plane (cm)

y – Tracer coordinate along the line of draft in the horizontal plane (cm)

z – Tracer coordinate perpendicular to line of draft in the vertical plane (cm)

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CHAPTER 1

INTRODUCTION

1.1 Background

A major challenge facing the agricultural sector in Ghana is food insecurity. Ghana is not able to produce enough food to feed its people and this has led to over dependence on imported food (Rakotoarisoa et al., 2011). This tends to impact negatively on the Ghanaian economy and ultimately the livelihoods of individuals and families. Therefore, more food needs to be produced at lower costs and in a sustainable manner to help solve this problem. One of the surest ways in achieving this is through effective mechanization (Darfour and Rosentrater, 2016).

Agricultural mechanization involves the use of agricultural machinery to undertake farm operations in order to improve timeliness and efficiency of these operations. Additionally, it aids human labour so as to increase overall output economically and also ensures environmental protection. Operations in crop production where farm machineries are used include land preparation, planting, cultivation, fertilizer application and harvesting.

In recent years, the agricultural sector in Ghana has seen an increased demand for mechanization. Most of this demand concentrates on land preparation, using tillage implements such as disc ploughs and mouldboard ploughs till the land to create a favourable soil physical environment for crop production. (Houssou et al., 2013)

Tillage is the manipulation of the soil from a given or known condition into a desired condition by mechanical means. The desired conditions vary according to need, which includes pulverising, cutting, inverting or moving the soil (Alam, 1989). Some of the tillage

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implements that are used include the mouldboard plough, disc plough, harrows, tillers, sub soilers, cultivators etc.

A study by FAO (1998) revealed that the most prevalent primary tillage implement used in Ghana is the disc plough aggregation and this has not changed till date. Thus, disc ploughing has a wide application in Ghanaian farming operations. The disc plough operates by cutting, lifting and throwing to one side a layer of soil (furrow slice). It is adapted for use in hard, dry soils or bushy lands with rocks or stumps. More attention, therefore, needs to be focused on disc ploughs in soil and tillage researches in Ghana since it is the widely used tillage implement in Ghana.

Whenever a farm implement is passed through the soil, there is a reaction between the implement and the soil. The soil reacts to this implement-soil interaction through actual physical displacement. This interaction between the implement and the soil is a dynamic process.

The dynamic response of the soil to the implement is the main factor in determining its performance. There are many factors that affect the performance of a disc plough. These factors can be divided into three: soil, plough and mode of operation. Soil variables include: soil moisture content, organic matter, soil penetration resistance, soil bulk density and structure. Plough variables include: plough weight, disc angle, tilt angle, radius of curvature and disc diameter. Mode of operation variables include: forward speed, width of cut and ploughing depth. (El-Shazly et al, 2008).

Each time a farm implement engages the soil, the soil particles are displaced from their original positions. The soil particles move in various directions and through various distances. Soil movement by tillage operations, mostly, occur in two directions; that is the vertical movement and the horizontal movement of soils (Lobb, 2008). In seedbed

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preparations for example, soil is intended to move in the vertical direction to loosen up the soil and also to break - up large clods in order to optimize soil - to - seed contact; soil however, moved in both directions during this process.

Some tillage operations are carried out with the specific objective of moving soil vertically. Operations are also carried out to move soil solely in the horizontal direction; such practices include ridging or bedding (Lobb, 2008). Nonetheless, soil movement whether horizontally or vertically leads to soil variability on the field, as well as, modification of the soil profile.

In any soil profile, there are distinct layers of the various soil constituents. The concentration of soil constituents vary with depth. When an implement engages the soil during tillage operations, the soil particles are displaced from their original position due to soil movement. Depending on the ploughing depth, there is transfer of subsoil, as well as, surface soil, leading to a redistribution of the soil constituents (Li, 2006). The soil profile, therefore, changes after the passage of tillage implement. The manner in which the soil profile changes depend also, on the type of implement passed through the soil.

Soil redistribution after tillage has been studied for mouldboard plough through studies of changes in soil profile. A number of research have been done in the area of soil movement, but most of these studies were concentrated on slopes and with implements such as chisel plough, mouldboard plough, harrow etc. Furthermore, changes in the soil profile have been evident using mouldboard plough (De Alba et al., 2004). However, there has not been any account of similar study for the disc plough in Ghana. Since disc plough is the predominantly used primary tillage implement in Ghana, there is the need to study what happens to the soil particles in terms of displacement when the disc plough is passed through the soil for the benefit of the crop.

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Several methods (trench, the step and the tracer) have been used by researchers to quantify soil movement with the tracer method as the most widely used method. In the tracer method, motion detection units (tracers) are inserted into the soil at certain depths and the soil ploughed with a tillage implement. A review of literature on examples of tracers used some soil movement studies include aluminium cubes (Heckrath et al., 2006; Van Muysen et al., 2000, 2002, 2006), small pebbles or stones (Dercon et al., 2007 ; Zhang et al., 2004) , steel bolts (Lindstrom et al., 1990) and plastic spheres with metal core (Govers et al., 1994). After ploughing, the new positions of the tracers are measured and correlated to soil movement (Sharifat, 1999).

The tracer method was chosen for this study and the tracers used were coloured beads with densities similar to the density of the soil at the study field.

1.2 Problem Statement

Even though we have different types of primary tillage implements, disc ploughs are the widely used tillage implements in Ghana. In view of this, some studies have been done on the disc plough and its effect when used. In these researches, problems associated with the disc plough were mentioned and one of such studies was done by the FAO (1998). It was reported that deep ploughing was one of the few problems associated with soil tillage in Ghana (FAO, 1998). Deep tillage involves ploughing with a tillage implement to depths greater than 25cm (Unger, 1979). Even though deep tillage is known to have some useful effects under specific soil conditions, it also has adverse effects on the quality of soil and eventually on the crop yield (Mckenzie, 2010). If that is the case one would suggest 'why not stick to ploughing at shallower ploughing depths' in order to avoid the negative effects of deep ploughing.

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To probe this question further, it was found in a study by Mahama and Mensah (1997) where limitations of depth of cut in relation to top soils were researched. It was recorded that when the disc plough cuts at a smaller depth, large portion of unploughed lands are left and when it cuts too deep it cuts some of the subsoil instead of just the topsoil as desired. One has to be careful not to cut too deep, but there is a limitation to this. The depth of top soils in most parts of the West African sub region has been defined to be 15cm by (Ahn, 1977). For the disc plough with 55cm diameter to plough and not leave some unploughed land, it has to plough as deep as 22cm. This implies that the till layer would go beyond the top soil. Hence, mixing up with the subsoil and affecting the quality of the tilled layer. Soil undergoes a lot of changes during tillage depending on several factors. These changes either have a positive or negative impact on the soil and eventually the crop. Van Muysen et al. (2000) recorded that, tillage causes movement of the topsoil along with the implement for a certain distance. The extent of movement depends on some factors including slope gradient, speed and depth of cut. Variations in soil constituents after redistribution of soil depend also on the extent of movement of the soil particles. This study, similar to other research on soil movement by tillage was focused on sloping land. Since most agricultural lands in Ghana are characterized by gentle slopes less than 1% (MOFA, 2013), it would interest the agricultural engineer or farmer to know the extent of soil movement, as well as, the factors that affect soil redistribution on gentle lands.

Also, though the changes that occur in the soil profile after ploughing with different types of mould board ploughs have been made evident, none has been recorded for the disc plough. The dynamics of soil in the cutting process of a disc plough, where the soil particles change their positions has not been made clear in order to relate them to some of the problems investigated concerning disc ploughs in Ghana. It is, therefore, necessary to know how soil

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particles are displaced in the vertical direction by disc plough tillage because this knowledge will help to provide information on how the soil profile has been modified.

1.3 Objectives of study

This study, therefore, seeks to investigate the displacement of soil particles after passage with a disc plough. Information from this study will help our farmers or machinery operators, by guiding them to plough at optimum ploughing depths and speeds.

The overall objective of this research is to study the effect of tillage speed and depth on soil displacement by the disc plough on clayey loam soil in Ghana.

The specific objectives are to;

- Measure soil displacement after tillage with a disc plough.
- Study the effects of different forward speed and depth of cut on soil displacement by tillage with a disc plough.

1.4 Expected Outcome (Contribution to knowledge)

Information from this research will aid in guiding farmers to plough at the optimum depth and forward speed in a particular soil condition. Information from this research can be utilized in the development of a working model to demonstrate the effect of operational parameters on soil displacement by tillage.

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CHAPTER 2

LITERATURE REVIEW

2.1 Background

The population of Ghana was estimated to be 25.9 million as at 2013.Out of this number, the agricultural sector employs about 54.1% (FAO, 2015). This indicates that almost half of the national workforce is engaged in agricultural activities; including crop and animal production, harvesting, processing, sales and marketing of agricultural produce.

Economic indicators show that the agricultural sector accounts for about 23% of the national Gross Domestic Product (GDP) (GSS, 2015). This finding makes it evidently clear that agriculture plays a very significant role in the growth and development of the Ghanaian economy. Though a large number of Ghana's population are involved in agriculture, their contribution to the nations GDP is low. This implies that with agricultural productivity being low; Ghana is not secure when it comes to production of domestic foodstuff to feed its citizenry. We rely heavily on food imports from other countries to compliment the insufficient food produced. In spite of these challenges facing the agricultural sector, it would keep on playing a very crucial part in improving food security and sustaining economic development in the country. One sure way to achieve agricultural growth and development is by increasing investments in agriculture, as well as, adopting the use of improved technology.

Therefore, for a rapidly growing population like Ghana's, there is the need to boost agricultural productivity and this can be achieved by applying appropriate farm mechanization practices. Agricultural mechanization can radically change the present state of agricultural production in Ghana and enhance economic growth as well.

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In recent years, there has been an increase in the demand for agricultural mechanization in Ghana. (Diao et.al , 2014). Mechanization in agriculture involves the use of farm implements or machines to ensure timeliness of farm operations with the ultimate aim of increasing efficiency of agricultural productivity. Mechanization is employed in several farm operations including land preparations, sowing or planting, irrigation, plant protection (mechanically), manure and fertilizer application, harvesting, transportation, storage and processing. Among all the farm operations, tillage is recorded as the most demanded mechanized operation in Ghana (Houssou et al., 2013). According to Diao et.al (2014), presently, demand in mechanization in Ghana is focused on tractorized ploughing. And it is most prevalent in the Northern and Brong-Ahafo regions where availability of land is high and the ratio of land to farm labour force is high, as well. They also stated that the demand of other mechanized farm operations such as planting, and harvesting will only emerge if agricultural land productivity and farm profits are enhanced.

Tillage is the manipulation of the soil through mechanical means. The objective of tillage varies according to need which includes pulverising, cutting, inverting or moving the soil. Tillage is grouped into two; primary tillage and secondary tillage. Primary tillage implements include mouldboard plough, disc plough, chisel plough, tillers. Secondary tillage implements include harrows, cultivators and ridgers. In Ghana, the disc plough is known to be the predominantly used primary tillage implement. Hence, it requires that more tillage research should be geared towards the usage of disc ploughs in order to improve its performance in accordance with conditions of Ghana.

According to Liu et al. (2007) tillage implements like most soil engaging tools cause movement of soil, which affects the draft requirement of the implement. Sharifat (1999) also stated in his study that ‘the search for efficient crop production led to investigation of soil response to tillage tools and soil-machine behaviour’. Since tillage is regarded as the most

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energy intense operation, not all the energy transferred to the soil results in useful work. This could be attributed to the outcome of interactions between the soil and machine.

2.2 Soil Displacement by Tillage tools.

Soil particles are subject to movement when they are disturbed by both human and natural processes. Human processes such as tillage operations and natural soil particle moving operations by the action of wind, water also displaces soil.

When an implement engages the soil during tillage operations there is soil movement and this is as a result of the application of force by the implement. The soil particles move in various directions. Movement of tillage implement causes the direct movement of the soil particles located right in front of it in the direction of travel of the tool, whereas, other particles are caused to move in the perpendicular direction (Sharifat, 1999). These movements could be in the horizontal direction. The horizontal movement of soil by tillage is characterized in some cases by the amount of soil that is moved as well as how far it is moved. Information on the extent of soil translocation is important in assessing the rate and extent at which soil constituents are dispersed. Much of the dispersed soil is not only redundant but can contribute to soil erosion (Lobb, 2008).

INTEGRI PROCEDAMUS

Research have been done in the area of soil movement by tillage tools. It was reported by Van Muysen et al. (2000), that the study of the movement of soil material due to tillage began in 1934. They also reported that soil is moved in the direction of tillage when using mouldboard plough and higher tillage speeds result in larger lateral displacements.

Sharifat (1999) studied soil translocation by some tillage tools in a soil bin. The tillage implements initially used were 300 mm wide sweep and a 14 mm Conserva-Pac knife opener,

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followed by four different narrow tines. Soil translocation was measured by the displacement of small plastic blocks positioned in the soil. His result showed an exponential relationship between soil movement and depth. He developed a mathematical model for soil movement with speed of operation of the tillage tool since it was difficult to model soil parameters. The predicted soil movement correlated well with the experimental data.

Van Muysen et al. (2000) conducted a study to investigate the effect of variations in chisel tillage depth and tillage speed on net soil displacement and the associated tillage erosion rates for up slope and down slope on a loamy soil under two different soil conditions. The first condition was primary pass on a consolidated soil under stubble vegetation and the second condition was a secondary pass on a freshly tilled loosened soil. Numbered aluminium cubes were inserted into the soil for the measurement of soil translocation. The experimental results showed that soil condition, tillage depth, tillage speed and slope gradient are functions of the average displacement distance and concluded that chisel tillage in the Belgian Loam Belt was very erosive.

Van Muysen et al. (2002) investigated the effect of variations in tillage speed and depth on net soil displacement and the associated tillage erosivity for mouldboard tillage in two contrasting directions. The results showed that the average soil displacement distance is not only a function of slope gradient, but it is also strongly affected by tillage speed and tillage depth. Van Muysen et al. (2006) also studied the effect of a typical tillage sequence, including multiple mouldboard, chisel and harrow passes, on soil translocation and tillage erosion during a period of 3 years and observed that soil translocation was in excess of 10m. In another study on tillage translocation and tillage erosion in cereal- based production in Manitoba, Canada by Li (2006), translocation caused by four tillage implements was examined. It was determined that secondary tillage implements could be as erosive as primary tillage implements.

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It was noted, however, from the above soil displacement studies that, almost all of them where concentrated on slopes using other tillage implements and none was related to disc plough tillage.

Soil movements by tillage do not only lead to the redistribution of soil throughout the field or landscape, it also redistributes the soil within the profile (Papiernik et. al, 2007). The soil profile comprises of distinct layers of soil constituents such as soil nutrients and soil water which differ according to depth. The percentage of soil nutrients for example is higher in the topsoil region than in the subsoil. Depending on the tillage implement used, the soil profile could change, thus the topsoil could be transferred to the subsoil region or be mixed up, thereby, diluting and compromising the nutrient quality of the soil. The modifications made to the soil profile due to its redistribution by tillage eventually affect the yield.

Detailed studies about the changes that occur in the soil profile after tillage with different types of mould board plough had already been done (Figure 1). However, none has been recorded for the disc plough and so this raises a question ‘What are the changes that occur in the soil profile after tillage with the disc plough?’ This has to be answered since disc plough is the most widely used tillage tool in Ghana.

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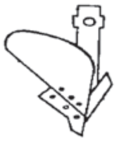
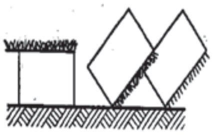
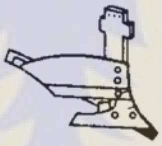
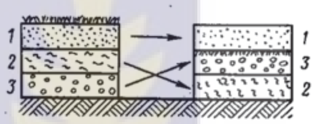
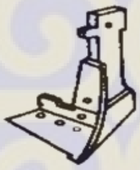
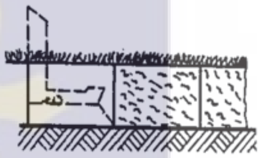
Type of Tillage Implement	Pictorial View	Soil Profile after Passage of Implement
Typical Mouldboard plough		
Slatted Mouldboard Plough		
Mouldboard plough without the mouldboard component		
Disc Plough		?

Figure 1. Profiles of some primary tillage implements

Even though, disc plough is the widely used primary tillage implement in Ghana, just a little is known about the effect the tool has on soil movement in other to relate it to its performance. Amongst the very few researches in the area of disc plough tillage and its effect in usage, Mahama and Mensah (1997) conducted a study and reported that ploughing with a disc plough can leave some of the land unploughed and this depends on the depth of cut of

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the plough. Thus, the percentage of unploughed land depends on the depth of cut, as well as, the disc diameter (Table 1).

Table 1. Untouched land percentage with varied disc diameter and depth of cut

Disc Diameter D cm	**Untouched land 'η' percent at varied depth**			
	10cm	15cm	20cm	25cm
66	65.4	42.2	31.7	25.4
60	75.0	50.0	37.6	30.1
55	92.7	61.8	46.4	37.0

(Source: Mahama and Mensah, 1997)

Ahn (1977) reported that the average depth of topsoil in the West African sub-region is 15cm. This suggests that if the disc plough works within a depth of 15cm with a disc diameter of the range 66-55cm, it is going to leave about 42.2 to 61.8% of unploughed land depending on the disc diameter used.

Another question is raised as to how the tractor operator should plough so that the redistribution of the soil doesn't highly affect the profile of the soil by causing so much variability. Studying soil displacement by disc plough will aid in finding solutions to some problems associated with the usage of disc ploughs.

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CHAPTER 3

MATERIALS AND METHODS

MATERIALS

3.1 Site

The study was conducted at The Livestock and Poultry Research Centre, University of Ghana. This is approximately 15 kilometres from the main campus of university. The dominant soil in this area is clayey soil.

3.2 Tracer Selection

Soil displacement is normally measured using the tracer method, where tracers are inserted into the soil in plots perpendicular to the direction of tillage. After the tillage operation the new positions of the tracers are located and their displacements from the initial positions are then measured. There are different types of tracers used in tillage translocation studies. In soil movement studies where tracers are used, the movement of the tracers are assumed to be similar to the soil clods. Hence the bulk density of the soil must correlate to that of the tracer being used.

Beads were used as tracers in this study. They are normally used as ornaments for the waist, wrist and neck in some traditions in Ghana. They are manufactured with several kinds of materials such as glass, plastic and ceramics. This choice was made after a number of considerations. They were selected based on the fact that they were easy to handle, harmless, readily available and their presence in the soil was easily detected.

Prior to choosing the type of beads, soil samples were taken from the study field to determine their bulk densities. Five different kinds of beads with different material compositions, shapes and sizes were selected. The density of each tracer was then determined.

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Figure 2. Tracer Beads used in the study of soil displacement.

Coloured beads (red, yellow and white) of the appropriate density were used as tracers in the study (Figure 2).

3.3 Tractor

The tractor used in this study was a Massey Ferguson 375E 2WD wheel tractor with a 55.9 kW output power (Figures 3). The tractor was aggregated with a 3 bottom disc plough for the tillage experiment.

Figure 3. Massey Ferguson 375E tractor.

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3.4 Disc plough

A three bottom disc plough was aggregated to the tractor for use in this field study. The specifications of the disc plough are shown in Table 2.

Figure 4. Three Bottom Disc Plough

Table 2. Specifications of the Three Bottom Disc Plough

Nomination	Specification
Weight	420kg
Working width	750mm
Maximum working depth	250mm
Disc Diameter	660mm
Maximum Height	1220mm
Tractor compatibility	50-80hp
Bearings	Taper roller
Frame type	Angular Frame
Manufacturer	Shangdong Yuntai Machinery

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3.5 Wooden Soil Profiler

To determine the curvature of the study field and also to measure vertical coordinate displacement of the tracers in the 'z' direction, a profiler was fabricated for this study. It had several movable pointers in the vertical direction (Figure 5).

Figure 5. Field Data collection with Wooden Soil Profiler.

INTEGRI PROCEDAMUS

The following materials aided in measurements on the selected field; tape measure, marking pegs, hammer and profiler. The tape measure and marking pegs aided in measuring and marking the selected field for the experiment. The tape measure was also used in measuring horizontal coordinate displacement in the x and y directions.

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METHODS

3.6 Soil Bulk Density

The soil bulk density at the study site was verified, using the core method, to help in the selection of an appropriate tracer. Nine soil samples were taken randomly from the field using a cylindrical soil core sampler having a radius (r) of 5cm at the following depths; 10 cm, 15cm and 20cm. In taking the soil samples the soil core sampler was gently driven into the soil to a depth enough to fill the inner cylinder and carefully removed. Each of the five soil samples was then transferred into well labelled moisture cans. The mass of the moisture cans containing the soil samples were determined and recorded as M_w. The soil samples were oven-dried at 105°C for 24 hours. After oven-drying, the moisture cans were then put in a dessicator to cool for some time. The dried soil samples were removed from the dessicator, weighed and recorded as M_d. The volume of the core sampler was determined using the formula for calculating volume of a cylinder (πr^2h).

The soil bulk density was calculated using the formula below:

$$Soil\ Bulk\ density(\rho_s) = \frac{\mathrm{M_w} - \mathrm{M_d}}{\pi r^2 \mathrm{h}} \times 100. \qquad [1]$$

3.7 Soil Texture

Prior to the field experiment, the soil texture was determined to confirm the type of soil on the field using the hydrometer. Particle size analysis method was used to determine the texture. Ten soil samples were taken at random from field the using a core soil sampler at 20cm. The samples were then air- dried for 24 hours and then sieved through a 2mm sieve. Some quantity of the sieved sample (40g) were taken and weighed, each weighed sample was then put in a well labelled small container. One hundred millilitres (100 ml) of sodium hexametaphosphate

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(also known as 'cargon') was measured, poured into the containers with the sieved soil samples and they were tightly sealed. They were then placed in a mechanical shaker for one hour. After vigorously shaking the mixture for one hour, the each container was removed and emptied into a 1000ml measuring cylinder. Distilled water was added to the mixture in the cylinder till the 1000ml mark was reached. The mixture was then stirred thoroughly to achieve suspension of all the soil particles in the cylinder. The cylinders were then left to stand undisturbed for five hours. A calibrated hydrometer was lowered gently into each cylinder after the five hours. The hydrometer readings were taken when the hydrometer was unwavering. The level of the hydrometer above the meniscus in each cylinder was recorded as the hydrometer reading (H). Following the hydrometer reading, the soil in each cylinder was sieved using a 45µm sieve. The sieved soil was poured into pre- weighed (M_c) well labelled moisture cans.

They were then dried in an oven at 105°C for 24 hours, and weighed as M_s. The following formulae were used in determining the percentage particle size:

$$\text{Weight of Sand (g)} = M_s - M_c \qquad [2(a)]$$

$$Percentage\ weight\ of\ Sand\ \% = \frac{M_s - M_c}{40g} \times 100; \qquad [2(b)]$$

$$Percentage\ weight\ of\ Clay\ \% = \frac{H}{40g} \times 100; \qquad [2(c)]$$

$$Percentage\ weight\ of\ Silt\ \% = 100 - [(Clay\%) + (Sand\%)]. \qquad [2(d)]$$

3. 8 Soil Moisture Content

The moisture content of the soil on the field was determined to ensure it was in the recommended range for tillage using the oven dry method. Nine soil samples were taken from the field with the aid of a core sampler at the following depths; 10 cm, 15cm and 20cm. Each

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soil sample was then transferred into well labelled cans. The weight of the cans containing the soil samples were determined and recorded as M_w. The soil samples were put in an oven set at 105°C for 24 hours. After oven-drying, the moisture cans were then put in a dessicator to cool for some few minutes. The dried soil samples were removed from the dessicator, weighed and recorded as M_d.

The moisture content was calculated using the formula below:

$$MoistureContent(W_s) = \frac{M_w - M_d}{M_d} \times 100. \qquad [3]$$

3.9 Determination of Densities of Beads

The density of each of the five sampled beads was determined using the displacement method. This was to ensure that the appropriate one with density similar to the soil density was selected. The samples were purchased from the local Ghanaian market. Each sample was well labelled and weighed using an electronic weighing scale (figure 5) and recorded as M_b. To determine the volume of each of the sampled beads, a 5ml graduated cylinder was used. The graduated cylinder was filled with water to the 2.5ml mark and this was recorded as V_1. Each sample bead was gently submerged into the graduated cylinder and the new reading was recorded as V_2. The volume of the bead (V_b) is the volume of the displaced water.

The Density was calculated using the formula below:

$$Density\ of\ bead(\rho_b) = \frac{M_b}{V_2 - V_1} = \frac{M_b}{V_b} \qquad [4]$$

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Figure 6. Electronic Balance used in determining the mass of tracers.

The calculated density of each of the sampled beads was then compared to the averaged bulk density of the soil at the study field. The bead with its density approximately equal to the averaged bulk density was selected as the appropriate bead for this study.

3.10 Experimental Design and Procedure

To study soil displacement by disc plough and also to find the effect of ploughing speed and depth on soil displacement with disc plough, a 3^2 factorial experiment was designed. The field was divided into nine experimental plots, and each plot was subjected to different treatment combinations. (Table 3)

Table 3. Factorial Experimental Design (3^2)

FACTORS		**Depth of Cut , cm (H)**		
		12	**15**	**18**
Ploughing Speed, km/hr (S)	**5**	S_1H_1	S_2H_1	S_3H_1
	7	S_1H_2	S_2H_2	S_3H_2
	9	S_1H_3	S_2H_3	S_3H_3

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The length of each plot along the direction of tillage was 50cm and the width of each plot perpendicular to the direction of tillage was 110cm. The dimension of the plot width was selected based on the width of the disc plough used for the study. Holes were created and 27 tracers were inserted into the soil per plot. One tracer was inserted per hole. A total of 243 tracers were incorporated into the nine plots. The depth of placement of the tracers corresponded with the ploughing depth of the plot. For example, if Plot 1 was ploughed at a depth of 12cm, the tracers were also inserted at a depth of 12cm. The disc plough used for the study consisted of 3 discs which were 35cm apart. Hence the tracers were placed such that they were along the path of the disc, this was to ensure that the disc did not by-pass the tracers or to ensure that the disc actually displaced the tracers. Nine tracers were grouped together 5cm apart as illustrated in the field layout (Figure 7). The plots were ploughed at 3 different depths and 3 different speeds. The ploughing speeds used were **5, 7**and **9km/hr** (S_1, S_2 and S_3 respectively). This choice was based on the recommended field speeds for disc plough tillage by Sumner and Williams (2007) and the ploughing depths used were **12**, **15** and **18cm** (H_1, H_2, and H_3 respectively).

The tracers were numbered to aid in identification and the exact position of each tracer prior to the tillage was recorded in x-y-z coordinate directions.

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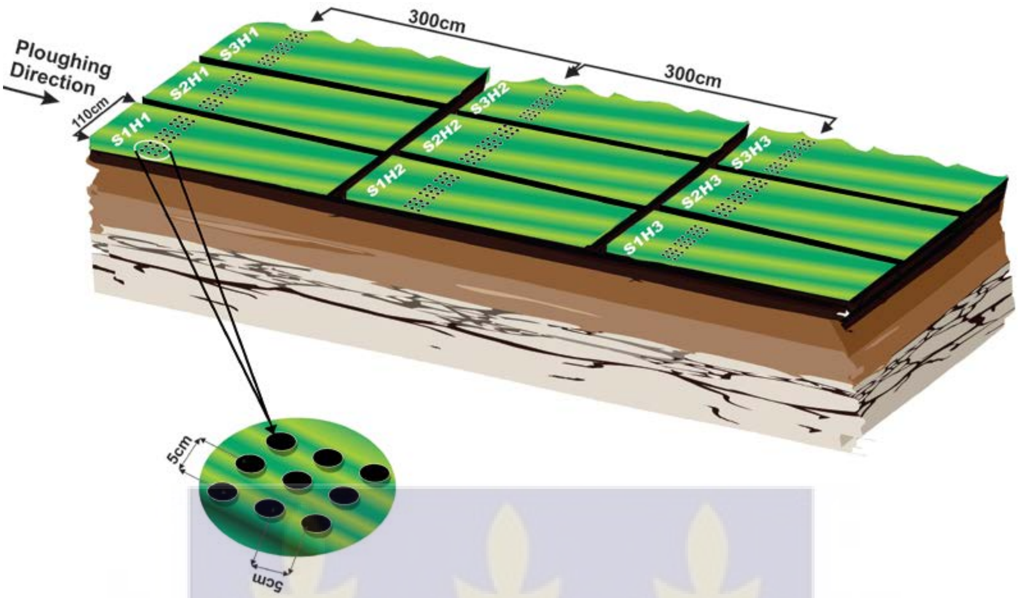

Figure 7. Field layout design

After establishing each plot the field was ploughed according to the sequence illustrated in Figure 7.

3.11 Soil Displacement Measurement.

After the field was ploughed, the new position of each tracer was located and recorded. Figure 8 shows a section of the ploughed field exposing some of the displaced tracers. The x-y-z coordinate position of each tracer was recorded accordingly (Figure 8). The x and y coordinates positions were recorded by measuring the length of displacement in the x and y direction from their original positions. Thus, how far the tracers moved from their original positions in the x and y directions. This was done using a tape measure. Whereas, measurement in the z direction for each tracer was done using the soil profiler. The soil profiler had pointers in the form of small canes which were movable in the z direction. By placing the base of the pointer on the tracer, the displacement in the z direction was read on a graph as the change in length of the pointer.

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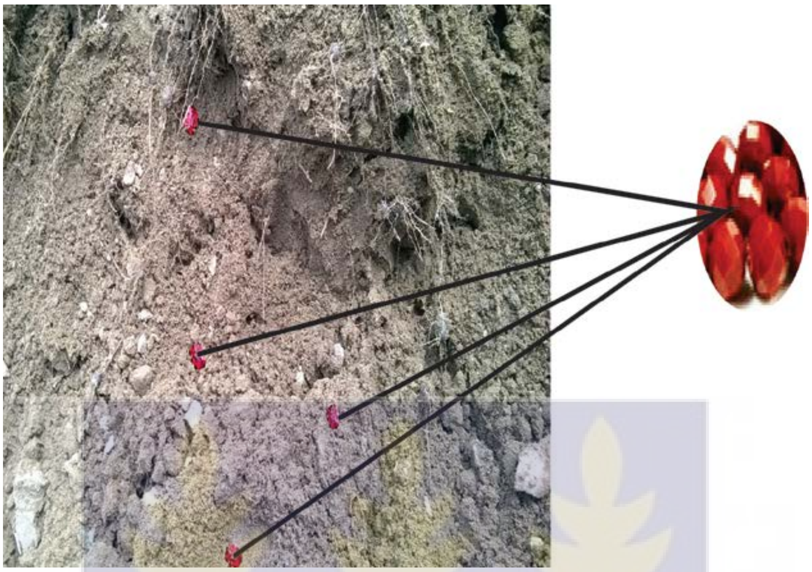

Figure 8. Section of ploughed land revealing some displaced tracers

Figure 9. Measuring the position (in x-y-z coordinate) of each displaced tracer

Figure 9 shows how the new position of one of the tracers was being measured in the x-y-z coordinate directions.

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3.12 Data Analysis

Using the x-y-z coordinates of the recorded positions (initial and final), the displacement distance of each tracer was calculated. The calculation was achieved by using the 3-dimensional displacement distance formula, given as;

$$Displacement\ distance(Dcm) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \qquad [5]$$

Where; $(x_1, y_1, z_1) = initial\ coordinate\ positions$

$(x_2, y_2, z_2) = initial\ coordinate\ positions$

After calculating the displacement distance for each tracer, the average displacement distances for each of the 9 plots were also calculated for further analysis.

Displacement measurements were taken for a total of 243 tracers and the data obtained was analyzed statistically. Data taken on the displacement distances were used to determine the averages ($\bar{x}$), variances (σ^2) and standard deviation (σ) which are indications of the variability in the data. The averages were estimated at 95% confidence level as ($\bar{x} \pm 2\sigma$).

An experimental 3^2 factorial design was used to study soil displacement. The data were analysed by using a two-way Analysis of Variance (ANOVA) to detect whether there was a significant difference between the means of the calculated displacement distances for the ploughing speeds, as a well as, the ploughing depth. The two-way ANOVA was chosen for this analysis because the experiment consisted of two factors (Ploughing speed and Depth).

A second two way ANOVA test was conducted to determine if ploughing speed affected the measured displacement values of each tracer in the vertical (z) direction.

The pattern of movement of the tracers correlates to the soil movement pattern. The tracer displacement pattern describes the conditions of the displaced soil in all the experimental plots on the field. The pattern of soil movement was determined using Teraplot Graph Software,

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Version 13. Through visual inspection of the trends of the plotted graphs, soil redistribution pattern in the vertical direction was predicted.

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CHAPTER 4

RESULTS AND DISCUSSION

The results of the laboratory tests to determine soil physical characteristics; bulk density, soil texture, and soil moisture content, as well, the results of the field experiments conducted during the study are presented and discussed in this chapter.

4.1 Soil Bulk Density

Determination of soil bulk density was extremely useful because it aided in the selection of the appropriate tracer for the field experiments. The results of the tests are represented in Table 4.

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Table 4. Bulk Densities of Soil Samples

Sampling depth(cm)	**Sample**	**Mass of wet soil, M_w(g)**	**Mass of dry soil, M_d(g)**	**Bulk density, ρ_s(g/cm^3)**	**Average**
10	1	234.81	200.95	1.71	1.76
	2	245.48	209.72	1.78	
	3	247.34	211.40	1.79	
15	4	253.88	215.86	1.83	1.79
	5	248.94	212.50	1.80	
	6	237.08	203.50	1.73	
20	7	245.01	210.00	1.78	1.80
	8	243.03	207.75	1.76	
	9	256.18	218.47	1.85	
	Average ($\bar{x}$)			**1.78**	
Standard Deviation (σ) = $\sqrt{\frac{1}{n}\sum_{i=1}^{n}(\rho_s - \bar{x})^2}$ =				**0.04**	

The dry bulk density of the study field was found to be 1.78 ± 0.1 g/cm^3($\bar{x} \pm 2\sigma$) (Table 4) Hence, the bead with density similar to the average bulk density of soil was selected for the experiments. Table 4 reveals that soil bulk density increased as the sampling depth increased from 10cm to 20cm. However, their differences are insignificant.

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4.2 Soil Texture

The fields where the field experiments were conducted are known to have a high clay composition. However, there was the need to be definite on this issue, hence some field tests were carried out. The study field was selected and soil texture analysis was performed on ten soil samples randomly taken from the selected field. The result obtained confirms a high clay and silt contents (Table 5).

Table 5. Particle Size Distribution of Soil Samples

Sample Replicates	**Soil Composition**		
	Clay (%)	Silt (%)	Sand (%)
1	35.00	27.00	47.15
2	30.35	29.15	40.50
3	36.70	30.05	33.25
4	36.70	30.05	33.25
5	36.35	35.20	28.45
6	30.74	33.96	35.30
7	32.00	24.85	43.15
8	29.55	28.40	42.05
9	35.25	29.45	35.30
10	30.48	22.52	47.00
Mean ($\bar{x}$)	**33.31**	**29.06**	**37.63**
Standard Deviation(σ)	**2.95**	**3.79**	**5.57**

The mean values of clay, silt and sand were 33.31, 29.06 and 37.63 respectively with standard deviations of 2.95, 3.79 and 5.57 respectively. Using the mean values to determine

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soil type with the soil classification chart illustrated in figure 10, the soil type was identified as clay loam / sandy clay loam.

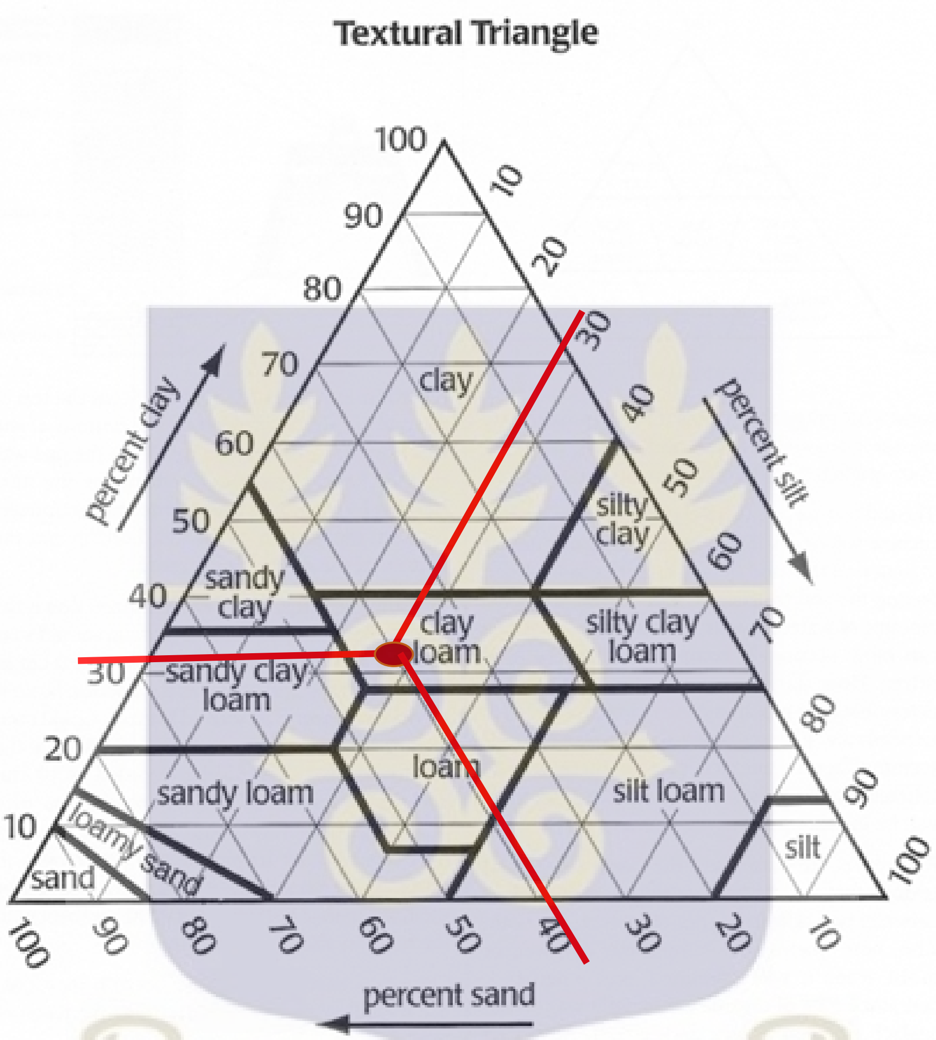

Figure 10. Soil classification chart showing the type of soil on the study field

4.3 Soil Moisture Content

To verify this, nine soil samples were taken randomly from the field and the soil moisture content determined. The results of the tests are represented in Table 6.

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Table 6. Moisture Content of Soil Samples

Sampling depth(cm)	Sample	Mass of wet soil, W_w(g)	Mass of dry soil, W_d(g)	Moisture content, W_s(%)	Average
	1	234.81	200.95	16.85	
10	2	245.48	209.72	17.05	
	3	247.34	211.40	17.00	16.67
	4	253.88	215.86	17.61	
15	5	248.94	212.50	17.15	
	6	237.08	203.50	16.50	17.09
	7	245.01	210.00	16.67	
20	8	243.03	207.75	16.98	
	9	256.18	218.47	17.26	17.00
Average ($\bar{x}$)				**17.00**	
Standard Deviation $(\sigma) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\mathbf{W}_{si} - \bar{x})^2}$				**0.31**	

With a 95% confidence level, the mean value of the moisture content of the soil on the study field falls within the limits; $\bar{x} \pm 2\sigma$. The moisture content test of the soil on the study field gave an average moisture content of 17.23 ± 0.62% (Table 6). This falls within the acceptable range for tillage in clayey loam soils, although it would have a slightly high coefficient of friction between the plough and soil according to the Bukhtin Theory (Listopad and Demidov, 1986) of frictional relationship with increasing moisture content of three major groupings of soil. The difference in moisture contents at the various sampling depths are also insignificant.

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4. 4 Determination of Bead Particle Density

The densities of the sampled beads are presented in Table 7. Sample 2 has a density of 1.68g/cm^3. This value falls within the range of 1.78 ± 0.1 g/cm^3 which is the average value of soil bulk density on the field. Sample 2 was, therefore, selected as the tracer for the study.

Table 7. Densities of Sampled Beads

Sample	Mass, M_b (g)	Volume, V_b(cm^3)	Density, ρ_b (g/cm^3)
1	3.85	1.50	2.57
2	1.35	0.80	1.68
3	2.55	1.30	1.96
4	3.50	1.50	2.33
5	1.40	1.00	1.40

The selected sample was manufactured with glass and had an oval-like shape.

4.5 Soil Displacement Distances

Soil displacement was evident with change in position of the tracers from their original positions to new positions after tillage with the disc plough. The x, y and z coordinate positions of each tracer before and after ploughing were recorded (Appendixes A, B and C). Using the initial and final (x, y and z coordinate) locations of the tracers, displacement distances of each individual tracer was calculated with (Equation 5). The average displacement distance for each plot was then determined. Table 8 shows a more

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comprehensive representation of the averaged displacement distances of 27 replicate tracers for each plot.

Table 8. Displacement Distances of the Experimental Designs

Plot Combinations	Average tracer displacement distance, D (cm)	Standard Deviation
S1H1	56.7	8.7
S1H2	54.1	11.2
S1H3	52.7	11.6
S2H1	64.5	12.7
S2H2	61.2	18.0
S2H3	53.2	8.9
S3H1	70.9	16.5
S3H2	65.0	21.3
S3H3	60.1	17.7
Ave. Total ($\bar{x}$)	**59.8**	**14.1**

Standard Deviation= $\sqrt{\frac{1}{n}\sum_{i=1}^{n}(D_i - \bar{x})^2}$ = **6.2**

The average calculated displacement distances for the experimental designs ranged between 52.7 and 70.9cm (Table 8) .This indicates that the tracers moved 52.7 to 70.9cm away from their initial positions along the direction of tillage. With a 95% confidence level, an overall average displacement distance of 59.8 ± 12.5cm for all the plots was obtained with the formula; $\bar{x} \pm 2\sigma$.

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Lobb(2008) conducted several studies on tillage translocation with various tillage implements (Table 9). Amongst the implements used, the chisel plough is seen to have the highest displacement where 90% of the translocated soil moved a distance of 209 cm.

Table 9. Tillage translocation of some operations

Plough Type	Tillage translocation: soil movement on level land	
	Ave. distance of soil movement in till layer, T_L(m)	Distance to which 90% of translocated soil is moved, λ_{90} (m)
Mouldboard	0.18	0.49
Chisel plough	0.29	2.09
Cultivator	0.19	1.41

(Source: Lobb, 2008)

The difference between Lobb's results and that of this study is due to the different implements used. They have different designs, hence vary in size and geometry and are also operated under different conditions. Furthermore, a careful look at the summary statistic of the averages of the calculated displacement distances (Table 8) shows that the average displacement distance for S_1 plots were the lowest whiles (S_3) plots had the highest readings. Hence it can be inferred that a higher ploughing speed results in higher displacement distances.

Variations are seen in averaged displacement distances of the tracers from plot to plot by visual inspection. Each plot was subjected to different treatments. Hence, for a more in-depth understanding of the observed variations, the data obtained were analyzed statistically using Analysis of Variance (ANOVA), with 95% Confidence Level.

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4.6 Analysis of Variance Tests

The first two–way ANOVA test (Table 10) was performed to evaluate the variations in the displacement data obtained. The factors of this two- way ANOVA test were the ploughing speed (S) and the depth of cut (H) of the disc plough. From the first ANOVA results (Table 11), it was seen that at a 95% Confidence Interval (CI), the p-value for speed (0.000195) was lesser than the set alpha value (0.05).This indicates that, there was significant difference between displacement distances for the three different ploughing speeds. Thus, the three different speeds (S_1, S_2 and S_3) did not yield the same displacement distances.

It can, therefore, be inferred that the ploughing speed has a highly significant ($p \leq 0.05$) effect on the distances at which the soil particles are moved by the disc plough.

The ANOVA test also showed that there was significant difference between the means of the displacement distances for the three different depths of cut (H_1, H_2, H_3) used in this experiment. From the ANOVA results it was deduced that at a 95% Confidence Interval (CI), the p-value for depth of cut (0.005783) was also lesser than the set alpha value (0.05). This result supports the claims that the depth of cut affects the distance over which soil particles are displaced by tillage.

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Table 10. Variations in the calculated displacement distances

Factors		H_1	H_2	H_3	Total
	Replicates	27	27	27	81
S_1	Sum	1530.50	1461.05	1530.50	4522.05
	Average	56.69	54.11	56.69	55.83
	Variance	76.89	126.32	76.89	92.52
	Replicates	27	27	27	81
S_2	Sum	1741.91	1652.78	1437.34	4832.02
	Average	64.52	61.21	53.23	59.65
	Variance	161.51	323.04	79.00	205.86
	Replicates	27	27	27	81
S_3	Sum	1914.86	1755.43	1622.10	5292.39
	Average	70.92	65.02	60.08	65.34
	Variance	271.39	454.58	314.44	358.03

Table 11 .Results of First Analysis of Variance Test

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Factor A(Speed)	3709.639	2	1854.819	8.86029	0.000195	3.03441
Factor B(Depth)	2205.582	2	1102.791	5.26793	0.005783	3.03441
Interaction	1321.269	4	330.317	1.57789	0.180934	2.41022
Within	48985.72	234	209.341			
Total	56222.21	242				

SS= Sum of squares; df= degree of freedom; MS= Mean of squares; F= calculated F-test value; P-value = probability value; F crit= F-test value from Fisher's distribution table

In order to determine whether the ploughing speed has any effect on the measured vertical displacement of the tracers (the extent to which the tracers were displaced in the vertical direction) another ANOVA test was conducted. Table 12 shows the mean values of the

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measured vertical displacement distances of the tracers and Table 13 is the table of the ANOVA results obtained.

Table 12. Variations in mean values of the measured vertical displacement distances

Factors		$H_1(z)$	$H_2(z)$	$H_3(z)$	Total
S_1	Replicates	27	27	27	81
	Sum	469.69	367.31	507.12	1344.12
	Average	17.40	13.60	18.78	16.59
	Variance	16.73	16.07	31.61	25.79
S_2	Replicates	27	27	27	81
	Sum	427.72	358.70	501.94	1288.36
	Average	15.84	13.29	18.59	15.91
	Variance	39.73	41.39	25.90	39.53
S_3	Replicates	27	27	27	81
	Sum	608.93	496.16	449.76	1554.85
	Average	22.55	18.38	16.66	19.20
	Variance	22.28	26.98	12.82	26.38

Table 13. Results of Second Analysis of Variance Test

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Speed	488.1145	2	244.0573	9.40317	0.000118	3.034414
Depth	572.3452	2	286.1726	11.0258	2.65×10^{-5}	3.034414
Interaction	692.2061	4	173.0515	6.66742	4.25×10^{-5}	2.410222
Within	6073.418	234	25.9547			
Total	7826.084	242				

SS= Sum of squares; df= degree of freedom; MS= Mean of squares; F= calculated F-test value; P-value = probability value; F crit= F-test value from Fisher's distribution table

From the result of the second ANOVA performed on the measured displacement distances data, it was seen that at 95% confidence Interval, there was significant difference between the means of the measured vertical displacement distances for the nine experimental plots. At a 95% Confidence Interval (CI), the p-value for speed (0.000118) was lesser than the set alpha value (0.05). This further indicates that, the ploughing speed has a highly significant ($p \leq$

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0.05) effect on the displacement distance of the tracers in the vertical direction. As reported by Van Muysen et al. (2002), displacement in the direction perpendicular to the ploughing direction (the vertical direction) is affected by speed. He stated that lateral displacement increases with increase in speed on level land.

4.7 Tracer Displacement Graphs

The graphs in Appendix D represent the movement patterns of each recovered tracer with reference to the original position of the tracers after tillage for each plot. It is observed that majority of the tracers moved over distances less than 1m.

In general, the graph showed that the distance moved by the soil particles was directly proportional to the ploughing speed. An increase in the ploughing speed resulted in an increase in the distance over which the soil particles where thrown. It was also noted that the graphs followed a similar pattern, producing an undulating or wavy motion of soil particle movement during tillage.

4.8 Effect of Ploughing Speed on Soil Displacement.

Figures 20, 21 and 22 are charts representing the effect of increasing ploughing speed on soil movement by the disc plough. The results of the displacement distances of the nine experimental plots were grouped into three graphs. Each figure represents graphs with the same ploughing depth but varying ploughing speeds. In Figure 20, the graph shows that at constant ploughing depth of 12cm, the displacement distances of the tracers increased with increasing speed. Plot $\mathbf{S_1H_1}$ (with 5km/hr speed and 12cm depth) had the lowest tracer displacements followed by Plot $\mathbf{S_2H_1}$ (with 7km/hr speed and 12cm depth) and Plot $\mathbf{S_3H_1}$

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(with 9km/hr speed and 12cm depth) showed to have the highest displacements. In general, increasing the ploughing speed increased soil movement. This support the claims made by Sharifat (1999), who reported that increasing a tool's operational speed increases the movement of soil particles. Though, the extent of movement will depend on the type of tool or the tool geometry.

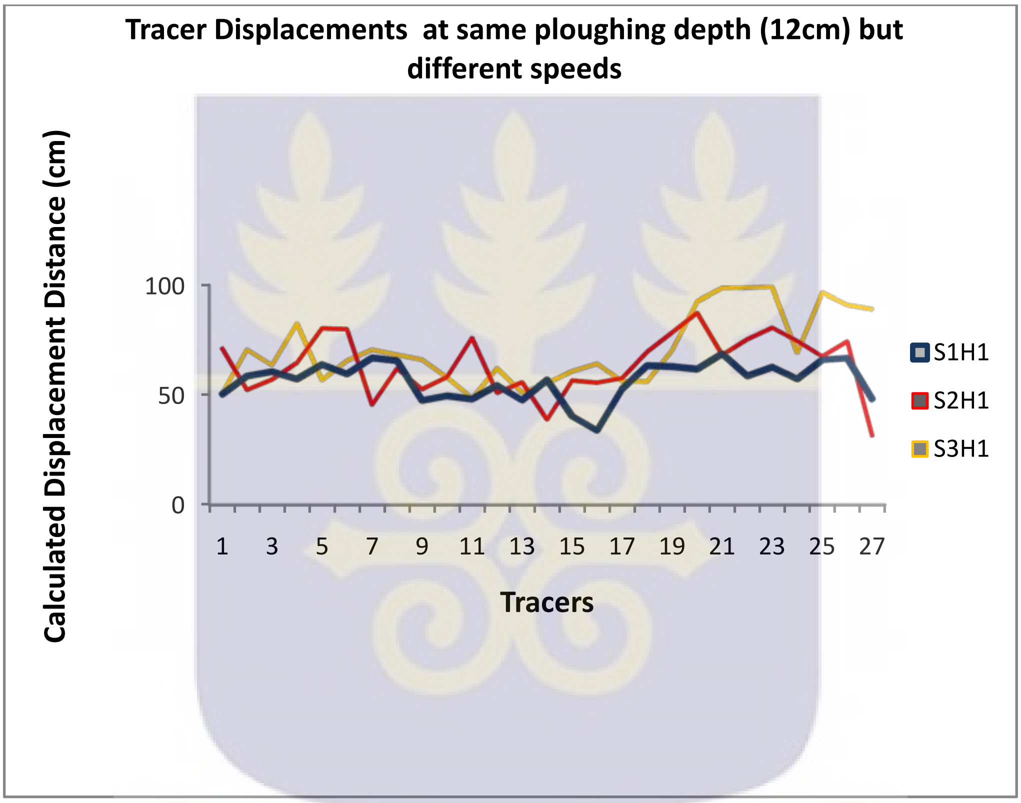

Figure 11. Tracer Displacement Pattern Graphs for S_1H_1, S_2H_1 and S_3H_1

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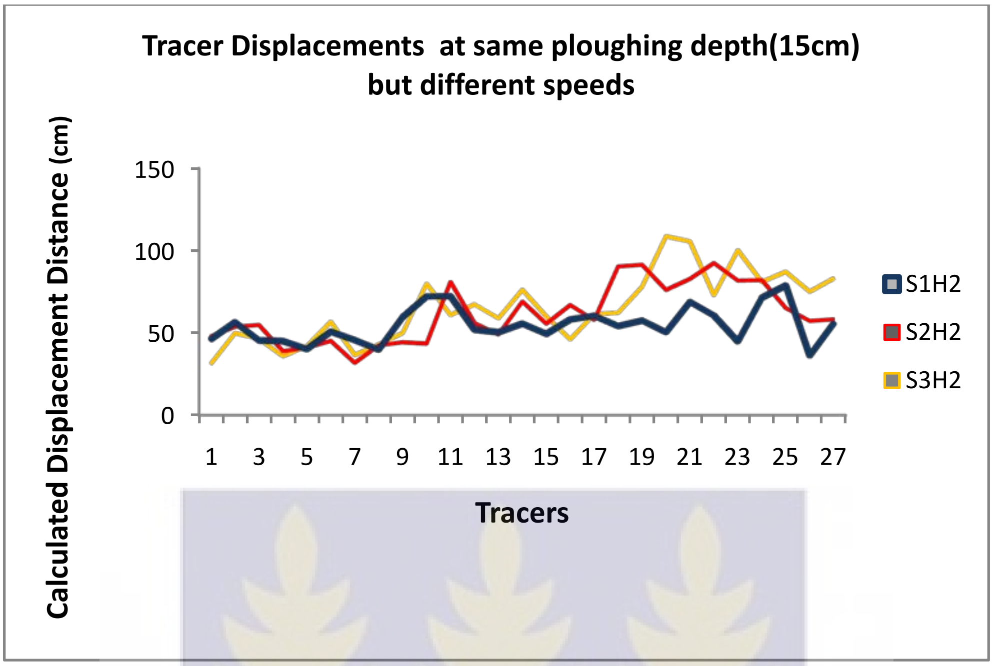

Figure 12. Tracer Displacement Pattern Graphs for S_1H_2, S_2H_2 and S_3H_1

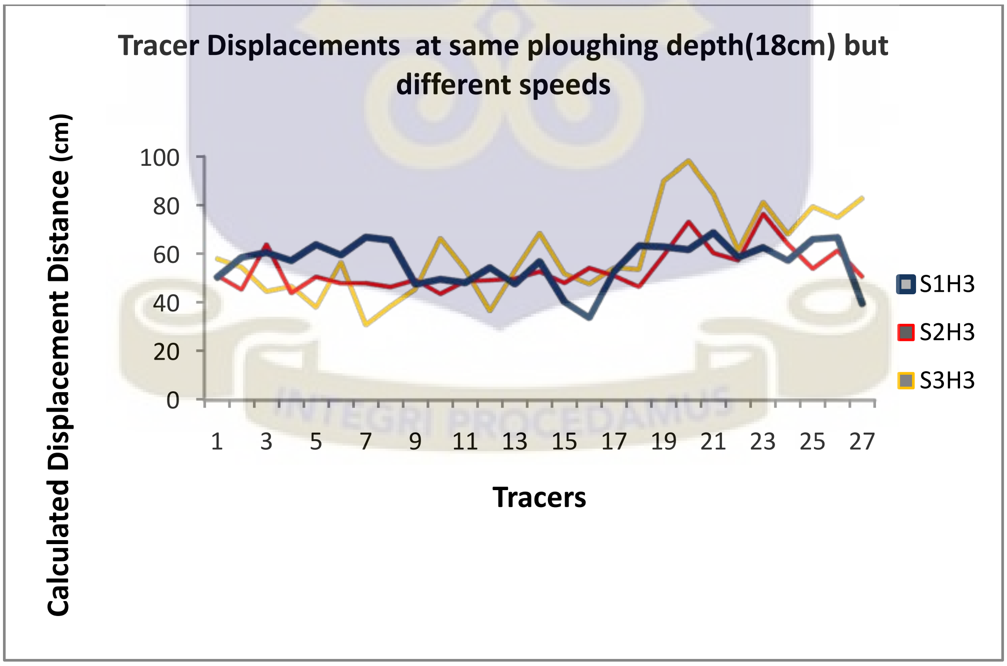

Figure 13. Tracer Displacement Pattern Graphs for S_1H_3, S_2H_3 and S_3H_3

Figures 11, 12 and 13 show that, increasing ploughing speed resulted in an increase in soil displacement distance at all the ploughing depths used in this study.

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4.9 Effect of Ploughing Depth on Soil Displacement.

Figures 14, 15 and 16 represent the averages of the calculated displacement distance of the nine experimental plots. This shows the effect of increasing ploughing depth on soil displacement by disc plough tillage. A careful look at Figure 14, shows that at a constant speed (S_1) of 5km/hr, tracer displacement decreased as ploughing depth increased from 56.7cm to 52.7cm. Thus, average displacement distance decreased from S_1H_1 to S_1H_3. The same was seen in Figure 15 where at a constant speed of 7km/hr, displacement decreased from 64.5cm to 53.2cm as depth of cut increased. The pattern remains the same for Figure 16, where, at a constant speed (S_3) of 9km/hr displacement decreased from 70.9cm to 60.1cm. From these deductions, it can be said that soil movement or displacement is inversely proportional to the ploughing depth when using a disc plough. Increasing the ploughing depth decreases movement of soil particles. This supports the findings of Sharifat and Kushwaha (1997) who reported that soil movement was inversely proportional to ploughing depth. Where, they studied soil movement at different depths between 0 – 75mm.

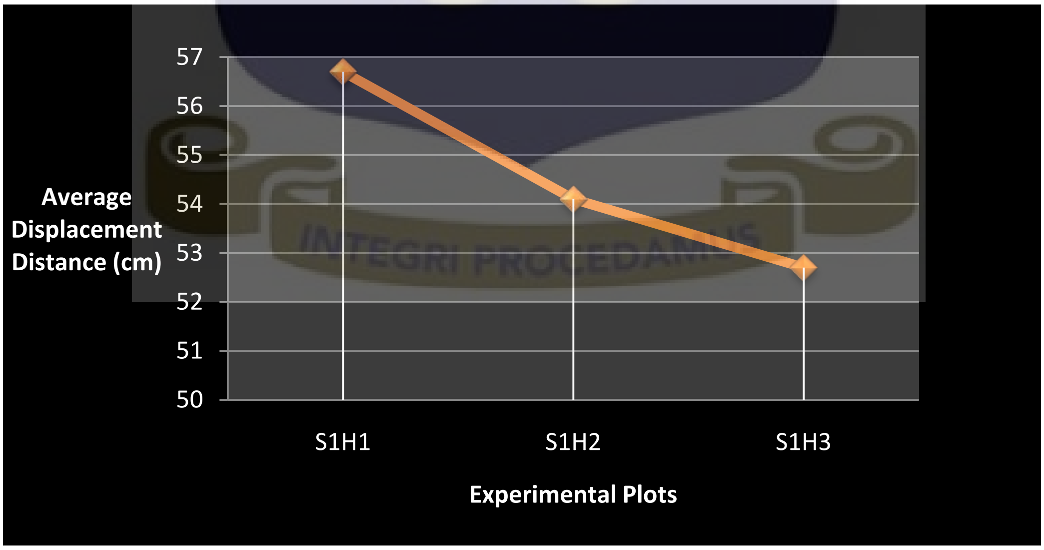

Figure 14. Displacement distance of tracers for different depths of cut (12cm, 15cm and 18cm) at 5km/hr

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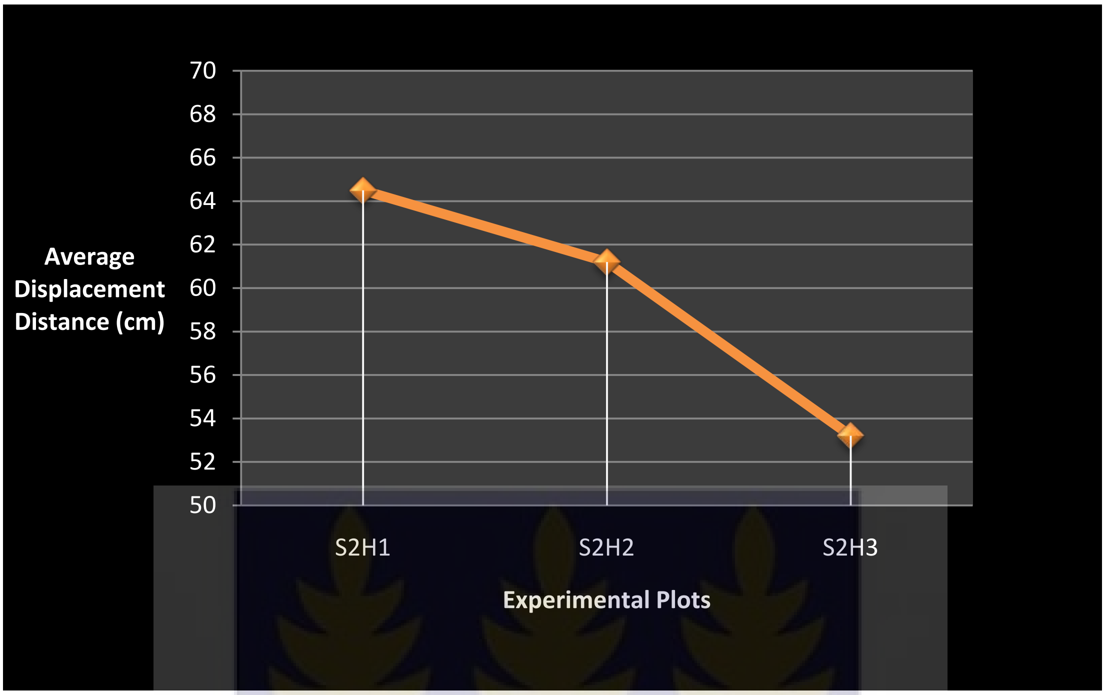

Figure 15. Displacement distance of tracers from different depths of cut (12cm, 15cm and 18cm) at 7km/hr

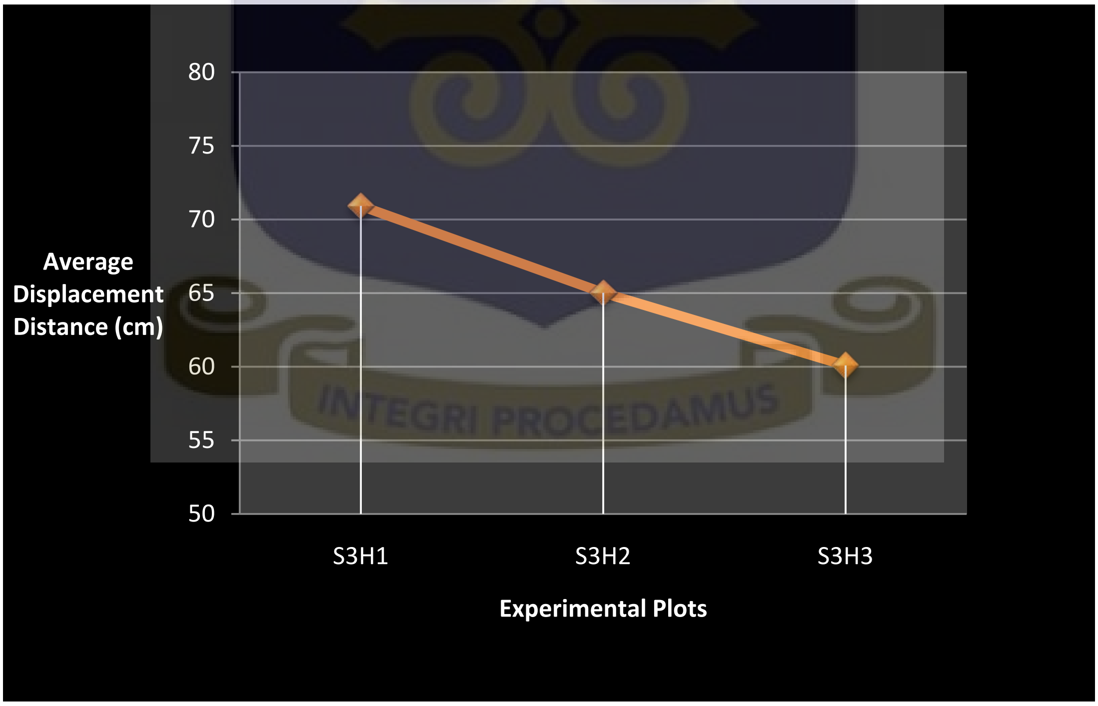

Figure 16. Displacement distance of tracers from different depths of cut (12cm, 15cm and 18cm) at 9km/hr

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For the purpose of clearly visualizing how the tracers were displaced in the soil after tillage, three dimensional scatter plots were drawn for each experimental design. Figure 17 is a representative graph for S_1H_1 design. Appendix E contains remaining plot designs.

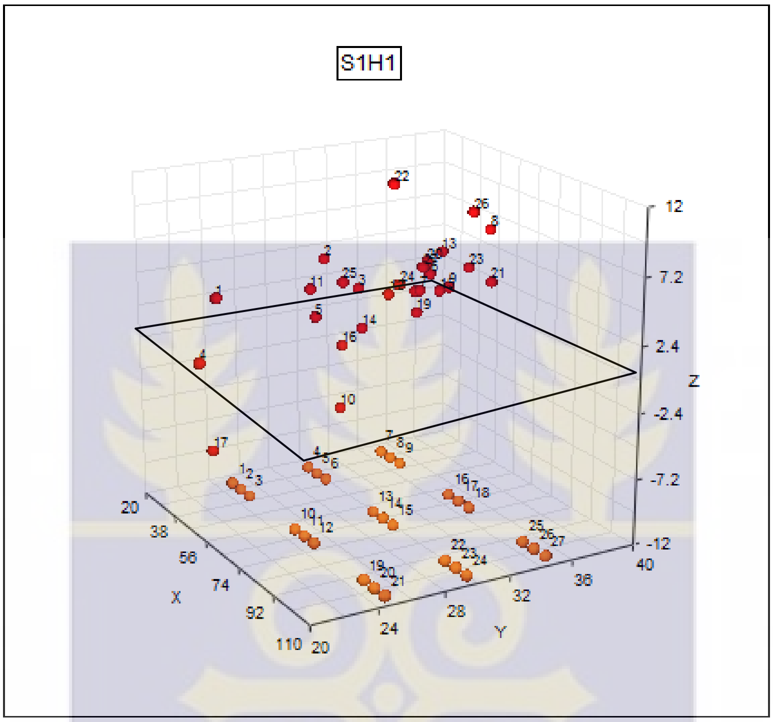

Figure 17. Three Dimensional (3D) Scatter Plot for S_1H_1design.

4.10 Pattern of Soil displacement within the soil profile.

Soil redistribution by tillage plays a vital role in modifying the soil profile. Vertical movement of soil particles within the till layer causes variability in the soil profile. In studying the modifications of the soil profile by disc plough, scatter graphs were drawn for the experimental design. Measured displacements in the vertical direction (z - direction) were plotted. The horizontal axis of the scatter graph represents the surface of the field. The graphs show final positions of each tracer after tillage with the disc plough. The graphs were drawn with respect to the different depths of cut under the same ploughing speed.

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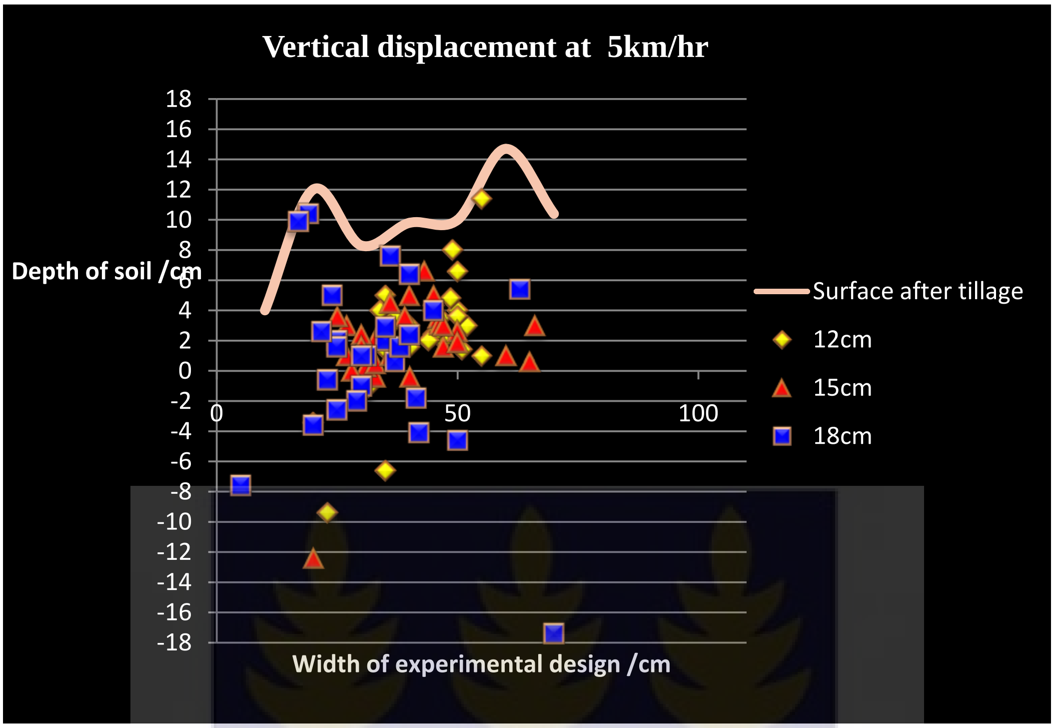

Figure 18.Vertical tracer displacement at speed S_1 and varied ploughing depths.

Considering Figure 18, it is clearly evident that majority of the tracers moved above the surface of the field. Most of the tracers were found within 12cm of the upper surface of the field. Some of the tracers were also found below the surface of the field. The graph showed that the tracers were spread between -10 to 12cm and clustered between -2 to 7cm, depth of the soil. Thus, the data in figure 18 showed the profile of clustered displacement were found within 9cm and also within a spread of 22cm. There was no significant difference in vertical displacement with depth of placement of the beads at the ploughing speed of 5km/hr. In order to further evaluate the redistribution of tracers within the soil profile, a table was constructed (Table 14). The soil profile was divided into horizons each with a depth of 6cm. The numbers of displaced tracers available within each horizon were counted (Table 14).

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Table 14. Distribution in the profile zones at speed 5km/hr

Depth of cut	12cm (◆)	15cm(▲)	18cm(■)	
PROFILE (cm)	Number of tracers			Total
13...18	0	0	0	**0**
7...12	3	1	4	**8**
0...6	21	23	13	**57**
0... -6	1	2	8	**11**
-7... -12	2	0	1	**3**
-13... -18	0	1	1	**2**

From Table 14, it can be seen that with a ploughing speed of 5km/hr, the zone with the largest count of tracers is within 6cm above the initial surface of the field (0 – 6cm) regardless of the depth of cut or depth of placement of the tracers. It can, therefore, be said that when the disc plough is moved at 5km/hr, majority of the soil particles below the soil surface are moved above the surface of the soil, within the 0 – 6cm depth.

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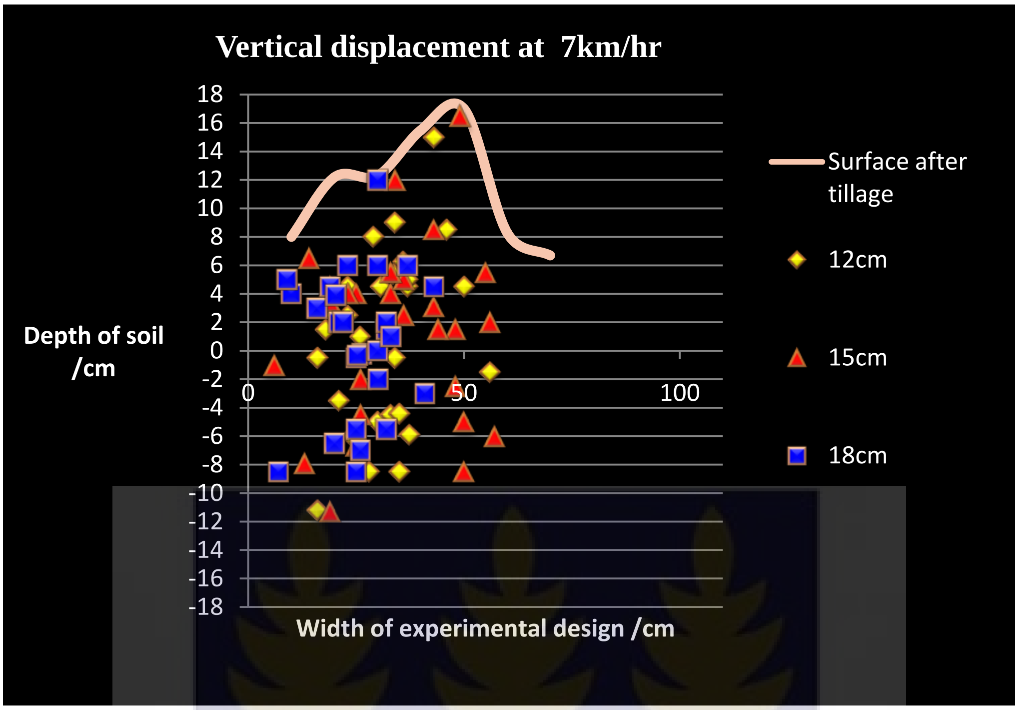

Figure 19. **Vertical tracer displacement at speed S_2 and varied ploughing depths.**

At 7km/hr, there is no significance in the spread of the tracers with depth. The tracers are distributed approximately equally below and above the initial surface of the field (Figure 19). The soil particles are thoroughly mixed within the till layer regardless of the depth at which the tracers were placed.

In comparison, at 5km/hr majority of the displaced tracers were clustered between -4 to 8cm zone of the profile while at 7km/hr majority of tracers were spread between -8 to 8cm zone. Even though, in both cases majority of the tracers were between 0 to 6cm zone with 57 and 36 tracers, at 5km/hr and 7km/hr respectively. Ploughing with disc plough at 5km/hr moves and inverts the soil. As speed increases, the soil particles get mixed up within the tilled layer.

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Table 15. Distribution in the profile zones at speed 7km/hr

Depth of cut	12cm (◆)	15cm(▲)	18cm(■)	
PROFILE (cm)	Number of tracers			Total
13...18	1	1	0	**2**
7...12	5	3	1	**9**
0...6	9	13	14	**36**
0... -6	8	5	8	**21**
-7... -12	4	5	4	**13**
-13... -18	0	0	0	**0**

Table 15 shows that the displaced tracers are concentrated in the profile zone of 12cm (6cm below and 6cm above the initial soil surface), though a larger amount of the tracers were found between 0 – 6cm. A similar profile is seen in Table 14. But comparing Tables 14 and 15, it can be seen that the tracer distribution is stronger between 0 – 6cm for 5km/hr than 7km/hr. In practice, majority of the displaced soil particles are moved to 0 to 6cm zone of the profile.

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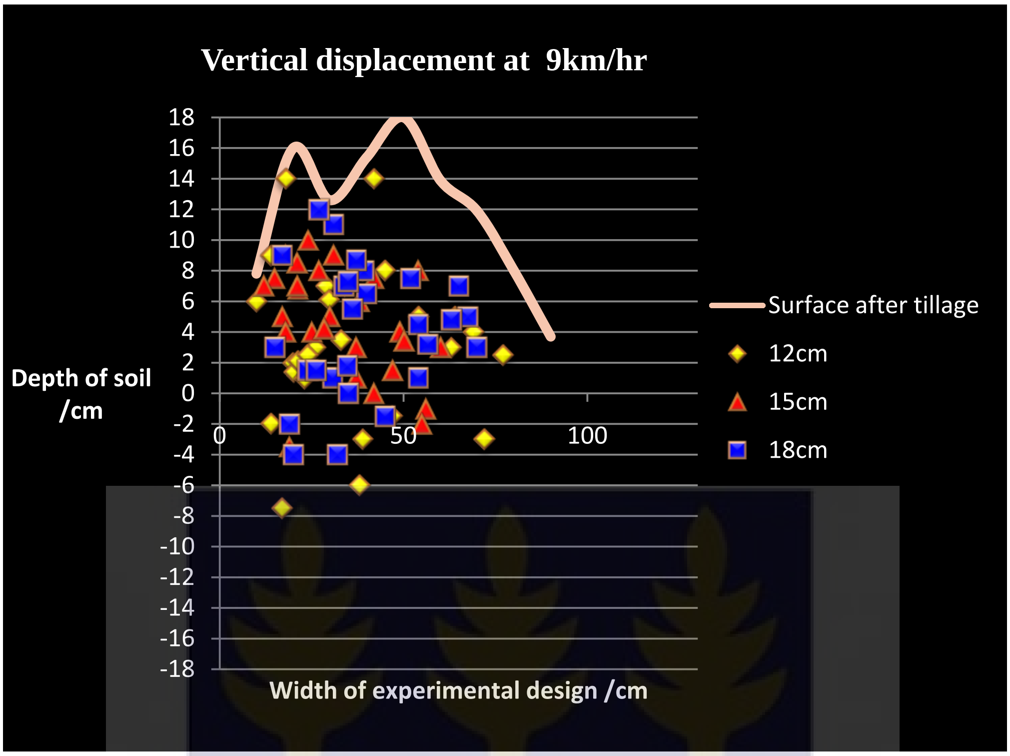

Figure 20. Vertical tracer displacement at speed S_3 and varied ploughing depths

Figures 19 and 20 show a trend similar to vertical displacement of tracers in figure 35, majority of the tracers were translocated above the original soil surface, whereas, some remained below the original soil surface. The spread of the tracers are not influenced by the depth of placement. The tracers are accumulated at one side, therefore, we can say that the disc plough throws the soil slice to one side and this is also seen in all the plotted graphs. The accumulation or clustering of the tracers seems to be affected by the depth and speed of ploughing. Hence, regardless of the ploughing depth and speed, the tracers get clustered in a similar manner as can be seen in all the plotted graphs. Table 16 shows the distribution of the tracers within the set profile zones.

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Table 16. Distribution in the profile zones at speed 9km/hr

Depth of cut	12cm (◆)	15cm(▲)	18cm(■)	
PROFILE (cm)	Number of tracers			Total
13...18	2	0	0	**2**
7...12	5	11	10	**26**
0...6	14	12	12	**38**
0... -6	4	4	5	**13**
-7... -12	2	0	0	**2**
-13... -18	0	0	0	**0**

From Table 16, it can be seen that the largest number of displaced tracers were concentrated 12cm above the initial surface of the field, that is, between 0 – 12cm. However in comparing Tables 14, 15 and 16, it was noted that the largest number of displaced tracers is located 6cm above the initial ground surface.

In evaluating the effect of speed on forward or horizontal displacement of soil particles using a disc plough the distances moved by the tracers in the horizontal direction (x-y direction) were plotted. It was observed that the variations in depth of cut did not affect the displacement in the horizontal direction. However, ploughing speed had an effect on horizontal displacement.

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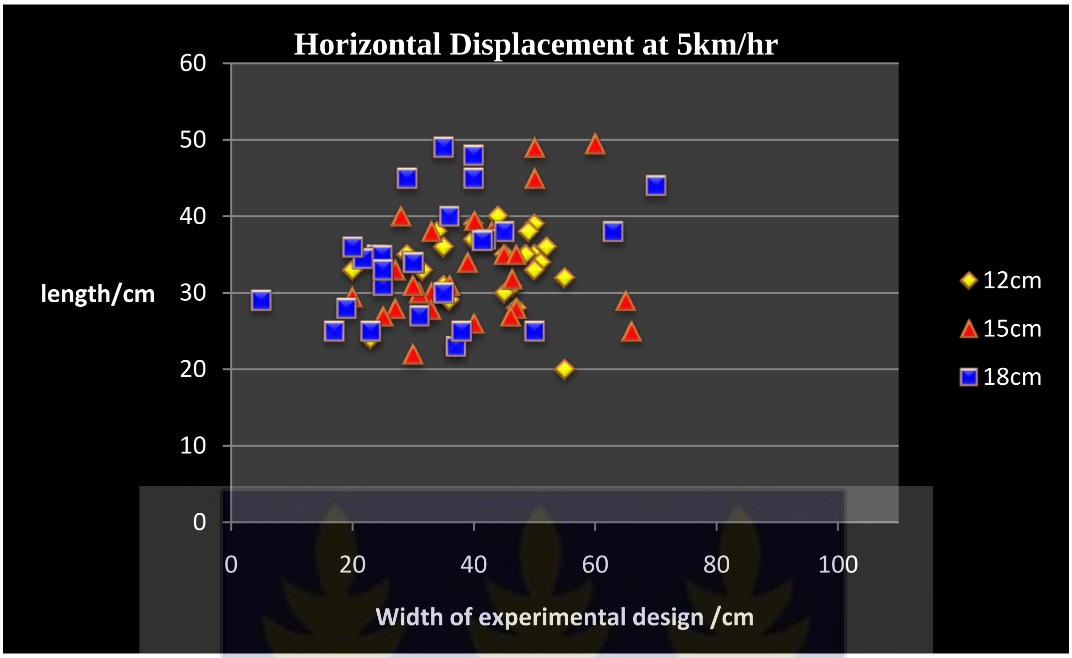

Figure 21. Horizontal tracer displacement at speed S_1 and varied ploughing depths.

From Figure 21, it is seen that at ploughing speed of 5km/hr, the tracers were displaced between 20cm to 50cm in the y – direction. It is also observed that ploughing at 5km/hr produced the least displacement distance in the horizontal direction regardless of the depth of cut.

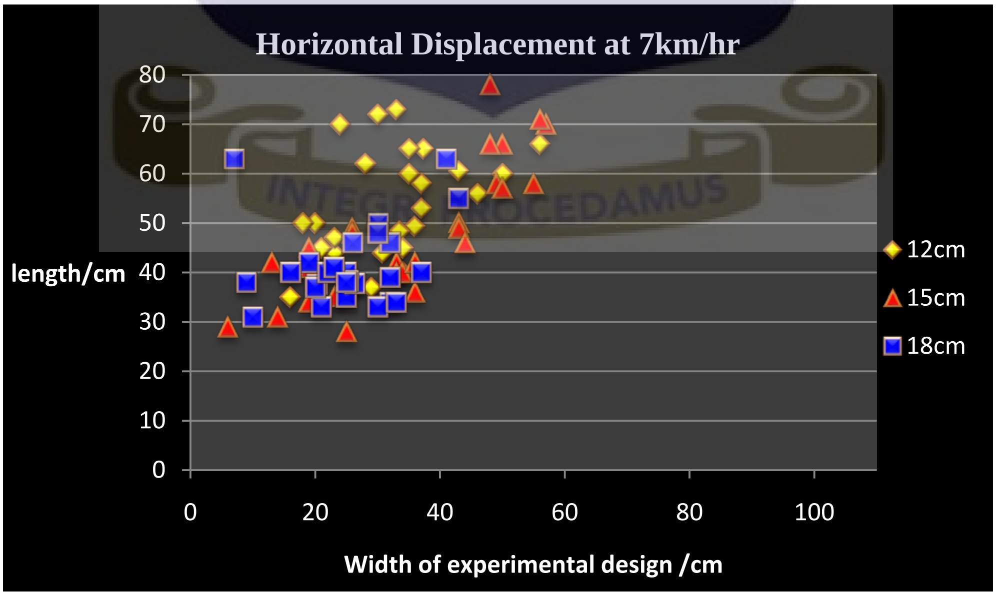

Figure 22. Horizontal tracer displacement at speed S_2 and varied ploughing depths.

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At 7km/hr, horizontal displacement is observed to fall between 25 – 80cm regardless of the depth of cut or depth of placement of the tracers. There is an increase in horizontal displacement with increase in ploughing speed from 5km/hr to 7km/hr (Figure 22).

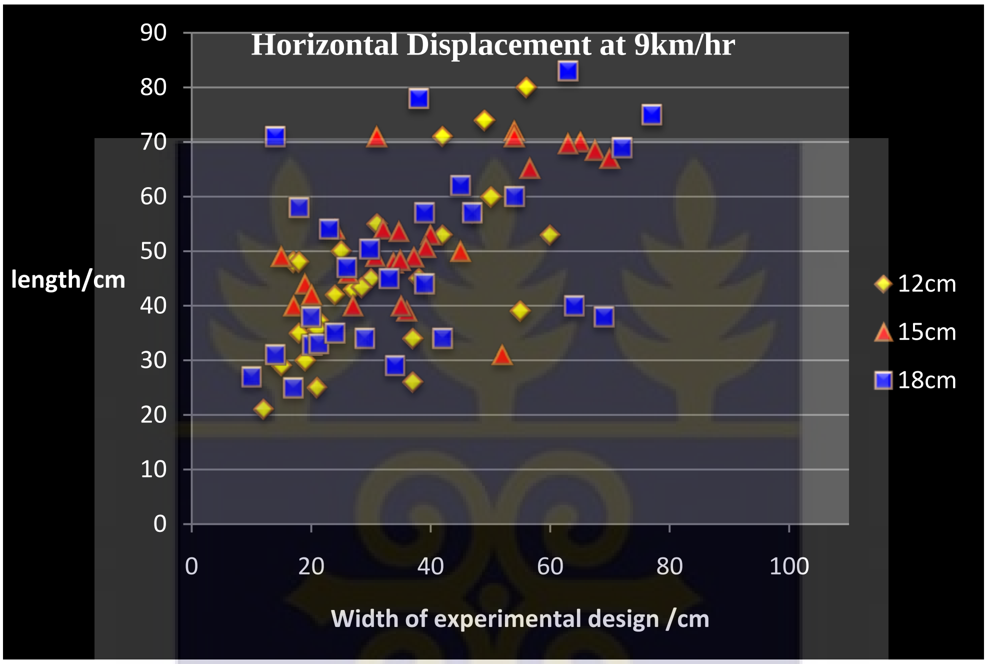

Figure 23. Horizontal tracer displacement at speed S_3 and varied ploughing depths.

Again, at a ploughing speed of 9km/hr, it is seen that the tracers are spread between 20 – 90cm along the horizontal axis (Figure 23). Also, there has been an increase in tracer displacement. It can be concluded from Figures 21, 22 and 23 that horizontal displacement increases with increase in ploughing speed.

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4.11 Soil Profile Modification

This section discusses how disc plough tillage alters the soil profile. As part of the objectives, this study sought to investigate the ability of the disc plough to mix and/or invert some of the soil layers during tillage operations. Table 17 shows a summary of the distribution of tracers in the soil profile for all the experimental designs.

Table 17.Summary of tracer distributions in the profile.

PROFILE (cm)	SPEED OF AGGREGATE 5km/hr	7km/hr	9km/hr		
		Tracer No.		Total No.	Percentage (%)
13...18	0	2	2	**4**	**2**
7...12	8	9	26	**43**	**17**
0...6	57	36	38	**131**	**53**
0... -6	11	21	13	**45**	**19**
-7... -12	3	13	2	**18**	**7**
-13... -18	2	0	0	**2**	**1**

Generally, the soil profiles at all the speeds exhibit similar distribution of tracers along the profile. Thus, the movement of soil particles is concentrated between 12cm to –6cm of the profile with percentages of 17%, 53% and 19%. Also regardless of the depth of placement of tracers or the ploughing speed, it is observed that 53% of the number of tracers was found within 6cm above the initial field surface. Therefore, whether the ploughing speed is at 5km/hr, 7km/hr or 9km/hr, majority of the displaced soil tracers are located within a depth of

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6cm above the original soil surface. As the speed increases, there is seen to be an appreciable amount of movement of the particles to the next zone, thus between 6 to 12cm and –6 to 0cm with percentages of 17% and 19%, respectively.

Again, with majority of the particles transported between 12cm to –6cm of the profile, it was also noticed that particle movement decreased as we move above and below this zone. Looking at the percentages of tracer distribution, it was revealed that the disc plough transforms the soil profile by turning and then mixing soil materials within 12cm above and 6cm below the original soil surface. Majority of the soil materials from the subsurface get exposed at the surface and also particles from the soil profile zones get mixed up homogenously. Their proportions depend on the ploughing depth.

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The experiments presented in this study were intended to investigate how soil particles are displaced during tillage by a disc plough. As well as, to study the effect of ploughing depth and ploughing speed on soil displacement by a disc plough. The tracer technique was successfully used in assessing soil displacement by the disc plough. The main conclusions are as follows:

- Prior to performing the field experiments, it was established that the type of soil on the study field was clayey loam through the soil texture analysis. The soil bulk density was also determined and this served as a guide in the selection of the appropriate bead for the study of soil movement by disc plough. Interestingly, as a result it has been established from this study that glass beads with densities ranging between 1.78 ± 0.1 g/cm^3 can be used as tracers in any soil displacement by tillage study.
- Results from the experimental study showed that on the average the disc plough tillage moved soil particles through a distance of 59.8 ± 12.5cm. This is relatively high when compared with other tillage implements and this could be attributed to the operating conditions, as well as the, tool design. This distance is likely to differ if disc plough tillage is performed on sloping land. With this information however, we now have knowledge of the extent of dispersion of soil constituents on a fairly levelled field by disc plough tillage.
- Experimental results from the study indicated that the factors of operations considered in this study, ploughing speed and depth have significant effects ($p \leq 0.05$) on soil displacement by the disc plough. Soil particle movement was directly proportional to ploughing speed. Increasing ploughing speed generally led to increase in soil displacement for disc plough.

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- The reverse of this trend was, however, seen for the other operational factor, the depth of cut. Soil particle displacement was inversely proportional to ploughing depth. It was found that the tracers placed in the soil at shallower depths moved further than tracers that were inserted at deeper depths.
- From the results obtained for the set objectives of this study and the deductions made, the nature of the soil profile after disc plough tillage has been made clear. Soil displacement by disc plough tillage did not only lead to redistribution of soil particles throughout the surface layer of the field, it also resulted in modifications within the soil profile. With regards to the ploughing depths considered in this study, the disc plough is seen to alter the soil profile by transporting soil particles from their original positions to the uppermost horizon. The experiment shows also that most of the tracers were spread within the 12cm to –6cm zone according (Table 16). The disc plough mixes majority of the transported soil particles within the top 12cm and below 6cm of the original surface, regardless of the ploughing speed. However, the extents to which the displaced soil particles are mixed or spread vary at the various speeds. It was observed that at higher speeds, the displaced tracers were highly mixed and spread but at lower speed, the tracers were concentrated even though in all cases most of the tracers were found within 0 to 6cm of the profile.

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Furthermore, due to the soil particle displacement patterns observed, as well as, the deductions made from the results of the analyzed data, the following recommendations are proposed to help farmers or farm machinery operators utilize the disc plough in order to achieve high performance results:

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- If the intention of tillage is not to mix the soil profile it would be appropriate to plough at lower speeds but if the intention is to adequately mix whatever material within the soil, then 9km/hr was found to have that ability.
- To prevent a large proportion of the subsoil from mixing with the topsoil, it is suggested that the ploughing depth should, as much as, possible not exceed 18cm. This avoids the occurrence or minimizes the occurrence of compromising the quality due to the effect on nutrient and untouched land percentage.
- It is also suggested, that further studies be done to investigate soil movement pattern by disc plough for different soil types and under different soil and operational conditions.

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APPENDIXES

Appendix A

Tracer Displacement measurements at 5km/hr

Field Test One

	S_1-H_1(5km/hr-12cm)			
	Position of displaced tracer in x-y-z coordinate			
Tracer Number	X	Y	Z	Displacement distance, D(cm)
1	37	23	18.6	47.37045
2	35	30	20	50.24938
3	46.4	30.8	18.5	58.62257
4	55	20	16	60.67125
5	47	28	17	57.28874
6	50	35	19	63.92183
7	45	35	17.4	59.60503
8	50	39	21.6	66.98925
9	52	36	18	65.75713
10	35	31	8.4	47.50326
11	36	29	18	49.60847
12	29	35	15.9	48.15402
13	34	38	19	54.41507
14	31.5	32.9	13.9	47.61585
15	40	37	16.6	56.96104
16	20	33	11.6	40.29342
17	23	24	5.6	33.70994
18	35	36	16.4	52.82007
19	51	34	16.4	63.45045
20	48.5	35	19.8	63.0023
21	44	40	17	61.84658
22	55	32	26.4	68.89093
23	40	39	18	58.69412
24	50	33	18.6	62.72926
25	45	30	19	57.32364
26	49	38	23	66.13622
27	54	34	20	66.87301
	Average Displacement, $\bar{x}$ (cm)			**56.7**

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Field Test Two

	S_1-H_2(5km/hr-15cm)			
	Position of displaced tracer in x-y-z coordinate			
Tracer Number	X	Y	Z	Displacement distance, D(cm)
1	27	28	15	41.68932717
2	33	30	11.6	46.08210065
3	47	28	13.6	56.37339798
4	32.9	27.8	14.1	45.28462246
5	31	30	12.3	44.85855548
6	25	27	15.6	39.96698638
7	40	26	17	50.64582905
8	30	31	14.4	45.47922603
9	30	22	13.6	39.61009972
10	45	35	17	59.48949487
11	66	25	15	72.15261603
12	65	29	12.6	72.28250134
13	33	38	12.5	51.85797914
14	36	31	16.5	50.29164941
15	46	27	15.5	55.54502678
16	36	31	13	49.25444142
17	46.3	31.8	15.1	58.09266439
18	43	38	18.6	60.32379298
19	39	34	15.6	54.04035529
20	40.1	39.4	11.6	57.39927183
21	28	40	12	50.27922036
22	50	45	14.6	68.83429378
23	47	35	15	60.48966854
24	27	33	13	44.57577818
25	50	49	13.9	71.37373466
26	60	49.5	13	78.86222163
27	20	29.5	-4.4	35.91114033
	Average Displacement, $\bar{x}$ (cm)			**54.1**

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Field Test Three

	S_1-H_3(5km/hr-15cm)			
	Position of displaced tracer in x-y-z coordinate			
Tracer Number	X	Y	Z	Displacement distance, D(cm)
1	37	23	18.6	47.37045
2	35	30	20	50.24938
3	31	27	19	58.62257
4	24	35	23	60.67125
5	36	40	25.6	57.28874
6	45	38	22	63.92183
7	38	25	19.6	59.60503
8	30	34	17	66.98925
9	30	34	19	65.75713
10	35	49	20.9	47.50326
11	29	45	16	49.60847
12	25	31	20	48.15402
13	19	28	28.4	54.41507
14	17	25	27.9	47.61585
15	5	29	10.4	56.96104
16	42	37	13.9	40.29342
17	24.6	34.9	19.6	33.70994
18	21.7	34.5	20.6	52.82007
19	63	38	23.4	63.45045
20	41.4	36.8	16.2	63.0023
21	23	25	17.4	61.84658
22	40	48	24.4	68.89093
23	40	45	20.4	58.69412
24	25	33	15.4	62.72926
25	50	25	13.4	57.32364
26	20	36	14.4	66.13622
27	70	44	0.6	66.87301
	Average Displacement, $\bar{x}$ (cm)			**52.7**

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Appendix B
Tracer Displacement measurements at 7km/hr
Field Test Four

	S_2-H_1(7km/hr-12cm)			
	Position of displaced tracer in x-y-z coordinate			
Tracer Number	X	Y	Z	Displacement distance, D(cm)
1	26	37	16	47.96874
2	37	58	19.5	71.50699
3	29	37	23	52.33546
4	30.7	44.0	19.5	57.06746
5	35.9	49.4	21.3	64.70873
6	50	60	19.5	80.50000
7	43	60.6	30	80.13339
8	16	40	14.5	45.45602
9	33.5	48.3	20.4	62.16008
10	23	44	17.5	52.64266
11	34	45	14.5	58.23444
12	46	56	23.5	76.18563
13	21	45	11.5	50.97303
14	23	47	19.5	55.84129
15	16	35	3.8	38.67092
16	20	50	17.5	56.62376
17	18	50	16.5	55.64396
18	34	40	24	57.72348
19	35	60	6.5	69.76568
20	30	72	10	78.63841
21	56	66	13.5	87.6028
22	28	62	6.5	68.33923
23	37.3	65.0	9.1	75.47071
24	33	73	10.5	80.79759
25	35.0	65.1	10.6	74.71062
26	37	53	20	67.66092
27	24	70	9	74.54529
	Average Displacement, (cm)			**64.5**

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Field Test Five

	S_2-H_2(7km/hr-15cm))			
	Position of displaced tracer in x-y-z coordinate			
Tracer Number	X	Y	Z	Displacement distance, D(cm)
1	33	42	16	55.75841
2	19	41	15.5	47.77290
3	36	36	17	53.67495
4	33	40	17.5	54.72888
5	14	31	18.5	38.72015
6	25	28	16	40.80441
7	23.1	35.1	16.0	44.99479
8	6	29	11	31.59114
9	19	34	16.5	42.29953
10	13	42	4.1	44.15665
11	25	35	5.3	43.33694
12	49	58	28.5	81.10025
13	26	49	7.5	55.97544
14	19	45	0.7	48.85171
15	43	50	20.5	69.05976
16	26	48	10	55.49775
17	43	49	15.1	66.91793
18	34	40	24	57.72348
19	57	70	6	90.47099
20	56	71	14	91.5041
21	50	57	7	76.1446
22	50	66	3.5	82.87491
23	48	78	13.5	92.57564
24	55	58	17.5	81.82451
25	48	66	9.5	82.15991
26	44	46	13.5	65.07111
27	36	42	14.5	57.1861
	Average Displacement, (cm)			**61.2**

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Field Test Six

	S_2-H_3(7km/hr-18cm)			
	Position of displaced tracer in x-y-z coordinate			
Tracer Number	X	Y	Z	Displacement distance, D(cm)
1	10	31	22	39.30649
2	19	42	22.5	51.29571
3	9	38	23	45.32108
4	30	48	30	64.06247
5	21	33	20	43.93177
6	32	34	19.5	50.59891
7	16	40	21	47.92703
8	20.3	37.6	21.9	48.03079
9	25	35	17.5	46.43544
10	26.3	37.8	17.8	49.37094
11	20	37	11.5	43.60333
12	25	40	12.5	48.79805
13	25.3	38.3	17.7	49.22736
14	22	40	20	49.83974
15	23	41	24	52.78257
16	30	33	18	48.09366
17	32	39	20	54.26785
18	33	34	19	51.04900
19	25	38	9.5	46.46773
20	37	40	24	59.53990
21	43	55	22.5	73.35019
22	30.1	49.9	16.0	60.42376
23	32	46	12.5	57.41298
24	41	63	15	76.64855
25	7	63	9.5	64.09563
26	26	46	11	53.97222
27	30	48	24	61.48170
	Average Displacement, (cm)			**53.2**

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Appendix C

Tracer Displacement measurements at 9km/hr

Field Test Seven

	S_3-H_1(9km/hr-12cm)			
	Position of displaced tracer in x-y-z coordinate			
Tracer Number	X	Y	Z	Displacement distance, D(cm)
1	19	44	16	50.52722
2	40	53	24.5	70.77606
3	33.8	47.8	25.0	63.65752
4	31	71	29	82.72243
5	27.0	40	30	56.82429
6	52	31	25.5	65.69056
7	39.2	50.7	26.0	70.71164
8	37.2	48.9	26.7	68.39708
9	34.9	48.3	25.3	66.16335
10	36	39	23.5	58.04524
11	20	42	14	48.57983
12	24	54	19.5	62.22741
13	17	40	27	51.16640
14	15	49	21	55.38050
15	30.7	49.0	19.0	60.84772
16	32	54	14	64.31174
17	26.2	45.9	19.5	56.31734
18	35	40	18	56.11595
19	54.7	58.3	42.8	70.46910
20	54	72	22.5	92.76988
21	65	70	25	98.74209
22	67.5	68.5	23	98.88124
23	70	67	21	99.14636
24	45	50	16.5	69.26218
25	63.0	69.7	22.8	96.66336
26	54	71	19	91.20307
27	59.1	65.8	24.1	89.25882
	Average Displacement, (cm)			**70.9**

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Field Test Eight

	S_3-H_2(9km/hr-15cm)			
	Position of displaced tracer in x-y-z coordinate			
Tracer Number	X	Y	Z	Displacement distance, D(cm)
1	17	25	7.5	31.14884
2	34	29	22	49.80964
3	20	38	17	46.18441
4	10	27	21	35.63706
5	20.2	32.8	16.4	41.88352
6	26	47	18	56.64804
7	14	31	13	36.41428
8	21.3	33.0	17.1	42.81335
9	29	34	22	49.80964
10	45	62	23	79.98750
11	23	54	16	60.83584
12	18	58	29	67.29785
13	33	45	18.5	58.78988
14	14	71	24	76.24303
15	39	44	12	60.00833
16	24	35	17.5	45.90479
17	42	34	29	61.32699
18	29.8	50.4	21.1	62.20103
19	64	40	20	78.07689
20	77	75	17.5	108.90480
21	63	83	18	105.74500
22	39	57	23	72.79423
23	72	69	12	100.44400
24	69	38	19	81.03086
25	38	78	9	87.22958
26	47	57	13.5	75.10160
27	54	60	20	83.16249
	Average Displacement, (cm)			**65.0**

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Field Test Nine

	S_3-H_3(9km/hr-18cm)			
	Position of displaced tracer in x-y-z coordinate			
Tracer Number	X	Y	Z	Displacement distance, D(cm)
1	25	50	16	58.14637
2	27	43	20	54.57105
3	18	35	21	44.60942
4	21.2	37.2	18.8	46.70066
5	15	29	19.5	38.02959
6	30	45	17	56.69215
7	12	21	19	30.75711
8	21	25	20.5	38.55191
9	21.1	35.6	19.0	45.58054
10	31	55	21	66.5357
11	17	48	17	53.68426
12	19	30	8.5	36.5137
13	24	42	22	53.14132
14	42	53	12	68.68042
15	37	34	13	51.90376
16	37	26	15	47.64452
17	28.4	43.4	16.2	54.38628
18	18	48	16	53.70289
19	49	74	16	90.18315
20	56	80	11	98.27004
21	42	71	19.5	84.76585
22	38	45	18	61.58734
23	60	53	15	81.44937
24	55	39	10	68.16157
25	50.1	59.9	15.4	79.58594
26	47	57	13.5	75.1016
27	54	60	20	83.16249
	Average Displacement, (cm)			**60.1**

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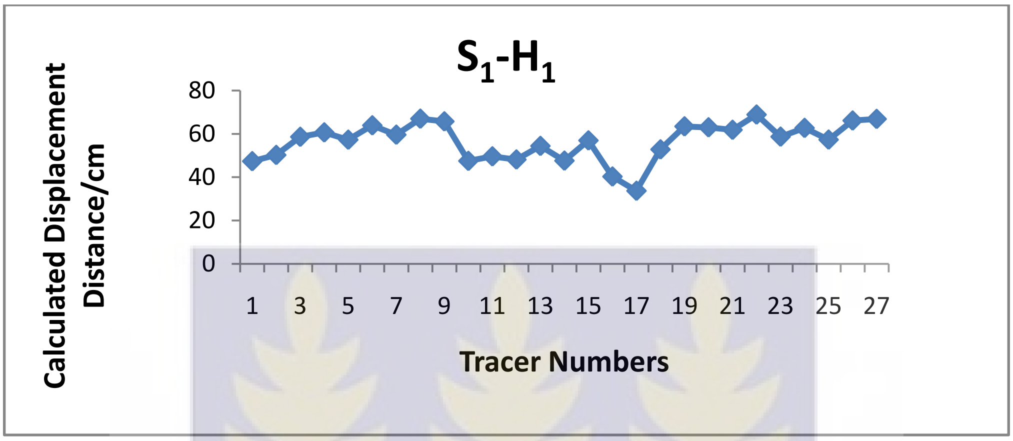
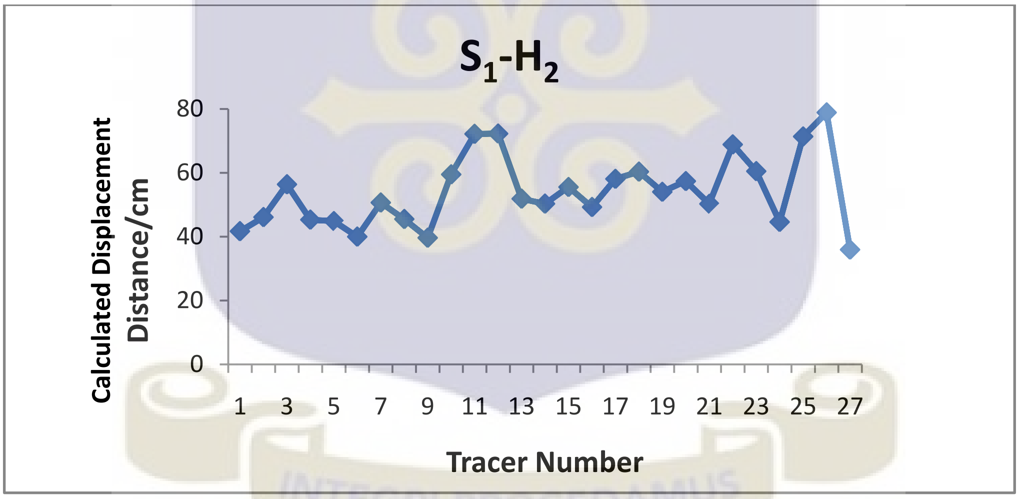
Appendix D
Tracer Displacement Graphs



Graph of calculated tracer displacement distances for S_1-H_1 design



Graph of calculated tracer displacement distances for S_1-H_2 design

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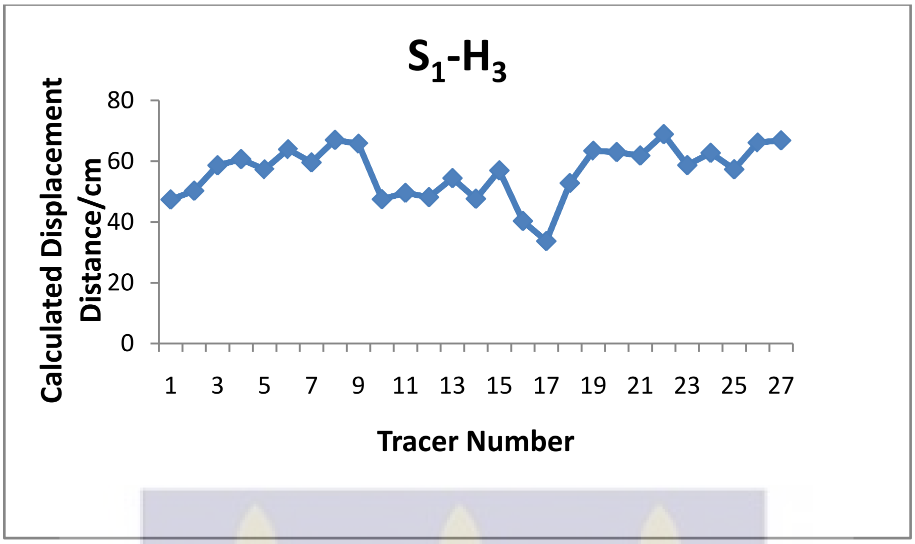
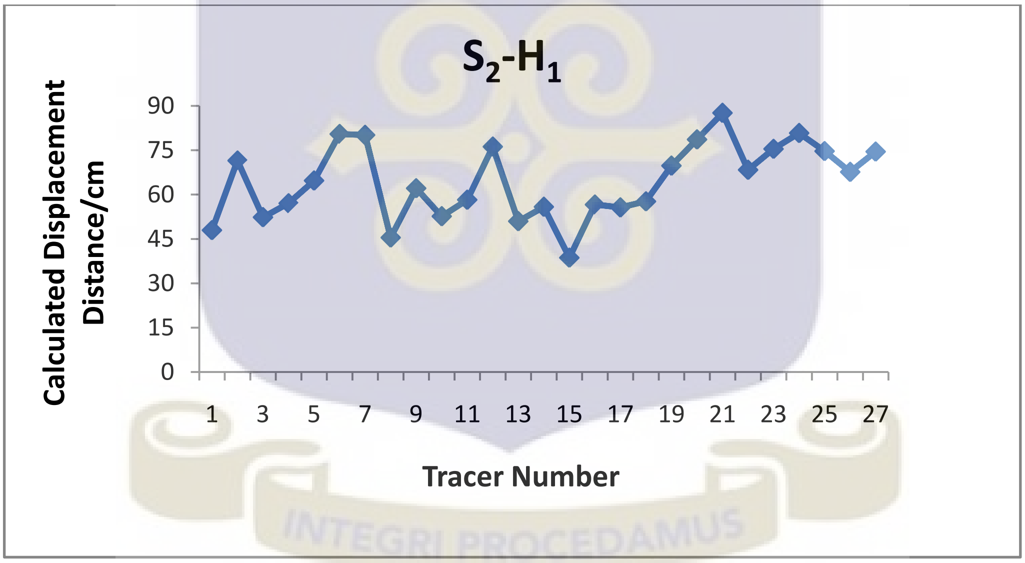


Graph of calculated tracer displacement distances for S_1-H_3 design



Graph of calculated tracer displacement distances for S_2-H_1 design

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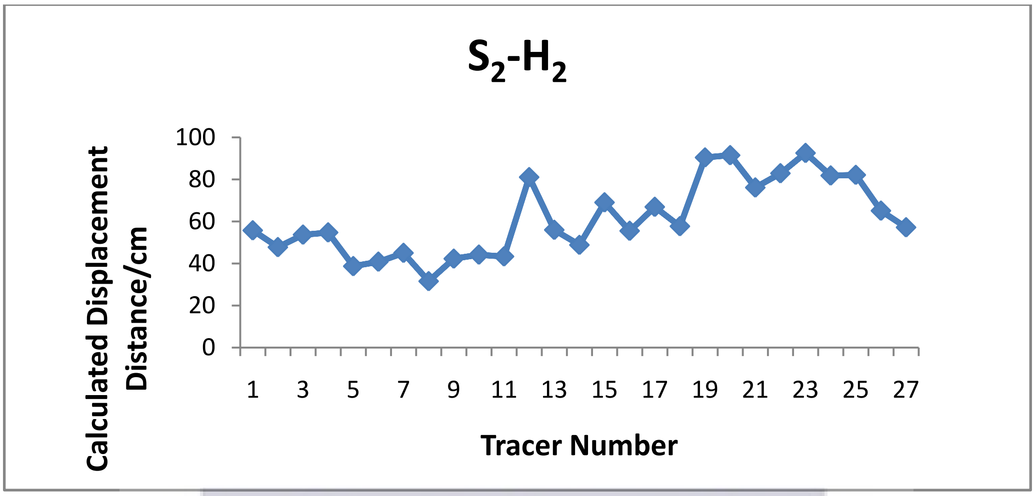
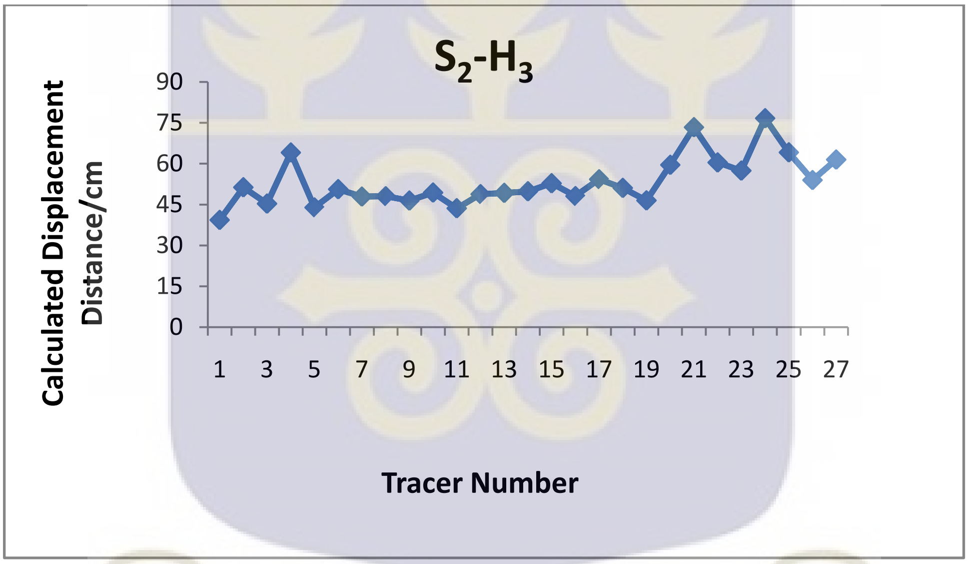


Graph of calculated tracer displacement distances for S_2-H_2 design



Graph of calculated tracer displacement distances for S_2-H_3 design

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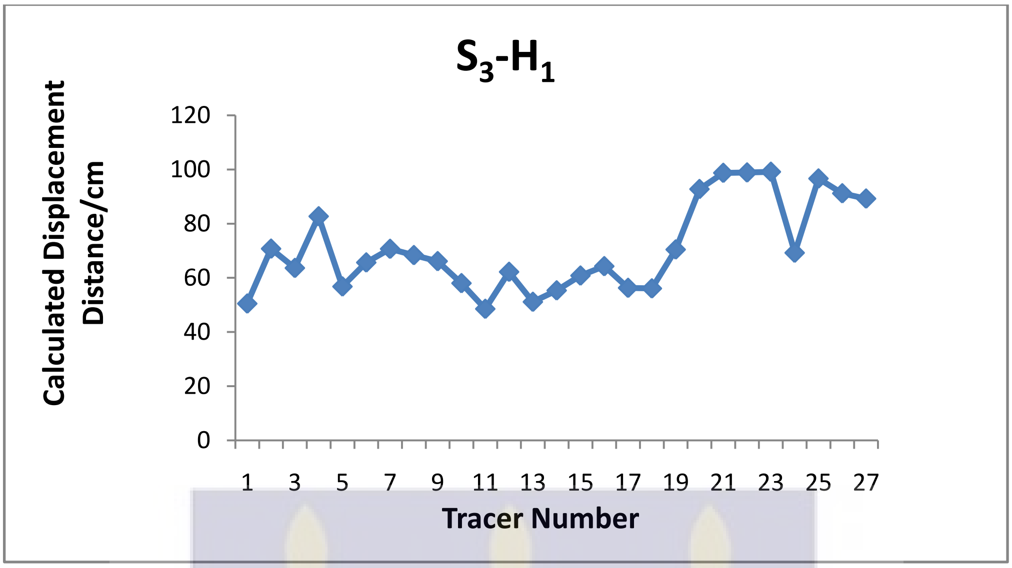
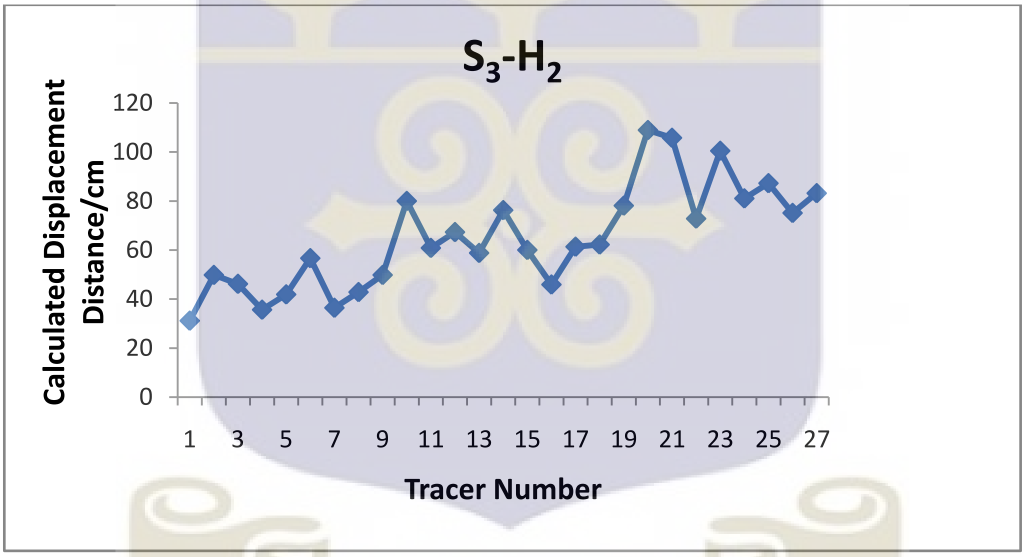


Graph of calculated tracer displacement distances for S_3-H_1 design



Graph of calculated tracer displacement distances for S_3-H_2 design

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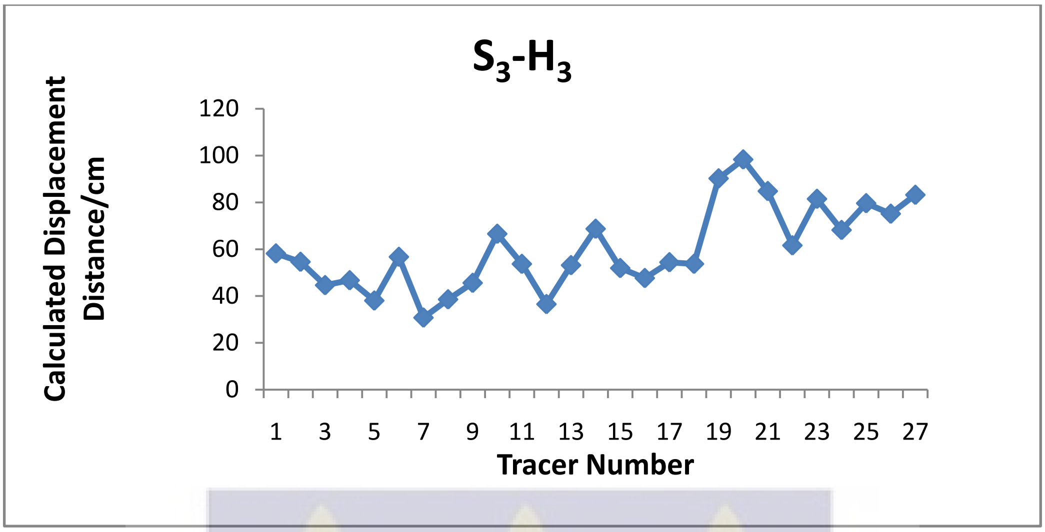

Graph of calculated tracer displacement distances for S_3-H_3 design

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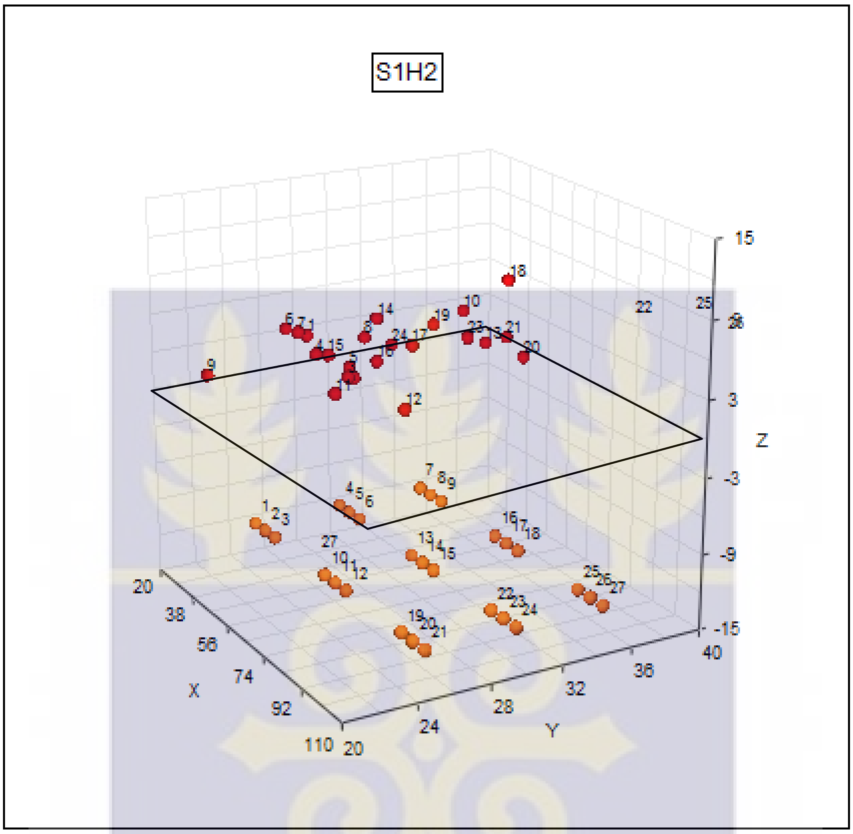
APPENDIX E

Three Dimensional Scatter Plots for Experimental Designs



Three Dimensional (3D) Scatter Plot for S_1-H_2 design.

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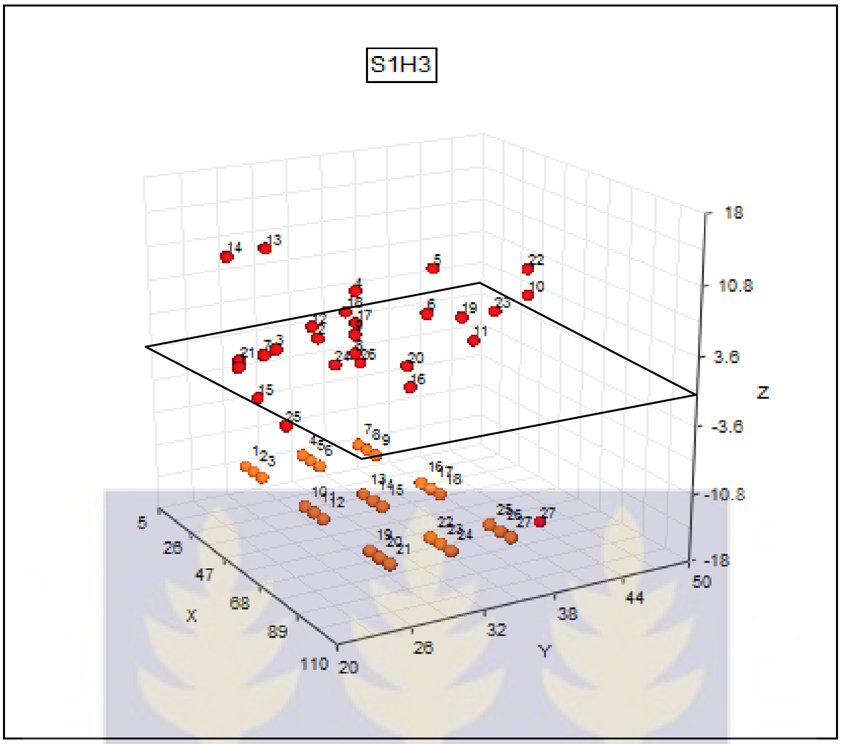
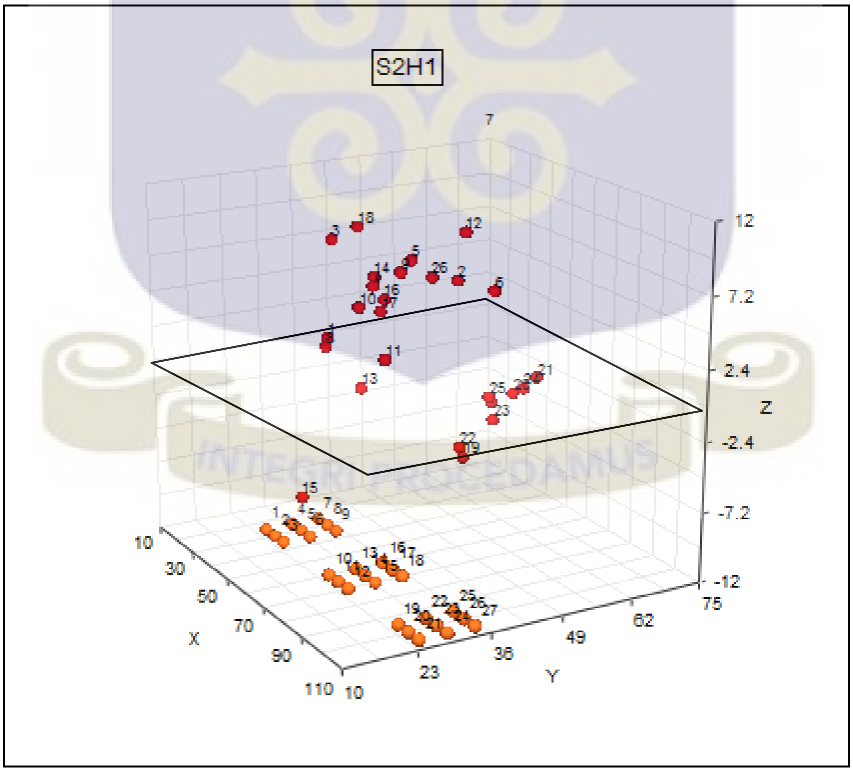


Three Dimensional (3D) Scatter Plot for S_1H_3 design.



Three Dimensional (3D) Scatter Plot for S_2H_1 design.

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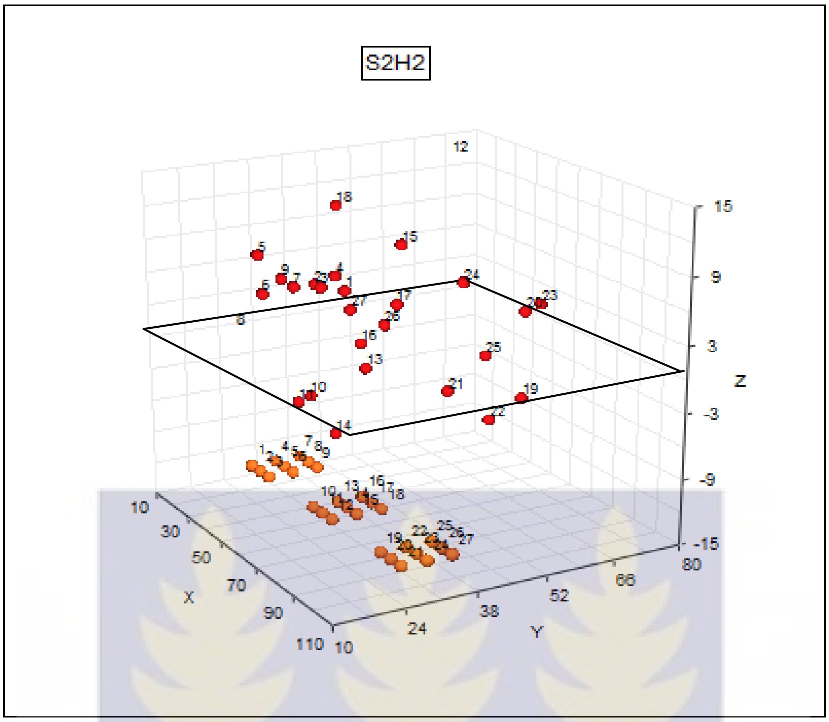

Three Dimensional (3D) Scatter Plot for S_2H_2 design.

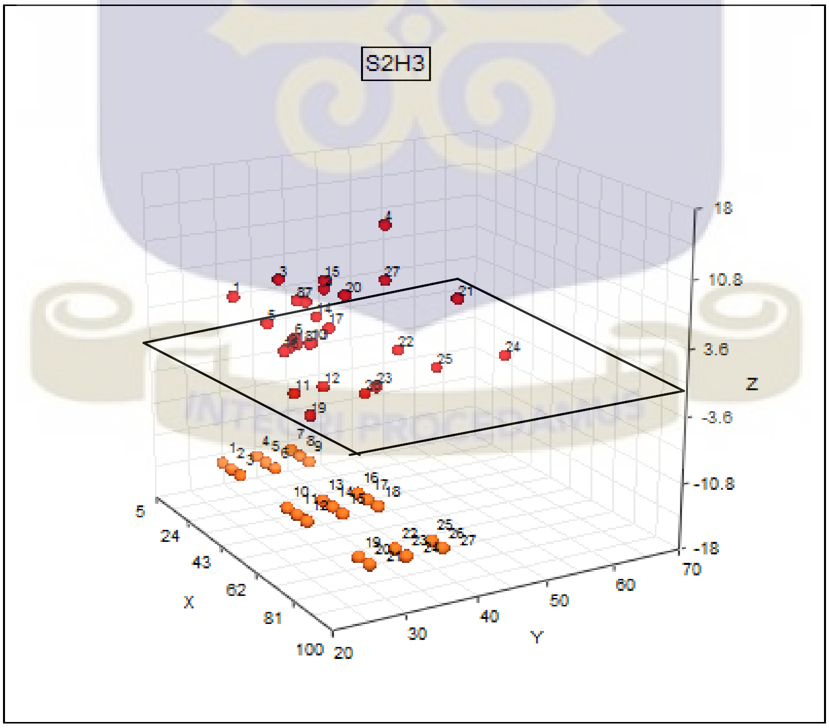

Figure 31. Three Dimensional (3D) Scatter plot for S_2H_3 design.

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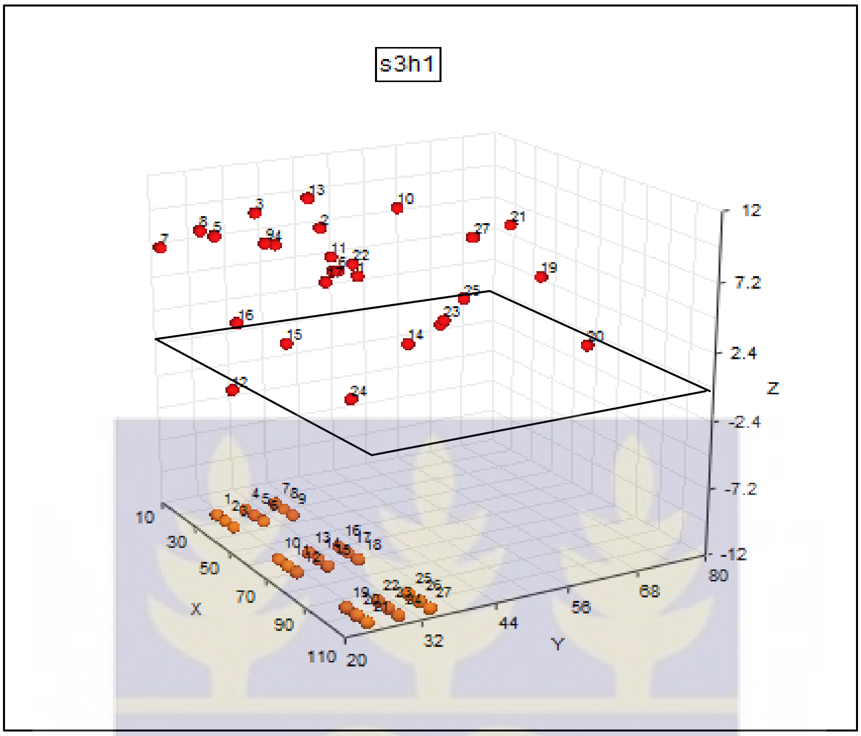
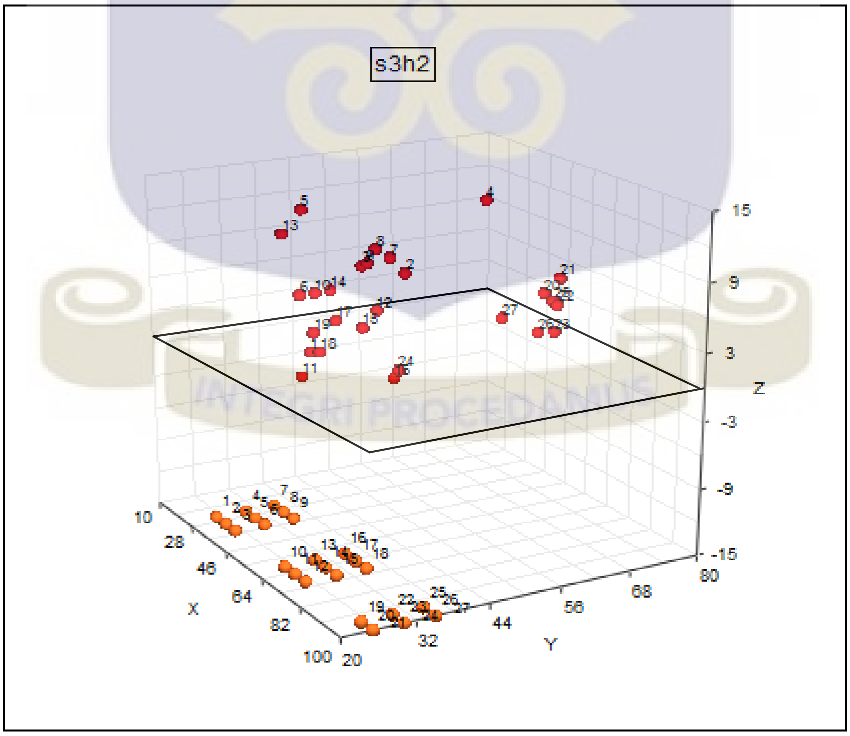


Three Dimensional (3D) Scatter Plot for S_3H_1 design.



Three Dimensional (3D) Scatter Plot for S_3H_2 design.

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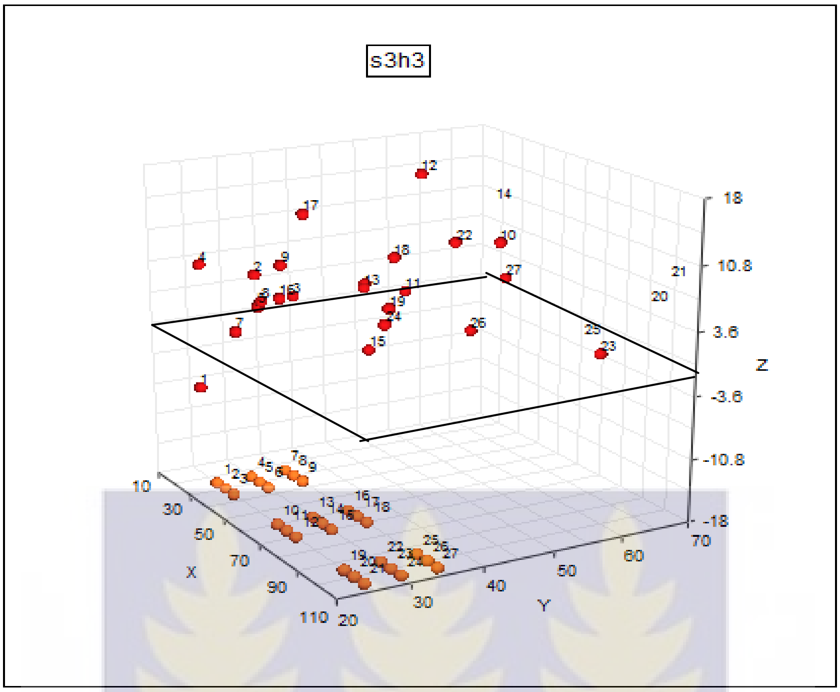

Three Dimensional (3D) Scatter Plot for S_3H_3 design.