EFFECTS OF SPRINKLER IRRIGATION ON SOIL PHYSICAL PROPERTIES AND GREEN GRAM CROP YIELD

BY

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DECLARATIONS

Declaration by the candidate

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Declaration by supervisors

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DEDICATION

This thesis is fondly dedicated to my wife Selah Serem and our four children; Sidney Serem, Perpetua Serem, Dylan Serem and Wayne Serem. I thank them collectively for their deep understanding and moral support as I undertook the study. I believe the knowledge gained out of this study will be greatly invaluable to them and my country.

ABSTRACT

Kenya's land area is 582,646 Km^2 with 17% suitable for rain-fed agriculture and 83 % classified as arid and semi-arid and cannot reliably support agricultural activities unless under irrigation . Insufficient water resources make the selection of an efficient irrigation system essential. Sprinkler irrigation is one such tool and despite having been proven to be economical and efficient is known to cause soil compaction leading to reduction in crop yield. The broad objective of the study was to determine the effect of sprinkler size on soil compaction and subsequently on green gram crop yield. Field trials were carried out at Wei Wei Irrigation Development Project in West Pokot County to determine the impact of sprinkler size on soil physical properties and subsequently on crop yield. Completely randomized block design was used as a framework for carrying out the trials. Three different sprinkler size treatments (Jalpari, Taiwan and Naan sprinkler types) with two replications each in six experimental trial plots were tested under subsoiled plots (B, D and F) and non subsoiled plots (A, C and F). Green gram crop was planted under four irrigation schedules of 5 hours each per sprinkler type to harvest. Soil analysis, penetration resistance, sprinkler characteristics, infiltration rates for the different trial plots, irrigation water runoff and soil erosion were determined. The experimental trials plots soils were sandy loam with an average soil bulk density of 1.6 g/cm^3 and an optimum compaction moisture content of 17.53%. This soil can easily be compacted and suitable moisture range for land preparation with minimal compaction was determined to be 15.3-17.53% by Proctor compaction test. The soil's penetration resistance was highest for non subsoiled plots at a depth of 0-20 cm compared with subsoiled plots by 38 bars. The penetration resistance values were between 144 and 160 bars against recommended values of 10-20.68 for crop production. These values were high and indicate that the soil was prone to compaction. Soil compaction was high for Jalpari Sprinkler type (146 bars) with more discharge at the end of experiment compared to Taiwan (142.5 bars) and Naan (145 bars) which had less. Jalpari sprinkler type caused runoff of 0.17 mm/ per irrigation schedule, soil erosion of 0.27 tons/ha/year against RUSLE modeled value of 0.35 tons/ha/year. The difference between the two values was associated with estimated RUSLE parameters which were derived from the experimental project's region's existing data. Plots with Taiwan sprinkler having a water application rate of 8.5 mm/hr, DU of 75.88% and CU of 83.2% produced the highest yield with a positive net income of Kshs 80,421.40 per hectare in a subsoiled plot. However yield differences due to sprinkler type were not significantly different. Statistical analysis on yield and tillage type showed similar trend except in yield per plant which had an F-ratio value of 26.1 against the table's value of 18.51. It could be concluded that sprinklers with high discharge cause compaction, runoff, soil erosion and lower yield. It was recommended that tillage be carried out at soil moisture content range of 15.3-17.53% with an effort of 600 $KN\text{-}m/m^3$ or less since this did not create compaction. Taiwan sprinkler and sub soiling which gave the best yields were recommended. Further research on soils, sprinkler types and machinery were also recommended.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
C	Cover Management Factor
CU	Coefficient of Uniformity
DU	Distribution Uniformity
Ha	Hectares
ISMES	Instituto Sperimentale Modelli e Strutture
K	Soil Erodibility Factor
KF20	Kenya Seed Company 20
Kg	Kilogrammes
KVDA	Kerio Valley Development Authority
LS	Slope Length and Steepness Factor
Lts	Litres
Mds	Man Days
MTEF	Medium-Term Expenditure Framework
NRCS	National Resources Conservation Service
NS	Non Subsoiled
P	Support Practice Factor
R	Rainfall Erosivity Factor
RUSLE	Revised Universal Soil Loss Equation

Sch	Schedule
SS	Subsoiled
TP	Test Pit
*u*PVC	Ultra Polyvinyl Chloride
USLE	Universal Soil loss Equation
WWIDP	Wei-Wei Integrated Development Project

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First I would like to express my profound gratitude to my supervisors, Eng. Prof. Emmanuel C. Kipkorir and Prof. Wilson K. Ng'etich for their invaluable support, encouragement and suggestions throughout the research study, data analysis and thesis writing. Their criticism and advice contributed greatly to this thesis. My sincere thanks go to the staff of the Schools of Engineering, Agriculture and Biotechnology, University of Eldoret for their support whenever there was need for equipment use. I also wish to extend my gratitude to the management and staff of Kerio Valley Development Authority especially the Managing Director, Mr. Francis C. Kipkech for approving my study leave and giving moral and material support for carrying out the research study at WWIDP. I also wish to thank the institution's staff at WWIDP particularly Kipruto Cheptum for his relentless assistance in managing the research project. I am also indebted to the Ministry of Transport and Infrastructure (*North Rift Regional Materials Laboratory)* Eldoret for carrying out the soil tests for me in their laboratory for this study. Finally gratitude goes to my family, friends and those who provided moral, financial and material support during the period of the study.

CHAPTER ONE

INTRODUCTION

1.1 Background

Agricultural crop performance is a function of available soil moisture, meteorological parameters and soil physical properties (Olla *et al*, 2009). Poor soil properties can impair water infiltration into soil, crop emergence, root penetration and crop nutrient and water uptake, all of which result in depressed crop yield.

Wei Wei Integrated Development Project (WWIDP), the focus of this study, is located on the lowlands of Pokot County (Figure 1.1). The project was conceived in 1984 through "*District Focus on Rural Development*" and the lessons learned as a result of the national drought of 1984. The project was constructed in 1987 and is operated under overhead sprinkler irrigation system. The present cultivated area is 275 ha with 325 ha envisaged for construction in 2014/2015.

West Pokot County is less endowed with water resources because of erratic and low seasonal rainfall patterns. In the upper and lower midland zones, the annual average rainfall ranges between 700 mm and 1200 mm (Jaetzold *et al*, 2011). These annual rainfall averages seem high but evaporation (ETo; 2289 mm/yr) and distribution is unfavourable throughout the county (Jaetzold *et al*, 2011; Toromo *et al*, 2012). The Agro-ecological zones are less suitable for crop production both in the highlands and lowlands. In the last few years, increase in acreage of crop production has not kept pace with population increase. From 2001 to 2007 the acreage increased by 5% and the population by 15% (Jaetzold *et al*, 2011) which confirms the un-proportional increase.

The land area of Kenya is 582,646 Km^2 with 17% suitable to support rain-fed agriculture and 83 % classified as arid and semi-arid and cannot reliably support any agricultural activities unless technologies such as irrigation are used. WWIDP lies within such a zone and the development of its irrigation potential is deeply rooted and is part of the national plans for the development of arid and semi-arid lands which are embedded as national priorities in the Vision 2030 and the current MTEF.

The Project has had an overall positive impact on food and insecurity in the area. Despite these achievements there has been a decline in management of field operations such as optimal use of water and land for crop production. Soil erosion, irrigation water run-off and poor drainage in the farm are suspected to have led to deterioration of soil physical properties and consequently affected crop yield negatively.

Studies carried out before project inception, design stage, construction and operation have concentrated on areas of soil types, sprinkler performance and water infiltration (Toromo *et al*, 2012; ISMES, 2007). Soil compaction associated with long term use of land has not been studied and is currently suspected to be an impediment to crop performance. This study attempted to address the issue of compaction due to sprinkler irrigation.

This study was aimed at contributing towards the project objective of crop production by finding out how the available scarce water resource could be optimized while minimizing soil compaction scientifically and statistically by relating the various processes of water movement and soil properties under a sprinkler irrigation system.

The data obtained during the study was statistically evaluated and analyzed using the ANOVA technique. ANOVA is a general technique that can be used to test the hypothesis that the means among two or more groups are equal, under the assumption that the sampled populations are normally distributed (Kothari, 2004). The variables hypothesized to influence the dependent variable are investigated using the method. Two-way ANOVA was used in this study since the variables were more than one namely, three sprinkler types and tillage. The yield was the dependent variable. This version of ANOVA can also use repeated measures structure and include interaction effects.

1.2 Statement of the problem

Wei-Wei project soils are of sandy–clay in nature and are subject to cracking, prone to erosion and compaction (ISMES, 2007). The soils demonstrate moderate fertility and are very low in nitrogen content.

Soil compaction is a problem throughout the project area and has caused a lot of water run-off, water logging, serious drainage problems, soil erosion and reduction in crop yields. Maize seed, sorghum and green gram crop yields dropped from 1.9 million tons in 2006 to 1.4 million in 2009 (Arap Kese and Associates, 2007). The project farmers have been applying higher fertilizer rates to circumvent the low productions but this has not proved to be a remedy since crop performance continues to decline. Soil compaction is suspected to be caused largely by livestock, farming population, machinery and irrigation water. The first two have been contained through training and enforcement of project by-laws/constitution through the project technical team and the local administration.

Compaction under intensive mechanized agriculture of both dry and irrigated land has not been addressed due to limited technical knowledge by the farmers and this has been further aggravated by mechanical impact of irrigation water droplets and rain drop which enhance soil dispersion and further lowers infiltration capacity, particularly for high clay-silty contents.

The project lies on an Arid and Semi-Arid zone initially a pastoralist area. Over the years there has been a shift to mixed farming hence a lot of dependency on the project. This shift and the increasing population approximated at 8,841 people in Wei Wei division (population census, 2009) necessitates a study to determine the magnitude of compaction by different sprinkler types for appropriate soil management and crop productivity for project sustainability and food security in the area. Green gram crop with a maturity period of 2-3 months was used in the study. The crop is short and does not obstruct sprinkler sprays. The other crops grown in the project were cereals (Maize and Sorgum) which grow up to 1.5 m high the height of the risers. Crops which grow to this height interfere with sprinkler sprays and where not used in the study.

1.3 Research objectives

The broad objective of this study was to determine the effect of sprinkler size on soil compaction and subsequently on green gram crop yield. The specific objectives of the study were:

i) To determine desirable soil moisture range for land preparation.

ii) To determine the extent of soil compaction by sprinkler water drops on soil infiltration, runoff and resulting erosion rate.

iii) To compare green gram crop yields and profits from the different sprinkler size treatments.

1.4 Hypotheses

The study is based on the following hypotheses:

i) Sprinklers with large water drops discharge cause soil compaction and subsequently affect infiltration, runoff and erosion.

ii) Sprinkler size reduce crop yield significantly under low and high discharges and low coefficient of uniformities.

iii) Subsoiling improves soil physical properties and subsequently crop yield.

1.5 Justification and significance of the study

The objective of WWIDP was to provide self sufficiency in food production through irrigated farming and as an alternative to pastoral farming. This was to be achieved through optimal use of land and water resources under modern agricultural practices. In the last few years crop production has been declining despite efforts by the farming community and Kerio Valley Development Authority (KVDA) to employ modern agricultural methods and practices. Some of the causes suspected to be associated with the decline in crop productivity are reduction of fertility due to soil erosion, lack of efficient and optimal use of irrigation water, use of sprinklers not synchronized with water infiltration into the soils and poor land use practices. The poor land use practices are suspected to include soil compaction by sprinkler water drops. The study on the soil physical properties and quantifying profits was therefore important in addressing this issue.

1.6 Limitations /assumptions of the study

The statistical analysis of the data was done using ANOVA technique. ANOVA requires at least three replications for each treatment for good results. However the project's irrigation design and the associated logistics limited it to only two replications. The other assumptions made during the study were that the soils were uniform throughout the trial plots and soil moisture content and wind speed were constant. Compaction due to machinery operation was assumed equal to penetration resistance measured in the first schedule of the trials. These assumptions may affect slightly the accuracy of the results obtained.

1.7 Study area

1.7.1 Location

Wei-Wei Integrated Development Project (WWIDP), located in West Pokot County, is an irrigation project constructed through funding from the Italian Government. The project is situated at longitude 35^{o} 30′ East and latitude 1^{o}30′ North and elevation of between 960 m and 939 m above sea level (Figure 1.1). The current project area under cultivation is 275 ha (Phase I & II) with an expected expansion of a further 325 ha. The project was established in 1987 (ISMES, 1987) to enhance food security, income generation, environmental conservation, transfer of modern farming technology and institutional capacity building.

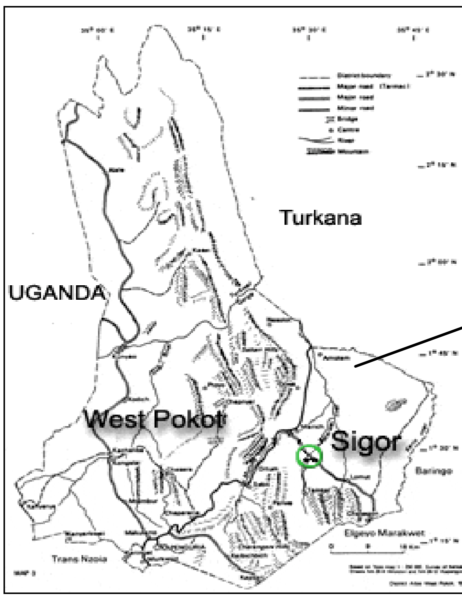

Figure 1.1a: West Pokot County

(Source: ISMES, 1987)

Figure 1.1b: Kenya Map

(Source: ISMES, 1987)

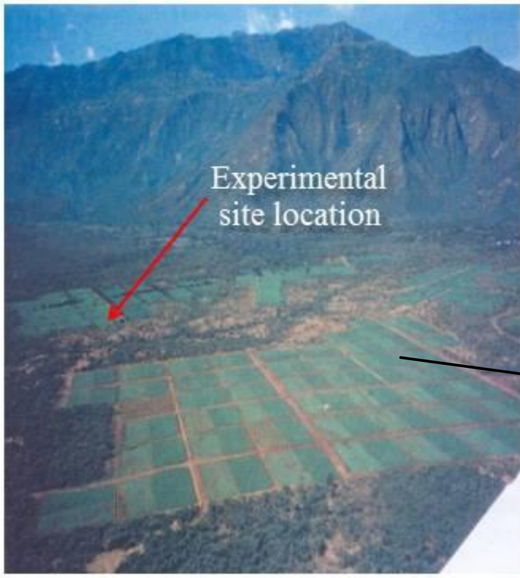

Figure 1.1c: WWIDP Areal View

(Source: ISMES, 1987)

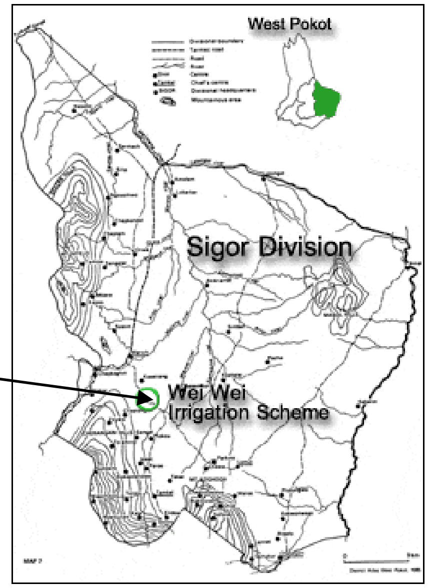

Figure 1.1d: Pokot Central District

(Source: ISMES, 1987)

The project uses an overhead rotary sprinkler irrigation system with design pressures of 2.5 bar and sprinkler emissions of 0.3 l/s (ISMES, 1987). The project benefits from crop cultivation of two to three seasons annually depending on the type of the crop and it's maturity period. The project currently benefits 225 households. The project gets its irrigation water from Wei Wei river through a 5 km, 1000 mm diameter steel pipeline. This is further distributed within the farm by use of *u*PVC pipes.

1.7.2 Climate

Rainfall is bimodal with the long rains falling between March and June and the short rains between September and November. The rainfall amounts range from 700 mm in the lowlands to 1600 mm in the high attitudes with poor distribution during the year (Jaetzold *et al*, 2011). Temperatures in the lowlands range from 15 ^{0}C to 30 ^{0}C but the highlands may experience temperatures as low as 9 ^{0}C. The high evaporation rate (ETo: 2,289 mm/year) indicates that crops hardly survive without additional water supply, thus the project area may well be defined as Arid and Semi-Arid Land (ASAL).

1.7.3 Hydrology

The average annual discharge of Wei Wei River at the project intake is 1 m^3/s and the water is chemically suitable for irrigation (Table: 1.1). The sediment load in recent years has increased due to deforestation of the project's catchment area for resettlement, agriculture and livestock use.

Table: 1.1: Chemical Analysis of Wei Wei River

Element	Unit	Quantity	Acceptable chemical range for irrigation water
P.H		6.9	6.5-8.4
Conductivity	micromhos/cm	95	0-3
Sodium	me/litre	0.26	0-40
Potassium	me/litre	0.06	0-2
Calcium	me/litre	0.14	0-20
Magnesium	me/litre	0.42	0-5
Carbonates	me/litre	nil	0-0.1
Bicarbonates	me/litre	0.77	0-10
Chlorides	me/litre	0.18	0-30
Sulphates	me/litre	0.02	0-20
Nitrates	me/litre	-	0-10
Fluorides	me/litre	-	-
Sodium Adsorption Ratio (SAR)	me/litre	0.81	0-15

(Source: Kinyanjui and Kanake, 1986; FAO, 1976)

1.7.4 Geology of the area

According to the geological survey report which covers the whole of the Cherangani hills area (Miller, 1956 and IAO, 1999), the Wei Wei river valley is composed of recent alluvial sediments, while the adjacent plains and foot slopes consist primarily of basement system rocks, namely fine grained hornblende gneisses (Viz: rocks rich in ferromagnesian minerals). The physiography of the area is closely related to the geology. It comprises the foot slopes of the Cherangany hills, the piedmont plain (or coalescing alluvial fanlands), the alluvial valley of the Wei Wei river, and minor valleys with recent alluvial fans.

1.7.5 Population

The population of Pokot Central District is 179,516 people (Population census, 2009 and Jaetzold *et al*, 2011). The population density is 61 persons per Km^2. Since 32, 548 households inhabit an area of 2,898.7 Km^2; the available land per household is 8.91 ha. This is a relatively small ratio compared to the number expected to support pastoralism of 10-15 ha per livestock unit (Jaetzold *et al*, 2011). More than 80% of the district is non-arable.

1.7.6 Land use

Rain-fed and irrigated agriculture is practiced within the project area and its surroundings. In the recent past irrigation has been modernized by investing in sprinkler irrigation systems through the assistance of the Italian Government and Kerio Valley

Development Authority (KVDA). Since time immemorial the Pokot community has been practicing irrigated agriculture using traditional methods (furrow irrigation) which are still being used outside the project area today.

Traditional crops grown with the support of irrigation are maize, cassava, mango, citrus, bananas and pawpaws. New crops were successfully introduced by the WWIDP and include cowpea *(Vignaunguiculata*) and green gram (*Vigna radiata syn. Phaseolus aureus*). Traditional crops are grown mainly along the escarpment during the long rains and include finger millet and sorghum. The areas cleared for cultivation are cropped for two to three years and then abandoned (shifting cultivation system) to rejuvenate. The farms are planted along the contours. To prevent crop damage by winds and improved sprinkler water application the farms have been planted with windbreak trees. Soil erosion prevention is being practiced but in a small scale. Recently Vetiver Grass (*Vetiveria zizanioides*) was introduced with the objective of stabilzing the embankments of drainage systems and the hill slopes. Pastoralism is practiced in the plains and on adjacent plateaus. Cattle, sheep, goats and recently camel are reared.

1.8 Thesis overview

The structure of this thesis comprises chapter one, which is a discussion of the statement of the problem, the research objectives and contribution to the research. It also provides the usefulness of assessing the soil physical properties and relating it to crop performance. The study area has been outlined including its location, climate, geology, land use and cover conditions. Chapter two gives a review of existing studies of irrigation systems and factors affecting soil properties. This chapter also discusses compaction, effects on crop yield and remedies for achieving a good seed-bed. The methodology is presented in chapter three. The results and discussions are presented in chapter four while the conclusions and recommendations are given in chapter five. References and appendices are given as an addendum to this thesis.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Water is very essential for plant growth; it is available in the soil in varying amounts, depending on soil characteristics (Olla *et al*, 2009). Water is absorbed into the soil by gravity and capillary forces, whereby it is attracted to and held on a thin molecular film around soil particles. The amount of water in a soil is also affected by the soil infiltration rate which is a function of soil physical properties.

Soil physical properties are very important to the health and general well being of the soil and consequently to the well being of crops grown on the soil. The rigidity, supporting power, drainage, moisture retention capacity, ease of root penetration, plasticity, aeration and retention of nutrients are intimately connected to the soil physical properties (Youndeowel *et al*., 1996).

Soil structure refers to the arrangement of particles into aggregates, it determines the extent to which the soil supports plants, animal and microbial life (Rowell, 1994). On the other hand, soil consistency refers to the degree of cohesion of a soil. It is also a measure of the resistance of a soil to deformation when worked upon, or its resistance to insertion of an instrument.

This section highlights sprinkler irrigation system, soil parameters such as infiltration, compaction, water runoff, soil erosion and modeling using RUSLE, crop yields and other related existing studies.

2.2 Irrigation methods

Irrigation is the artificial application of water to land or soil. It is used to assist in the growing of agricultural crops, maintenance of landscapes, and re-vegetation of disturbed soils in dry areas and during periods of inadequate rainfall. Maintenance of landscapes includes keeping growth of plants, airborne dust and soil movement outdoors by use of irrigation that could cause major cleanliness and environmental concerns. A crop requires a certain amount of water at some fixed time interval of its period of growth (Arora, 2007). Additionally, irrigation also has a few other uses in crop production, which include protecting plants against frost, suppressing weed growing in grain fields and helping in preventing soil consolidation.

Irrigation methods differ, depending on some factors such as topography, water resources, crop type, land tenure system, available power source, the growing season and the rain and water regimes (Dupriez *et al*. 2002). Irrigation methods come under two broad classifications namely surface and sub-surface irrigation (FAO, 1988). Surface irrigation refers to water application above the ground level, while sub-surface irrigation means water application below the ground surface (Olla *et al*, 2009). Irrigation methods can also be classified based on the system of water application to the field; this includes flood irrigation. This technique imitates flooding in its implementation, and methods such as check basin irrigation, border irrigation, furrow irrigation and flooding are included. This method allows sheet of water to be distributed to the field.

Other irrigation types include the sprinkler and trickle (i.e. drip) irrigation; these are irrigation methods that allow water application to the field under pressure. Sprinkler irrigation imitates rain in its application and the pressure is obtained through pumping or gravity with careful selection of nozzles, operating pressures and sprinkler spacing. A sprinkler head should discharge water at a rate which could be simultaneously absorbed by the soil, therefore the infiltration rate of the soil should not be lower than the water application rate. Sprinkler irrigation which is a pressurized system is considered in this study.

2.3 Sprinkler irrigation

Sprinkler irrigation is a method of applying irrigation water which is similar to natural rainfall (FAO, 1988). Water is distributed through a system of pipes usually by pumping. It is then sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground. The pump supply system, sprinklers and operating conditions must be designed to enable a uniform application of water. The sprinkler system capacity should irrigate an area adequately and is expressed in m^3/s or mm depth/unit area. The system capacity is dependent on:

a) Peak crop water requirements during the growing season.

b) Effective crop rooting depth.

c) Texture and infiltration rate of the soil.

d) The available water-holding capacity of the soil.

e) Water source capacity.

f) Permitted pumping rate.

A sprinkler irrigation conveyance system consists of a mainline, sub-mainlines and lateral pipes. Main pipes deliver water from the pump or source to the laterals. In some cases these pipelines are permanent and are laid on the soil surface or buried below ground. In other cases they are temporary, and can be moved from field to field. The main pipe materials used include asbestos cement, plastic or aluminium alloy.

The laterals deliver water from the mainline or sub-mainline to the sprinklers. They can be permanent but more often they are portable and made of aluminium alloy or plastic so that they can be moved easily. The most common type of sprinkler system lateral layout is shown in Figure 2.1.

Sprinklers are best suited to sandy soils with high infiltration rates although they are adaptable to most soils. The average application rate from the sprinklers (in mm/hr) is always chosen to be less than the basic infiltration rate of the soil so that surface ponding and runoff can be avoided. Sprinklers are not suitable for soils which easily form a crust. If sprinkler irrigation is the only method available, then light fine sprays which cannot easily be lost through evaporation should be used. The larger sprinklers producing larger water droplets are to be avoided. Surface seals form under the influence of external forces such as mechanical compaction, raindrop impact, slaking and breakdown of soil aggregates during wetting (Asgedom and Asegawa, 2005).

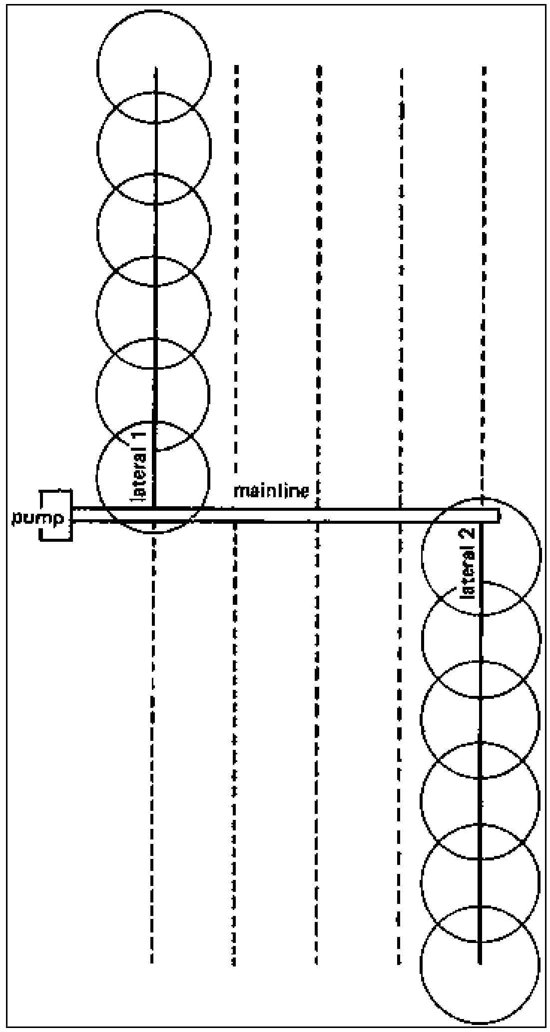

Figure 2.1: Hand-moved sprinkler system using two laterals (1 and 2)

(Source: FAO, 1988)

2.4 Sprinkler drop sizes

As water sprays from a sprinkler it breaks up into small drops between 0.5 and 4.0 mm in size (FAO, 1988). The small drops fall close to the sprinkler whereas the larger ones fall close to the edge of the wetted circle. Large drops can damage delicate crops and soils therefore in such conditions it is best to use the smaller sprinklers.

Drop size is controlled by pressure and nozzle size. When the pressure is low, drops tend to be much larger as the water jet does not break up easily. To avoid crop and soil damage small diameter nozzles are used operating at or above the normal recommended operating pressure.

2.5 Wetting pattern

The wetting pattern from a single rotary sprinkler is not very uniform (Figure 2.2). Normally the area wetted is circular (Figure 2.3). The heaviest wetting is close to the sprinkler (Figure 2.3). For good uniformity several sprinklers must be operated close together so that their patterns overlap. For good uniformity the overlap should be at least 65% of the wetted diameter. This determines the maximum spacing between sprinklers.

Figure 2.2: Wetting pattern for a single sprinkler (side view)

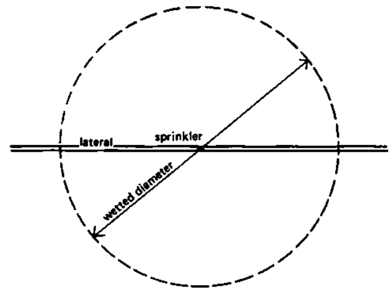

Figure 2.3: Wetting pattern for a single sprinkler (top view)

2.6 Infiltration

Infiltration is the process by which water on the surface penetrates the soil (Uloma *et al*, 2013). It refers to the vertical movement of water downwards from the soil surface to replenish the soil water and moisture deficiency, with the excess percolating down to build up the water table by gravitational flow (Diamon, 2004). It is related to overland flow and groundwater, determining the fraction of irrigation or rain water that enters the soil and thus, affecting the amount of runoff responsible for soil erosion (Zhidong et al 1988). It can be quantified by cumulative infiltration or infiltration capacity. The infiltration rate is expressed in terms of volume of water per unit area and time (for instance mm/hr).

In irrigation, problems occur if the water does not enter the soil rapidly enough during a normal irrigation cycle to replenish the soil with water needed by the crop before the next irrigation. If the sprinkler application rate is greater than the soils infiltration rate, water will pond on the soil surface and then runoff will occur (Schwankal, 2007). To avoid runoff the sprinkler application rate should be matched to the final or basic intake rate as opposed to the initial (Fig. 2.4). This is critical in minimizing runoff.

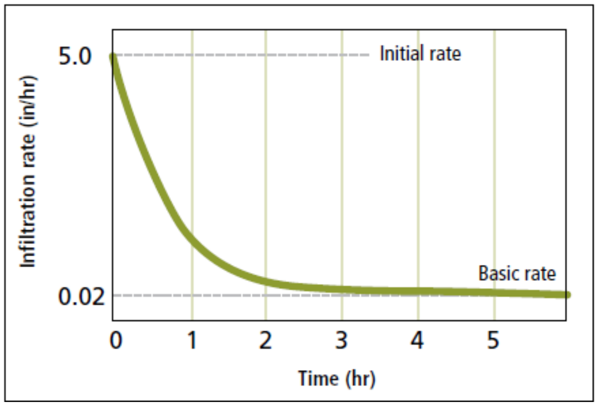

Figure 2.4: Idealized Intake rate versus time

(*Source*: Schwankal et al, 2007)

The slope of the land under irrigation, chemical composition of the soil and the irrigation water can affect the intake rates and amount of runoff. Table 2.1 indicates the maximum water application rates for various soil types at slopes of between 0 and 12%.

Table 2.1: Recommended maximum water application rates

Soil Type	Maximum application rate (mm/hr) at slope		
	0-5%	5-8%	8-12%
Coarse sandy soil	38.1-50.8	25.4-38.1	19.05-25.4
Light sandy soil	19.05-25.4	12.7-20.32	10.0-15.24
Silt loam	7.62-12.7	6.35-10.16	3.81-7.62
Clay loam, Clay	3.81	2.54	2.03

(Source: NRCS, 1984)

2.7 Compaction

Compaction increases the structural strength or bulk density of soils, decreasing its porosity and forcing a smaller distribution of pore sizes within the soil (Gregory *et al*; 2006). The Authors performed soil infiltration tests on non-compacted and compacted sandy soil of sand-silt composition of 89.3% and 10.6% respectively on a construction site in North Central Florida. The test results in the two situations reduced infiltration rates by 29 % from 99 to 70%. They also discovered that compaction has a significant influence on soil hydraulic properties such as soil water retention, soil water diffusivity and unsaturated hydraulic conductivity. The reduction in pore spaces reduces capillary movement of water between pores. This makes the soil retain more water and reduces water diffusivity and hydraulic conductivity.

In agricultural crop production compaction increases bulk density and penetrometer resistance while it reduces penetrability of roots to soil and crop yield (Taser *et al*, 2005 and Hamza, 2005). The authors gave penetration resistance of 10 bars and above as sufficient to decrease crop yield. Soil compaction may significantly impair productivity of soil by decreasing the aeration, soil water storage and crop water use efficiency (Hamza *et al*; 2005). Soil compaction is the main form of soil degradation and affects 11% of the land area in surveyed countries of the world (Ramazan *et al*; 2012). For an adequate productivity, the pore space of a soil should be around 50% of its volume (Taser *et al;* 2005).

A limited degree of soil compaction under the seeding depth tends to increase the soil moisture content in the vicinity of planted seeds, encouraging capillary ascent of water from subsoil. It also provides a better seed-soil contact and rapid germination and reduces the rate of soil drying (Kobaissi, *et al* 2013). However, an excessive compaction can hamper root growth, limit nutrient uptake and decrease soil aeration thus affecting crop yield. McLaughlin, (2005) and Ramazan, (2012) performed experiments on compaction using wheel traffic and tillage operations on corn and results indicated it negatively affected crop height and yield. The critical depth for harmful soil compaction in agricultural soils is the subsoil layer below the arable topsoil. In ploughed soils it is located in a depth of about 30 – 60 cm (Plate 2.1).

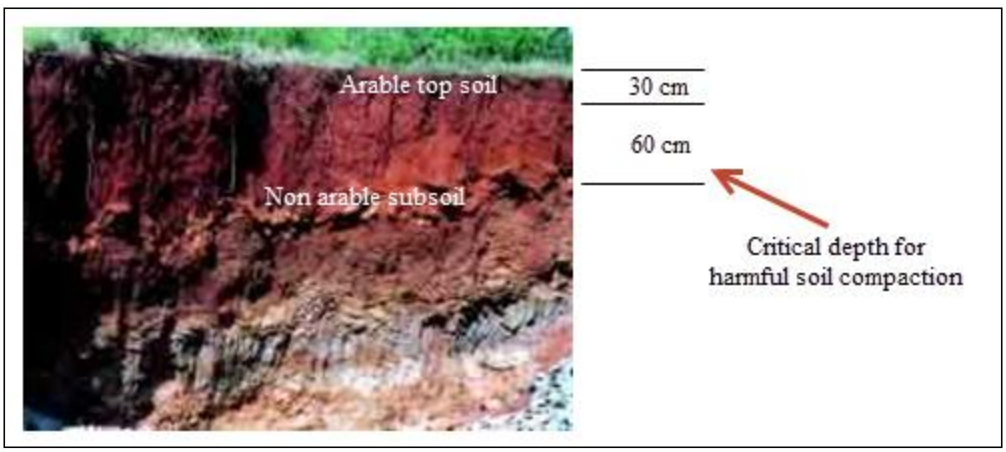

Plate 2.1: Critical depth for harmful soil compaction

(Source: Gachene and Gathiru, 2003)

Compaction can be reduced by tillage. This operation breaks apart soil aggregates permitting soil particles to move apart or be forced closer together. This improves the soil structure, increases pore spaces, infiltration, aeration and nutrient uptake (Hoorman *et al*, 2009).

The proctor test is used to determine the maximum compatibility of soil penetration resistance and the effect of soil compaction on root growth. Bulk density is also used to measure root penetration resistance of a soil but a soil penetrometer is a better indicator.

2.8 Runoff and soil erosion

Erosion is a process of detachment and transport of soil particles by erosive agents (Barthes and Roose, 2001). Soil erosion can be serious under sprinkler irrigation if the water application rate exceeds the soil infiltration capacity and runoff occurs. This is further aggravated if the land under irrigation has natural slopes higher than those permissible under the sprinkler system design.

Irrigation-induced erosion from sprinkler irrigation resembles that from rainfall in many ways. In both cases, water droplet impact can deteriorate surface soil structure by fracturing soil aggregates, thereby producing aggregate fragments, primary particles, or both that can obstruct surface pores leading to surface sealing and increased runoff (Sun *et al*, 2012). Water that does not infiltrate into the profile accumulates on the surface and, once surface depression storage is satisfied, runs off, often transporting detached soil down slope or off-site. Water droplet impact not only detaches soil but also increases turbulence in shallow flow, increasing the amount of sediment the flow can transport.

Lehrsch *et al*, (2012) using test plots found that soil aggregate stability decreased from 66 percent to 55 percent when the irrigation's droplet energy increased from 0 per cent to the lowest rate under investigation. Sugar beet seedling emergence increased by 6.4 percent when droplet energy was reduced by 50 percent from the highest rate studied. This indicates that irrigation water affects soil structure which is a key factor affecting water movement and retention in soil, erosion, crusting, nutrient recycling, root penetration and crop yields.

2.9 Modeling soil erosion

Erosion impact may be quantified by expressing the ratio between yields before and after the start of accelerated erosion, or the magnitude of yield decline per unit time in the area subject to degradation (Mannering, 1981). It is important to note here that some soil erosion(tolerable soil loss) may be necessary to maintain favorable soil productivity without any erosion, prolonged weathering under tropical conditions might result in the formation of indurated horizons that render the soil profile unfavorable for crop growth (Mannering, 1981).

Poor soil water storage is enhanced by soil erosion and surface runoff management (Cheserek *et al*, 2009). Knowledge of causative factors and use of erosion prediction models can help address long-range land management planning under natural and agricultural conditions. Even though it is hard to find a model that considers all forms of erosion, some models were developed specifically to aid conservation planners in identifying areas where introducing soil conservation measures will have the most impact on reducing soil loss (Angima *et al*, 2003) and consequently improve crop yield.

Modeling of soil erosion provides ways of soil erosion control and water management. The revised Universal Soil Loss Equation (RUSLE), an empirical soil erosion prediction model founded on the universal soil erosion loss equation (USLE) (Weischmeier and Smith, 1978) can be used for soil erosion and water management planning. The model is a science-based tool that has been improved over the last several years (Gaffney *et al*, 2003) and calculates annual sheet and rill erosion from rainfall and the associated runoff for a landscape profile (Jones and Shaw, 1996). It is a computation method which may be used for site evaluation and planning purposes and to aid in the decision process of selecting erosion control measures. It provides an estimate of the severity of erosion and numbers to substantiate the benefits of planned erosion control measures.

RUSLE computes the average annual erosion expected on hillslopes by multiplying several factors together: rainfall erosivity (*R*), soil erodibility (*K*), slope length and steepness (*LS*), cover management (*C*), and support practice (*P*). The values of these factors are determined from field and laboratory experiments. The *R*-factor is measured as the product (*EI*) of total storm energy (*E*) and the maximum 30-min intensity (*I*30) for all storms over a long time. The *EI* parameter quantifies the effects of raindrop impact and reflects the amount and rate of runoff likely to be associated with the rain. The *K*-factor reflects the ease with which the soil is detached by splash during rainfall and/or by surface flow, and therefore shows the change in the soil per unit of applied external force of energy. This factor is related to the integrated effect of rainfall, runoff, and infiltration and accounts for the influence of soil properties on soil loss during storm events on sloping areas.

For tropical soils, unstable soil aggregates, modified silt, sand, and the corresponding base saturation are used to determine *K*. The *K*-factor derived from the USLE nomograph is applicable to tropical soils that have kaolinite as the dominant clay mineral, but less applicable where Vertisols dominate. The *LS*-factor accounts for the effect of slope length and slope gradient on erosion. RUSLE provides conversion tables for determining *LS* on uniform slopes. Soil loss increases more rapidly with slope steepness than it does with slope length).

The *C*-factor measures the effects of all interrelated cover and management variables. Values of *C* can vary from near zero for well-protected soils to 1.5 for finely tilled, ridged surfaces that are highly susceptible to rill erosion. RUSLE software provides extensive crop database values, including some tropical crops, which are used to evaluate the *C*-factor, especially when plant growth characteristics are known, or the user may develop a more appropriate database from experimental data. The *P*-factor is the ratio of soil loss with specific support practice to the corresponding loss with up and down slope tillage. These practices proportionally affect erosion by modifying the flow pattern, gradient, or direction of surface runoff and by reducing the amount and rate of runoff. Values for *P*-factor range from about 0.2 for reverse-slope bench terraces, to 1.0 where there are no erosion control practices.

The soil loss computed by RUSLE is the amount of sediment lost from a landscape profile described by the user and is given by equation 2.1.

A = RK (LS) C P…………………...…………………………………….... (2.1)

Where:

A = average soil loss (ton/ha/yr)

R = rainfall erosivity factor (MJ.mm/ha.hr.yr)

K=soil erodibility factor (ton/ha/unit R)

LS = slope factor (dimensionless)

C = cover factor (dimensionless)

P = prevention practices factor (dimensionless)

RUSLE, which was developed for field use in the USA, uses inputs and produces output in US customary units, thus factor values have to be converted to SI units (Système International d'Unités).

2.10 Crop yields and compaction

Soil compaction caused by mechanical force affects the vegetative and generative plant growth. Ramazan *et al*, (2012) conducted experiments on seed maize at various states of compaction and observed a reduction in grain yield from 4415.20 kg/ha to 2522.32 kg/ha at zero and four tractor passes respectively. Crop root length and height were also reduced proportionally according to the degree of compaction.

2.11 Green grams

Green grams (*Vigna radiata*) are plants belonging to the legume family (Plate 2.2). It is grown in Kenya in arid and semi-arid regions at altitudes of 0-1600 metres above sea level. It is a warm season crop with optimum growth temperatures in the range of 25-30 ^{o}C with a maximum temperature of 35 ^{o}C. The crop optimally grows in well aerated drained sandy loamy soils at a pH of between 6 and 7.3. The seed-bed should have a fine tilth free of clods. At sowing seed rows are spaced at 30-45 cm with 15 cm between seeds and light soil covering is done to ensure good seed germination.

The crop is sensitive to weed, disease and pest infestation. High prevalence of these infestations reduces crop production drastically. Management of the crop should be highly emphasized. In rural Kenya harvesting and threshing is done manually. The crop is harvested when the pods turn yellowish after which they are dried, threshed and cleaned. Seeds are dried to a moisture content of 12 % before storage or marketing. The yield from a well managed plot ranges between 1,250 and 1,500 Kilograms per hectare.

Plate 2.2: Green grams crop at flowering stage

(Source: Author, 2014)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Overview of approach

The field trials were carried out at WWIDP. The plot area targeted for the research work was 1 ha (2.5 acres) with a complete set of hand move sprinkler irrigation equipment. The primary data collection was carried out at project site and through tests at laboratories at University of Eldoret and the Ministry of Transport and Infrastructure (*North Rift Regional Materials Laboratory)* at Eldoret town. The tests determined seven major parameters namely; maximum dry density of soil (and optimum moisture), degree of soil compaction, application rate (by sprinkler irrigation), water infiltration, runoff, soil erosion and crop yield. Secondary data was collected from KVDA and WARMA offices in West Pokot County.

3.2 Data collection

3.2.1 Soil sampling

Soil sampling was carried out within the trial plot before any land preparation was done. The soil sampling points were identified in a zigzag pattern (*http:www.cropnutrition.com/afu-soil-sampling, accessed 24th October 2014*) as outlined in Figure 3.1 and were sited approximately 30 m between each other and the same distance away from the plot boundary. This method provided minimal biasness in distribution of sampling sites and ensured homogeneity. Furthermore the points were within the four outside corner blocks with sprinklers Jalpari (block A), Taiwan (Block B), Naan (Block E) and Jalpari (block F) respectively (Figure 3.1 and 3.3) and along the double ring infiltrometer positions as indicated in Figure 3.7 section 3.4.

The top surface of the soil and plant growth was removed using a shovel. Soil samples were removed from the sampling pits up to a depth of 40 cm, the ploughing depth of land preparation. This depth also approximates the root depth of green gram crop. The soils were mixed by rolling action and weights of 70 kg collected in tagged plastic bags for testing. The collected samples were then labeled TP1, TP2, TP3 and TP4 and analyzed for soil texture by use of sieve analysis. The sieves used were of sizes 20 mm, 2 mm, 0.425 mm, and 0.075 mm. USDA textural triangle was used to classify the soil and soil calculator to determine the soil hydraulic properties.

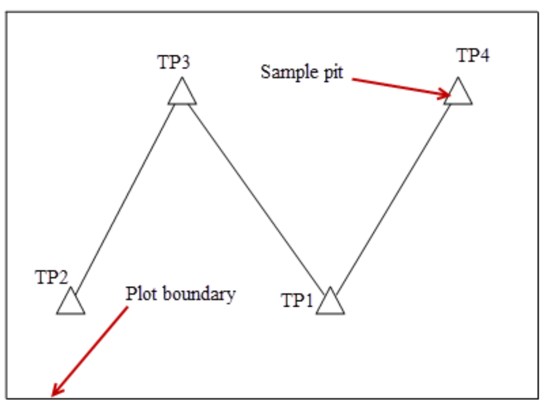

Figure 3.1: Soil sampling pattern and pits

(Sources: Author, 2014)

3.2.2 Proctor compaction test

Soil samples collected as outlined in section 3.2.1 were dried and passed through 20 mm diameter sieve. Four samples weighing 2500 gm were measured and their initial moisture content determined. The samples used were from pits TP1, TP2, TP3 and TP4 on the trial plot.

The compaction tests on the soils were carried out using the equipment in Plate 3.1 and methodology developed by Proctor, (1933). This is a laboratory method of experimentally determining the optimal moisture content at which a given soil type will become most dense and achieve its maximum dry density. The test normally shows that the dry density of a soil for a given compactive effort depends on the amount of water the soil contains during soil compaction.

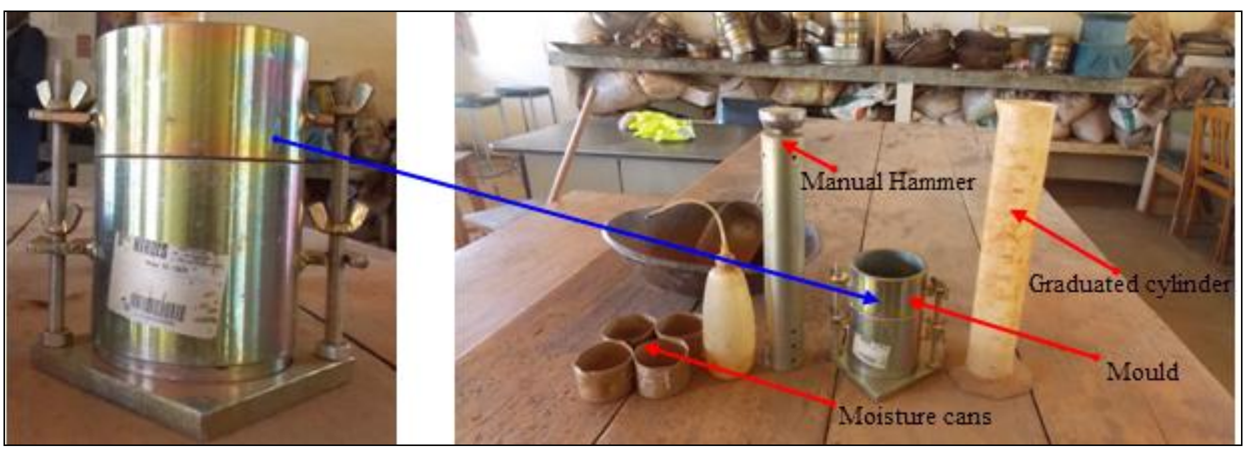

Plate 3.1: Standard Proctor compaction test equipment

(Source: Ministry of Transport and Infrastructure - North Rift Regional Materials Laboratory, Eldoret)

The laboratory tests were carried out on the four soil samples using the Standard Proctor Test (ASTM D698). This was done by compacting sun dried soil samples at known moisture content into a cylindrical mould of standard dimensions (height-116.43 mm by diameter-101.6 mm) using a compactive effort of 2.5 Kg (600 KN-m/m^3). The moisture content was added to the soil samples first at 8% percent and then at intervals of 2%. The soil was compacted into the mould to 3 equal layers, each receiving 25 blows from a standard weighted hammer at a height of 304.8 mm. This process was then repeated for various moisture contents and the dry densities determined for each. The test was stopped when the last sample becomes wet and starts to disperse. The graphical relationship of the dry density to moisture content was then plotted to establish the compaction curve. The maximum dry density was finally obtained from the peak point of the compaction curve and its corresponding moisture content, also known as the optimal moisture content (Figure 4.2).

3.2.3 Measurement of Soil penetration resistance

The effect of compaction due to sprinkler water drops was measured using a Penetrometer with a 30-degree steel cone at the end of a steel shaft and a pressure gauge on the other end (Plate 3.2). The Penetrometer during the measurements was pushed into the soil at a rate of 2.5 cm per second to depths of 0-20 cm. The penetration resistance was measured on the soil before application of irrigation water and again measured thereafter at time interval of six days. This was repeated for several irrigation schedules and the degree of compaction inferred from the differences in penetration resistance between the two measurements. The penetration resistance trials in the three sprinkler type areas were laid out as in Figure 3.2. The penetration resistance due to long term machinery operations was taken as the average of resistances measured in the first schedule when compaction due to sprinkler was insignificant.

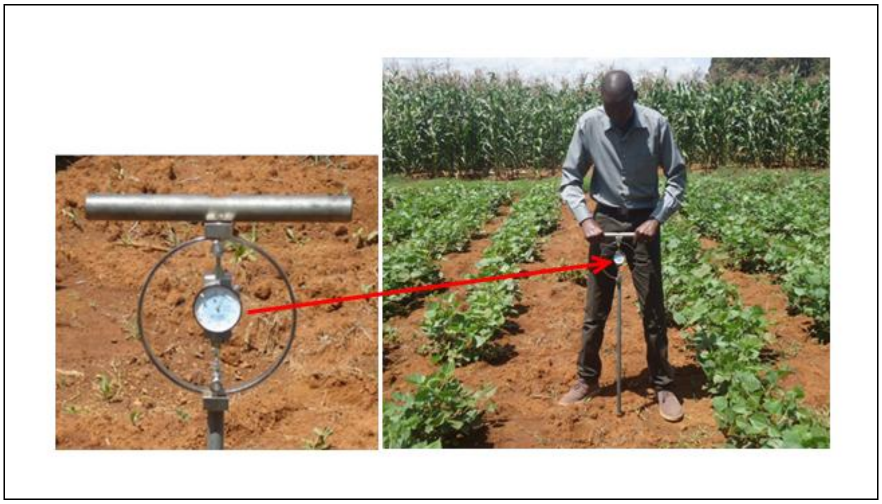

Plate 3.2: Measurement of soil penetration resistance using a cone Penetrometer (Source: Author, 2014)

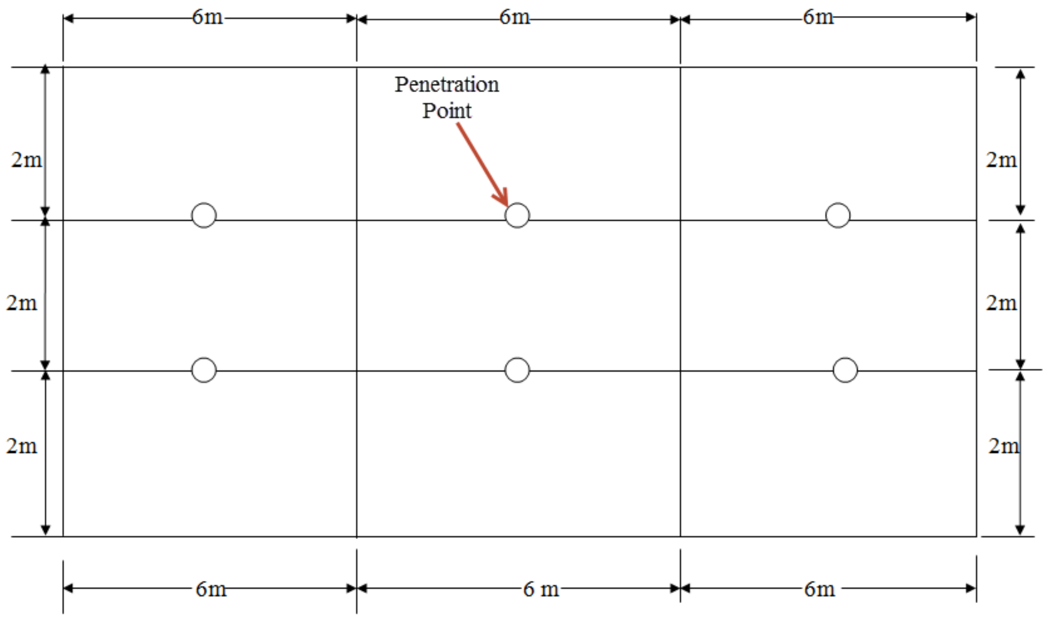

Figure 3.2: Layout of soil penetration points in each trial plot

(Source: Author, 2014)

3.2.4 Measurement of applied irrigation water

Three types of sprinkler heads (Taiwan, Jalpari and Naan) of different nozzle sizes (Plate 3.3 a-c) were used in carrying out the trials. The three types of sprinklers Taiwan, Jalpari and Naan have design discharges of 9 mm/hr, 11.6 mm/hr and 7.8 mm/hr. The most commonly used type of sprinkler, Taiwan (Plate 3.3 a) at the project was considered in the three sprinklers and was taken as a control. Applied irrigation water (precipitation) was measured alternately for each set of sprinkler type with catch cans spaced at three metres (square grid) between each other evenly distributed on the trial plots (Figure 3.7, section 3.4). The amount of water collected in the catch cans was measured in mm using a graduated cylinder. The catch cans used had surface areas of 37.44 cm^2. The sprinkler water data collected from the catch cans were standardized to that of a normal rain gauge of surface area 118.82 cm^2. The operating pressure of the sprinklers was also measured in bars using a pressure gauge (Plate 3.4).

Plate 3.3 a: Taiwan sprinkler

Plate 3.3 b: Jalpari sprinkler

Plate 3.3 c: Naan sprinkler

Plate 3.4: Pressure gauge

The precipitation data obtained was processed using MS-EXCEL programme. The coefficient of uniformity (CU) and distribution uniformity (DU) which are common indices describing uniformity were also determined. CU is defined as the variability of water application about the average application depth. High variability implies low sprinkler performance and low CU. CU of 84% is desirable (Keller and Bliesner, 1990). The CU was calculated using Christiansen's formula, equation 3.1 (Vories and Von Bermuth, 1986; Allen, 1993). This was expressed as:

$$CU = 100[1 - \frac{\sum X}{mn}] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where:

CU is the coefficient of uniformity (%)

$\sum X$ is summation of absolute deviations from the mean depth of observations

m is the mean depth of observations

n is the number of observations

The other common index describing uniformity is distribution uniformity (DU) defined as the ratio of the least amount of infiltrated water to the average amount (Hanson, 2005). High DU means water is evenly applied across the surface being irrigated and low DU uneven distribution and results in spot application. DU of 75% is recommended (Hanson, 2005). DU was determined using equation 3.2 expressed as:

$$DU = 100[\frac{M_4}{M}] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

Where:

DU is the distribution uniformity (%)

M_4 is the mean depth of the lowest quartile of the observations

M is the mean depth of all observations

3.2.5 Measurement of infiltration rates

Determination of soil infiltration rates was carried out using ASTM D-3385 standard procedure. In both the baseline and actual trials data collection, soil moisture content was viewed as influencing infiltration rate uniformly across the trial plots. Initial infiltration rates were carried out on the farm before land preparation to establish the behaviour of the soil under dry and undisturbed conditions (no tillage). Four infiltration tests were carried out at soil sampling points TP1, TP2, TP3 and TP4 as indicated in Figure 3.1 in section 3.2.1.

The effect of compaction on infiltration rates was measured using a double ring infiltrometer (Plate 3.5). The two rings were driven into the ground to a depth of 5 cm without disturbing the soil and partially filled with water to a depth of 10 cm (Eijkelkamp, 2012 and Akinbile 2010). The double ring design helps prevent divergent flow in layered soils. The outer ring acts as a barrier to encourage only vertical flow from the inner ring. The tests were taken at various irrigation schedules and levels of compaction by the three sprinklers with different nozzle sizes (Plate 3.3 a-c). Infiltration rates were measured before initial irrigation water application and thereafter at six days intervals (irrigation schedule) until the crop were harvested. This was measured by first noting the time and the water level in the inner ring (reference level) as indicated on a measuring rod (graduated transparent ruler). The drop in the water level in the inner ring was measured first at short intervals (1-2 min) and thereafter at appropriate longer intervals (20-30 min). The data was processed, analyzed and graphs of infiltration rates versus time plotted. An infiltration equation was also determined using the data.

Plate 3.5: Double ring infiltrometer

(Source: Author, 2014)

3.2.6 Measurement of runoff and soil erosion

Runoff and soil erosion were determined using runoff plots laid out as in Figure 3.3. Three runoff plots measuring 5 m by 10 m were designed within the trial plot with one collector tank each of 10 litres placed at the bottom end corner of each plot (Plate 3.6). The collector tank was ensured placed with its edge at original ground level.

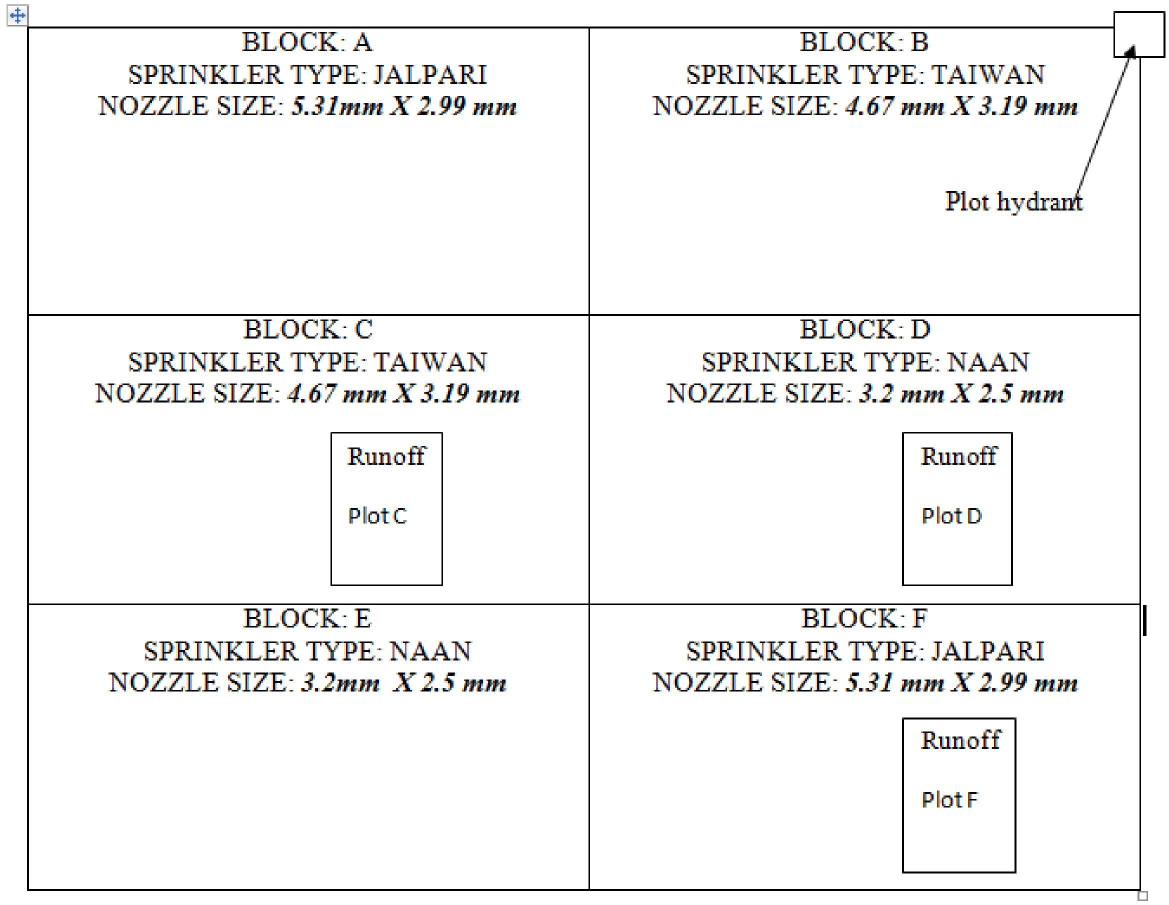

Figure 3.3: Runoff plot layout within the trial blocks

(Source: Author, 2014)

One runoff plot was designed for each sprinkler type (Jalpari, Taiwan and Naan). Three metre length of corrugated iron sheets were cut with a pair of scissors to 30 cm by 300 cm width and inserted along the marked runoff plot boundaries to a depth of 5 cm. This was inserted deep enough and lengths of metal sheets overlapped to prevent leakages underneath. The height of the sheets were ensured 20 cm above ground to prevent water splash from adjacent plots entering into the runoff plot.

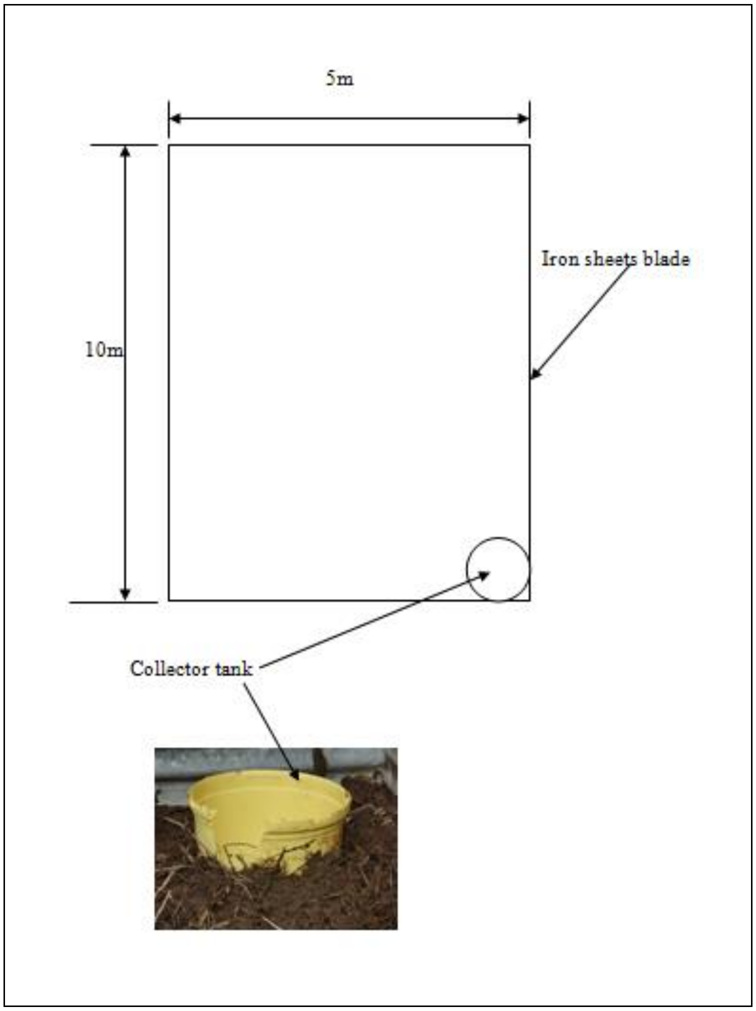

Plate 3.6: Runoff plot layout and collector tank

(Source: Author, 2014)

The amount of runoff collected in the tanks was measured in litres and later converted into mm depth. This amount of runoff was determined over the five hour irrigation duration set. Similarly the soil loss during the period was collected, dried and weighed in grams. This was later converted into tons/ha/yr to conform to RUSLE.

From the soil sampled and the area existing RUSLE model parameters soil loss was predicted. It was important to know from the prediction how serious erosion is under the soil types determined and on a wider area since this could not be measured directly. The factors R, K, LS, C and P used in RUSLE were determined using local and generated primary data. The rainfall erosivity R-factor was calculated using measured rainfall intensity and the annual average soil erodibility K-factor from soils sampled and analyzed from the area (section 3.2.1).

Soil erodibility factor (K) was calculated using inherent soil physical properties (Angima et al, 2002). This is a procedure for tropical soils and uses equation 3.3.

$$K = -0.03970 + 0.00311X_1 + 0.00043X_2 + 0.00185X_3 + 0.00258X_4 - 0.00823X_5 \quad (3.3)$$

Where:

X_1 is the percent unstable aggregates < 0.25 mm

X_2 is the product of the percent of silt (0.002-0.01 mm) and sand (0.1-2 mm) present in the sample,

X_3 is the percent base saturation of the sample,

X_4 is the percent silt present (0.002-0.050 mm),

X_5 is the percent sand in the soil (0.1-2 mm).

Length and slope factors were calculated from survey data obtained from the plot. The C-factor values were computed from existing cropping patterns in the project, including maize, sorghum, legumes, fruit crops and other crops. Conservation practice factor P was derived from existing agricultural practices.

3.2.7 Crop yield

Green grams (KF20 variety) was planted on a 1 ha unit at a spacing of 40 cm x 15 cm to determine the effect of irrigation on soil compaction and yield production. The field was sub-divided into six trial plots with two replications of each of the sprinkler sizes. Half the plot area (0.5 ha) was not subsoiled and operated under normal project practices while the other half was subsoiled to reduce initial compaction and cropped. The experiments were carried out and replicated as indicated in Figure 3.6.

The crop harvested was sampled from an area of 24 m x 6 m from each block. This area did not have a water application overlap with any other type of sprinkler. The crop from the plots was harvested, dried, weighed and the results compared and related to the tests carried out in section 3.2.1 to 3.2.5. Cost benefit and ANOVA statistical analyses were also carried out on the yield.

3.3 Field layout

The field trial plot was surveyed using a Theodolite. The perimeter and the elevations at appropriate intervals were taken within the field and the data analyzed using AutoCAD 2013 software. The layouts indicated in Figures 3.4 and 3.5 were drawn using the software. Three profiles within the plots were determined using the software and in each a gradient was determined. The average gradient of the trial plot was determined by taking an average of the three gradients in the three profiles. The gradient was then used in calculation of the LS factor in RUSLE.

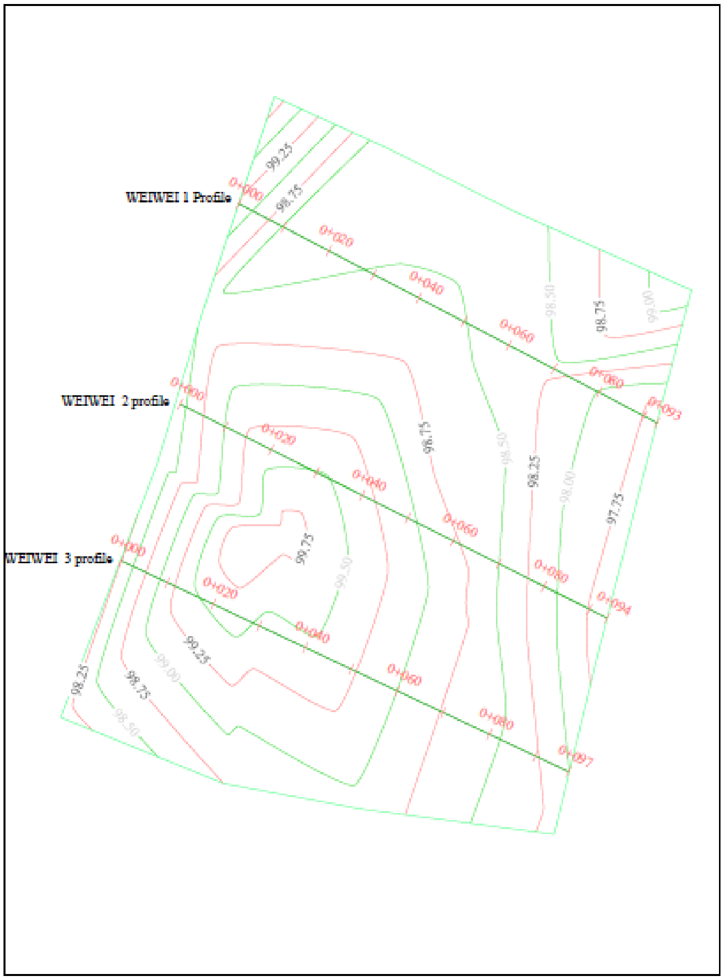

Figure 3.4: Trial plot layout showing profile 1, 2, 3 and contours

(Sources: Author, 2014)

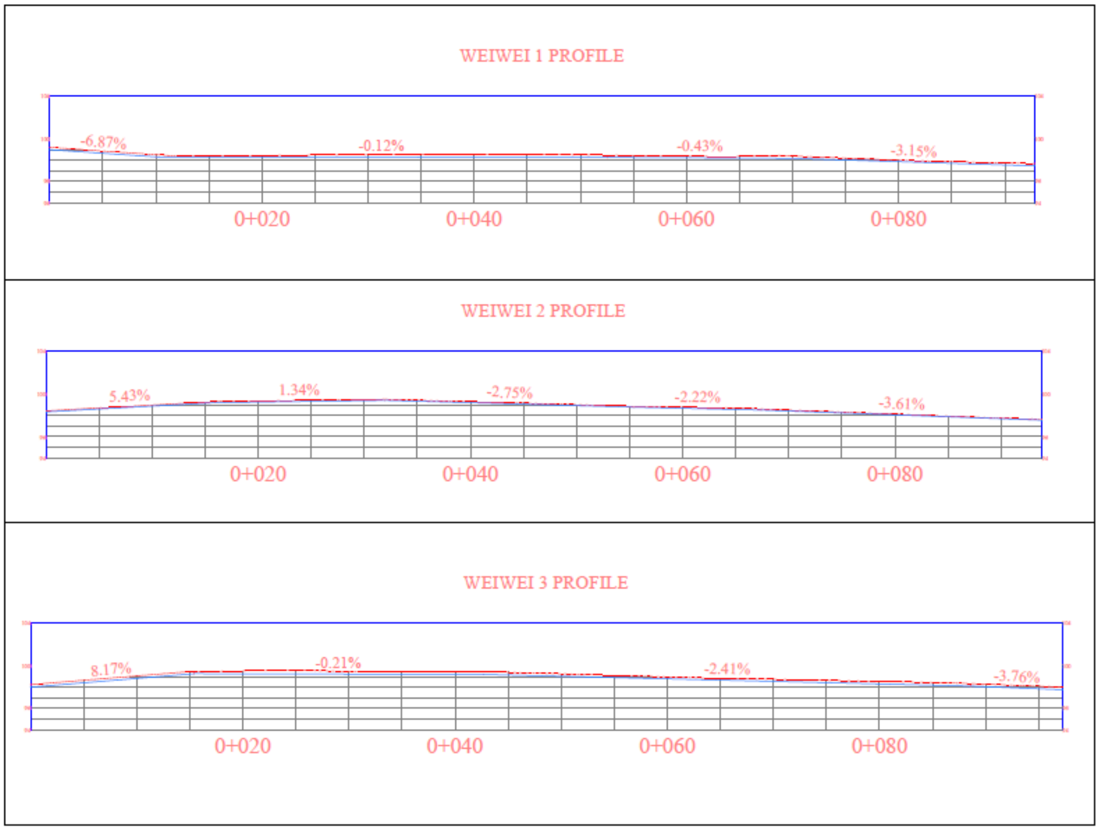

Figure 3.5: Profiles 1, 2, 3 and gradients in %

(Source: Author, 2014)

3.4 Experimental design

The experimental design which was used in carrying out the research was a completely randomized design (Kothari, 2004). In the design two principles were involved; the principles of replication and randomization. The principle of replication (two replications in this experiment) ensured that the statistical accuracy was increased. The replicated plots were assigned to experimental treatments (sprinkler sizes) and thereafter randomized within the field of 1 ha. With three sprinkler types and two replicates a total of six (3 x 2) plots were considered. In the six plots three were subsoiled and the other three prepared under the normal project operations of ploughing and harrowing. Randomization protects the experiment from the effects of extraneous factors such as soil fertility. Each plot had two lateral positions for uniformity of irrigation water application. The laterals had four risers each fitted with sprinkler heads. The sprinkler head types were Taiwan, Jalpari and Naan with different nozzle sizes but known water discharges. The laterals used were movable sets and were regularly shifted to the next position once the set irrigation duration is attained. In WWIDP irrigation water is applied at five hour duration and at five-six days interval for Green grams.

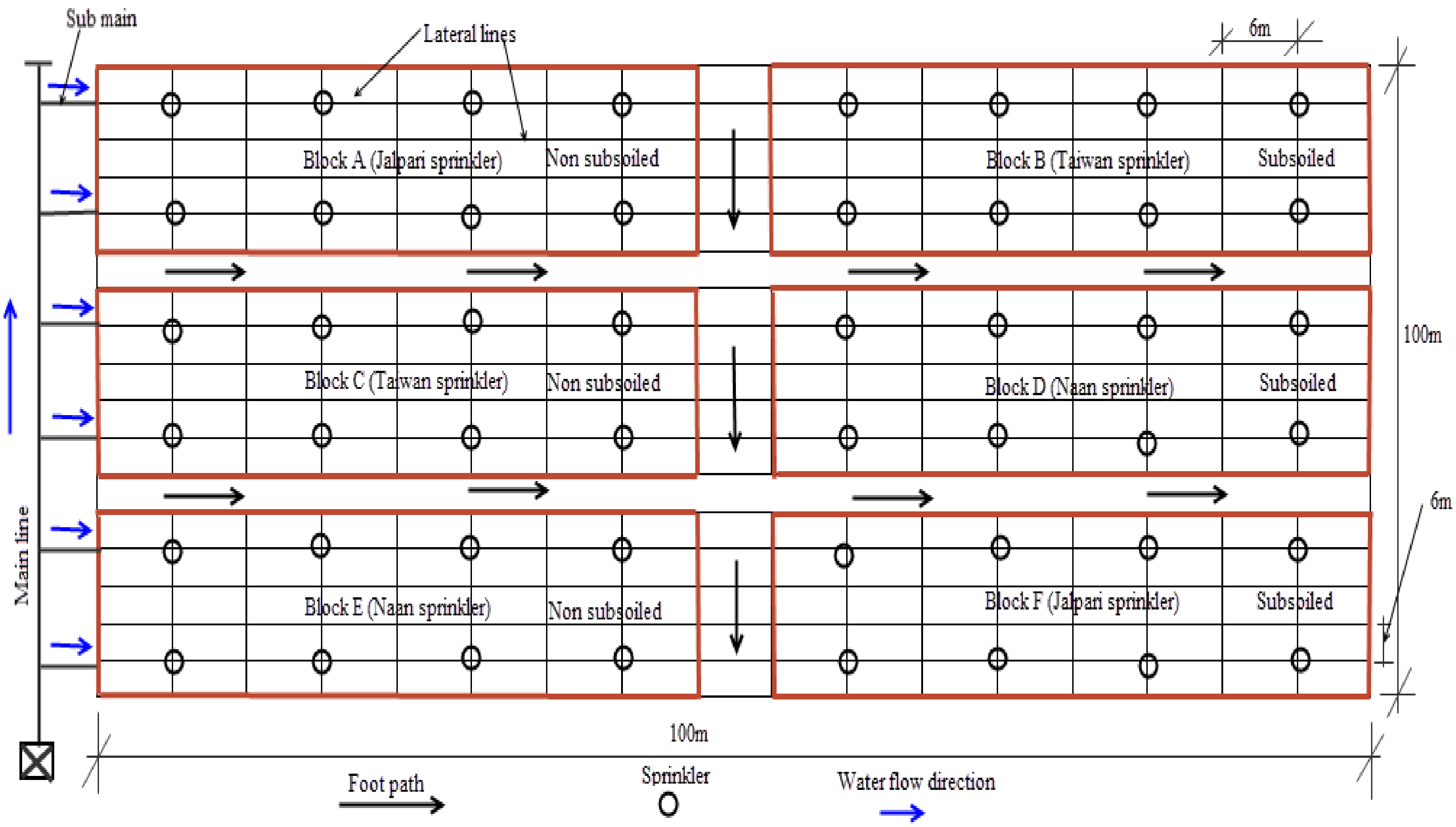

Figure 3.6: Field layout and sprinkler system design (Source: Author, 2014)

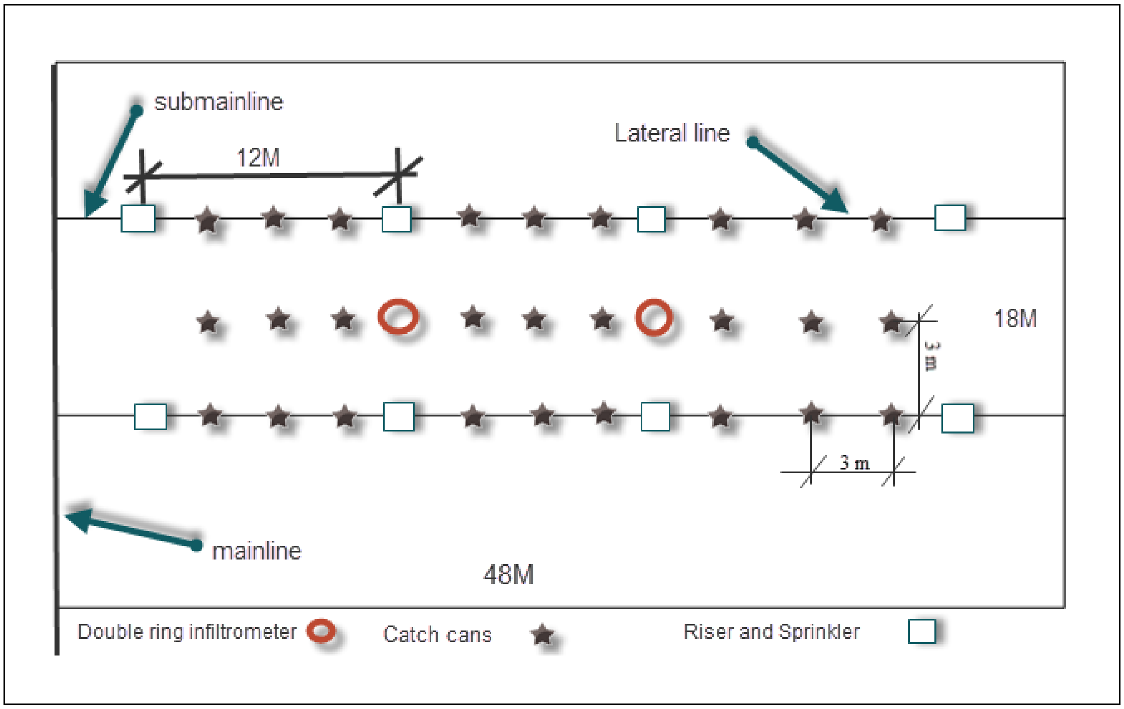

Figure 3.7: Plot layout with double ring infiltrometer, catch cans and sprinklers (Source: Author, 2014)

3.5 Statistical analysis

The Analysis of variance (ANOVA), a technique important in comparing more than two treatments against set variables was used. ANOVA is essentially a procedure for testing the difference among different groups of data for homogeneity (Kothari, 2004). Factors which are hypothesized or said to influence the dependent variable can be investigated using the method. If one factor is considered and the differences investigated amongst its various categories having numerous possible values then one-way ANOVA will be used. If two factors are considered, then two-way ANOVA will be used. In this research study two-way ANOVA was used and data was tested at 5% significance level.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Soil compaction

4.1.1 Soil sampling

The sieve analysis results obtained for sample points TP1, TP2, TP3 and TP4 are as shown in Table 4.1. The soil hydraulic properties determined using the soil hydraulic calculator are also indicated in Table 4.2.

Table 4.1: Sieve analysis of soil samples

S. No	Soil Sample No.	Soil texture	% Passing
1	TP1	Clay	2.6
		Silt	29.0
		Sand	68.4
2	TP2	Clay	5.3
		Silt	44.7
		Sand	50.0
3	TP3	Clay	2.6
		Silt	34.2
		Sand	63.2
4	TP4	Clay	5.3
		Silt	42.1
		Sand	52.6

The average percentage of soil passing the sieves of clay, silt and sand from above data was 3.95%, 37.5% and 58.55%, respectively. Soil classification was carried out using USDA textural triangle (Figure 4.1) and soil hydraulic calculator (*http://hydrology.nmsu.edu/teaching/soil456/soilwater.html, accessed 25th March 2014).*

The soil texture was classified as sandy loam and had the parameters listed in Table 4.2.

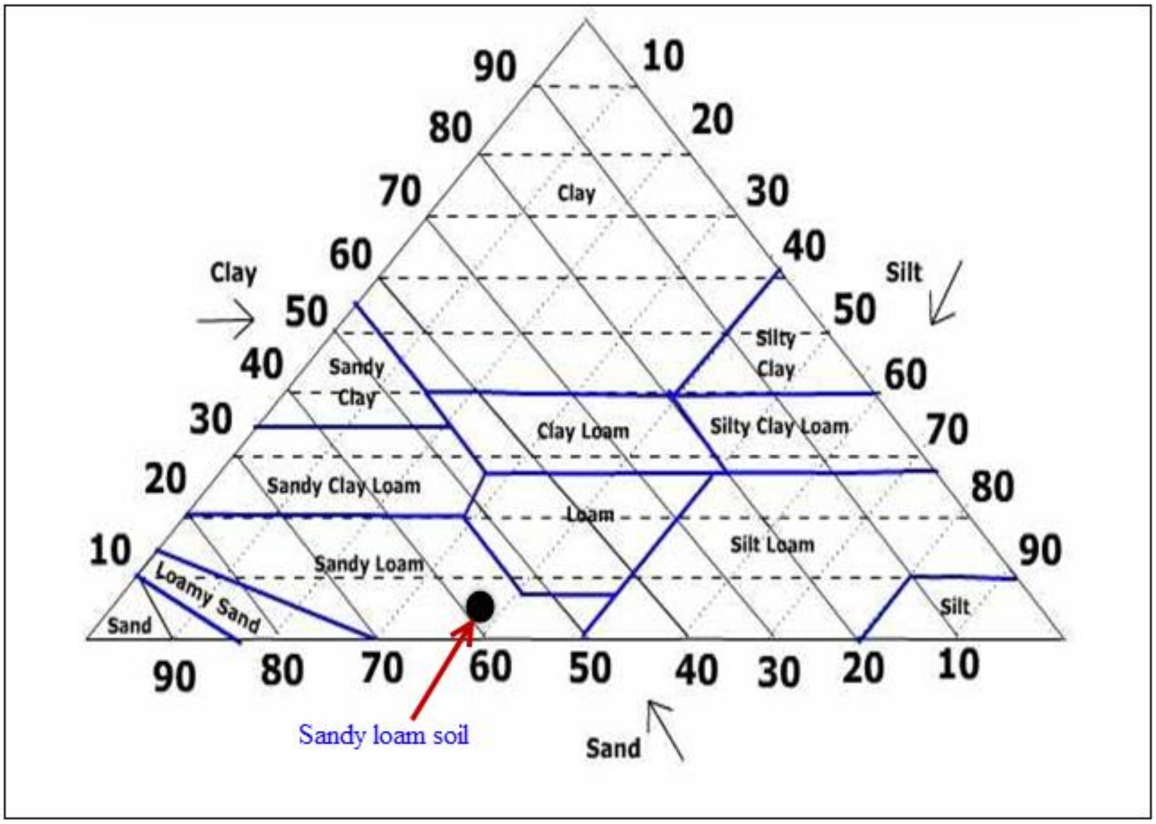

Figure 4.1: USDA Textural triangle indicating project soil type

Table 4.2: Soil hydraulic properties

Parameter	**Unit**	**Quantity**
Wilting point	cm^3 water/cm^3 soil	0.07
Field capacity	cm^3 water/cm^3 soil	0.2
Bulk density	g/cm^3	1.68
Porosity	cm^3 voids/cm^3 soil	0.37
Saturated hydraulic conductivity	cm/hr	5.28
Available water	cm^3 water/cm^3 soil	0.13

4.1.2 Proctor compaction test

The proctor compaction test was carried out using the four soil samples obtained using the soil sampling procedure explained in section 3.2.1. The dry densities and optimum moisture contents determined for each soil sample are indicated in Tables IA, IB, IC and ID in appendix I.

The dry densities of the samples ranged from 1.398 g/cm^3 to 1.622 g/cm^3 while the moisture contents ranged from 12.3 % to 22.7% (Appendix I). The maximum dry densities of the four soil samples TP1, TP2, TP3 and TP4 obtained graphically after plotting the moisture contents against the dry densities were 1.529 g/cm^3, 1.579 g/cm^3, 1.622 g/cm^3 and 1.555 g/cm^3 respectively. The average maximum dry density for the four soil samples was 1.571 g/cm^3. Similarly the optimum moisture contents for the four samples were 18.7%, 18.3%, 15.3% and 17.8% with an average value of 17.525%. The compaction curves for the four soil samples are as depicted in figure 4.2. The curves show that there is a slight variation in the soils within the farm with TP3 having the highest dry density and TP1 the lowest. TP2 and TP4 have intermediate dry densities.

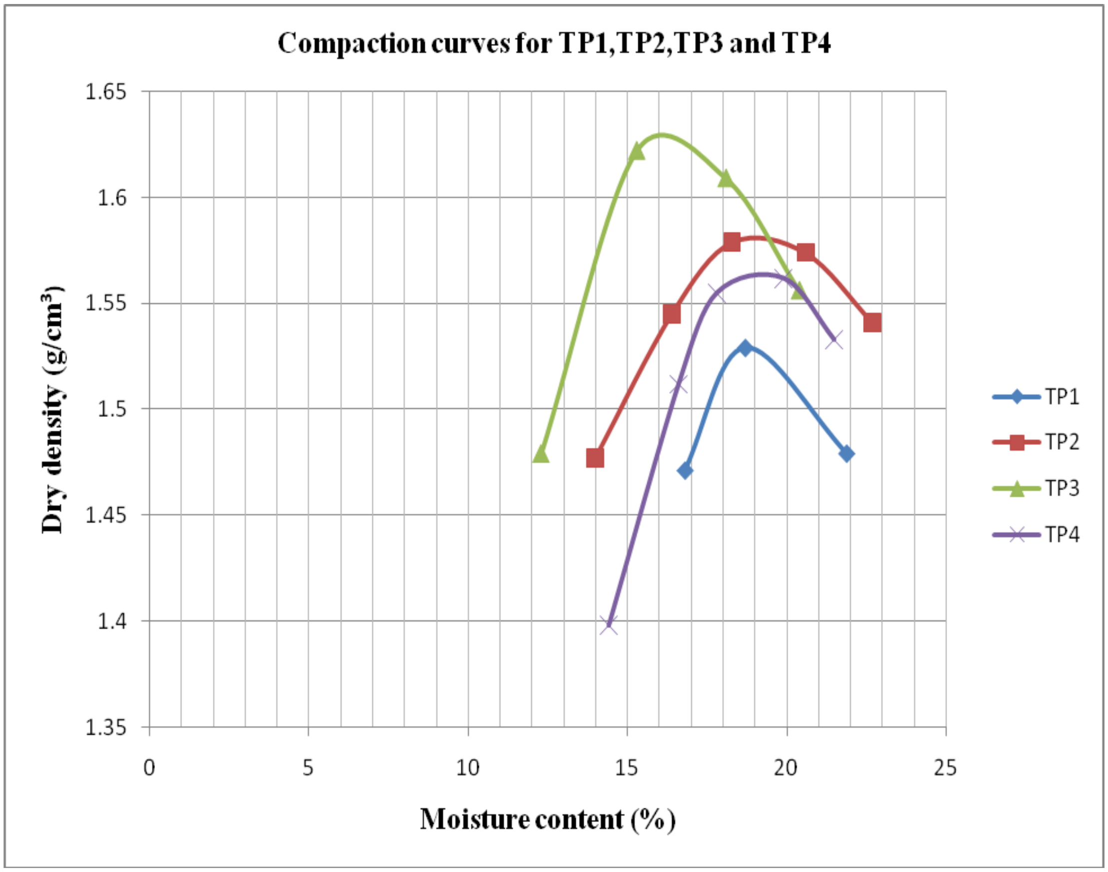

Figure 4.2: Combined compaction curves for soil samples TP1, TP2, TP3 and TP4 (Source: Author, 2014)

4.1.3 Desirable moisture range for land preparation

The USDA textural triangle in section 4.1.1 gave the soil type within the experimental plot as Sandy loam. This soil type according to ASTM D-698 had a maximum bulk density of 1.83 g/cm^3. Ross, (2010) gives the dry bulk density of sandy loam to loamy sand soils in the range 1.4 to 1.6 g/cm^3. USDA, (1999) gives an ideal bulk density for crop growth for the same soil as less than 1.4 g/cm^3 and crop restricting growth as greater than 1.80 g/cm^3. From the experimental data and the crop restricting soil densities it is concluded that the ideal moisture range for land preparation from the experiment was in the range 15.3-17.53%. This moisture range was ideal for working on the project soil with machinery since at these percentage moisture contents bulk densities restricting crop growth were never achieved for the four soil samples. In the current setup of the project system dry and compacted soil were wetted by irrigation water prior to land preparation to soften the soil. The wetting was estimated arbitrarily since the tillage depth and the initial moisture content of the soils were never determined. This kind of arbitrary water application was inappropriate since it could create compaction or a wet dispersed soil structure unknowingly.

4.1.4 Soil penetration resistance

Initial soil penetration resistance measurements were carried out on the trial plot before any tillage was done. The trials results are indicated in Table 4.3. The average soil penetration resistance derived from the measurements was 160 bars. The penetration resistance of 160 bars was an overestimate since the soil was too dry during the measurements (Duiker, 2002).

Table 4.3: Initial soil penetration resistance in the field trial site

	Initial soil penetration resistance (bars)				
	Test 1	Test 2	Test 3	Test 4	Test 5
Rep. 1	132	184	146	165	150
Rep. 2	143	142	161	175	185
Rep. 3	157	168	161	166	166
Rep. 4	152	168	171	132	170
Average	146	165	160	160	168

In the study trials compaction due to long term machinery operations was not determined and this was assumed to be equal to the average penetration resistance measured in the first schedule of each of the subsoiled and non subsoiled plots. This was estimated at 129 bars for both the trial plots. Compaction due to sprinkler water drops was considered insignificant in this first schedule. The penetration results achieved from the trials after irrigation water application are indicated in Table 4.4 and displayed in Figure 4.3.

Table 4.4: Trials soil penetration resistance for different sprinkler types and blocks

	Soil penetration resistance (bars)					
Sprinkler type	Jalpari (NS)	Jalpari (SS)	Taiwan (SS)	Taiwan (NS)	Naan (SS)	Naan (NS)
Block	A	F	B	C	D	E
Irrigation Schedule						
1	134	108	127	135	131	141
2	140	133	136	142	140	143
3	143	140	143	142	140	140
4	146	143	143	145	145	144
5	146	146	143	145	145	141
Penetration resistance increase	12	38	16	10	14	0

The penetration resistance measurements in schedule 1 were higher in non subsoiled plots compared to subsoiled plots. Initially average penetration resistance in schedule 1 for subsoiled plots was 122 bars. Non subsoiled plots had an average penetration resistance of 137 bars. Subsoiling reduced the penetration resistance between the two types of tillage by 15 bars. In subsoiled plots Jalpari sprinkler had the highest increase in penetration resistance of 38 bars compared to Taiwan and Naan which had 16 and 14 bars respectively (Table 4.4). The high increase in resistance range was due to high moisture content of the soil in schedule 1, hence low penetration resistance. In non subsoiled plots the increase in penetration resistance was 12, 10 and 0 bars for Jalpari, Taiwan and Naan sprinklers respectively. Jalpari sprinkler caused the highest soil compaction under the two tillage types.

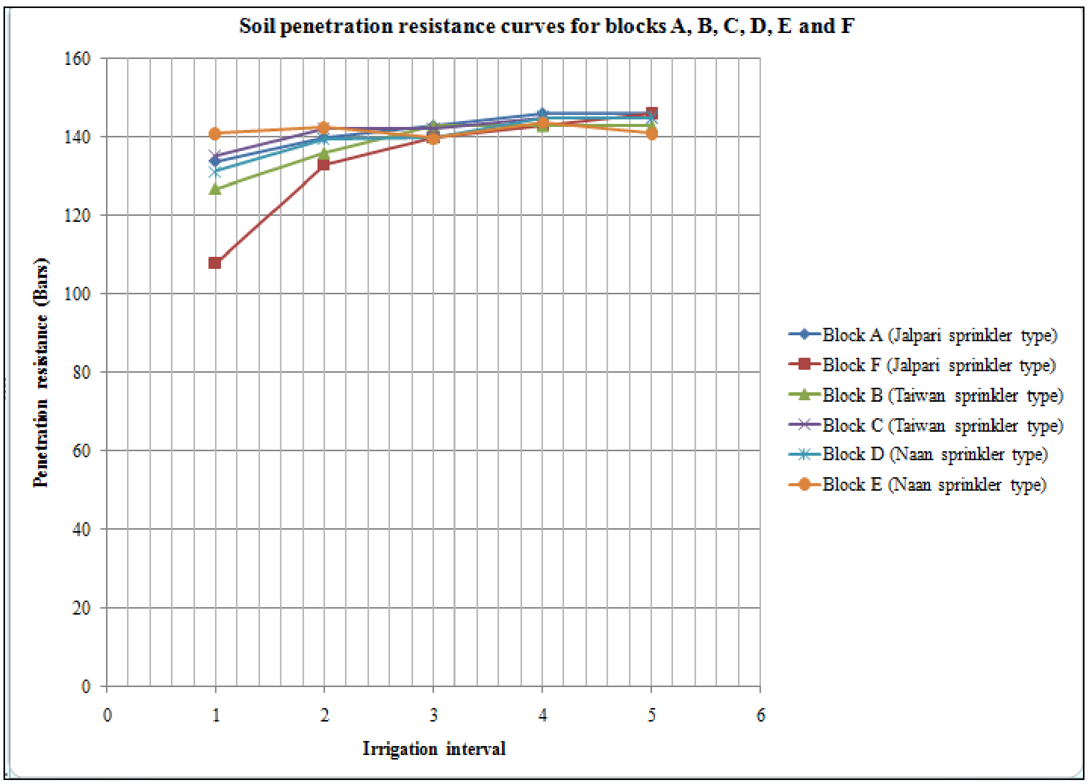

Figure 4.3: Soil penetration resistance curves for blocks A, B, C, D, E and F (Source: Author, 2014)

The resistance values for all the sprinkler types approached an average common value of approximately 144.5 bars after the fifth irrigation schedule. The values showed a trend between applied irrigation water, subsoiled and non subsoiled areas. Penetration resistance was lower for sprinklers with high water application rates at the beginning of the schedules and increased with time to as high as 146 bars in the fifth schedule. The high discharge by the sprinklers and the initial high porosity of the soil due to tillage increased dispersion and reduced penetration resistance.

As in the initial tests the trials penetration resistance measurements were overestimated since the soil was slightly dry during the data collection (Duiker, 2002). The author gives the best conditions for penetration resistance measurements as 24 hours after soaking rain. However maximum root restricting soil resistance values are given as 20.68 bars (Duiker, 2002) and 10 bar (Taser *et al,* 2005 and Hamza, 2005). These values were lower than those obtained in the trials.

4.2 Impact of sprinkler type on soil physical properties

4.2.1 Applied irrigation water

The applied irrigation water in mm/hr was calculated from catch can measurements (mm) spread across the plot at a grid of 3 m by 3 m for each sprinkler type as indicated in Figure 3.12. The arrangement of the sprinkler lateral system was 12 m x 18 m .The data obtained is shown in Tables 4.5, 4.6 and 4.7 per lateral for each sprinkler type.

Table 4.5: Taiwan Sprinkler discharge measurements per catch can in block B

7.62	8.25	9.84	8.89	6.98	7.62	10.47	9.84	7.62	7.93	9.52	7.93	5.71
7.93	9.20	11.43	9.52	7.93	9.20	12.06	12.06	9.52	10.16	12.06	10.79	7.62
12.06	10.16	12.06	9.52	8.57	9.20	12.69	12.69	11.74	11.43	14.28	12.69	6.03
8.25	11.11	11.74	8.89	7.93	9.52	13.01	11.74	12.38	11.43	14.28	12.69	9.20
7.93	9.84	9.84	8.25	7.93	9.52	11.11	9.20	7.30	8.57	10.16	8.89	7.30

Table 4.6: Jalpari Sprinkler discharge measurements per catch can in block A

8.25	8.57	8.89	9.52	9.84	6.66	7.93	7.93	6.98	7.93	8.57	6.66	7.62
15.23	14.92	16.82	21.26	20.63	19.04	14.92	13.01	15.55	15.87	15.23	14.92	14.28
22.53	15.87	19.99	19.99	13.33	20.63	19.04	19.04	9.52	18.41	21.58	17.45	8.89
10.16	13.96	17.45	19.99	16.50	20.63	16.19	14.92	16.19	16.19	20.63	17.14	10.47
8.25	8.89	11.74	13.33	12.69	12.38	12.38	12.06	12.06	13.33	12.69	10.16	6.66

Table 4.7: Naan Sprinkler discharge measurements per catch can in block D

4.76	4.44	4.76	4.13	4.44	4.44	4.76	4.76	5.40	5.40	4.13	3.81	2.86
6.03	6.35	8.25	6.35	4.76	6.03	8.57	7.93	6.35	6.98	8.25	6.03	3.81
5.08	7.93	9.84	6.66	5.40	6.98	10.79	8.89	6.66	9.52	10.16	6.35	4.13
6.35	6.98	7.30	5.71	5.71	7.62	8.57	7.62	7.93	11.11	12.69	6.66	6.03
3.49	2.54	2.54	3.49	3.49	3.49	4.13	4.13	5.71	6.03	4.76	4.13	2.22

The average measured water application rates for the three sprinklers Taiwan, Jalpari and Naan were 9.83 mm/hr, 13.85 mm/hr and 6.04 mm/hr respectively. The manufacturer's discharges for the sprinklers were 9 mm/hr, 11.6 mm/hr and 7.8 mm/hr for Taiwan, Jalpari and Naan sprinklers respectively (ISMES, 1987). The data was processed using MS-EXCEL programme. The coefficient of uniformity (CU) and distribution uniformity (DU) were determined and the values are as shown in Table 4.8.

Table 4.8: Analysis of catch can data and application uniformity parameters

Sprinkler type	Mean discharge (mm/hr)	Standard deviation (mm)	Variance	Skewness	Kurtosis	Coefficient of Uniformity (%)	Distribution Uniformity (%)
Taiwan	9.83	1.98	3.91	0.26	-0.63	83.42	75.88
Jalpari	13.85	4.55	20.74	0.09	-1.13	72.04	57.85
Naan	6.04	2.22	4.93	0.71	0.37	71.2	58.46

Statistically Taiwan and Naan sprinklers had less standard deviation (and variance) compared to Jalpari sprinkler type. The kurtosis and skewness were also less.

CU values of 100% means the same amount of water infiltrates everywhere in the field (Hanson, 2005 and Siosemarde *et al*, 2012). This is not achievable due to non uniformity in water application and field conditions. The CUs achieved in the trials were 83.42%, 72.2%, and 71.2% for Taiwan, Jalpari and Naan sprinklers respectively. Keller and Biesner (1990) give a desirable CU of 84%. Kara *et al*, (2008) tested five sprinklers on a spacing of 18 m x 12 m and achieved CUs greater than 84%. Sprinkler irrigation lateral arrangements that give less than 84% are discouraged. In this study Taiwan sprinkler gave CU values closer to that suggested by Keller and Biesner (1990).

DUs calculated from the experiments were 75.88%, 57.85% and 58.46% for Taiwan, Jalpari and Naan sprinklers respectively. *http://www.naandanjain.com/contact-us*, accessed 26th March 2014 give a conventional value of minimum DU of 75% and recommended levels of 85% and above. Taiwan sprinkler with a DU of 75.88% met the minimum recommended value while Jalpari and Naan had lower values.

The catch can data was collected in the months of February and March when wind speed values were averaging 1.03 km/hr and 1.01 km/hr respectively. The wind speeds in the project go as high as 6.8 km/hr (Toromo *et al*, 2012). It is always suggested that sprinkler irrigation be carried out when the prevailing wind speed is less than 9 km/hr (Ruzika, 1992). In WWIDP wind speeds of 1.5 km/hr or less are recommended for efficient water application (Toromo *et al*, 2012). The experiment was therefore carried out within acceptable recommended wind speed conditions.

4.2.2 Infiltration rates for different sprinkler type trial plots

The base line infiltration rates carried out before land preparation indicated infiltration rates ranging from 840 mm/hr to as low as 12 mm/hr (Table 4.9). The tests were carried out at between 35 to a maximum of 150 minutes. The infiltration rates were high at the start of the trials due to the relatively high matric potential gradient of the dry soil (Lili *et al*, 2008). The initial infiltration rates for the various tests ranged from 840-96 mm/hr and reduced gradually to steady state rates of 12-36 mm/hr. Sandy loam soil normally has high initial and steady infiltration rates due to its coarse texture and large pore spaces which promote fast infiltration (Makungo *et al*, 2011 and Gregory *et al*, 2005). The average steady state infiltration rate of the soils from Table 4.9 was 24 mm/hr. This was within the range of base infiltration rate of sandy loamy soils which is 20-30 mm/hr (FAO, 1988 and Thomas *et al*, 2004). For this composition of sandy loam soil the hydraulic conductivity equivalent to the base infiltration rate was concluded as 24 mm/hr.

Table 4.9: Maximum and minimum infiltration rates for TP1, TP2, TP3 and TP4

Sampling point	Maximum infiltration rate (mm/hr)	Base infiltration rate (mm/hr)
TP1	840	36
TP2	96	24
TP3	120	24
TP4	96	12

The infiltration rates measurements for each sprinkler type in the trial plots Blocks A, B, C, D, E and F were also determined during the period of the study. The maximum and minimum infiltration rates in mm/hr determined are depicted in Table 4.10. Schedule 1 refers to the start of the experimental trials and schedule 4 the end. Each schedule was undertaken after six days time interval.

Table 4.10: Maximum and minimum infiltration rates for each irrigation schedule

Block	Schedule 1		Schedule 2		Schedule 3		Schedule 4	
	Max	Min	Max	Min	Max	Min	Max	Min
A	288	92	118	63	116	64	82	64
B	667	109	420	116	88	63	84	61
C	240	91	110	63	93	63	87	63
D	449	90	288	53	118	75	120	68
E	631	231	500	120	418	92	324	79
F	373	82	135	58	109	79	92	70

The results achieved for each trial indicated that the initial infiltration rate curve was higher than the subsequent ones (Appendix III). In each experimental trial the steady state infiltration rate reduced gradually and it reached its lowest values in the fourth schedule at between 61 and 79 mm/hr. The experiments were carried out at time durations of between 2.5 – 3.3 hours to achieve fairly steady state infiltration rate. This was based on the fact that it takes 2-6 hours for the soil infiltration rate to reach steady state (Lili *et al*, 2008). Makungo *et al*, (2011) carried out infiltration tests for 5-7 hours on sandy loam soil in South Africa and attained initial soil infiltration rates of between 133.5-325 mm/hr. He also attained steady state infiltration rates of between 50-110 mm/hr for the same soil. This compared well with the results achieved in the trials of initial infiltration rates of 96-840 mm/hr and steady state infiltration rates of 61-79 mm/hr on the same soil.

Kostiakov equation was used to model the infiltration rates (Table IIIA, Appendix III) and equation 4.1 was determined from the trial plots data:

$$f_t = 590.32\, t^{-0.321} \qquad (4.1)$$

Where:

f_t is infiltration capacity in mm/hr

t is time in hours

In this study the subsoiled plots B, D and F had slightly higher initial and steady state infiltration rates compared to that of non subsoiled plots A and C. This was because subsoiling improved the soil's porosity, water infiltration and reduced its bulk density (Hoorman *et al*, 2009). Experimental trial plot E had abnormally high initial rates. This was associated with soil variations within the field. The yield in Kg/Ha (Table 4.15) had a direct correlation with the sprinkler type used, soil infiltration rates and the type of soil tillage. From the data the subsoiled plots had higher infiltration rates and yield compared to non subsoiled areas. Similarly this was attributed to improved porosity and soil structure.

4.2.3 Irrigation water runoff measurements

Irrigation water runoff was not observed in experimental plots block C and D but in F (Table 4.11). The block in which this was observed was operated under Jalpari sprinkler type with nozzle sizes of 5.31 mm x 2.99 mm and average measured discharge of 13.85 mm/hr (Table 4.8). Block C and D experienced no runoff and were operated under Taiwan and Naan sprinklers with discharges of 9.83 mm/hr and 6.04 mm/hr respectively. WWIDP soils can tolerate water application rates up to 10 mm/hr (ISMES, 2007). Water applications in excess of this rate create runoff and with sufficient slope soil erosion. The average water runoff measured was 8.5 litres equivalent to 0.17 mm depth over a plot area of 50 m^2 for duration of five hours.

Table 4.11: Measured runoff

Block	Sprinkler Type	Sprinkler Nozzle sizes	Runoff (litres) Rep.1	Runoff (litres) Rep.2	Average Runoff (litres)	Average Runoff (mm depth)
C	Taiwan	4.67 mm x 3.19 mm	0	0	0	0
D	Naan	3.2 mm x 2.5 mm	0	0	0	0
F	Jalpari	5.31 mm x 2.99 mm	7.5	9.5	8.5	0.17

4.2.4 Soil erosion

Soil erosion measurements were carried out in trial plots C, D and F as shown in Figures 3.8 and 3.9. Soil erosion and water runoff were not observed in trial plots blocks C and D but in block F after 18 days of irrigation water application (i.e. three irrigation schedules). The measured eroded soil was 29.5 gm over an area of 50 m^2 and it is indicated in Table 4.12.

Table 4.12: Measured eroded soil

Block	Sprinkler Type	Sprinkler Nozzle sizes	Soil erosion measured (g) Rep.1	Soil erosion measured (g) Rep.2	Average (g)
C	Taiwan	4.67 mm x 3.19 mm	0	0	0
D	Naan	3.2 mm x 2.5 mm	0	0	0
F	Jalpari	5.31 mm x 2.99 mm	40	19	29.5

The determined percentage inherent soil physical properties and RUSLE parameters are indicated in Tables 4.13 and 4.14. The percentage base saturation of the area soil was taken as 70% (Kinyanjui and Kanake, 1986).

Table 4.13: Percent estimates of inherent soil physical properties

	Physical properties	TP1	TP2	TP3	TP4	Average
X1	% unstable aggregates less than 0.25 mm	50	62.5	60	65	59.4
X2	Product of % of silt (0.002-0.01 mm) and sand (0.1-2 mm) present in sample	550	800	475	562.5	596.9
X3	% base saturation of the soil	70	70	70	70	70
X4	% silt present (0.002-0.050 mm)	25	40	35	35	33.8
X5	% sand in the soil (0.1-2 mm)	40	40	45	37.5	40.6
K	Soil erodibility factor	0.22	0.40	0.20	0.32	0.28

Table 4.14: Estimated RUSLE parameters

Parameter	Unit	Value
A	Tons Ha^{-1} $year^{-1}$	0.35
R	MJ mm ha^{-1} h^{-1}	23.68
K	-	0.28
LS	-	0.36
C	-	0.60
P	-	0.10

From the values in Table 4.14 the calculated annual soil loss using RUSLE was 0.35 tons / ha / year. The calculated soil loss using the values in Table 4.12 was 0.0059 tons/ha in one irrigation schedule (5 hours). This was a soil loss of 0.27 tons / ha /year using an irrigation period of 275 days annually. Ninety days in a year were set aside for harvesting and land preparation under the irrigation system used. The soil loss obtained from the runoff plots and that calculated using RUSLE were different. This was associated with estimated RUSLE parameters derived from primary and secondary data from the experimental area. Since the measured erosion and RUSLE soil loss prediction are closely similar RUSLE could be adopted for use in the project especially when dealing with large catchments.

4.3 Crop yield

4.3.1 Graphical representation of crop yield

The crop planted was sampled in each of the six blocks and an area of 6 m x 24 m harvested. The yield data is depicted in Table 4.15 and graphically displayed in Figures 4.4, 4.5 and 4.6. The differences in plant population between sowing and harvest (Table

4.15) were associated with loss of plants during germination, uprooting during weeding, rotting, physiological disorders and non uniform application of irrigation water.

Table 4.15: Crop yield

Non subsoiled plots	Block	Sprinkler type	Yield (Kg/ha)	No. of plants at harvest	Weight (g) per plant	No. of plants at planting
	A	Jalpari	552.08	2119	3.75	2576
	C	Taiwan	437.50	1901	3.31	2576
	E	Naan	208.33	1467	2.04	2576
Subsoiled plots	B	Taiwan	1190.97	2306	7.44	2576
	D	Naan	506.94	1764	4.14	2576
	F	Jalpari	1027.78	1883	7.86	2576

In Table 4.15 and Figure 4.4 for every sprinkler type the yield in the subsoiled (SS) blocks exceeded that in non subsoiled (NS) plots. This was because the subsoiled plots had better soil infiltration, aeration and nutrient uptake (Hoorman *et al*, 2009). The non subsoiled plots had less of these qualities which support plant growth.

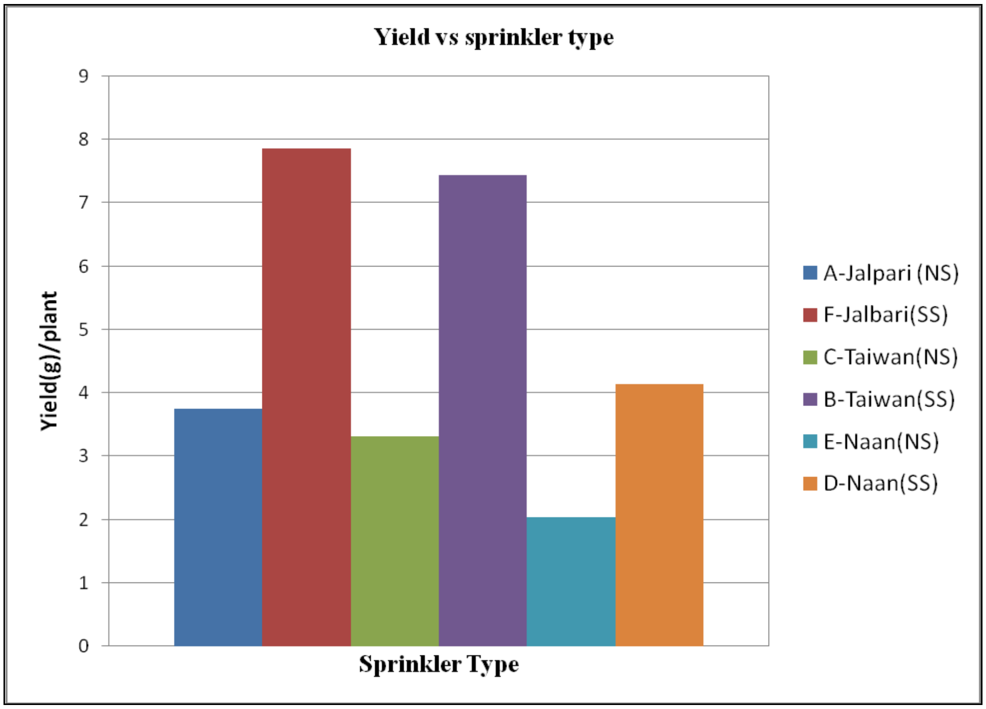

Figure 4.4: Yield in grams per plant and sprinkler type

(Source: Author, 2014)

The weight of 1000 green gram grains sampled from each of the six sprinkler type plots showed that the weights per grain obtained from non subsoiled plots were higher compared to that from subsoiled areas as depicted in Figure 4.5. This was an indication that the non subsoiled areas green grams had higher densities compared to subsoiled areas but less in total plot output.

Table 4.16: Weight of 1000 green gram grains and sprinkler type

Non subsoiled plots			Subsoiled plots		
Block	Sprinkler type	Weight (g)	Block	Sprinkler type	Weight (g)
A	Jalpari	69.2	B	Taiwan	67.1
C	Taiwan	70.4	D	Naan	71.4
E	Naan	71.9	F	Jalpari	68.5

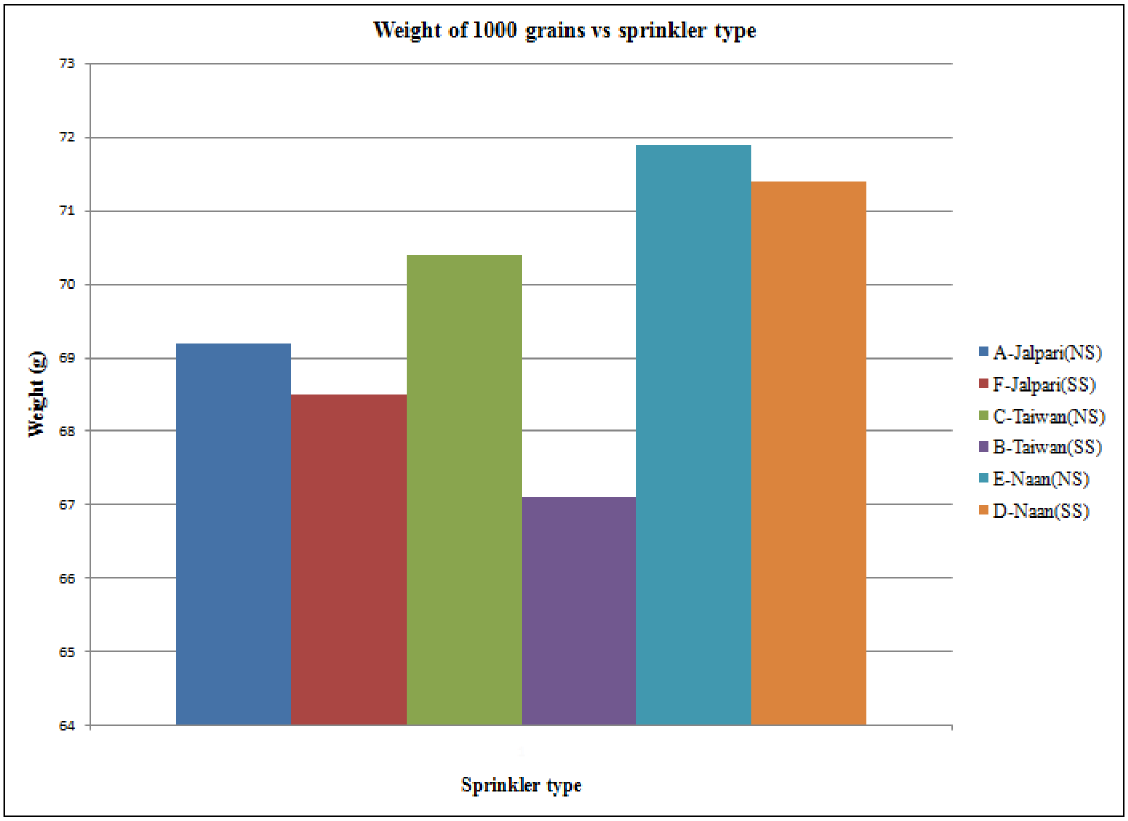

Figure 4.5: Weight of 1000 green gram grains and sprinkler type

(Source: Author, 2014)

The number of plants obtained from the six plots was more in subsoiled plots except in block A where Jalpari sprinkler type was used. Subsoiled plots had better soil structure, aeration and nutrient movement because of improved porosity. In block A the number of plants was more compared to block F but with insignificant difference.

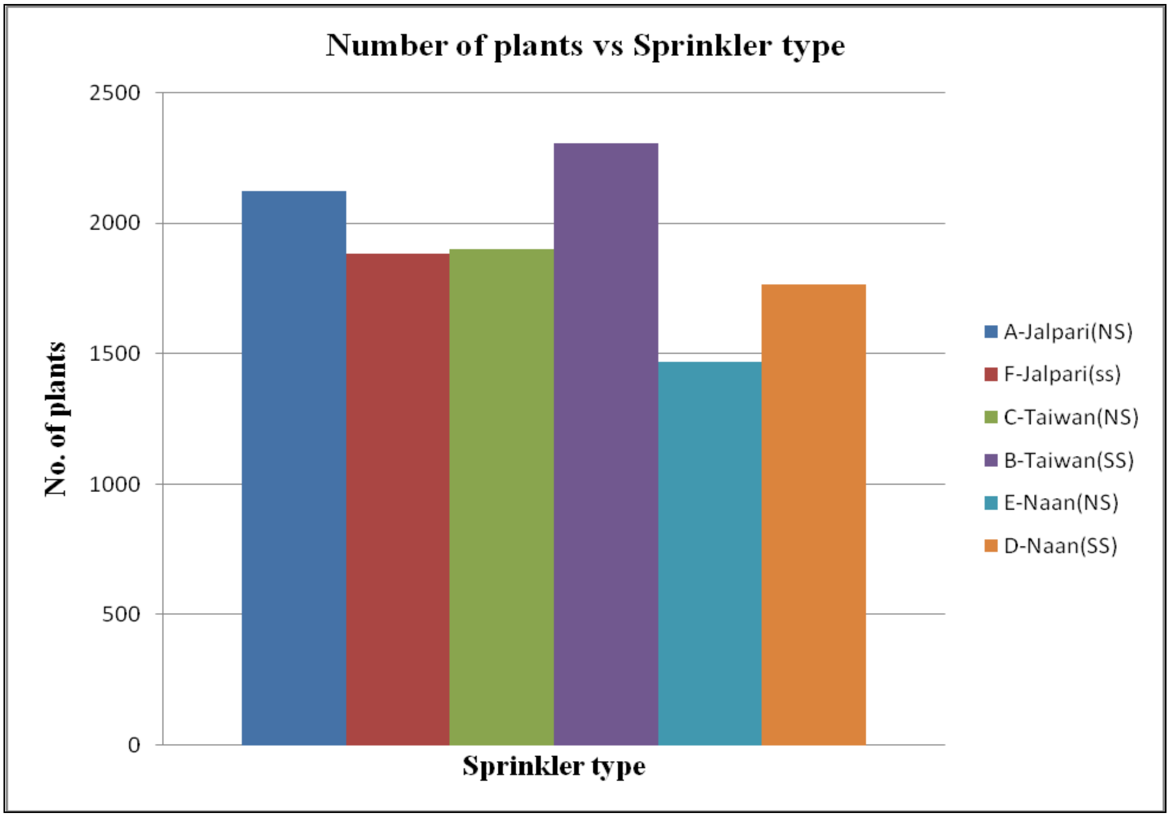

Figure 4.6: Number of plants and sprinkler type

(Source: Author, 2014)

4.3.2 Economic analysis of crop yield

In the cost benefit analysis (Table 4.17) for non subsoiled plots Jalpari (Block A), Taiwan (Block C) and Naan (Block E) sprinklers had losses of Kshs 15,412.10, Kshs 32, 599.10 and Kshs 66,974.60 per hectare respectively. These losses indicate that it was not profitable to use these sprinklers for irrigation water application in non subsoiled plots since they give negative gains. In the subsoiled areas (Table 4.18) Jalpari (Block F) and Taiwan (Block B) sprinklers had net profit income of yield of Kshs 55,942.90 and Kshs

80,421.40 per hectare, respectively. Naan sprinkler (Block D) had losses of Kshs 22,033.10. The high surpluses in blocks B and F was expected since subsoiling improves water infiltration, nutrient uptake, aeration and penetration resistance of the soil. The best crop production was with the use of Taiwan sprinkler which had the highest surplus worth Kshs 80,421.40 per hectare.

Table 4.17: Cost benefit analysis for non subsoiled plots

	Yield (Kg/Ha)	Selling Rate (Kshs/Kg)	Total Revenue (Kshs/Ha)	Production Cost (Kshs/Ha)	Surplus (Kshs/Ha)
Jalpari (Block A)	552.08	150	82,812.00	98,224.10	-15,412.10
Taiwan (Block C)	437.50	150	65,625.00	98,224.10	-32,599.10
Naan (Block E)	208.33	150	31,249.50	98,224.10	-66,974.60

Table 4.18: Cost benefit analysis for subsoiled plots

Sprinkler Type/Block	Yield (Kg/Ha)	Selling Rate (Kshs/Kg)	Total Revenue (Kshs/Ha)	Production Cost (Kshs/Ha)	Surplus (Kshs/Ha)
Jalpari (Block F)	1,027.78	150	154,167.00	98,224.10	55,942.90
Taiwan (Block B)	1,190.97	150	178,645.50	98,224.10	80,421.40
Naan (Block D)	507.94	150	76,191.00	98,224.10	-22,033.10

4.4 Statistical crop yield analysis

The yield data collected was subjected to ANOVA statistical analysis at 5% significance level. Two-way ANOVA was used since the data was classified on the basis of two factors; sprinkler type and land preparation. The dependent variable in the analysis was yield and independent variables were the three sprinkler sizes and two tillage types. Since the trials did not have repeated values, the sum of squares could not be calculated directly (Kothari, 2004). The residual or error variation was calculated by subtraction. The sum of squares (SS) for total variance and variance between treatments was calculated for three yield scenarios (dependent variables) namely total yield, yield per plant and number of plants in each experimental plot measuring 6 m x 24 m. The ANOVA statistical analyses were set up for the given treatments as shown in Tables 4.19, 4.20 and 4.21.

Table 4.19: ANOVA table for yield in Kg per plot

Source of Variation	SS	d.f	MS	F-ratio	5% limit of the tables values
Between columns (i.e between soil tillage type)	80.67	(2-1)=1	80.67	14.80	F(1,2)=18.51
Between rows (i.e between sprinkler type)	54.74	(3-1)=2	27.37	5.02	F(2,2)=19.0
Residual error	10.9	(2-1) X (3-1)=2	5.45		
Total	146.31				

Table 4.20: ANOVA table for yield in grams per plant

Source of variation	SS	d.f	MS	F-ratio	5% limit of the tables values
Between columns (i.e between soil Tillage type)	17.82	(2-1)=1	17.82	26.21	F(1,2)=18.51
Between rows (i.e between sprinkler type)	8.52	(3-1)=2	4.26	6.26	F(2,2)=19.0
Residual error	1.36	(2-1) X (3-1)=2	0.68		
Total	27.7				

Table 4.21: ANOVA table for number of plants per plot

Source of Variation	SS	d.f	MS	F-ratio	5% limit of the tables values
Between columns (i.e between soil tillage type)	417	(2-1)=1	417	0.01	F(1,2)=18.51
Between rows (i.e between sprinkler type)	80275	(3-1)=2	40137.5	0.69	F(2,2)=19.0
Residual error	116524	(2-1) X (3-1)=2	58262		
Total	197216				

From tables 4.19 and 4.21 the yield differences due to tillage type were insignificant at 5% significance level for total yield and number of plants per plot with calculated F-ratios of 14.8 and 0.01 respectively. The F-ratios were lower than the critical value of F-distribution at 5% significance level (Table IXA Appendix IX) which was 18.51 for both scenarios. The yield difference per plant against tillage was significant with an F-ratio of 26.21 against a value of 18.51 (Table 4.20). It is concluded that the difference in the values was due to tillage type within the field plots. Similarly the yield differences between sprinkler treatments were insignificant at 5% level for total yield, yield per plant and number of plants with calculated F-ratios of 5.02, 6.26 and 0.69, respectively which were lower than the F-distribution value of 19.0.

4.5 Discussion

The soil sampled had an average percentage of clay, silt and sand of 3.95%, 37.50% and 58.55% respectively. This soil was classified as sandy loam using USDA textural triangle. The calculated bulk densities for the soil using a soil calculator and Proctor compaction test were 1.68 g/cm^3 and 1.52 g/cm^3 respectively. The bulk densities from the two methods are slightly higher than the average value for crop growth for the same soil which is in the range 1.4-1.6 g/cm^3 (Ross, 2010). The maximum dry density for the same soil according to ASTM D-698 was 1.83 g/cm^3. This density is higher than 1.6 g/cm^3 the upper limit for plant growth. The maximum density as given by ASTM D-698 indicates that with high loads on the soil bulk densities above the recommended values (Ross, 2010) are achievable and these are detrimental to plant growth. Safe bulk densities for land preparation can be estimated using the results from Figure 4.2. In this study with a compactive standard effort of 600 KN-m/m^3 (ASTM D 698) and desirable moisture range of 15.3-17.53% safe compaction on project soils can be achieved during land preparation by using machinery with loads within the given standard effort since densities attained will be within the limits recommended by Ross, (2010) for crop growth.

The second objective of the study was to determine the extent of soil compaction by sprinkler water drops on soil infiltration, runoff and resulting soil erosion. This was estimated through the soil penetration resistance, infiltration, runoff and soil erosion rates. The initial soil penetration resistance measurements at depths of 0-20 cm resulted in an average value of 160 bars. The trials values ranged from as low as 108 bars at schedule 1 to 146 bars at schedule 5. These values are higher than the maximum root restricting soil resistance values of 10 bar (Taser *et al* 2005 and Hamza 2005) and 20.68 bar (Duiker, 2002). The penetration resistances of subsoiled plots were lower at the start of the experiments compared to non subsoiled plots. Similarly penetration resistance was low with high discharge sprinklers and slightly high in low discharge sprinklers both in subsoiled and non subsoiled plots during the first irrigation schedules. The penetration resistance of the highest discharge sprinkler (Jalpari) continued to rise and exceeded the other sprinklers in the fifth schedule at 146 bars. The rise in soil penetration resistance was associated with gradual impact of sprinkler water drops on the soil. The compaction was concluded to have caused reduction in crop yield, runoff and soil erosion. The compaction by Jalpari sprinkler type caused runoff and soil erosion of 0.27 tons/ha/year against RUSLE modeled value of 0.35 /tons/ha/year. The difference between the two values was associated with estimated RUSLE parameters which were derived from the experimental project's region's existing data.

To prevent runoff and soil erosion the sprinkler's discharge should not be more than the project's recommended value of 10 mm/hr (ISMES, 1987). Jalpari sprinkler with a discharge of 13.85 mm/hr, CU of 72.2% and a DU of 57.85% under a spacing of 12 m x 18 m applied more water and did not meet the recommended characteristics of DU(>75%) and CU (>84%) as given by Keller and Biesner, (1990). Taiwan and Naan did not cause any runoff and soil erosion. Taiwan sprinkler had the best characteristics of water application of DU (75.88%), CU (83.2%) and water application rate of 9.83 mm/hr which is closer in magnitude to the project's recommended value of 10 mm/hr (ISMES, 1987). Naan sprinkler with a lower water application rate of 6.04 mm/hr required longer time duration to supply sufficient moisture to the soil. This is inefficient under the project operational conditions since it provides for longer water scheduling periods associated with time loss.

ISMES, (1987) recommends the water application rate for the project soils as 10 mm/hr. The determined sandy loam soil base infiltration rates were 24 mm/hr (initial measurements), 52.8 mm/hr (Soil hydraulic calculator), and 60-79 mm/hr (experimental trials measurements). These soil infiltration rates are moderate (20-60 mm/hr) to moderately rapid (60-90 mm/hr) as given by Landon, (1991). The infiltration rates of the soil measured decreased with the number of irrigation schedules. The reduction being due to available moisture in the soils at subsequent irrigation schedules and effects of soil compaction as a result of sprinkler water drops. Compared to the two sprinklers Jalpari sprinkler had generally lower infiltration rates at every irrigation schedule. The infiltration equation for the soils was determined using Kostiakov equation. This equation can be used to estimate infiltration rates in the project.

The yield determined for each sprinkler type with subsoiled blocks exceeded that in the non subsoiled areas. The yields exceeded by 475.7 kg/ha, 753.47 kg/ha and 298.61 kg/ha for Jalpari, Taiwan and Naan sprinklers, respectively. The cost benefit analysis carried out on yield resulted in negative surpluses for all non subsoiled plots and block D (Naan sprinkler) in the subsoiled plots.The negative surplus in yield for block D was associated with low water application by Naan sprinkler (6.04 mm/hr) as opposed to the recommended application rate of 10 mm/hr (ISMES, 1987). Jalpari (Block F) and Taiwan (Block B) sprinklers in the subsoiled plots had positive net income of yield of Kshs 55,942.90 and Kshs 80,421.40 per hectare respectively. The highest yield was achieved with the use of Taiwan sprinkler which had a water application rate of 8.5 mm/hr, DU of 75.88% and CU of 83.2% (Keller and Biesner, 1990; Kara et al, 2008). The yield with Jalpari sprinkler type was lower because it had poor performance characteristics, high penetration resistance, runoff and soil erosion which reduced yield. Subsoiling improves water infiltration, nutrient uptake, aeration, penetration resistance of the soil and yield.

However, statistically yield differences due to sprinkler type were not significant at 5% significant level for total yield, yield per plant and number of plants with calculated F-distribution ratios of 5.02, 6.26 and 0.69 respectively which were lower than the F-tables value of 19.0 (Table 9A appendix 9). Statistical analysis on yield and tillage type showed similar trend except in yield per plant which had an F-ratio value of 26.1 against the table's value of 18.51. It is concluded that sprinklers with high discharge cause compaction, runoff and soil erosion and lower yield.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The objective of this study was to determine the effect of sprinkler size on soil compaction and subsequently on crop yield. The study involved laboratory determination of desirable moisture range for land preparation using the Proctor test, effect of sprinkler compaction on infiltration rate, runoff, soil erosion and yield. Lastly a comparison was made on crop yields from the different sprinkler treatments. The results indicated that sprinklers especially with high discharge cause compaction and reduce crop yield. Compaction can be controlled by using an appropriate sprinkler and carrying out tillage at moisture content and compactive efforts that do not create soil particle-to-particle stresses resulting in porosity reduction primarily through a more efficient packing of the particles.

5.2 Conclusions

i) From the soil samples particle size analysis the soils were classified as sandy loam with average percentages of clay, silt and sand as 3.95%, 37.50% and 58.55% respectively. The same soil had a bulk density of 1.68 g/cm^3 (USDA textural triangle), 1.571 g/cm^3 (Proctor test) and saturated hydraulic conductivity of 52.8 mm/hr (soil hydraulic calculator. The results from the proctor test indicate that the sandy loam soil had compaction tendencies to densities unsuitable for crop production. To achieve an ideal moisture range for land preparation the moisture content for the soils during tillage was determined to be in the range 15.3-17.53%. Since the bulk density achieved at this moisture content was less than the crop restricting density of 1.6 g/cm^3. This finding is recommended for adoption by the project.

ii) From the study subsoiling improves crop yield. This is because subsoiling improves soil physical properties such as water infiltration, nutrient uptake, aeration and penetration resistance of the soil. Sprinkler water drops were determined to cause compaction since the sprinkler with the highest dicharge (Jalpari) of 13.85 mm/hr caused the highest penetration resistance of 146 bars, runoff of 0.17 mm depth of water per irrigation schedule and soil erosion of 0.11 tons/acre/year. Taiwan and Naan sprinklers had fairly lower penetration resistance and did not cause runoff and soil erosion. Taiwan sprinkler had the best characteristics with DU of 75.88% and CU of 83.42% and is recommended for use in the project.

iii) The yields from the different sprinkler size treatments were influenced by sprinkler water application rate, sprinkler characteristics and soil tillage type. Taiwan sprinkler had the best characteristics of water application rate of 9.83 mm/hr, DU of 75.88% and CU of 83.2%. The sprinkler also realized the best gross yield of 1190.97 Kg/ha and a positive net income of Kshs 80,421.40/ha under subsoiled plots. Jalpari and Naan sprinklers had poor sprinkler characteristics resulting in poor yield. Statistically yield differences due to sprinkler type were not significantly different at 5% level for total yield, yield per plant and number of plants. Statistical analysis on yield and tillage type showed similar trend except in yield per plant which had an F-ratio value of 26.1 against the table's value of 18.51. The difference was associated with soil variations within the trial plots. Taiwan sprinkler with the best characteristics was recommended for use in the project.

5.3 Recommendations

i) It is recommended that land preparation be carried out in the project when the soil moisture content is in the range 15.3-17.53% as determined from this study. This should be carried out with implements of loads within the standard effort of 600 KN-m/m^3 or less. The project should avoid use of field traffic when soils are wet since this can easily compact the soil, reduce infiltration and cause runoff.

ii) The project should adopt the use of Taiwan sprinkler type with DU of 75.88% and CU of 83.42% for green gram crop production since the uniformity coefficients determined were within recommended values in related research and had the best yields and benefits as found in this study.

iii) The project should avoid the use of sprinklers with sprinkler discharges of more than 10 mm/hr and with nozzles similar to that of Jalpari sprinklers of sizes 5.31 mm x 2.99 mm since this cause compaction and runoff. The sprinklers used should have uniformity coefficients within recommended values and nozzle sizes similar to that of Taiwan of range 4.67 mm x 3.19 mm.

iv) Improve soil organic matter, soil structure and biological activity in the soil by using best agronomic management practices such as incorporating organic matter in the soil, subsoiling, crop rotation and intercropping. This improves soil physical properties and reduces compaction.

v) Soil and mineralogy composition tests are recommended for the project to establish the type and best rates of soil fertilizer application since soil compaction may not be the only impediment to crop production.

vi) Further research on sprinkler size, water drop impacts and soil compaction due to plant and machinery should be studied.

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APPENDICES

Appendix I: Proctor compaction tests

Table IA: laboratory Proctor compaction test-TP1

Soil sample weight used (g)	2500	2500	2500
Initial moisture content (%)	2.8	2.8	2.8
Water added %	14	16	18
Water added (ml)	350	400	450
Weight of compacted soil sample + Mould (g)	6662	6754	6742
Mould weight(g)	5040	5040	5040
Compacted soil sample weight(g)	1622	1714	1702
Moisture content (%)	16.8	18.7	21.9
Dry density (g/cm^3)	1.471	1.529	1.479

Average maximum dry density = 1.529 g/cm^3 Optimum moisture content=18.7 %

Table IB: laboratory Proctor compaction test-TP2

Soil sample weight used (g)	2500	2500	2500	2500	2500
Initial moisture content (%)	5	5	5	5	5
Water added %	8	10	12	14	16
Water added (ml)	200	250	300	350	400
Weight of compacted soil sample + Mould (g)	5441	5549	5615	5643	5736
Mould weight (g)	3851	3851	3851	3851	3851
Compacted soil sample weight (g)	1590	1698	1764	1792	1785
Moisture content (%)	14	16.4	18.3	20.6	22.7
Dry density (g/cm^3)	1.477	1.545	1.579	1.574	1.541

Average maximum dry density = 1.579 g/cm^3 Optimum moisture content = 18.3%

Table IC: laboratory Proctor compaction test-TP3

Soil sample weight used (g)	2500	2500	2500	2500
Initial moisture content (%)	4.7	4.7	4.7	4.7
Water added %	18	10	12	14
Water added (ml)	200	250	300	350
Weight of compacted soil sample + Mould (g)	5419	5617	5645	5620
Mould weight (g)	3851	3851	3851	3851
Compacted soil sample weight(g)	1568	1766	1794	1769
Moisture content (%)	12.3	15.3	18.1	20.4
Dry density (g/cm^3)	1.479	1.622	1.604	1.556

Average maximum dry density = 1.622 g/cm^3 Optimum moisture content=15.3 %

Table ID: laboratory Proctor compaction test-TP4

Soil sample weight used (g)	2500	2500	2500	2500	2500
Initial moisture content (%)	2.6	2.6	2.6	2.6	2.6
Water added %	12	14	16	18	20
Water added (ml)	300	350	400	450	500
Weight of compacted soil sample + Mould (g)	6550	6705	6770	6808	6799
Mould weight (g)	5040	5040	5040	5040	5040
Soil sample weight (g)	1510	1665	1730	1768	1759
Moisture content (%)	14.4	16.6	17.8	19.9	21.5
Dry density (g/cm^3)	1.398	1.512	1.555	1.562	1.533

Average maximum dry density = 1.555 g/cm^3 Optimum moisture content = 17.8%

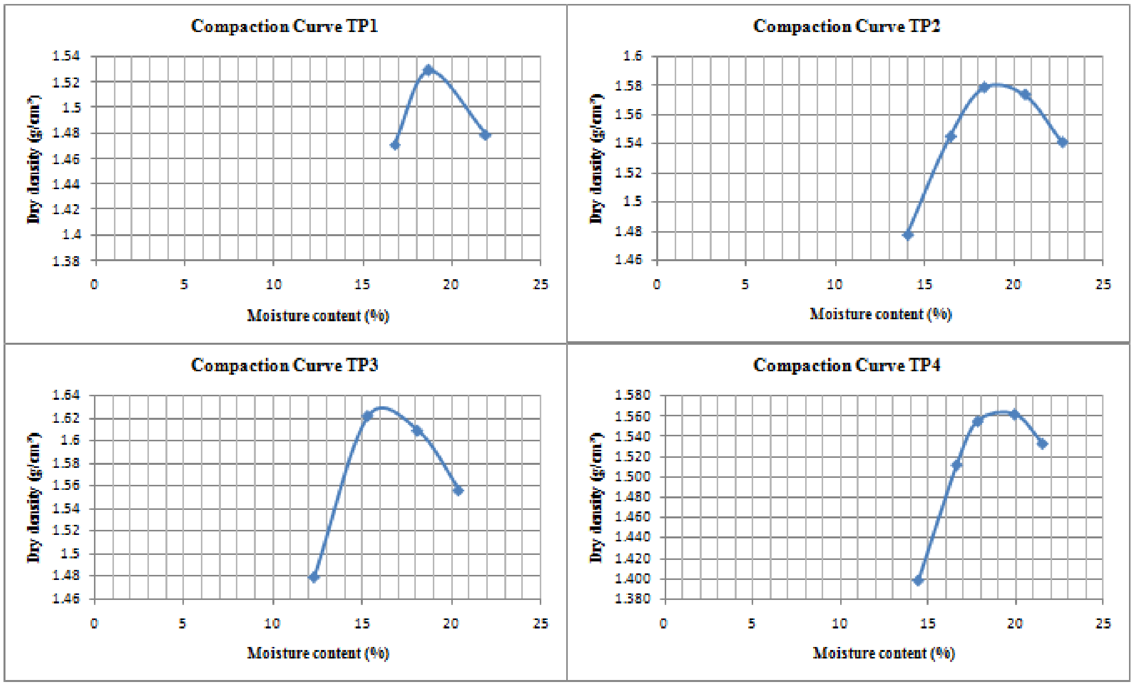

Figure IA: Compaction curves TP1, TP2, TP3 and TP4

Appendix II: Baseline infiltration rate curves

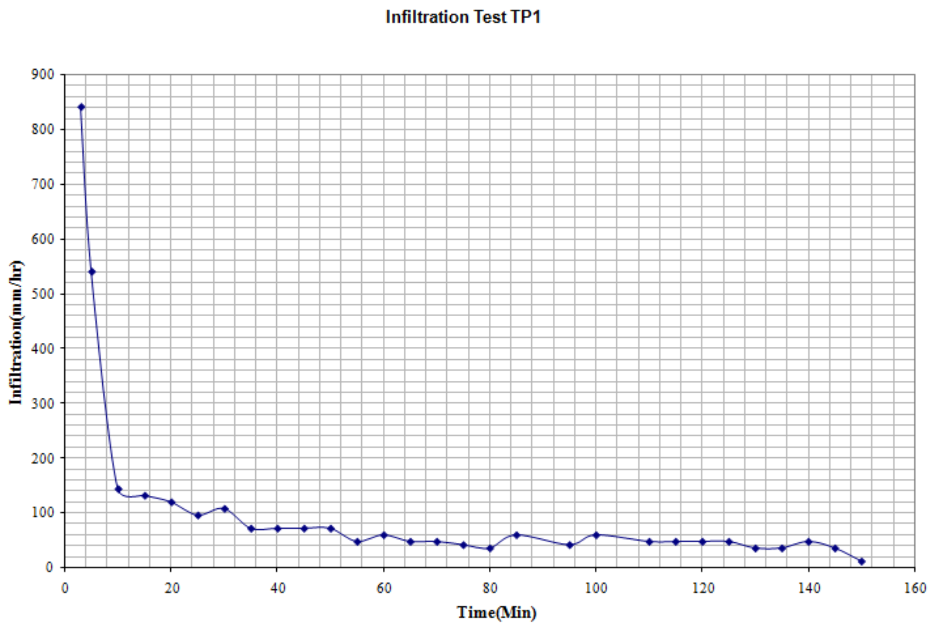

Figure IIA: Baseline infiltration test curve 1

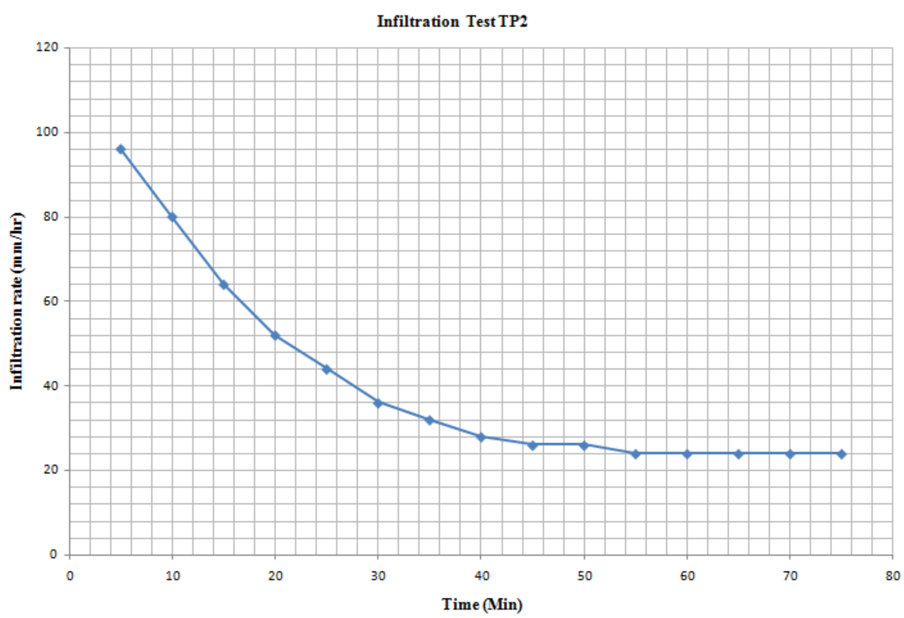

Figure IIB: Baseline infiltration test curve 2

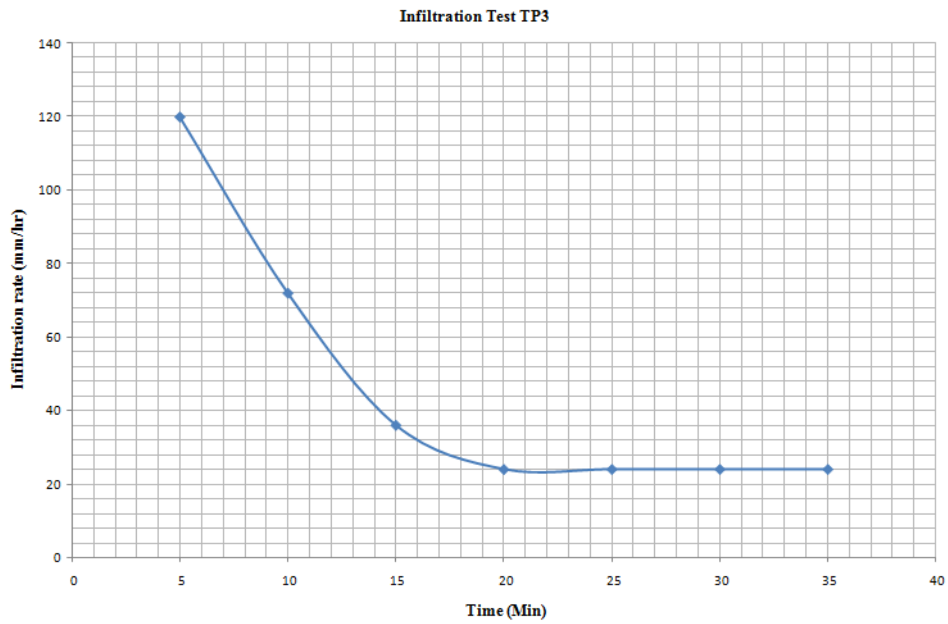

Figure IIC: Baseline infiltration test curve 3

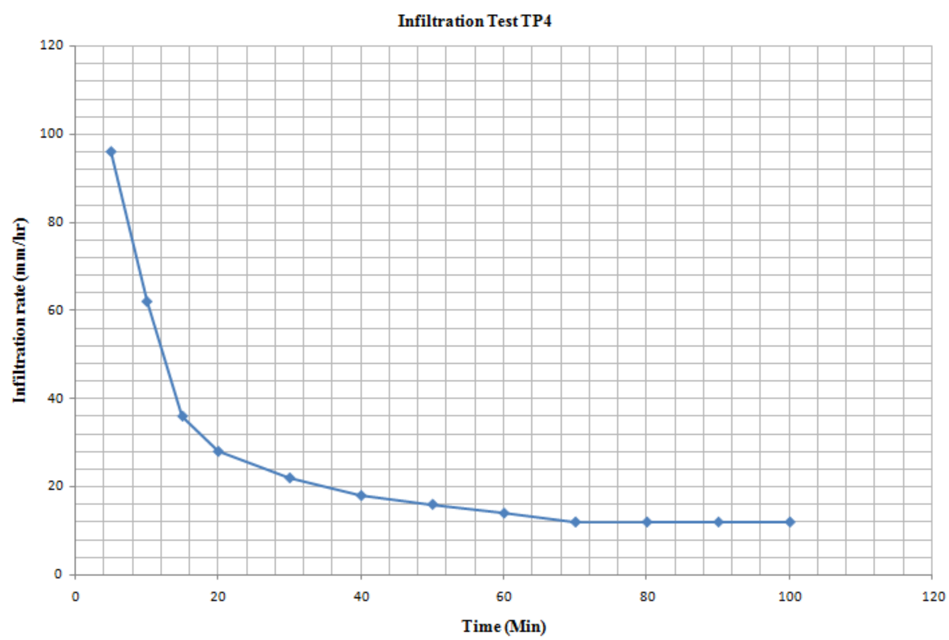

Figure IID: Baseline infiltration test curve 4

Appendix III: Infiltration rate curves for different sprinkler type trial plots

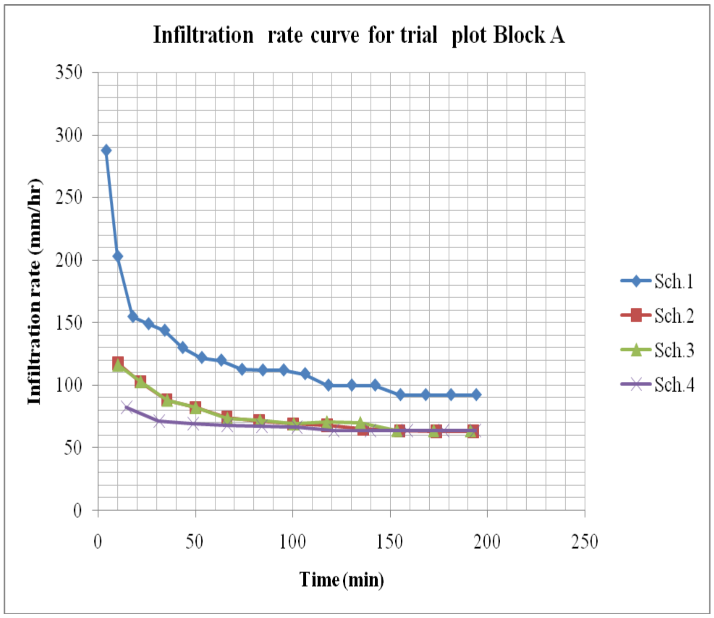

Figure IIIA: Infiltration rate curves for trial plot block A

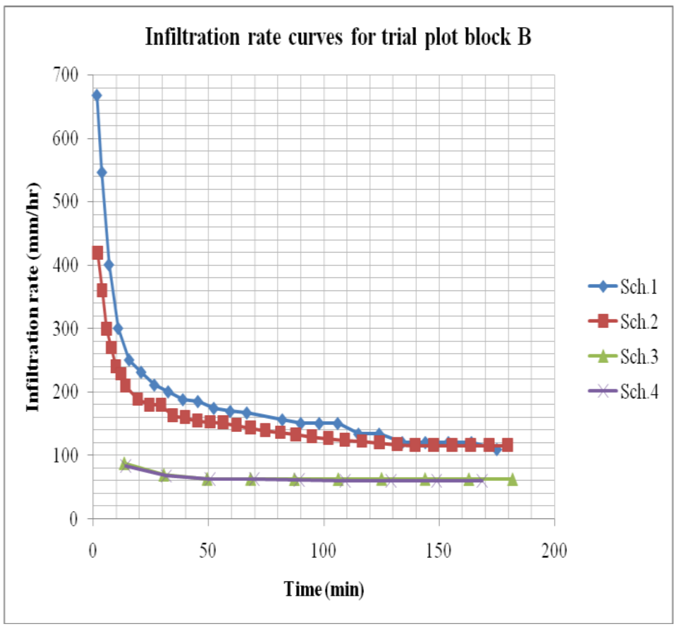

Figure IIIB: Infiltration rate curves for trial plot block B

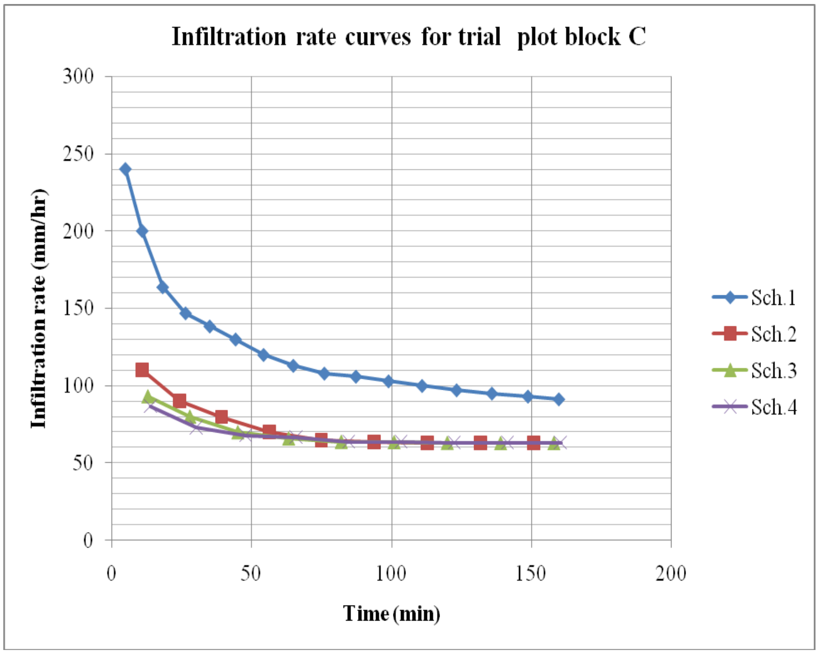

Figure IIIC: Infiltration rate curves for trial plot block C

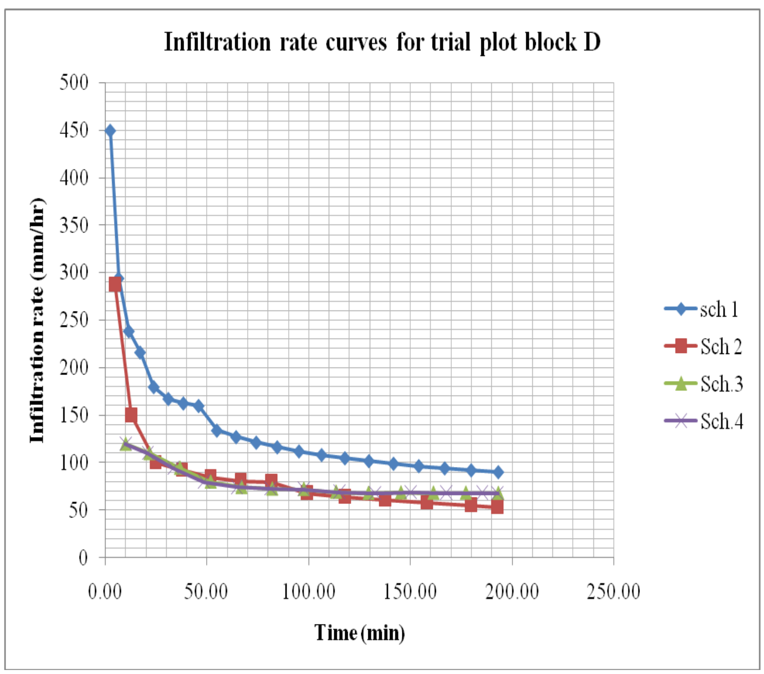

Figure IIID: Infiltration rate curves for trial plot block D

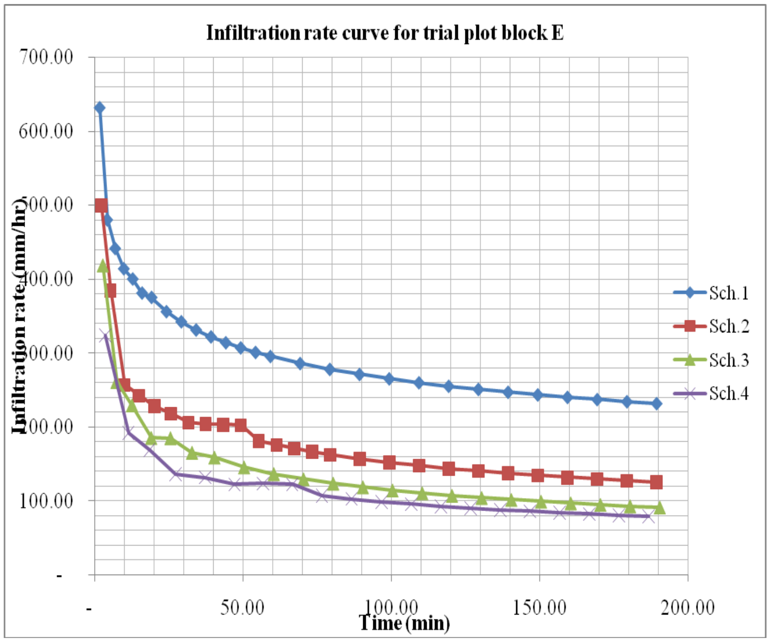

Figure IIIE: Infiltration rate curves for trial plot block E

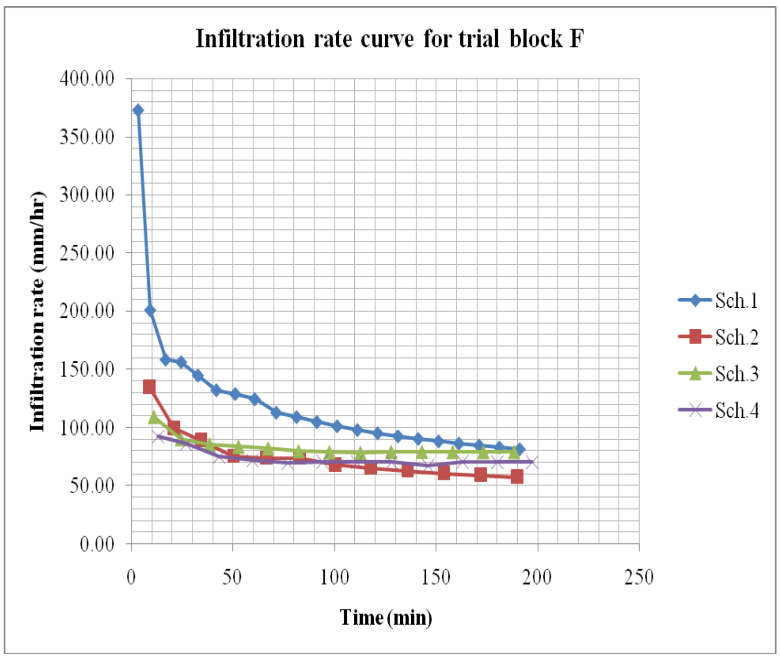

Figure IIIF: Infiltration rate curves for trial plot block F

Table IIIA: Kostiakov equation infiltration parameters in blocks A-F

Block	Parameter a	Parameter n	R^2
A	384.59	-0.278	0.977
B	797.99	-0.379	0.982
C	606.74	-0.367	0.994
D	606.74	-0.367	0.994
E	679.20	-0.205	0.995
F	466.66	-0.332	0.976
Average	590.32	-0.321	0.986

Kostiakov equation for infiltration in the trial plot was determined to be $F_t = 590.32\ t^{-0.321}$

Appendix IV: Crop yield

Table IVA: Total crop yield and plant population for 144 m^2 experimental plots

Block	Sprinkler Type	Plot dimensions	Area (m^2)	Yield (kg)	No of plants at harvest	No of plants at planting
A	Jalpari	6 m x 24 m	144	14.80	1883	2576
B	Taiwan	6 m x 24 m	144	17.15	2306	2576
C	Taiwan	6 m x 24 m	144	6.30	1901	2576
D	Naan	6 m x 24 m	144	7.30	1764	2576
E	Naan	6 m x 24 m	144	3.0	1467	2576
F	Jalpari	6 m x 24 m	144	7.95	2119	2576

Table IVB: Weights of 1000 green gram grains sampled from total crop yield

Block	Sprinkler Type	Weight (g)	Weight (g)	Weight (g)	Average Weight (g)
		Replicate 1	Replicate 2	Replicate 3	
A	Jalpari	67.1	72.7	67.9	69.2
B	Taiwan	64.6	65.3	71.5	67.1
C	Taiwan	72	68.7	70.5	70.4
D	Naan	68.8	75.8	69.7	71.4
E	Naan	73.6	70.5	71.6	71.9
F	Jalpari	65.3	71.8	68.5	68.5

Appendix V: Crop production cost

Table VA: Green gram production cost per Ha

S.no	Activity/Input	Unit	Quantity	Rate per unit (Kshs)	Total Cost (Kshs)
1	Ripping(sub-soiling)	Ha	0.5	2,400.00	3,000.00
2	Ploughing	Ha	1	6,000.00	6,000.00
3	Harrowing	Ha	1	4,800.00	4,800.00
4	Tilling	Ha	1	1,600.00	1,600.00
5	Seed	Kg	16	200.00	3,200.00
6	Pesticides	Lts	1	1,500.00	1,500.00
7	Fertilizer	Kg	100	49.60.00	4,960.00
8	Irrigation water	Ha	1	1,000.00	1,000.00
9	Weeding	mds	57.77	205.00	11,842.00
10	Bird scaring	mds	14	205.00	2,870.00
11	Day/night guards	mds	62	205.00	12,710.00
12	Winnowing	mds	4	205.00	820.00
13	Harvesting	mds	31.46	205.00	6,450.00
14	Irrigator	mds	62	205.00	12,710.00
15	Planting	mds	11	205.00	2,255.00
16	Threshing	mds	8	205.00	1,640.00
				Sub-Total	77,357.00
				Supervision cost 30 % of sub-total	23,207.10
				Grand Total	100,564.10

Appendix VI: Meteorological data

Table VIA: Meteorological data for WWIDP for the month of February 2013

Date	**Rainfall (mm)**	**Wind speed Km/hr.**	**Min. temp (°C)**	**Max. temp (°C)**	**Dry bulb temp (°C)**	**Relative humidity (%)**
01-02-2013	0	0.42	16	17	28	49
02-02-2013	0	0.15	15	17.5	22	35
03-02-2013	0	0.30	15	17	20	45
04-02-2013	0	0.48	16	18	21	29
05-02-2013	0	0.73	15.5	17.5	23	49
06-02-2013	0	0.03	16	17	23	49
07-02-2013	0	1.61	16	17.5	22	41
08-02-2013	0	1.80	15.5	17.5	24	44
09-02-2013	0	2.18	16	17	25.1	51
10-02-2013	0	1.13	15.5	16.5	26	52
11-02-2013	0	3.59	15	17	22.4	61
12-02-2013	0	0.45	15	17.5	21	53
13-02-2013	0	0.94	16.5	17	20.3	67
14-02-2013	0	1.22	16.5	17	23	49
15-02-2013	0	0.79	15	18	27	53
16-02-2013	0	0.73	16	17	24	57
17-02-2013	0	0.73	18	19	22	48
18-02-2013	0	0.77	15.5	17	24	44
19-02-2013	0	0.74	16	17.5	21	53
20-02-2013	0	1.13	15	16.5	24	50
21-02-2013	0	0.71	17	17.5	26	35
22-02-2013	0	1.66	16	17	25	51
23-02-2013	0	0.95	15	17	23.5	57
24-02-2013	0	1.00	16	18	22	69
25-02-2013	0	0.98	15	17	28.4	93
26-02-2013	0	1.23	16	18	24	92
27-02-2013	0	0.94	17	18	23	92
28-02-2013	0	1.55	16	18	21.5	56
TOTAL	0	28.94	443	486.5	656.2	1524
MEAN	0	1.03	15.8	17.4	23.4	54

Table VIB: Meteorological data for WWIDP for the month of March 2013

Date	Rainfall (mm)	Wind speed Km/hr	Min. temp (ºC)	Max. temp (ºC)	Dry bulb temp (ºC)	Relative humidity (%)
1-03-2013	0	0.92	16	26	28	43
2-03-2013	0	1.13	15	20	20	32
3-03-2013	0	0.96	15	21	22	61
4-03-2013	0	0.83	17	20	21	83
5-03-2013	0	1.81	15	21	23	77
6-03-2013	0	0.04	18	19	21	68
7-03-2013	0	0.59	17	23	22	76
8-03-2013	0	1.34	16	23	24	77
9-03-2013	0	0.49	18	24	25	77
10-03-2013	0	0.00	17	27	27	78
11-03-2013	0	0.67	18	20	22	76
12-03-2013	0	0.35	19	24	21	75
13-03-2013	0	0.38	17	24	21	83
14-03-2013	0	0.86	17	25	23	84
15-03-2013	5	0.77	15	27	29	73
16-03-2013	7	0.42	20	25	23	77
17-03-2013	13	1.19	16	24	22	61
18-03-2013	5	1.75	17	26	24	70
19-03-2013	25	2.52	18	24	25	71
20-03-2013	30	3.31	18	22	23	84
21-03-2013	15	3.27	16	21	22	76
22-03-2013	8.1	2.23	17	25	25	77
23-03-2013	6.7	2.33	19	22	22	92
24-03-2013	1.5	0.51	18	22	22	92
25-03-2013	9.1	0.27	15	30	30	80
26-03-2013	6.2	0.34	17	26	28	79
27-03-2013	0	0.21	19	26	26	71
28-03-2013	41	0.43	15	24	24	77
29-03-2013	0.3	0.47	21	25	25	77
30-03-2013	25	0.42	17	24	24	63
31-03-2013	3.7	0.47	18	23	23	62
TOTAL	202	31.25	530	733	729	2272
MEAN	6.5	1.01	17	24	24	73

Table VIC: Meteorological data for WWIDP for the month of April 2013

Date	Rainfall (mm)	Wind speed Km/hr	Min temp (°C)	Max temp (°C)	Dry bulb temp (°C)	Relative humidity (%)
1-04-2013	0	-	14	9.9	27	26.1
2-04-2013	1.7	-	16	11	19	12.8
3-04-2013	0	-	19	13	21	19
4-04-2013	43	-	16	14	20	17
5-04-2013	33	-	19	13.2	22	20
6-04-2013	6	-	19.7	12.7	20	17.9
7-04-2013	18.2	-	16.8	17.6	21	19.7
8-04-2013	0	-	20.1	10	23	21
9-04-2013	2.8	-	22	11.9	24.1	22.2
10-04-2013	0	-	23	17	26	24
11-04-2013	63	-	17	10	21	19.9
12-04-2013	12.4	-	15.3	11.9	20	18
13-04-2013	30.1	-	11.6	10	20.3	19.9
14-04-2013	27.6	-	10.9	9	22	20.9
15-04-2013	2.3	-	18.3	14.6	28	25
16-04-2013	2.1	-	14.3	9.1	22	20
17-04-2013	0	-	17	13.6	21	18
18-04-2013	14	-	21	16.9	23	20
19-04-2013	6.3	-	19	15.5	24	21
20-04-2013	2.7	-	22.1	18	22	21
21-04-2013	0	-	23	17	21	19.9
22-04-2013	10.3	-	20	18.3	24	22
23-04-2013	7.2	-	23	15.2	21.7	20
24-04-2013	4.8	-	19.6	14.4	21	20
25-04-2013	3.6	-	27.7	25.2	29.2	27.1
26-04-2013	6.3	-	26	24	27	25
27-04-2013	6.8	-	25	22	25.6	22
28-04-2013	7.2	-	24	19	23	20.9
29-04-2013	7.7	-	25	18	24.8	21.6
30-04-2013	8.2	-	26	24	23	19
Totals	327.3	-	591.3	456.0	686.7	620.9
Average	10.9	-	19.7	15.2	22.9	20.7

Appendix VII: Soil physical properties

Table VIIA: Ideal and root-restricting bulk densities

Soil Texture	Ideal bulk density(g/cm^3)	Root growth restricting bulk density(g/cm^3)
Sand, loamy sand	< 1.60	> 1.80
Sandy loam, loam	< 1.40	> 1.80
Sandy clay loam, clay loam	< 1.40	> 1.75
Silt, silt loam	< 1.30	> 1.75
Silty clay loam	< 1.40	> 1.65
Sandy clay, silty clay	< 1.10	> 1.58
Clay	< 1.10	> 1.47

(Source: USDA, 1999.)

Table VIIB: Guideline basic infiltration rates for various soil types

Soil type	Steady infiltration rate (in/hr)	Infiltration class
Sands	>30	Very rapid
Sandy and silty soils	20-30	Moderately rapid to rapid
Loams	10-20	Moderately slow to moderately rapid
Clays	5-10	Slow to moderately slow
Sodic clayey soils	1-5	Very slow to slow

(Source: FAO, 1988; Thomas *et al*, 2004)

Appendix VIII: RUSLE

Table VIIIA: P Factor Values

Land Use Type	Slope %	P-Factor
Agriculture	0-5	0.10
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Other Land	All	1.00

(Source: Wischmeier and Smith, 1978 (MCMLXXVIII))

Appendix IX: Statistical table

Table IXA: Critical values of *F*-distribution at 5% significance level

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Table 4(a): Critical Values of *F*-Distribution (at 5 percent)

v_2 \ v_1	1	2	3	4	5	6	8	12	24	∞
1	161.4	199.5	215.7	224.6	230.2	234.0	238.9	243.9	249.1	243.3
2	18.51	19.00	19.16	19.25	19.30	19.33	19.37	19.41	19.45	19.50
3	10.13	9.55	9.28	9.12	9.01	8.94	8.85	8.74	8.64	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.04	5.91	5.77	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.82	6.68	4.53	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.15	4.00	3.84	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.73	3.57	3.41	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.44	3.28	3.12	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.23	3.07	2.90	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.07	2.91	2.74	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	2.95	2.79	2.61	2.40
12	4.75	3.88	3.49	3.26	3.11	3.00	2.85	2.69	2.51	2.30
13	4.67	3.80	3.41	3.18	3.02	2.92	2.77	2.60	2.42	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.70	2.53	2.35	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.64	2.48	2.29	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.59	2.42	2.24	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.55	2.38	2.19	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.51	2.34	2.15	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.48	2.31	2.11	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.45	2.28	2.08	1.84
21	4.32	2.47	3.07	2.84	2.68	2.57	2.42	2.25	2.05	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.40	2.23	2.03	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.38	2.20	2.01	1.76
24	4.26	3040	3.01	2.78	2.62	2.51	2.36	2.18	1.98	1.73
25	4.24	3.38	2.99	2.76	2.60	2.49	2.34	2.16	1.96	1.71
26	4.22	3.37	2.98	2.74	2.59	2.47	2.32	2.15	1.95	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.31	2.13	1.93	1.67
28	4.20	2.34	2.95	2.71	2.56	2.45	2.29	2.12	1.91	1.65
29	4.08	3.33	2.93	2.70	2.54	2.43	2.28	2.10	1.90	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.27	2.09	1.89	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.18	2.00	1.79	1.51
60	4.00	3.15	2.76	2.52	2.37	2.25	2.10	1.92	1.70	1.39
120	3.92	3.07	2.68	2.45	2.29	2.17	2.02	1.83	1.61	1.25
∞	3.84	2.99	2.60	2.37	2.21	2.10	1.94	1.75	1.52	1.00

v_1 = Degrees of freedom for greater variance.

v_2 = Degrees of freedom for smaller variance.

(Source: Kothari, 2004)