TILLAGE AND VARIETY EFFECTS ON SOIL MOISTURE CONTENT, BIOLOGICAL NITROGEN FIXATION AND SOYBEAN (*GLYCINE MAX* L. MERRIL) YIELD IN WESTERN KENYA

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DECLARATION AND RECOMMENDATION

Declaration

I declare that this thesis is my original work and has not been presented to any University for the award of any degree.

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Recommendation

This thesis has been submitted with our recommendation as University and field supervisors.

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DEDICATION

This thesis is dedicated to my parents Mark and Mary Omondi and to my uncle Caleb for their love, support and patience.

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ABSTRACT

Soybean production in Kenya is low and falls below demand. Although it is being promoted in Western Kenya its yield remains low. This has been attributed to several factors including low rainfall amounts and unreliable rainfall within seasons. This unreliable rainfall distribution leads to mid-season drought. If this occur biological nitrogen fixation, growth and yield of soybean is greatly affected. However there have been technologies such appropriate tillage methods that can increase soil moisture storage. This technology has not been tried in Western Kenya on soybean hence this study was conducted to establish the influence of different tillage methods and varieties on biological nitrogen fixation, growth and yield of soybean and also on soil moisture content. To achieve this objective; a two season study was established in four sites: Bungoma, Ugunja, Alupe and Rarieda representing four agro-ecological zones of Western Kenya. The experiment were laid in randomized complete block design in a split plot arrangement of two tillage methods (no till and till – use of hoes of 15 cm width and 20 cm depth) as the main plot and three soybean varieties (SB19, SB20 and Nyala) as the sub-plots. The data was analyzed using ANOVA and means separated using DMRT at $p<0.05$. Soil moisture was not different between tillage methods in all sites except in Rarieda where no till had higher soil moisture content than till. Nitrogen fixed was different between tillage methods at Bungoma and Alupe with no till having higher amount of N fixed than till. Nyala variety fixed highest amount of nitrogen at Alupe (19.4 kg ha^{-1}) and Rarieda (16.6 kg ha^{-1}) while SB19 fixed highest amount of N at Ugunja (16.9 kg ha^{-1}) and SB20 at Bungoma (14.0 kg ha^{-1}). There were interactions of tillage methods × soybean varieties with no till × Nyala interaction fixing higher amount of nitrogen at Alupe site than other sites. Soybean grain yield was not different between the tillage methods in all the sites. Among the sites; Alupe site gave the highest grain yield. Practicing no till in areas receiving low or unpredictable rainfall increases soil moisture content and nitrogen fixation leading to enhanced soybean grain yield.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AEZ	Agro-ecological Zone
BNF	Biological Nitrogen Fixation
CIAT	International Centre for Tropical Agriculture
IITA	International Institute for Tropical Agriculture
KARI	Kenya Agricultural Research Institute
LM	Lower Midland
TGx	Tropical Glycine Cross
TSBF- CIAT	Tropical Soil Biology and Fertility Institute of CIAT

CHAPTER ONE

INTRODUCTION

1.1 General introduction

Low soil fertility is among the major biophysical factors negatively affecting agricultural production in sub-Saharan Africa (Hilhorst et al., 2000). This limitation has traditionally been addressed through application of various cultural methods including use of animal manure, recycling of crop residues and shifting. However, these cultural methods of managing soil fertility are no longer sustainable due to increasing pressure on land resources as a result of increasing human population (TSBF, 2002) as well as increasing competing use of crop residues (Palm et al., 2001). To the majority of small holder communities, animal manure is increasingly becoming insufficient due to declining cattle population, that is triggered by the shrinkage of communal grazing land as well as emerging of new and re-emerging of old fatal livestock diseases (Baijukya, 2004).

Use of mineral fertilizers, a factor, which contributed to achieving "green revolution" in Asia, cannot entirely solve the poor soil fertility menace in sub-Saharan Africa Kenya included. Mineral fertilizer application in most sub-Saharan countries is reported to be below 9 kg ha^{-1} and continues to decline (Ridder et al., 2004). Mineral fertilizers target more cash crops than food crops and some farmers are reluctant to use them because of unavailability and high prices, thus they do not give immediate returns (Odendo et al., 2004). Improvement of soil fertility requires judicious application of integrated approaches including use of mineral and organic fertilizers, and as well as capitalizing on biological nitrogen fixation by legumes (Giller, 2001). However soil nutrients can only be absorbed and used effectively by crops in the presence of sufficient soil moisture.

Soil moisture stress is among the primary limiting factor in crop production as it affects many physiological and biochemical processes (Purcell et al., 2007). The success of a crop depends upon the amount of moisture stored which also depends on the nature of the soil. Moisture loss from the soil by evaporation and erratic rainfall in the middle of the season leads to crop failure. No tillage method and mulch management has been reported to have improve soil moisture storage (Gicheru et al., 2004).

Soybean (*Glycine max* L. Merril) is a legume species native of East Asia which has oil content of 20%, 40% protein content, 35% carbohydrate content and 5% ash content of the total dry weight. In Kenya, soybean is being promoted as an alternative source of proteins, cooking oil, income to farmers and for soil fertility improvement (Misiko et al., 2008). Soybean can obtain more than 80% of its total nitrogen from biological nitrogen fixation (Salvagiotti et al., 2008). The world production of soybean is estimated at 249 million metric tons. In Kenya soybean production is estimated at 2,165 metric tons (FAO, 2010). This production is very low compared to consumption requirement of 50,000 metric tons annually (Jagwe and Nyapendi, 2004). This low production can be attributed to many factors although the most fundamental is soil moisture which is always from the rainfall. The distribution and amount of rainfall which replenishes soil moisture in Western Kenya have increasingly become unpredictable and this is largely attributed to the changing climate. The main objective of this study was to evaluate soybean performance under different tillage managements at different agro-ecological zones of Western Kenya.

1.2 Statement of the problem

Yields of different varieties of soybean in Western Kenya are currently lower than their potential. These low yields are attributed to several factors such as: use of low yielding soybean varieties, low soil fertility, poor crop management (weeding, disease and pest control) and unfavorable weather conditions (high temperatures, low soil moisture due to low rainfall or its unreliability) among others. Low soil moisture availability incidences especially in the middle of a growing season is increasing as climate continue to change. This is more of a challenge to small holder farmers since most of them depend entirely on rainfall to grow their crops. In addition to low soil moisture and unreliable rainfall, most soils of Western Kenya have low soil fertility notably nitrogen and phosphorus. While low soil nutrients can be alleviated by application of mineral fertilizers, their costs are always beyond most small scale farmers’ ability. Biological nitrogen fixation can reduce over dependency on mineral nitrogen fertilizers. However most parts of Western Kenya have low native rhizobial population.

1.3 Objectives of the study

The main objective of the study was to increase soybean yields in nutrient and water deficient soils of Western Kenya through use of appropriate tillage methods and soybean varieties. The specific objectives were:

- To evaluate soil moisture content for soybean under no till and conventional tillage in major agro-ecological zones of Western Kenya.
- To evaluate growth and yield of soybean varieties under conventional tillage and no till in different agro-ecological zones of Western Kenya.
- To determine biological nitrogen fixation of soybean varieties under conventional tillage and no till at different agro-ecological zones.

1.4 Hypothesis

- Soil moisture content for soybean production is equally available under no till and conventional tillage in different agro-ecological zones of Western Kenya.
- Soybean varieties growth and yield under conventional tillage and no till practices is similar in different agro-ecological zones of Western Kenya.
- Biological nitrogen fixation of soybean varieties is not affected under conventional tillage and no till at different agro-ecological zones.

1.5 Justification of the study

Soybean is a legume crop with high oil and protein content. It can supply most of its nitrogen requirement and provide residual nitrogen for subsequent crop when its tissues decompose. Although soybean production in Kenya has recently gained popularity, its overall yield remains low and production is below consumer demand. This low yield has been attributed to several factors among which are; insufficient soil moisture at critical growth stages of the crop. Several technologies have been examined to help curb low soil moisture availability. Some of them are: irrigation, (Neubert et al., 2007) cover-cropping, tillage and mulching (Gicheru et al., 2004) methods among others. Irrigation in Western Kenya is highly unlikely due to water shortages, skills and minimal purchasing power of irrigation equipment by small holder farmers (Neubert et al., 2007). Tillage methods have varied effects, which on one hand conventional till though still widely practiced is being associated with increased soil erosion, loss of soil organic matter and destruction of soil structure (Ferreira et al., 2000; Derpsch, 2008). On the other hand no till is said to have beneficial effects on soil moisture storage, soil temperature and soil carbon (Gicheru et al., 2004; Benites, 2008; Landers, 2008). Due to these variable findings it is therefore necessary to research on suitable tillage methods for different agro-ecological regions of Western Kenya. In addition tillage methods are reported to be specific to site (soil), crop, climate and timing of tillage (Kladivko, 2001) calling for the quest to investigate on their possible contribution to soybean in different agro-ecological zones.

Population density in Western Kenya range from 500 to 1200 persons per km^2 with farm sizes less than 0.2 ha per household (Ruto et al., 2011). This would therefore imply that farmers need to have better technologies to enable them produce high grain yield in these small farm sizes. In addition to the small farm sizes, there is poor soil fertility arising from continual cultivation with less inputs (Okalebo, 2000) especially inorganic fertilizers which is applied below 20 kg N and 10 kg P ha^{-1} (Ruto et al., 2011). The poor soil fertility could be addressed by soybean's ability to fix its own nitrogen however; low native rhizobia population negates this. Inoculation with rhizobia will boost the ability of soybean to fix nitrogen. High nitrogen fixation and optimal soil moisture will elevate soybean yield therefore this study addresses how different tillage methods can influence soil moisture availability and biological nitrogen fixation on soybean.

1.6 Thesis layout

The thesis has six chapters addressing the topic: Tillage effects on soil moisture availability and soybean (*Glycine max* L. Merril) yields in Western Kenya. The first Chapter lays out the basis of the study and its justification. Chapter two reviews the work done previously on the same topic and related subjects, while Chapter three addresses the objective of tillage methods and their influence on soil moisture under different soybean varieties in different agro-ecological zones of Western Kenya. Chapter four considers the influence of tillage methods on biological nitrogen fixation and Chapter five provides a summary of the research findings and gives practical recommendations and areas for further research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Grain legumes in smallholder agricultural systems in Western Kenya

As in many parts of sub-Saharan Africa, grain legumes in Kenya are grown for food security, income as well as for soil fertility improvement and maintenance. From a list of more than 30 species of grain legumes that are known to be grown across the tropics (Abate et al., 2012), only six, namely chickpea (*Cicer arietinum*), common bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), pigeonpea (*Cajanus cajan*) and soybean (*Glycine max*) are commonly grown in Kenya. In 2009, the grain legumes production in Kenya was estimated at 414, 000 tonnes from an area of 1,054,000 ha (FAO, 2010). This yield is low probably due to their production and marketing constraints. Abate et al., (2012) states that achieving high grain legumes yield is constrained by diseases, pests and weeds which have so far been well controlled in most of the legumes. They further state that poor soil fertility, extreme heat and drought are the most important factors that largely lead to low grain yields. In their definition of drought they emphasize that it is not necessarily lack of soil moisture but rather it is the result of erratic distribution of rainfall in many situations.

2.2 Soybean production, its potential and constraints

Soybean is a multipurpose crop grown for industrial oil production, human food, production of livestock feed, and also as a source of bio-energy (Myaka et al., 2005). It contains 40% proteins while other legumes contain about 20%. Its products are cholesterol-free, high in calcium, phosphorus, fiber, rich in iron, most essential minerals, and vitamins and have low levels of saturated fat (BIDCO, 2005). Its global production in 2010 was around 249.0 million metric tons (MT). The country with the greatest output was the United State of America (USA) with 90.6 MT, followed by Argentina (68.5 MT), Brazil (52.6 MT) and China (15.0 MT) (FAO, 2010). In Africa; Nigeria is the highest producer with an average production of 486,000 tons on an area of 553,260 hectares, followed by South Africa with 205,270 tons from 122,870 hectares and Uganda with 155,500 tons from 139,500 hectares (FAO, 2010).

In Kenya, the production is about 2,165 metric tons (FAO, 2010), which is far below the demand of 50,000 metric tons (Jagwe and Nyapendi, 2004). Soybean production per region is variable due to several factors such as: weather and soil fertility differences, biotic factors, market availability, cost of production among others. In Rift valley, Western, Central, Eastern and Nyanza the production was estimated at 191, 474, 98, 53, and 119 tons respectively from an area of 186, 814, 300, 86, 271 ha in that order in 2005 (MoA, 2006). In Western Kenya annual yield range for soybean is between 200 - 560 kg ha^{-1}. However, it has been demonstrated that it is possible to obtain high yields of up to 1600 kg ha^{-1} (Chianu et al., 2008). Soybean has various health benefits including healing and disease prevention. Eating small amounts of soybean protein daily is reported to prevent or lower the risk of heart diseases, breast, colon and prostate cancer (Sirtori, 2001). Soybean is also reported to be good for people with lactose intolerance and it is known to ease the symptoms of menopause (Levis et al., 2011) People who suffer from digestive problems or diabetes also stand to benefit from soybean-based foods (Mahasi et al., 2010). Hence, soybean could enrich most of the local dishes.

2.3 Soybean improvement

Research has been going on to increase soybean yields but with more focus on breeding and introduction of improved varieties. In 2009, KARI released five soybean varieties namely, ‘Black Hawk’ which matures within a period of 150 – 165 days, grows in an altitude of 800 – 1700 m above the sea level (asl) ‘EAI 3600’which matures within a period of 130 – 142 days, grows in an altitude of 800 – 1700 m asl, ‘Gazelle’ which matures within a period of 173 – 178 days, grows in an altitude of 1200 – 2400 m asl, ‘Hill’ which matures within a period of 140 – 145 days, grows in an altitude of 1200 – 2000 m asl and ‘Nyala’ which matures within a period of 83 – 93 days, grows in an altitude of 1200 – 2400 m asl. Its average grain yield is 0.7 – 2.5 t ha^{-1} and can grow in areas with minimum rainfall of as low as 300 mm annually (Myaka et al., 2005). IITA had released a total of 21 tropical bred soybean varieties for Africa by the year 2011. The grain yields ranged from 1 - 2.1 t ha^{-1} for the early maturing varieties depending on locations. For medium maturing varieties grain yields ranged from 1 - 2.7 t ha^{-1}. In the case of late maturing varieties grain yields ranged from 1.3 - 2.3 t ha^{-1}. Of importance in this study is TGx 1740-2F also called SB19; it matures within a period of 92 – 96 days, has more pods per plant up to the top of the plant, performs well under poor and erratic rainfall, and has better lodging resistance (Tefera, 2011). Its grain yield is between 1761 – 2232 kg ha^{-1}. The other soybean variety in this study is TGx 1448-2E which is also called SB20. It matures within a period of 115 – 117 days and has grain yield ranging between 2403 – 2458 kg ha^{-1} (Tefera, 2011). Management practices for example tillage methods, sowing method, weeding and pest and disease control are specific to a farmer and differ from one location to another although they can be manipulated to increase the yield potential of a crop. This has a far reaching influence on the climatic variability; for example better tillage methods will increase soil water holding capacity (Landers, 2008), soil organic matter among other benefits hence increase in soybean yields.

2.4 Biological Nitrogen Fixation (BNF) in soybean

Biological nitrogen fixation involves association of rhizobia and legumes. The rhizobium-legume symbiosis plays an important role in agriculture, because it offers the ability to convert atmospheric molecular nitrogen into forms useable by the plant (Jensen and Nielsen, 2003). Singh et al. (2003) reported that relative to early maturing soybean varieties, medium and late maturing varieties produce more biomass, fix more nitrogen and consequently contribute positively to the nitrogen balance of the soil. Most of the research to optimize symbiotic nitrogen fixation and to increase the use of legumes in crops systems has been in part stimulated by the increasing fertilizer prices and by environmental concerns (Sanginga et al., 2003).

Soybean can obtain up to 80% of its total nitrogen requirement from biological nitrogen fixation (Salvagiotti et al., 2008). Sanginga et al., 2003 reports that some soybean varieties can biologically fix 44 to 103 kg N ha^{-1} annually. However, the quantity of biologically fixed nitrogen can be reduced if the crop is supplied with starter nitrogen above 50 kg N/ha and or if soil available N is far below 10 kgha^{-1} (Van Kessel and Hartley, 2000). Other nutrients influencing biological nitrogen fixation include: P, Ca, Mg, and Zn (Hungria and Vargas, 2000). Inoculation of soybean with rhizobia in areas with low or ineffective native rhizobia is also reported to increase biological nitrogen fixation (Abaidoo et al., 2007).

Inoculated late and medium maturing soybean cultivars exhibit increased nitrogen content and dry matter in seed and vegetative parts (stem and leaves), nitrogen harvest index and seed yield

(Sogut,2006). However the same parameters can be reduced in quantities and quality if the native or indigenous rhizobia are substantial reducing the effective establishment of rhizobial strains in the inoculant (Abaidoo et al., 2007).

The amount of N_2 fixed is primarily controlled by four principal factors: the effectiveness of rhizobia-host plant symbiosis, the ability of the host plant to accumulate N, the amount of available soil N and environmental constraints to N_2 fixation (Van Kessel and Hartley, 2000). Soil environments is influenced by a combination of factors including acidity (leading to toxicities of Al and Fe), salinity, alkalinity (including high concentrations of Ca and boron) soil temperature, moisture, fertility (including nutrient deficiencies), and soil structure (Hungria and Vargas, 2000). Legumes should have effective root rhizosphere associations for effective N_2 fixation. Successful inoculant strains must be able to rapidly colonize the soil and tolerate environmental stresses, as well as compete with other soil micro-organisms (Slattery et al., 2001).

2.5 Measurement of biological nitrogen fixation

Measurement of biological nitrogen fixation is critical as it enables establishment of the amount of nitrogen fixed by different legumes and their potential on improving soil fertility. Several methods have been put forward such as the nitrogen balance method, nitrogen difference method, ureides method, ^{15}N isotope technique, acetylene reduction method, hydrogen evolution method and ^{15}N natural abundance method (Unkovich et al., 2008). ^{15}N natural abundance method was the technique used in this study. This technique involves two plants; a non N_2 fixing plant and a N_2–fixing plant, which is the legume. The ^{15}N natural abundance method applies the principle that where N_2–fixing plant is grown in a medium free of combined N (mineral N and or organic N) and is completely reliant upon symbiotic N_2 fixation for growth. The isotopic composition of the legume would be expected to be similar to that of atmospheric N_2 (δ ^{15}N %). On the contrary, if the non N_2 fixing plant is grown in a soil containing mineral N, its $\delta^{15}N$ value should be equal to that of soil mineral N taken up by the plant from the soil. The amount of N_2 fixed biologically is calculated in terms of % Ndfa (Unkovich et al., 2008).

^{15}N natural abundance method has several advantages over the other methods such as: it can be applied in glasshouse or field experiments, it allows N_2 fixation to be assessed in almost any situation where both N_2–fixing and non N_2–fixing plants are present at the same location. Its disadvantages are: complexity in choosing a non N_2 fixing reference species, the need to adjust isotopic fractionation within legume, the magnitude and variability in ^{15}N abundance of plant available soil N. To reduce variability due to the disadvantages; a non N_2 fixing reference plant should exploit the same N pool as the legume, have similar duration of growth and pattern of N uptake as the legume and receive no significant transfer of fixed N from the legume if they are growing in close association. The isotopic fractionation is adjusted by the 'B' value which is determined on plants grown in glasshouse in a sand culture using the same strain of rhizobia responsible for N_2 fixation at the site of study. However the 'B' values of most legume crops have already been determined (Unkovich et al., 2008).

2.6 Tillage methods and their effect on soil moisture

Soil moisture stress is a primary limiting factor in crop production as it affects many physiological and biochemical processes of the plants (Purcell et al., 2007). The success of a crop depends upon the amount of moisture stored and the nature of the soil. Moisture loss from the soil through evaporation (Jalota et al., 2001) and presence of erratic rainfall in the middle of the season leads to crop failure. In most legumes, high grain yield loss is reported to occur when moisture stress occurs at critical growth stages including flowering, podding and pod filling (Ahmed and Suliman, 2010; Al-Kaisi and Broner, 2012). This appears to suggest that in order to increase legume grain yield soil moisture stress has to be alleviated. Some of the methods to improve soil moisture availability or reduce deficit are: cover cropping, tree planting, rain water harvesting, mulching, conservation tillage and irrigation among others. However, some of these methods for example irrigation are scarcely practiced in most parts of Western Kenya due to lack of irrigation water, equipment, skills and sometimes economic power by the small holder farmers (Neubert et al., 2007). Tillage method and mulch management has been reported to have beneficial effects on soil moisture storage (Gicheru et al., 2004) and are also easy to apply by small holder farmers. Tillage methods and mulching can also be applied on soybean to improve water availability in the soil and enhance yield of most crops.

Tillage methods are divided into three categories: the first category is reduced tillage where 15% to 30% residue cover is left on the soil surface. This usually involves use of chisel plow and field cultivators. The second category is intensive tillage where less than 15% crop residue is left on the soil surface. This type of tillage method is usually referred to as conventional tillage. The last category of tillage methods is conservation tillage which leaves a minimum of 30 % of crop residue on the soil surface. Conservation tillage is further divided into: (i) No till which aims at 100% ground cover and no plow or disk is used. (ii) Ridge tillage which is a reduced tillage method that is a combination of no-till and conventional tillage and the crops are planted in ridges. (iii) Strip tillage which combines both no till and full tillage with the crops being planted in strips (Mahdi et al., 2009). Conventional tillage has been practiced for a long time and it is a common practice among small holder farmers (Chen et al., 2011). Ferna´ndez et al ., (2009) reported that conventional tillage is not sustainable over long term in more intensive production systems as it contributes to soil degradation, poor soil water retention, inefficient natural resources use and global warming. No till covers about 72 million hectares throughout the world (Derpsch and Benites, 2003); this is due to its greater profitability as a result of low input costs and increased yields in most cases. It contributes to accumulation of organic matter, improves soil structure and aggregation over time and soil moisture storage (Jaipal et al., 2002). The above variable benefits of tillage methods coupled with differences arising from location, implements used, skills, ecological and soil factors (Kladivko, 2001) necessitates a study of tillage methods influence on soil moisture availability under different soybean varieties in Western Kenya.

2.7 Soil moisture content under soybean

Low soil moisture negatively affects both biochemical and physiological functioning of a plant leading to yield reduction (Purcell et al., 2007). It has been shown that stored soil moisture can help sustain crops during periods of unreliable rainfall (Unger et al., 2006). Western Kenya has unreliable rainfall distribution leading to mid-season drought and hence low soybean grain yield. The most critical stage for water stress is the reproductive stage i.e. flowering and pod filling. Inadequate soil moisture at this stage can result in reduced number of pods and poorly filled pods. It has been shown that 10 % reduction in soil moisture use by soybean results in an 8 % reduction grain yield potential while the same reduction in soil moisture use during pod filling results in 10 % grain yield loss (Godsey, 2012).

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CHAPTER THREE

EFFECT OF TILLAGE METHODS ON SOIL MOISTURE CONTENT FOR SOYBEANS IN WESTERN KENYA

Abstract

A two season study was conducted to evaluate the impact of tillage methods on soil moisture content of soybean varieties grown in four sites representing four different agro-ecological zones of Western Kenya. The treatments were: two tillage methods (no till and till – use of hand hoes of 15 cm width and 20 cm depth) and three soybean varieties (Nyala, SB19 and SB20) in a randomized complete block design arranged in split-plot. Soil moisture content was determined at flowering and pod filling stages at depths of 0 – 10, 10 – 20 and 20 – 30 cm using gravimetric method then converted to volumetric. Soil moisture content at Bungoma, Ugunja and Alupe were not different between tillage methods. However at Rarieda no till had higher soil moisture content than till. Among the soybean varieties soil moisture content was high in plots with SB20 and SB19. Bungoma had the highest soil moisture most probably due to high rainfall amounts and Rarieda had the lowest. Farmers should practice no till in areas that receive low and unpredictable rainfall and grow soil cover crops to increase soil moisture content.

Keywords: Soil, till, no-till, productivity;

3.1 Introduction

The performance of a crop depends largely upon the amount of water stored in the soil at critical time when it is needed, (Jalota et al., 2001). However, the available soil moisture is influenced by tillage methods (Fuentes et al., 2003), soil physical properties and climatic factors especially rainfall distribution and reliability (Foller and Rockstrom, 2001). However, rainfall reliability is increasingly becoming unpredictable in most parts of Africa (Rockstrom et al., 2007) and this influences crop yields negatively. Therefore soil moisture retention technologies such as appropriate tillage methods need to be evaluated for their potential to improve crop yield, especially in areas that are receiving low amount of rainfall and or with unpredictable rainfall patterns.

Conventional tillage has been practiced for a longtime around the globe (Fowler and Rockstrom, 2001) due to its several advantages including loosening the soil hence increasing soil drainage, root development and acceleration of organic matter decomposition by soil micro-organisms, and improving soil aeration (Moussa-Machraou et al., 2010). However, the sustainability of conventional tillage has been questioned over time due to depreciation of natural resources such as water and climatic changes (Hobbs and Gupta, 2003). This has become the foundation as to why most researchers are now advocating for no till. Contrary to conventional tillage, no till minimizes soil and nutrient losses through leaching and erosion (Shipitalo et al., 2000; Schillinger, 2001), increase soil water storage (Malhi et al., 2001) and reduce production costs.

Conservation tillage is preferred due to less disturbance of soil mulch which reduces evaporation, soil sealing and crusting, increases infiltration and decreases soil erosion (Guerif et al., 2001). Mulch also modifies the micro-climate of the rhizosphere favorably, reduces soil temperature variations (Sharatt, 2002) and supplies nutrients when it decomposes (Cherr et al., 2006).

The influence of tillage on crop growth is reported to depend on crop species, climate, site and time of tillage (Martinez et al., 2008). In Western Kenya rainfall distribution and reliability also varies with space producing variable impact on crop preface between and across sites. Legumes including soybean are the most major crops whose yield is reduced by reduction of soil moisture or total lack of rainfall in the middle of the growing season. Soil moisture can be improved using several measures; for example by adopting appropriate tillage methods and mulching the soil

(Mulumba and Lal, 2008). In Kenya the information on the effect of tillage methods on soil moisture availability in areas under soybean is lacking. This study was initiated with the general objective of increasing soybean yields in nutrient and water deficient soils of Western Kenya through application of appropriate tillage methods and use of high yielding varieties. The specific objective was to evaluate soil moisture availability for soybean production under no till and conventional tillage in selected agro-ecological zones of Western Kenya.

3.2 Materials and methods

3.2.1 Description of study sites

The study was carried out at four sites in West Kenya namely: Kanduyi (0˚ 35´ N and 34˚ 35´ E) in Bungoma county; Ugunja (0˚ 09´ N and 34˚ 18´ E) in Siaya county; Alupe (0˚ 28´ N and 34˚ 07´E) in Busia county and Rarieda (0˚ 08´ N and 34˚ 23´ E) in Siaya county. The sites were selected to represents four major agro-ecological zones prominent in Western Kenya namely; Lower Midland 1 (LM 1), Lower Midland 2 (LM 2), Lower Midland (LM 3) and Lower Midland 4 (LM 4) respectively. These four agro-ecological zones are mainly differentiated in terms the amount of rainfall received per year, dominant soils types and their inherent fertility. The major characteristics of the zones are summarized in Table 3.1. All the sites where the experiments were laid had a history of conventional tillage and there was no fallow period in the last two seasons before the laying out of the experiment. At Bungoma, Ugunja and Alupe sites maize was the main crop for the past two seasons while at Rarieda cassava was the main crop.

Table 3.1: Selected agro-ecological characteristics of the study sites of West Kenya

Agro-ecological zone	Altitude (M)	Soil	Mean annual temperature ˚C	Mean annual rainfall (mm)
LM 1 – Lower midland sugarcane zone. (Bungoma)	1425	Well drained, deep to very deep, red to dark brown, friable sandy clay to clay (Ferralo – orthic).	21 – 22	1600 – 1800
LM 2 – marginal sugarcane zone (Ugunja).	1240	Well drained, deep, dark red (Orthic – rhodic ferralisols).	21 – 22	1450 – 1600
LM 3 – Lower midland cotton zone (Alupe).	1189	well drained, very deep, dark red (Orthic ferralisols)	22 – 22	1100 – 1450
LM 4 - Lower midland marginal cotton zone (Rarieda)	1135	Well drained, deep, low fertility (Ferralo – orthic acrisols)	22 – 22	900 – 1100

Source: Jaetzold et al., 2005.

3.2.2 Experimental design, treatments, establishment and management

At each site the experiment was laid out in randomized complete block design in a split-plot arrangement with three replicates. Tillage method (no till and conventional) was the main plot and soybean varieties the sub-plot (Figure 3.1). Tillage on till treatments was done prior to onset of rains by using a hand hoe at a depth 20 cm as this is the most common tool used by farmers in the area. This was done by first removing all plant debris and growing weeds followed by physical tilling of the land. In no till plots, the weeds growing in the experimental plots were killed using roundup which is a non-selective herbicide containing an active ingredient glyphosate (40% v/v) sprayed at a rate of 1.5 liters in 100 liters of water per hectare, two weeks before planting.

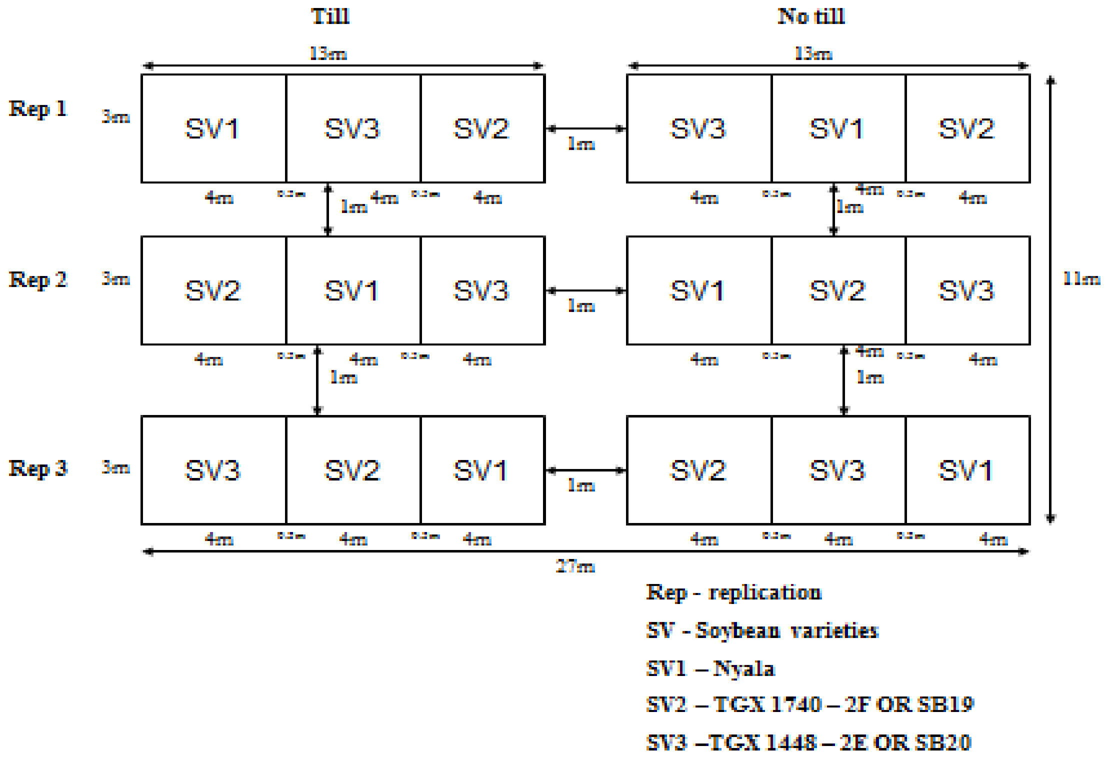

Figure 3.1: Experimental layout at all sites.

The soybean varieties Nyala a local early maturing (60 days) variety but susceptible to soybean rust disease and nodulating with specific soil-rhizobial strains and two IITA bred dual purpose and promiscuous soybean varieties TGx1740-2F (locally known as SB 19) and TGx1448-2E (locally known as SB 20) were used. The variety TGx1740-2F is medium maturing (80 days) whereas the variety TGx1448-2E is late maturing (120 days). The experiments were conducted for two seasons: long rains of 2011 (season 2011A) and repeated (at the same sites) in short rains of 2011 (season 2011B). Plots of 4 m x 3 m were demarcated on each main plot (till and no till) and planted with three soybean varieties (SB20, SB19 and Nyala) using a spacing of 50 cm between rows and 5 cm within the rows, resulting in a plant population of 400,000 plants per hectare. Planting was done at Bungoma on 24th March; at Ugunja on 21st March; at Alupe 18th March and at Rarieda on 26th March in season 2011A. In season 2011B, sowing dates were: 2nd Sept, 4th Sept, 23rd August and 31st August at Bungoma, Ugunja, Alupe and Rarieda respectively. Prior to planting, all plots received a basal application of 30 kg P ha^{-1} supplied as Triple Super Phosphate (TSP) and 30 kg K ha^{-1} supplied as Muriate of Potash (MOP). The fertilizers were applied in furrows of dug 5 cm depth and 5 cm away from the planting lines and covered with soil immediately after application. To enhance biological nitrogen fixation soybean seeds were inoculated with BIOFIX inoculant containing rhizobium strain USD 110 by a two-step method (Somasegaran and Hoben, 1994). The inoculants were applied at a rate of 10g kg^{-1} of seeds and the inoculated seeds were planted immediately after inoculation to ensure maximum survival of introduced rhizobial cells. Strips of weed fallow plots were left between the main plots in order to provide weeds for use as reference crop for determination of nitrogen fixation by soybean. Maize stovers with approximately 60% moisture content (were obtained from the local farmers where each experiment was located) were chopped at 10 – 15 cm length and applied as surface mulch at a rate of 4 t ha^{-1} between the rows soon after emergence in both till and no till. The chopping of the maize stovers was done to ease handling. The plots were kept weed free by periodic weeding where by in no till plots, weeding was done by hand pulling following appearance of weeds whereas in till plots weeding was done by scratching the top soil using a hand hoe on an interval of two to three weeks depending on weed population.

3.2.3. Soil sampling and analysis

Before planting, soil samples were taken from each field at a depth of 0-20 cm from 20 spots using the diagonal randomization method to obtain a composite sample of approximately 0.5 kg. The composite samples were air dried ground and sieved to pass a 2 mm sieve. Soil samples were analyzed at World Agroforestry Centre (ICRAF), Nairobi, Kenya for soil chemical properties (pH, Olsen P, Exchangeable Ca, Mg, K, CEC) and soil particle composition (sand, silt and clay) using standard methods as described in Okalebo et al., (2002). Total organic carbon (OC) was determined using chromic acid titration method and total soil nitrogen was determined using steam distillation and titrating the digest with HCl (Okalebo et al., 2002).

3.2.4 Determination of soil moisture content

From each treatment in both 2011 long rains and 2011 short rains growing seasons ,soils for moisture determination were collected using standard corings (with a known diameter of 5cm and height of 5cm) at depths 0-10 cm, 10-20 cm and 20-30 cm by hammering the coring into the soil using a compaction hummer. Soil moisture measurement in the plots was taken at planting and at critical stages of crop growth that is 50% flowering; pod filling and full seed (Liu et al., 2003). For each sampling, soils were taken from three positions randomly selected per plot. The corings were removed from the soil using a kitchen knife cleaned on sides and soil transferred into a well labeled polythene bag (17cm by 29 cm by 30 microns) of known weight. In the field the sampled soils were kept in a cool-box and transported to the lab where fresh weights were taken using an electronic top balance in before they were transferred into brown paper bags (size 2) of known weights and for drying in an oven at 105 ºC to constant weights. Weights of dry samples were recorded using the same electronic balance. Soil moisture content was then calculated using a gravimetric method then converted to volumetric water content (Hillel, 1980) using the relation:

$$\omega = \frac{M_w}{M_s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ equation 3.1}$$

$$\text{And} \qquad \theta = \frac{\omega\rho_b}{\rho_w} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{equation 3.2}$$

But: ρ_w is the density of water given as mass of water/volume of water, which is approximately equal to 1 g/cm^3

$$\text{Therefore: } \theta = \frac{M_w}{M_s} \times \rho b\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{equation 3.3}$$

Where: θ is the volumetric water content

ω is the gravimetric water content

ρ_b is the dry bulk density

M_w is the amount of water in soil (g)

M_s is the total dry soil mass (g)

3.2.5 Data analysis

Data collected was subjected to analysis of variance (ANOVA) at 5% level of significance and means were separated using Duncan's Multiple Range Test (DMRT) using SAS software version 9.00 (SAS, 2002).

The model in split-plot arrangement was:

$$Y_{jkb} = \mu + V_j + \alpha_k + \alpha_{jk} + \beta_a + \beta_{aj} + \alpha\beta_{ak} + \psi_p + \text{¥}_s + \alpha\beta\psi_{kacp} + \alpha\beta\text{¥}_{akc} + \alpha\beta\text{¥}\psi_{akcp} + Є_{jkb}$$

Where: μ-Exp. Mean, V_j - effect of jth block, α_k - kth main plot factor effect of tillage, ψ_p – season effect, ¥_s – location effect, β_a – ath sub-plot effect of soybean varieties, $_{,}$ $\alpha\beta\text{¥}\psi_{akcp}$ - interaction effects, α_{jk} – random error component of tillage, β_{aj}– random error component of soybean varieties, ϵ_{jkb} – random error component of split plot.

3.3 Results and discussion

3.3.1 Impact of tillage on soil moisture content under different soybean growth stages

Soil moisture content in season two (2011B) was higher than season one (2011A) at both flowering and pod filling stages (Table 3.2). This could be attributed to high rainfall amounts in second season in most of the sites (Figure 3.2). Among the sites Bungoma had the highest soil moisture in season 2011A and Rarieda the lowest at both flowering and pod filling stages (Table 3.2). This could as well be ascribed to rainfall amounts within the regions (Figure 3.2). In season 2011B Ugunja had the highest soil moisture at flowering and pod filling while Rarieda had the lowest. There were no differences in soil moisture between till and no-till when data for all sites and seasons were combined. However, no-till had higher moisture in Rarieda during season 2011A, while till had higher soil moisture in Alupe at pod filling during season one and at 50% flowering during season 2011B. There was no soil moisture difference under different till methods at Bungoma and Ugunja sites.

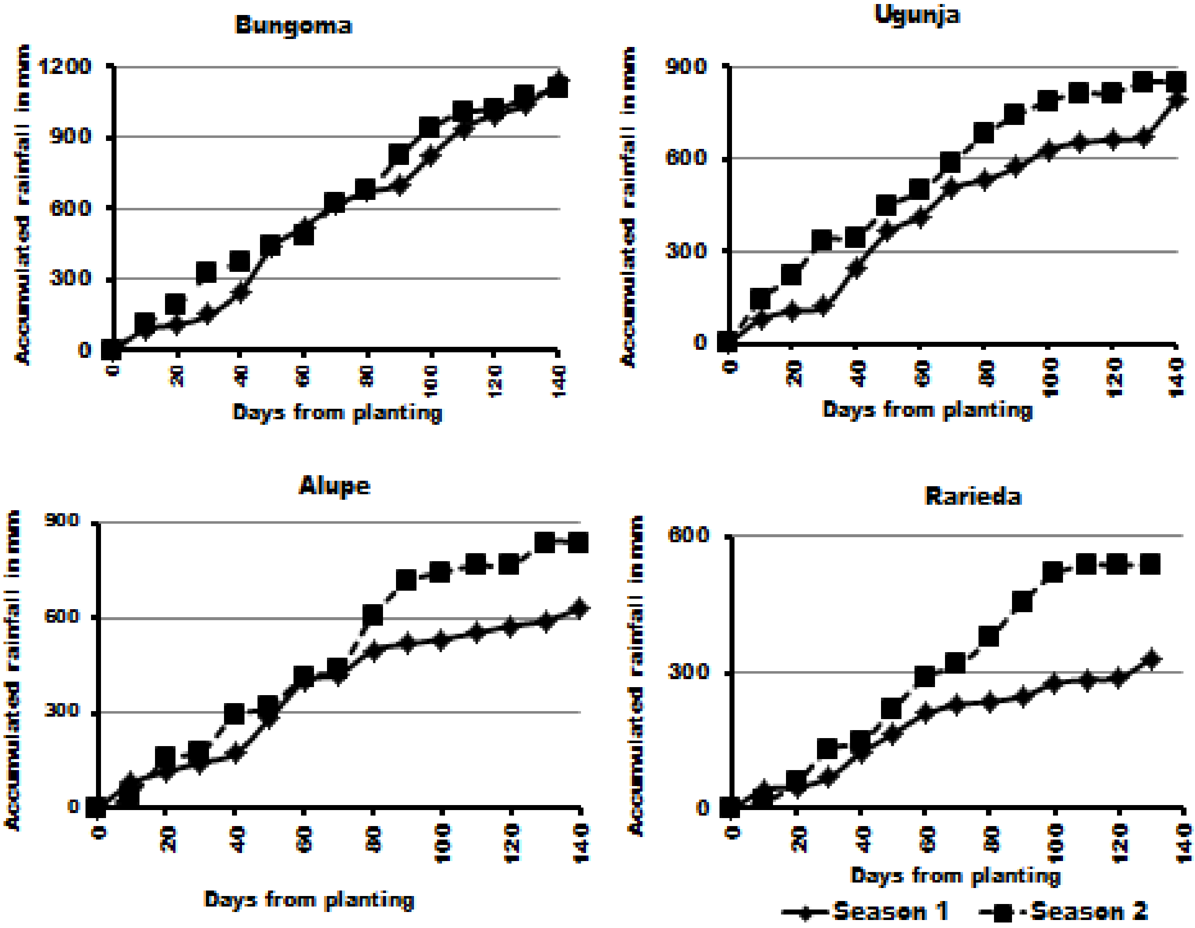

Figure 3.2: Cumulative rainfall at different sites for long rains (2011A) and short rains (2011B) at different experimental sites

Soil moisture at Bungoma and Ugunja was not different at flowering and pod filling stages between till and no till in season 2011A and 2011B. This probably arose due to sandy clay loam soil texture (Table 3.3) that could allow uniform infiltration rate of soil moisture in both till and no till plots. This was coupled with high amount of rainfall (Figure 3.2) in these sites (Lower Midland 1 and Lower Midland II respectively) helped mask the tillage effects on soil moisture. In addition the high cation exchange capacity (CEC) and organic carbon content (Table 3.3) at the two sites would have increased soil moisture retention regardless of the tillage method since most tillage characteristics on soil moisture content start showing after several seasons of cropping.

At Alupe there was significance difference between treatments in season 2011A at pod filling stage where till method had higher soil moisture than no till (Table 3.2). The difference could be due to soil texture at Alupe which was sandy clay (Table 3.3). This type of soil texture has a good water holding capacity hence the high amount of soil moisture content at pod filling.

No till had higher amount of soil moisture than till in Rarieda (Table 3.2). This could have been due to soil texture of loamy sand (Table 3.3). This type of soil texture increases soil moisture loss through evaporation and deep percolation in till plots compared to no till. In addition, the soil organic carbon at this site was low (Table 3.3) implying that soil organic matter was also low hence the soil particle aggregation was poor leading higher infiltration rate and reduced soil moisture retention.

Table 3.2: Tillage methods and their effect on soil moisture content (mm/mm) under soybean at different crop growth stages as recorded at different experimental sites in two seasons

Season	Soybean growth stage	Tillage method	Experimental site				
			Bungoma^1	Ugunja^1	Alupe^1	Rarieda^1	Mean^3
2011 long rains (season 1 – 2011A)	50% flowering	Till	0.246^{a}	0.189^{a}	0.252^{a}	0.184^{b}	0.205^{a}
		No till	0.254^{a}	0.180^{a}	0.245^{a}	0.202^{a}	0.207^{a}
		Mean^2	0.250^{a}	0.184^{c}	0.208^{b}	0.169^{d}	0.207^{b}
	At pod filling	Till	0.276^{a}	0.232^{a}	0.288^{a}	0.073^{b}	0.217^{a}
		No till	0.273^{a}	0.225^{a}	0.256^{b}	0.094^{a}	0.210^{a}
		Mean^2	0.274^{a}	0.228^{b}	0.223^{b}	0.074^{c}	0.214^{b}
2011 short rains (season 2 – 2011B)	50% flowering	Till	0.235^{a}	0.274^{a}	0.337^{a}	0.253^{a}	0.245^{a}
		No till	0.244^{a}	0.285^{a}	0.329^{b}	0.248^{a}	0.244^{a}
		Mean^2	0.240^{c}	0.279^{a}	0.257^{b}	0.194^{d}	0.244^{a}
	At pod filling	Till	0.248^{a}	0.269^{a}	0.347^{a}	0.278^{a}	0.246^{a}
		No till	0.244^{a}	0.270^{a}	0.341^{a}	0.227^{a}	0.245^{a}
		Mean^2	0.246^{b}	0.269^{a}	0.263^{a}	0.193^{c}	0.245^{a}

Means^1 with different letters are significantly different at $p<0.05$ within a crop growth stage and experimental site.

Means^2 with different letters are significantly different at $p<0.05$ among the experimental sites

Means^3 with different letters are significantly different at $p<0.05$ within a crop growth stage

Table 3.3: Top soil (0-20 cm) chemical and physical characteristics of the experimental sites

Site	pH	Olsen P	C.E.C	K	Ca	Mg	Na	clay	sand	silt	Soil texture	Total N	Total C
		ppm	Meq/100g	Meq /100g	Meq. /100g	Meq/100g	Meq/100g	%	%	%		%	%
Bungoma	5.3	12	8.39	0.27	3.66	0.94	0.05	24.8	69.6	5.6	sandy clay loam	0.08	1.04
Ugunja	4.8	13	6.90	0.29	1.60	0.87	0.14	28.9	55.5	15.6	Sandy clay loam	0.11	1.29
Rarieda	6.0	20	3.31	0.31	1.74	0.47	0.06	10.9	85.5	3.6	Loamy sand	0.04	0.40
Alupe	5.7	2	4.70	0.16	2.11	0.92	0.05	36.8	57.6	5.6	Sandy clay	0.12	1.12

3.3.2 Tillage effect on soil moisture in the soil profile

Soil moisture under till and no till in the profile was higher in Bungoma and lower in Rarieda in long rains (2011A) (Figure 3.3). Moisture in the soil profile could have been influenced highly by the amount of rainfall received in these regions (Figure 3.2). In both till and no till soil moisture within the profile was increasing with depth.

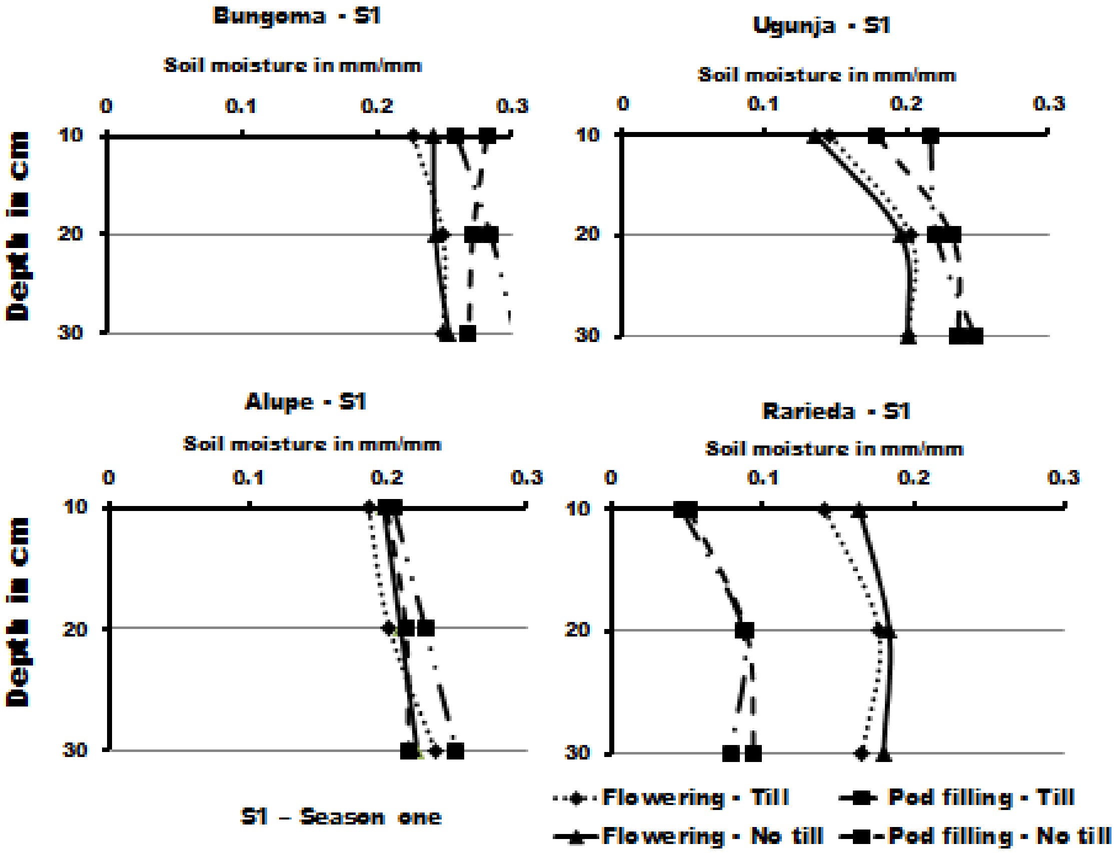

Figure 3.3: Soil moisture content within the profile under different tillage methods as observed at different experimental sites in long rains (2011A)

In short rains (2011B)soil moisture in the profile was higher at Ugunja and Alupe at flowering and pod filling stages (Figure 3.4). Rarieda still had the lowest soil moisture in the profile most probably due to the loamy sand soil texture (Table 3.3) that increased deep water percolation and low rainfall amounts (Figure 3.2). Soil moisture within the profile increased steadily from 0 cm to 30 cm depth both under till and no till.

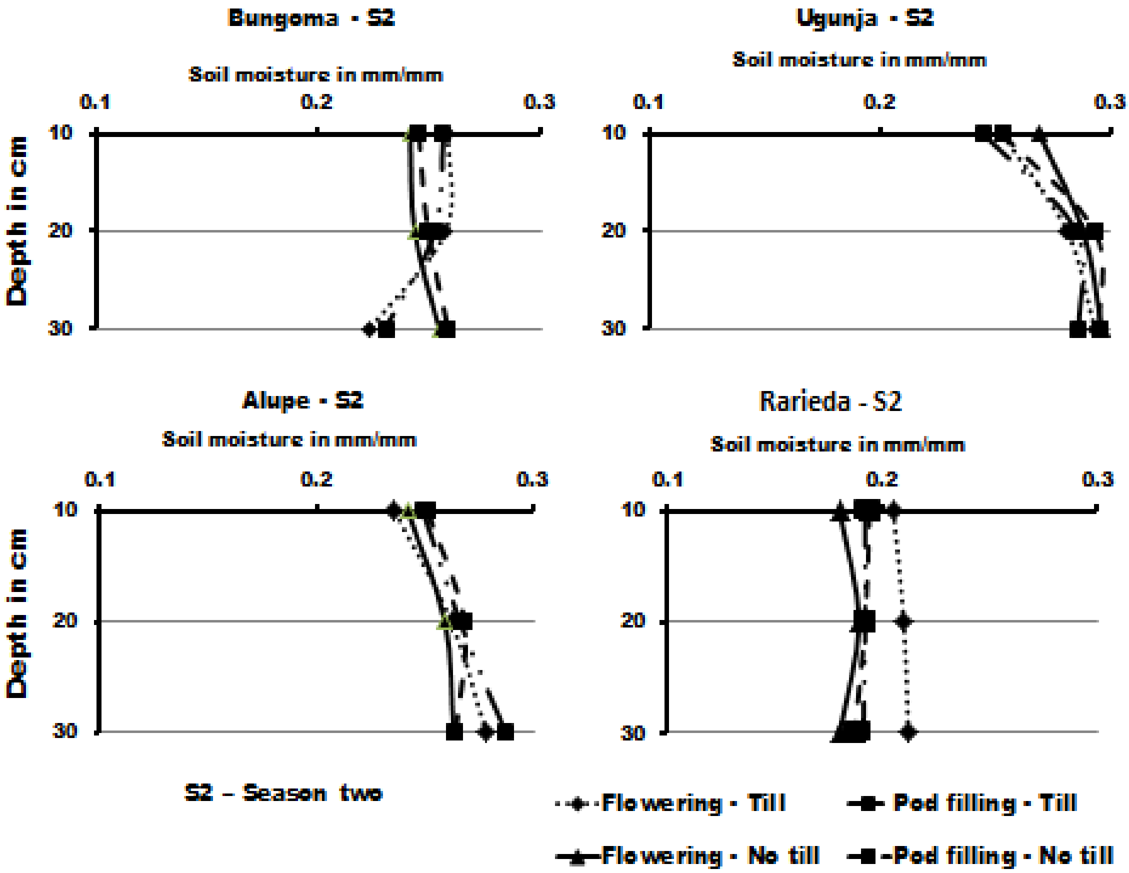

Figure 3.4: Soil moisture content within the profile under different tillage methods as observed at different experimental sites in short rain (2011B)

3.3.3 Influence of soybean varieties on soil moisture

Soil moisture differed significantly among soybean varieties. At both flowering and pod filling, soil moisture under plots planted with SB19 and SB20 varieties was higher than plots under Nyala (Figure 3.5). This difference in soil moisture could have risen due to differences in genetic composition of individual varieties. The genetic constitution could be manifested on soil water absorption by the roots and water use efficiency. Figure 3.6 explains the situation; high root biomass in SB20 leads to high soil moisture absorption which consequently leads to high shoot biomass. This substantially higher shoot biomass could protect the soil from increased evaporation as compared to Nyala whose shoot biomass was low.

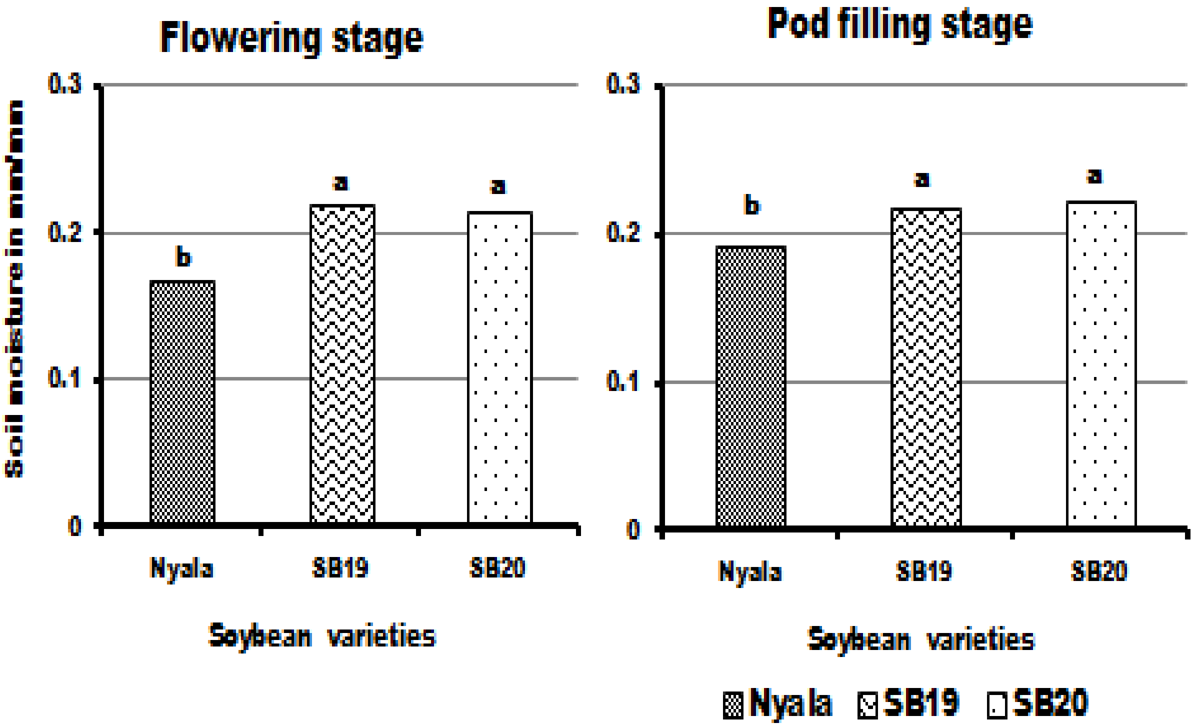

Figure 3.5: Soil moisture content under different soybean varieties at flowering and pod filling stages. Bars with different letters are significantly different at p<0.05 within a growth stage

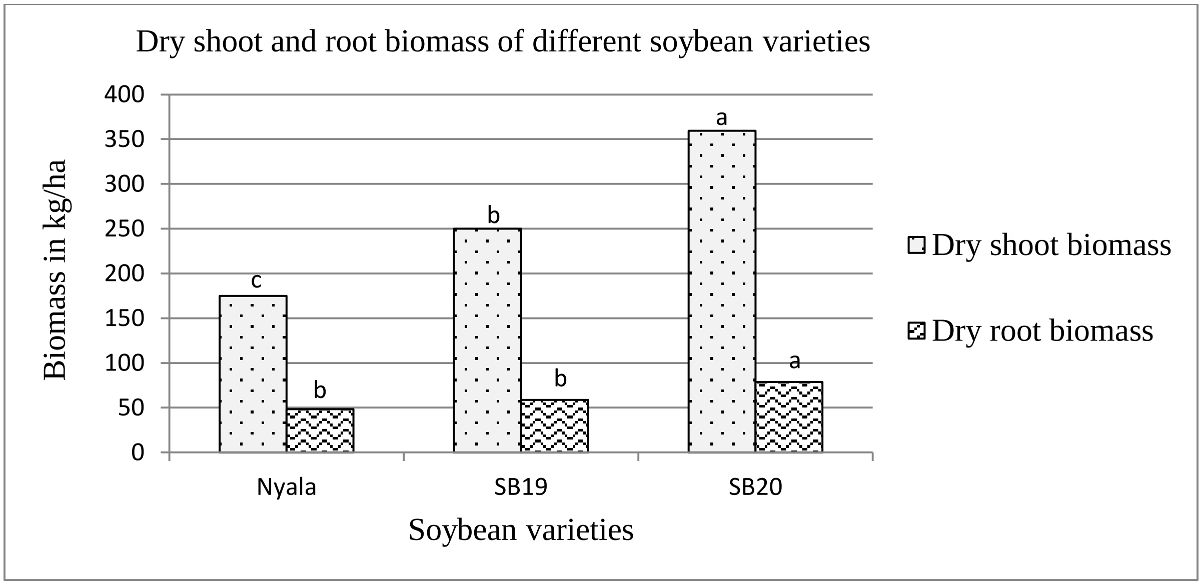

Figure 3.6: Dry shoot and root biomasses for different soybean varieties. Bars with different letters are significantly different at p<0.05 within a series i.e. within a given biomass.

There was no significance in soil moisture content with the interactions of varieties and tillage methods; varieties and profile depth. However there was difference between sites x soybean varieties interaction (Figure 3.7). At Bungoma site and all the soybean varieties had higher soil moisture than the other sites at flowering and pod filling stages (Figure 3.7). This is probably a result of high rainfall amounts received in the region (Figure 3.2).

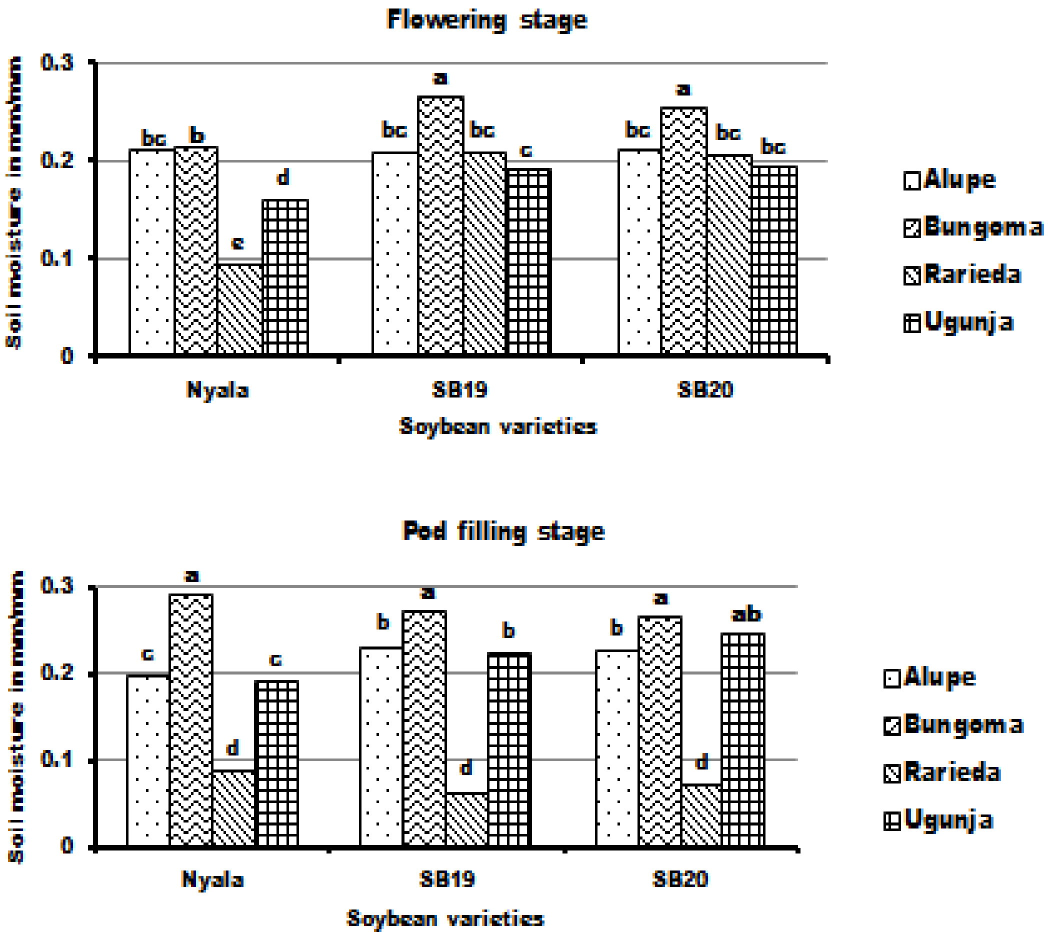

Figure 3.7: Soil moisture content under different soybean varieties at different experimental sites. Bars with different letters are significantly different at $p<0.05$ within a growth stage

3.4 Conclusion

Soil moisture content in high altitude area (Bungoma – LM1) was not different between till and no till. However in low altitude area (Rarieda – LM4) receiving low rainfall no till retained more soil moisture than till. Soil moisture was high in plots with SB20 and SB19 most likely due to high canopy cover which probably reduced evaporation. Bungoma had the highest soil moisture most probably due to high rainfall amounts. It is therefore prudent for farmers in areas receiving low and variable rainfall to practice no till and soil cover to increase soil moisture.

3.5 References

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CHAPTER FOUR

EFFECT OF TILLAGE ON BIOLOGICAL NITROGEN FIXATION AND YIELD OF SOYBEAN VARIETIES

Abstract

Low soil fertility has become a major impediment to crop production in most parts of sub-Saharan Africa. Over the years technologies have been generated to combat this problem and the most used is application of organic and inorganic fertilizers. However, inorganic fertilizers are not always available to most small holder farmers due to their high costs and poor accessibility. Use of legumes to fix biological nitrogen is a viable option. However, biological nitrogen fixation is influenced by soil moisture availability and consequently the type of tillage used. The aim of this study was to determine the effect of tillage methods on biological nitrogen fixation and grain yields of three soybean varieties. The study was conducted in four sites representing four agro-ecological zones of Western Kenya. The treatments were laid in a randomized complete block design in a split plot arrangement. Tillage methods (No tillage and conventional tillage) were main plots and soybean varieties (Nyala, SB19 and SB20) were subplots. Determination of N fixed was conducted using ^{15}N abundance method. The results showed that Nyala fixed higher amount of nitrogen under no till at Alupe (28.7 kg ha^{-1}) and Bungoma (11.3 kg ha^{-1}). At Ugunja and Rarieda the interactions between variety and tillage were not significant. Overall amounts of N fixed in no till plots were higher than till plots for all the sites combined. Soybean grain yield between the tillage methods was not different in all the sites and also between varieties. Alupe site had the highest grain yield (1543.0 kg ha^{-1}) and Nyala fixed high nitrogen across the four sites. No till should be encouraged to increase biological nitrogen fixation.

Keywords: Till, no till, soil moisture availability, biomass, N_2-fixation

4.1 Introduction

Poor soil fertility has been acknowledged as a major hindrance to high crop yield (Hilhorst et al., 2000). Researchers have devised some ways of alleviating this problem including application of organic and inorganic fertilizers. However, use of inorganic fertilizers by small holder farmers in sub-Saharan Africa is inadequate due to high costs, unavailability and sometimes lack of knowledge on usage. Materials for organic fertilizers are also difficult to acquire; farmers prefer supplying livestock with stovers rather than leaving them in the field to decay and consequently release nutrients. These challenges have led to exploitation of other economical ways of supplying nutrients to the crops and one of these ways is biological nitrogen fixation.

Biological nitrogen fixation (BNF) in legumes has for a longtime been a component of many farming systems throughout the world. Soybean for example is a legume which has the capacity to obtain its full nitrogen requirements through symbiotic nitrogen fixation and can contribute surplus N to the soil reserves for successive crops (Salvagiotti et al., 2008). Sanginga et al., 2003 reports that some soybean varieties can biologically fix 44 to 103 kg N ha^{-1} annually. However, this biological nitrogen fixation (BNF) process is affected by several factors: soil moisture content, temperature, mineral nitrogen content, native rhizobia population and soil pH among others (Hungria and Vargas, 2000). Soil moisture influences several biochemical and physiological functions of a crop including biological nitrogen fixation (Sinclair et al., 2007) hence its deficit is detrimental to crop growth and yield.

The method of tillage applied in crop production influences soil biophysical and chemical properties. Conservation tillage for example has been found to increase soil quality including soil moisture retention and reduce operation costs (Singh et al., 2008). Conventional tillage has also been found to enhance residue decomposition, expose harmful soil pests and allow extensive root growth. In Western Kenya where unreliable rainfall distribution and amounts prevails research to identify appropriate methods of tillage is warranted to conserve soil moisture and subsequently improve biological nitrogen fixation by legumes. Therefore the main objective of this study was to determine the effect of different methods of tillage on biological nitrogen fixation and yield of different soybean in different agro-ecological zones of Western Kenya.

4.2 Materials and methods

4.2.1 Experimental sites

A two season experiment starting in long rains of March to August, 2011 and short rains of September to December, 2011 were conducted in four sites representing four agro-ecological zones of Western Kenya as explained in section 3.2.1.

4.2.2 Experimental procedures

The experiment was laid in a complete randomized design in a split plot arrangement with three replicates. Tillage methods were: no tillage and conventional tillage being the main plots and three soybean varieties (Nyala, SB19 and SB20) were the sub plots. The main experimental plots measured 13 m by 11 m while the sub-plots measured 4m by 3m.

Conventional tillage was conducted using hoes of 20 cm length and 15 cm width while no tillage was done using glyphosate at 1.5 litres in 100 litres of water per hectare two weeks before planting. A basal rate of fertilizer was applied in the form of Triple Superphosphate (TSP) at a rate of 30 kg P ha^{-1} and potassium in form of Muriate of Potash (MOP) at a rate of 30 kg K ha^{-1} applied to all treatments in furrows of 5 cm depth and 3 cm away from the planting lines and covered with soil. All soybean seeds were inoculated using biofix inoculants strain USD 110 from Mea Limited – Kenya at 10g kg^{-1} of seeds and planted at a spacing of 50 by 5 cm. Maize stovers with 60% moisture content were chopped at 10 – 15 cm length and applied at a rate of 4 t ha^{-1} between the rows after emergence in both till and no till. Rust control was done using armistar Xtra from Syngenta at a rate of 1l/ha three times after flowering (this is the stage when the plants are highly susceptible) at an interval of two weeks. Weeding in no till was done by hand pulling depending on the appearance of the weeds while in conventional tillage it was done using hoes after every two to three weeks.

4.2.3 Soil characterization and data collection

Soil samples were taken for analysis of organic carbon content, total nitrogen, available phosphorus and potassium, pH, particle size according to standard procedures outlined by Okalebo et al., (2002).

Plants for biomass and N accumulation and assessment were randomly sampled in an area of $0.1m^2$ within the net plot at 50% flowering stage. These plant were cut at the first node from the ground using a kitchen knife, packed in a well labeled polythene bag (17cm by 29cm by 30 microns) of known weight followed by determination of field weight using an electronic balance (2000 g). At this stage, weeds from weedy fallow strips were samples in triplicates and brought to the lab for drying. The below ground part of the plant was excavated from the soil using a sharp spade and the soils were carefully removed and roots and nodules recovered. The roots with nodule intake were packed in the polythene bag (17cm by 29 cm by 30 microns) and kept in a cooler box ready for transfer to the laboratory. In the laboratory the plant samples were oven dried at 65 ºC to a constant weight (between 24 to 48 hours) and their dry weights determined. The roots were detached of nodules, nodule counted and the roots and nodules oven dried to determine their dry weights. Nodule colors were assessed as either good (>75 % nodules per root system; pink in color), moderate (25% – 75% nodules per root system; pink in color) and poor (<25% nodules per root system; pink or white in color or >25% nodules but white in color) (Alemayehu, 2009). The dry plant samples (including the weeds) were ground in an electric grinder (model – Retsch SM 100 comfort) to pass through 1 mm sieve prior to laboratory analysis.

Data collection on plant growth was done at 28, 42 and 56 days after planting (DAP) on ten tagged randomly selected plants from the net plot. Plant height was measured using a calibrated wooden ruler from the ground to the trifoliate leaf while chlorophyll content was measured using chlorophyll meter (model – CCM plus 200) on the middle leaf.

Yield data was collected at physiological maturity on number of pods per plant, number of seeds per pod, number of pods per plant, grain yield translated to kg ha^{-1}, weight of 100 seeds, haulms dry stovers weight translated to kg ha^{-1}. The total number of plants within the net plots was counted, uprooted and the roots cut away from the whole plant using a kitchen knife. Pods of ten randomly selected plants were counted per plot then ripped off the haulms and packed in brown paper sugar bags of size ten. The total fresh weights of the haulms and pods were taken and their subsample fresh weights were also taken respectively. The subsamples of haulms were taken to the lab for drying at 65 ºC in an oven (model – Memmert UNB 500) for a period of 24 – 48 hours. The pods subsamples were threshed, the fresh weights of the seeds and husks recorded. Both the seeds and husks were dried at 65 ºC in an oven (model – Memmert UNB 500) for a period of 24 – 48 hours and their weights taken.

4.2.4 Determination of N_2-fixation

The ground plants samples were used to determine the amount of nitrogen fixed using ^{15}N natural abundance method (Unkovich et al., 2008). Non N_2 fixing reference plants were three weed plants sampled from the fallow plots. The weeds were *Brassica napus*, *Sorghum sudanense* and *Oxalis corniculata*. The ^{15}N natural abundance method applies the principle that if N_2 – fixing plant is grown in a medium free of combined N (mineral N and or organic N) and is completely reliant upon symbiotic N_2 fixation for growth then the isotopic composition of the legume would be expected to be similar to that of atmospheric N_2 ($\delta\ ^{15}N$ %). On the contrary, if non N_2 fixing plant is grown in a soil containing mineral N, its $\delta^{15}N$ value should be equal to that of soil mineral N taken up by the plant from the soil. Determination of N fixed using ^{15}N abundance was conducted at Wageningen University – Netherlands. The amount of nitrogen fixed was calculated using the formulas shown below:

$$\delta\ ^{15}\mathrm{N} = \left(\frac{\text{Sample atom \% } 15_{\mathrm{N}}\ -\ 0.3663}{0.3663}\right) \times 1000 \text{………………..equation 4.1}$$

$$\%\ \mathrm{Ndfa} = \frac{\delta\ 15_{\mathrm{N}}\text{of reference plant} - \delta\ 15_{\mathrm{N}}\text{ of } \mathrm{N}^2 \text{ fixing legume}}{\delta\ 15_{\mathrm{N}}\text{ of reference plant} - \delta 15_{\mathrm{N}}\text{ of } \mathrm{N}^2} \times \frac{100}{1}\text{……equation 4.2}$$

$$\text{Total N accumulated by legume crop} = \frac{\text{\% legume total N} \times \text{Shoot biomass } (\frac{\mathrm{kg}}{\mathrm{ha}})}{100}\text{ ……equation 4.3}$$

$$\text{N-fixed (kg ha}^{-1}\text{)} = \frac{\text{\% Ndfa} \times \text{Total N accummulated by the legume crop}}{100}\text{………..equation 4.4}$$

Where: %Ndfa is percentage of N derived from the atmosphere through biological fixation

4.2.5 Statistical analysis

Data collected was subjected to analysis of variance (ANOVA) at 5% level of significance and the means were separated using Duncan's Multiple Range Test (DMRT) on SAS software version 9.00 (SAS, 2002).

4.3 Results and Discussion

4.3.1 Effect tillage on biological nitrogen fixation (BNF)

Nodule dry weight was different at Bungoma and Alupe sites between the tillage methods. However, percent active nodules were not significant between the tillage methods in all the sites (Table 4.1). Nodule dry weight was not different among the soybean varieties except at Alupe site while percent active nodules were significant among the soybean varieties at Bungoma and Alupe (Table 4.2). Nitrogen fixed biologically differed significantly between tillage methods at Alupe and Bungoma sites. At the sites where there were differences, high amount of nitrogen was fixed in no till than till (Table 4.3). This could be attributed to lack of disturbance on the rhizobial population through tilling leading to increased activity in no till plots. Zhang et al., (2012) confirms that in no till plots there are higher rhizobial population than till plots. Ferreira et al., (2000) further states that rhizobia isolate from no till plots fixes higher atmospheric nitrogen than till. In their review, Van Kessel and Hartley, (2000) also stated that no till lead to stimulation of nitrogen fixation. These results could further be confirmed by higher dry nodule weight in no till plots.

At Ugunja and Rarieda there were no differences in nitrogen fixed between the tillage methods (Table 4.3). This could have been due to low pH and high sodium content (Table 3.3) that affected the rhizobia activity at Ugunja and low soil nitrogen content at Rarieda that reduced take off of nitrogen fixation.

Table 4.1: Effect of tillage on soybean nodule dry weight (kg ha^{-1}) and percent active nodules at different sites

Site	Measured parameters	Tillage methods	
		Till	No till
Bungoma	Nodule dry weight (kg ha^{-1})	6.6^{b}	9.8^{a}
	Percent active nodules	76.7^{a}	77.3^{a}
Ugunja	Nodule dry weight (kg ha^{-1})	5.3^{a}	5.5^{a}
	Percent active nodules	79.0^{a}	86.5^{a}
Alupe	Nodule dry weight (kg ha^{-1})	4.2^{b}	7.4^{a}
	Percent active nodules	70.3^{a}	76.8^{a}
Rarieda	Nodule dry weight (kg ha^{-1})	4.2^{a}	4.3^{a}
	Percent active nodules	79.1^{a}	81.1^{a}

Means with different letters are significantly different at $p<0.05$ within a measured parameter (within a row)

Table 4.2: Nodule dry weight (kg ha^{-1}) and % active nodules of different soybean varieties at Bungoma, Ugunja, Alupe and Rarieda

Site	Measured parameters	Soybean varieties		
		Nyala	SB19	SB20
Bungoma	Nodule dry weight (kg ha^{-1})	6.7^{a}	8.1^{a}	7.0^{a}
	% active nodules	72.3^{b}	74.9^{ab}	86.5^{a}
Ugunja	Nodule dry weight (kg ha^{-1})	5.3^{a}	4.3^{a}	6.5^{a}
	% active nodules	85.2^{a}	84.9^{a}	79.1^{a}
Alupe	Nodule dry weight (kg ha^{-1})	6.3^{ab}	3.9^{b}	7.2^{a}
	% active nodules	85.7^{a}	71.3^{b}	72.0^{ab}
Rarieda	Nodule dry weight (kg ha^{-1})	3.6^{a}	4.0^{a}	4.9^{a}
	% active nodules	80.8^{a}	80.5^{a}	79.1^{a}

Means with different letters are significantly different at $p<0.05$ within a measured parameter (within a row).

Table 4.3: Effect of tillage methods on amount of nitrogen fixed (kg ha^{-1}) at different sites of West Kenya for the three soybean varieties

Tillage method	Experimental sites			
	Bungoma	Ugunja	Alupe	Rarieda
Till	6.5^{b}	5.7^{a}	8.1^{b}	5.8^{a}
No till	12.4^{a}	6.8^{a}	13.8^{a}	6.4^{a}

Means with different letters are significantly different at $p<0.05$ within an experimental site (within a column)

There were differences in nitrogen fixed among the soybean varieties at each site (Table 4.4). At Alupe, Nyala variety fixed the highest amount of nitrogen, at Bungoma it was SB20, at Rarieda it was Nyala and at Ugunja it was SB19 (Table 4.4). The difference in nitrogen fixed among soybean varieties could have been due to differences in soil moisture within their plots which could have enhanced the activity of the rhizobia at different sites. In Van Kessel and Hartley, (2000) review they also reported that increased soil moisture increases the potential of biological nitrogen fixation.

Table 4.4: Effect of tillage methods on amount of nitrogen fixed (kg ha^{-1}) by different soybean varieties in different sites

Tillage method x Soybean interaction	Experimental sites			
	Bungoma[1]	Ugunja[1]	Alupe[1]	Rarieda[1]
Till x Nyala	3.8^{c}	6.3^{b}	10.0^{b}	7.9^{a}
No till x Nyala	11.3^{ba}	7.4^{ab}	28.7^{a}	8.8^{a}
Till x SB19	7.0^{bc}	7.7^{a}	6.2^{b}	6.5^{b}
No till x SB19	8.8^{b}	8.9^{a}	5.8^{b}	7.3^{ab}
Till x SB20	10.7^{ba}	3.2^{c}	-	2.1^{c}
No till x SB20	17.2^{a}	3.5^{c}	7.0^{b}	3.4^{c}
Nyala[2]	6.5^{b}	13.5^{ab}	19.3^{a}	16.6^{a}
SB19[2]	7.9^{b}	16.9^{a}	6.0^{b}	13.7^{ab}
SB20[2]	14.0^{a}	6.4^{b}	7.0^{b}	5.4^{b}

Means[1] with different letters are significantly different at $p<0.05$ within an experimental site (within a column)

Means[2] with different letters are significantly different at $p<0.05$ between varieties.

- Missing

There were interactions of tillage method x soybean variety in all the sites (Table 4.4). At Bungoma the interaction of no till x SB20 fixed the highest nitrogen while till x Nyala interaction fixed the lowest. High nitrogen fixation in no till x SB20 interaction could have been due to high percentage of active nodules on SB20 roots (Table 4.2) compared to the other varieties. At Ugunja No till x SB19, at Alupe No till x Nyala and at Rarieda No till x Nyala (Table 4.4) interactions had highest N fixed probably due to higher soil moisture content presented by the no till method and the fact that no till have rhizobia isolates which fixes higher atmospheric nitrogen than till according to Ferreira et al., (2000).

4.3.2 Effect of tillage methods on growth and grain yield of soybean

Chlorophyll content index was not different between the tillage methods although, it was different among the soybean varieties in all the sites except Ugunja in season one (2011A) and Alupe and Rarieda in season two (2011B). Soybean variety Nyala had the highest chlorophyll content at the sites with differences in both season 2011A and 2011B. This could have been due to presence of adequate soil moisture throughout its growing period as it is an early maturing variety therefore can utilize its water efficiently before soil moisture deficit sets in. The presences of adequate soil moisture could have also boosted rhizobia activity leading to increased N fixation and consequently increased chlorophyll content as N forms an integral part of chlorophyll.

Plant height was also significant among the soybean varieties at Bungoma and Alupe only in season 2011A and in all the other sites in season 2011B except Rarieda (Table 4.5). Soybean variety SB20 had the highest plant height in Alupe season 2011A and Bungoma and Ugunja in season 2011B. This could have been due to genetic composition of the variety as it can also be attested to in its shoot and root biomass (Table 4.7). In instances where it did not have the highest plant height for example Bungoma season 2011A and Alupe season 2011B it could have been due to low soil moisture content leading to restricted vegetative growth.

Table 4.5: Effect of soybean variety on chlorophyll content index and plant height (cm) at different sites in long rain (2011A) and short rain (2011B) seasons

	Long rains 2011		Short rains 2011	
	Chlorophyll content index	Plant height (cm)	Chlorophyll content index	Plant height (cm)
Bungoma				
Nyala	22.0a	35.1a	30.6a	32.3b
SB19	20.1ab	33.7ab	30.4a	30.2b
SB20	18.1b	31.2b	21.6b	38.9a
Ugunja				
Nyala	17.4a	16.1a	28.5a	25.3ab
SB19	17.9a	15.5a	25.8ab	21.6b
SB20	15.9a	16.6a	21.1b	27.4a
Alupe				
Nyala	28.4a	37.1ab	26.0a	41.4a
SB19	23.5b	34.5b	26.5a	38.1a
SB20	19.6c	39.8a	24.2a	33.0b
Rarieda				
Nyala	27.9a	29.3a	26.7a	22.1a
SB19	23.3b	28.6a	24.9a	21.2a
SB20	22.7b	31.3a	25.0a	23.4a

Means with different letters are significantly different at $p<0.05$ within the site and parameter measured.

There was significant difference in chlorophyll between tillage methods at Ugunja and Rarieda in season one (2011A) and at Rarieda in season two (2011B). The differences in chlorophyll content at Ugunja and Rarieda could have been due to the differences in soil moisture content between the tillage methods. The plant height between the tillage methods was different at Bungoma and Ugunja in season 2011A and no difference in season 2011B (Table 4.6). Till exhibited higher plant height than no till at Bungoma and Ugunja in season 2011A most probably due to the differences in soil moisture content that improved the vegetative growth.

Table 4.6: Effect of tillage methods on chlorophyll content index and plant height (cm) at different sites in long rain (2011A) and short rain (2011B) seasons

	Long rains 2011		Short rains 2011	
	Chlorophyll content index	Plant height (cm)	Chlorophyll content index	Plant height (cm)
Bungoma				
Till	19.9a	38.3a	27.9a	34.7a
No till	20.2a	28.4b	27.2a	32.8a
Ugunja				
Till	19.6a	17.7a	24.9a	23.3a
No till	14.5b	14.4b	25.3a	26.2a
Alupe				
Till	24.1a	39.0a	26.2a	37.1a
No till	23.5a	35.3a	24.9a	37.9a
Rarieda				
Till	23.5b	30.0a	27.3a	22.4a
No till	25.8a	29.5a	23.7b	22.1a

Means with different letters are significantly different at $p<0.05$ within the site and parameter measured.

Root biomass, shoot biomass and grain yield was not different between the tillage methods. This could have been due to the fine tilth on till plots that encouraged vigorous growth and root expansion leading to vigorous growth hence compensating for accumulated moisture on the no till plots. There were differences among the soybean varieties on root and shoot biomasses (Table 4.7). SB20 variety had the highest root biomass which could have originated from its genetic composition. This high root biomass on SB20 could explain its high shoot biomass since it could absorb more moisture and nutrients from the soil to enhance faster and expansive growth. There were significant differences among root biomass, shoot biomass and dry grain yield among the sites (Table 4.8). The high root biomass at Alupe could have been the reason for high shoot biomass and consequently high dry grain yield. Expansive shoot biomass leads to increased photosynthesis and translocation of assimilates to the sinks (grains).

Table 4.7: Root biomass (kg ha^{-1}), shoot biomass (kg ha^{-1}) and dry grain yield (kg ha^{-1}) of different soybean varieties

Parameter measured	Soybean varieties		
	Nyala	SB19	SB20
Root biomass (kg ha^{-1})	48.5^b	58.6^b	78.9^a
Shoot biomass (kg ha^{-1})	174.9^c	249.9^b	359.5^a
Dry grain yield (kg ha^{-1})	923.4^a	1115.0^a	943.7^a

Means with different letters are significantly different at $p<0.05$ within the parameter measured (within the row)

Table 4.8: Root biomass (kg ha^{-1}), shoot biomass (kg ha^{-1}) and dry grain yield (kg ha^{-1}) at different sites

Parameter measured	Experimental sites			
	Bungoma	Ugunja	Alupe	Rarieda
Root biomass (kg ha^{-1})	60.0^b	67.8^{ab}	81.0^a	36.2^c
Shoot biomass (kg ha^{-1})	306.6^a	248.7^b	342.5^a	148.7^c
Dry grain yield (kg ha^{-1})	921.8^b	661.5^c	1543.0^a	$703.7b^c$

Means with different letters are significantly different at $p<0.05$ within the parameter measured (within the row)

Different experimental sites had different responses of root biomass, shoot biomass and grain yield under different seasons. At Bungoma root biomass, shoot biomass and grain yield was not significantly different between the tillage methods in seasons 2011A and 2011B (Table 4.9 and 4.10). There was no difference in root and shoot biomasses and grain yield at Ugunja in season 2011B (Table 4.10) although dry grain yield was different in season 2011A (Table 4.9). This could have been due to seasonal variation in the amount of rainfall received. In season one grain yield was different between tillage methods and in season two there was no difference. At Alupe there was no significance in root biomass, shoot biomass and dry grain yield between tillage methods of season one and two (Table 4.9 and 4.10). At Rarieda root biomass, shoot biomass and dry grain yield were not different in season one, however in season two there were differences. Root biomass, shoot biomass and dry grain yield were higher in till than no till in season 2011B (Table 4.10). The high root biomass in till was probably due to fine tilth of the soil thereby favoring its expansion. This high root mass could have led to high shoot biomass and consequently increased photosynthesis hence more photo-assimilates production and storage on the sink (grains). This led to higher dry grain yield under till than no till. There were no interactions between tillage methods x soybean varieties in all the sites.

Table 4.9: Effect of tillage methods on soybean root biomass (kg ha^{-1}), dry shoot biomass (kg ha^{-1}) and dry grain yield (kg ha^{-1}) in season one (2011A)

Parameter measured	Tillage method	Experimental site				
		Bungoma^{3}	Ugunja^{3}	Alupe^{3}	Rarieda^{3}	Mean^{2}
root biomass (kg ha^{-1})	Till	64.3^{a}	91.4^{a}	98.5^{a}	29.0^{a}	77.3^{a}
	No till	75.3^{a}	102.4^{a}	92.2^{a}	27.1^{a}	78.8^{a}
	Mean^{1}	69.8^{a}	96.1^{a}	95.2^{a}	28.0^{b}	
shoot biomass (kg ha^{-1})	Till	268.3^{a}	257.1^{a}	348.8^{a}	125.5^{a}	264.7^{a}
	No till	319.0^{a}	232.2^{a}	378.9^{a}	121.7^{a}	288.4^{a}
	Mean^{1}	295.6^{a}	246.2^{ab}	364.4^{a}	123.8^{b}	
dry grain yield (kg ha^{-1})	Till	962.0^{a}	390.6^{a}	1184.0^{a}	363.6^{a}	780.7^{a}
	No till	1044.4^{a}	131.0^{b}	1048.1^{a}	342.2^{a}	744.3^{a}
	Mean^{1}	1006.2^{a}	271.6^{b}	1118.4^{a}	355.4^{b}	

Means^{1} with different letters are significantly different at $p<0.05$ across the experimental sites.

Means^{2} with different letters are significantly different at $p<0.05$ between tillage methods of the measured parameter.

Means^{3} with different letters are significantly different at $p<0.05$ within the experimental site of the measured parameter.

Table 4.10: Effect of tillage methods on soybean root biomass (kg ha^{-1}), dry shoot biomass (kg ha^{-1}) and dry grain yield (kg ha^{-1}) in season two (2011B)

Parameter measured	Tillage method	Experimental site				
		Bungoma^3	Ugunja^3	Alupe^3	Rarieda^3	Mean^2
root biomass (kg ha^{-1})	Till	54.0^a	43.6^a	64.3^a	46.7^a	52.5^a
	No till	51.4^a	47.2^a	73.7^a	33.6^b	51.7^a
	Mean^1	52.7^b	45.6^{bc}	69.1^a	40.0^c	
shoot biomass (kg ha^{-1})	Till	300.7^a	240.8^a	326.9^a	198.5^a	266.2^a
	No till	327.9^a	262.0^a	320.6^a	117.1^b	262.1^a
	Mean^1	315.1^a	250.7^b	323.7^a	160.3^c	
dry grain yield (kg ha^{-1})	Till	882.6^a	983.6^a	2044.2^a	1058.0^a	1310.6^a
	No till	634.7^a	964.3^a	1766.1^a	608.7^b	1100.0^a
	Mean^1	774.2^b	973.3^b	1905.2^a	865.4^b	

Means^1 with different letters are significantly different at $p<0.05$ across the experimental sites.

Means^2 with different letters are significantly different at $p<0.05$ between tillage methods of the measured parameter.

Means^3 with different letters are significantly different at $p<0.05$ within the experimental site of the measured parameter.

Haulms dry weight, husks dry weight and 100 grains weight was not significant between the tillage treatments at different sites. However they were significant under different soybean varieties (Table 4.11 and 4.12). In season 2011A dry haulms weight was different among the soybean varieties at Bungoma and Alupe while dry husk weight was different at Rarieda only and weight of 100 grains was different at Bungoma, Alupe and Rarieda (Table 4.11). The high dry haulms weight in SB20 could be attributed to high vegetative growth as had been shown by the high plant height (Table 4.5 and 4.6) and high shoot biomass (Table 4.7). Soybean variety Nyala had the highest weight of 100 grains in the sites with differences. This could have risen due to early maturity thereby translocation more photosynthates to seeds making them larger before the soil moisture deficiency set in i.e. drought escape mechanism.

Table 4.11: Effect of soybean varieties on haulms dry weight (kg ha^{-1}), husks dry weight (kg ha^{-1}) and weight of 100 seeds in season one (2011A).

Site	Soybean varieties	Haulms dry weight (Kg ha^{-1})	Husks dry weight (Kg ha^{-1})	Weight of 100 grains (g)
Bungoma	Nyala	422.4^{b}	0.5^{a}	15.5^{a}
	SB19	541.1^{b}	0.4^{a}	10.9^{b}
	SB20	1023.1^{a}	0.4^{a}	11.6^{b}
Ugunja	Nyala	186.2^{a}	0.4^{a}	12.2^{a}
	SB19	245.6^{a}	0.4^{a}	11.5^{a}
	SB20	708.5^{a}	0.6^{a}	11.2^{a}
Alupe	Nyala	422.4^{b}	0.5^{a}	15.5^{a}
	SB19	541.1^{b}	0.4^{a}	10.9^{b}
	SB20	1023.1^{a}	0.4^{a}	11.6^{b}
Rarieda	Nyala	128.8^{a}	0.5^{ab}	13.7^{a}
	SB19	202.9^{a}	0.3^{b}	9.0^{c}
	SB20	162.2^{a}	0.6^{a}	10.5^{b}

Means with different letters are significantly different at $p<0.05$ within the site and parameter.

In season 2011B, dry haulms weight was different at Ugunja, dry husk weight was different at Alupe and weight of 100 grains was different in all the sites (Table 4.12). SB20 gave higher dry haulms weight at Ugunja and higher dry husk weight at Alupe than the other varieties. This could as well be attributed high vegetative growth as had been shown by the high plant height (Table 4.5 and 4.6) and high shoot biomass (Table 4.7). Soybean variety Nyala in season 2011B still had the highest weight of 100 grains in all the sites. This could as well be explained by its early maturity hence building larger grains before soil moisture deficiency sets in. In addition it had higher chlorophyll content in some of the sites (Tables 4.5 and 4.6) leading improved photosynthesis.

Table 4.12: Effect of soybean varieties on haulms dry weight (kg ha^{-1}), husks dry weight (kg ha^{-1}) and weight of 100 seeds in season two (2011B).

Site	Treatment	Haulms dry weight (Kg ha^{-1})	Husks dry weight (Kg ha^{-1})	Weight of 100 grains (g)
Bungoma	Nyala	1347.7^{a}	2.4^{a}	16.0^{a}
	SB19	1085.9^{a}	1.9^{a}	13.5^{ab}
	SB20	1573.5^{a}	1.9^{a}	11.7^{b}
Ugunja	Nyala	367.2^{b}	1.7^{a}	18.4^{a}
	SB19	592.8^{b}	2.2^{a}	13.2^{b}
	SB20	2036.0^{a}	1.8^{a}	12.1^{b}
Alupe	Nyala	1122.2^{a}	2.4^{b}	14.4^{a}
	SB19	895.0^{a}	1.3^{c}	11.3^{b}
	SB20	1527.3^{a}	3.8^{a}	11.4^{b}
Rarieda	Nyala	362.4^{a}	2.2^{a}	15.4^{a}
	SB19	428.5^{a}	1.8^{a}	13.4^{b}
	SB20	880.7^{a}	2.5^{a}	12.9^{b}

Means with different letters are significantly different at $p<0.05$ within the site and parameter.

4.4 Conclusion

The amount of N fixed generally was higher in no till plots than till plots at Bungoma and Alupe. This could have been due to lack of soil disturbance. This would consequently lead to increase in nodule activity on the roots. The weight of 100 grains was in most cases higher in Nyala than the other varieties and vegetative growth (plant height and shoot biomass) was also in most cases higher in SB20. These differences could have risen due to genetic and environmental such as soil moisture influence. Grain yield between the tillage methods and varieties was not different in all the sites most probably due to rainfall effect. Farmers should practice no till to increase N-fixation and consequently chlorophyll content and yields.

4.5 References

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CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

Soil moisture was not different between the tillage methods except at Rarieda. At Rarieda no till had the highest soil moisture content. This could have been due to the loamy sand texture of the soil that increased infiltration and deep percolation of soil water. This could have also been due to low organic carbon hence poor soil structure and high loss of water through evaporation. All these coupled with low rainfall would have accentuated the low soil moisture content situation on the till plots. The other three sites had no differences in soil moisture most likely due to good organic carbon, soil texture and CEC that stabilized soil moisture retention. In addition they were receiving moderate rainfall. Plots sown with soybean variety SB20 had the highest soil moisture content. This could be attributed to high vegetative growth as shown by plant height and shoot biomass. This vegetative growth provides ground cover hence reducing soil moisture loss through evaporation. Although it can also be argued that the high vegetative growth would lead to higher soil water use, and loss through transpiration. Despite this, the areas which receive higher rainfall amount for example Bungoma can sustain the growth and the same time conserve moisture through soil cover.

Nitrogen fixed was different at Bungoma and Alupe under the tillage methods. No till fixed the highest amount nitrogen in the two sites. This could have been due to lack of disturbance in the soil hence increasing the rhizobia activity. In addition the soil moisture was adequate for effective functioning of the rhizobia. At Ugunja the low N fixed could have been due to low pH and high sodium content which hinder growth and activity of rhizobia. At Rarieda N-fixation was reduced by the very low soil N which could not enable efficient nodule formation. Among the varieties Nyala fixed high N at Rarieda and Alupe, SB19 at Ugunja and SB20 at Bungoma. This fixation superiority of different varieties at different sites would have been influenced by soil moisture content. For example Nyala is an early maturing variety and fixes higher N at Rarieda because it can utilize the amount of soil moisture available to form active nodules before soil moisture deficiency sets in. SB20 fixes higher amount of N at Bungoma since it requires higher soil moisture and this receives high amount of rainfall than the other sites. SB19 is medium maturing variety and the moderate rainfall at Ugunja provides adequate soil moisture for nodule formation and rhizobia activity. Application of maize stovers as mulch could have also offered some confounding effect on N-fixation in the process of its decomposition as it could have caused temporary N deficiency in soil during plant growth.

5.2 Conclusions

Soil moisture in high altitude area (Bungoma – LM1) was not different between till and no till. However in low altitude area (Rarieda – LM4) receiving low rainfall no till retained more soil moisture than till. Soil moisture was high in plots planted with soybean variety SB20 and SB19 due to high canopy cover hence providing cover to the soil reducing evaporation. Bungoma had the highest soil moisture and this is attributed to high rainfall amounts.

Soybean varieties fixed more nitrogen under no till plots than till plots in all the sites and seasons. This could have been due to lack of soil disturbance. This would consequently lead to increase in nodule activity on the roots. Nyala variety fixed higher amount of nitrogen in all the sites compared to SB19 and SB20 largely due its short maturity growth period thereby able to form high number of root nodules when the soil moisture was still optimal. Grain yield between the tillage methods and varieties was not different in all the sites.

5.3 Recommendations

1. No till should be practiced in areas receiving low rainfall amounts like Rarieda (LM4) to increase soil moisture reserve.
2. Farmers should practice no till to encourage higher nitrogen fixation.
3. Further research should be done on the effect of soil water by profile and root mass on N-fixation in Western Kenya.

Annexes

Annex 1: Mean squares of soil moisture (mm/mm) at flowering and pod filling stages at Rarieda in season one

Source of variation	DF	Soil moisture at flowering (mm/mm)	Soil moisture at pod filling (mm/mm)
Block	2	0.0017	0.0027
Tillage method	1	0.0031*	0.0008
Block*tillage method	2	0.0002	0.0010
Variety	2	0.0779*	0.0023*
Tillage method*variety	2	0.0020*	0.0009
Tillage method error	2	0.0002	0.0010
Split plot error	44	0.0006	0.0007
Corrected total	53	0.0036	0.0009

* indicates significance at $p<0.05$.

Annex 2: Mean squares of soil moisture (mm/mm) at flowering and pod filling stages at Rarieda in season two

Source of variation	DF	Soil moisture at flowering	Soil moisture at pod filling
Block	2	0.0005	0.0015
Tillage method	1	0.0000	0.0015
Block*tillage method	2	0.0003	0.0002
Variety	2	0.0115*	0.0020
Tillage method*variety	2	0.0006	0.0006
Tillage method error	2	0.0003	0.0004
Split plot error	2	0.0006	0.0011
Corrected total	53	0.0007	0.0011

* indicates significance at p<0.05

Annex 3: Mean squares of soil moisture (mm/mm) at flowering and pod filling stages at Alupe, Bungoma and Ugunja in season one

		Alupe		Bungoma		Ugunja	
Source of variation	DF	Soil moisture at flowering (mm/mm)	Soil moisture at pod filling (mm/mm)	Soil moisture at flowering (mm/mm)	Soil moisture at pod filling (mm/mm)	Soil moisture at flowering (mm/mm)	Soil moisture at pod filling (mm/mm)
Block	2	0.0004	0.0005	0.0011	0.0011	0.0061	0.0002
Tillage method	1	0.0009	0.0050	0.0021	0.0005	0.0000	0.0014
Block*tillage method	2	0.0011	0.0010	0.0009	0.0006	0.0070	0.0007
Variety	2	0.0004	0.0129*	0.0309*	0.0045	0.0085	0.0019
Tillage method*variety	2	0.0014	0.0016	0.0035	0.0047	0.0005	0.0030
Tillage method error	2	0.0011	0.0016	0.0009	0.0006	0.0070	0.0007
Split plot error	44	0.0011	0.0019	0.0013	0.0015	0.0032	0.0016
Corrected total	53	0.0011	0.0023	0.0025	0.0017	0.0035	0.0016

* indicates significance at $p<0.05$

Annex 4: Mean squares of soil moisture (mm/mm) at flowering and pod filling stages at Alupe, Bungoma and Ugunja in season two

		Alupe		Bungoma		Ugunja	
Source of variation	DF	Soil moisture at flowering (mm/mm)	Soil moisture at pod filling (mm/mm)	Soil moisture at flowering (mm/mm)	Soil moisture at pod filling (mm/mm)	Soil moisture at flowering (mm/mm)	Soil moisture at pod filling (mm/mm)
Block	2	0.0006	0.0009	0.0050	0.0016	0.0010	0.0020
Tillage method	1	0.0004	0.0000	0.0046	0.0008	0.0010	0.0000
Block*tillage method	2	0.0010	0.0002	0.0146	0.0043	0.0033	0.0025
Variety	2	0.0129*	0.0121*	0.0111*	0.0101	0.0028	0.0425*
Tillage method*variety	2	0.0021	0.0022	0.0216*	0.0007	0.0011	0.0020
Tillage method error	2	0.0010	0.0000	0.0146	0.0043	0.0033	0.0025
Split plot error	44	0.0009	0.0017	0.0032	0.0032	0.0012	0.0035
Corrected total	53	0.0014	(52)0.0020	0.0047	0.0033	0.0013	0.0048

* indicates significance at p<0.05

() indicates different degrees of freedom (df)

Annex 5: Mean squares of treatments at Alupe in season one

Source of variation	DF	Root biomass (kg ha^{-1})	Shoot biomass (kg ha^{-1})	Dry nodule weight (kg ha^{-1})	% active nodule	Dry grain yield (kg ha^{-1})
Block	2	365.71	3612.49	0.1719	129.65	8063.74
Tillage method	1	558.30*	18502.04*	0.0727	2362.59	132711.25
Block*tillage method	2	154.21	10632.85	0.2132	0.94	60598.04
Variety	2	240.70	4266.73	3.9479	381.84	64132.17
Tillage method*variety	2	67.86	792.19	2.0453	151.99	11396.51
Tillage method error	1	153.27	18502	0.4111	0.94	60341
Split plot error	7	78.16	1296.54	1.0308	314.45	39754
Corrected total	16	178.52	3898.31	1.3531	(11)410.6040	43738.84

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)

Annex 6: Mean squares of treatments at Alupe in season two

Source of variation	DF	Root biomass (kg ha^{-1})	Shoot biomass (kg ha^{-1})	Dry nodule weight (kg ha^{-1})	% active nodule	Dry grain yield (kg ha^{-1})
Block	2	997.90	32243.42	2.38	29.30	470019.47
Tillage method	1	795.52	1249.59	86.77	183.62	131527.51
Block*tillage method	2	256.78	7733.16	41.13	54.90	434784.42
Variety	2	1053.89	72454.76	97.02*	103.90	952018.52
Tillage method*variety	2	601.78	13295.08	43.23	363.30	106157.39
Tillage method error	1	262.63	8208.92	41.13	54.80	434256
Split plot error	7	730.74	19627	19.43	114.11	391972
Corrected total	16	762.93	(15)27717.43	35.87	129.36	445091.5

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)

Annex 7: Mean squares of treatments at Bungoma in season one

Source of variation	DF	Root biomass (kg ha^{-1})	Shoot biomass (kg ha^{-1})	Dry nodule weight (kg ha^{-1})	% active nodule	Dry grain yield (kg ha^{-1})
Block	2	35.67	1417.44	3.46	112.08	1026.62
Tillage method	1	8.67	355.12	1.46	35.21	107133.05
Block*tillage method	2	121.53	4256.68	3.80	313.66	10800.09
Variety	2	140.25	658.04	1.33	32.38	112542.00
Tillage method*variety	2	160.75	463.32	1.87	0.49	37194.72
Tillage method error	1	118.65	4392.90	3.80	302.92	9777.21
Split plot error	7	106.87	714.93	5.75	45.18	28530
Corrected total	16	96.17	1264.82	(11)3.83	(10)97.37	40770.25

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)

Annex 8: Mean squares of treatments at Bungoma in season two

Source of variation	DF	Root biomass (kg ha^{-1})	Shoot biomass (kg ha^{-1})	Dry nodule weight (kg ha^{-1})	% active nodule	Dry grain yield (kg ha^{-1})
Block	2	41.28	6572.82	1.53	95.30	585112.85
Tillage method	1	185.56	1051.11	22.96	1.51	252929.621
Block*tillage method	2	242.42	1100.58	5.20	218.56	141385.00
Variety	2	821.63	161293.91*	16.61	443.47	700473.60
Tillage method*variety	2	64.90	7244.86	7.31	176.05	129093.19
Tillage method error	2	242.28	1100.58	5.24	218.95	139894
Split plot error	7	231.32	9733.70	8.33	250.28	(6)167235
Corrected total	16	275.60	25373.24	9.65	227.19	309293.6

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)

Annex 9: Mean squares of treatments at Ugunja in season one

Source of variation	DF	Root biomass (kg ha^{-1})	Shoot biomass (kg ha^{-1})	Dry nodule weight (kg ha^{-1})	% active nodule	Dry grain yield (kg ha^{-1})
Block	2	239.17	6820.42	0.70	196.78	82863.19
Tillage method	1	1482.07	34046.47	0.00	1338.96	531679.77
Block*tillage method	2	2226.97	6025.54	2.12	722.57	10580.54
Variety	2	257.33	6937.68	10.61	784.56	36355.55
Tillage method*variety	2	1624.24	309.09	1.69	517.62	24398.28
Tillage method error	1	2334.38	6080.70	1.54	690.50	22148
Split plot error	7	(5)938.06	(4)5632.24	(3)3.25	(3)502.19	(4)84614
Corrected total	16	(14)1206.22	(13)10722.13	3.33	(12)580.74	(13)106326.7

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)

Annex 10: Mean squares of treatments at Ugunja in season two

Source of variation	DF	Root biomass (kg ha^{-1})	Shoot biomass (kg ha^{-1})	Dry nodule weight (kg ha^{-1})	% active nodule	Dry grain yield (kg ha^{-1})
Block	2	441.92	11272.10	8.26	31.56	29805.25
Tillage method	1	3.64	3.65	1.24	447.16	399904.99
Block*tillage method	2	397.26	12444.88	1.79	545.63	154306.01
Variety	2	1157.32*	74567.22*	8.82	812.88	290325.09
Tillage method*variety	2	220.92	4062.84	7.52	163.22	5402.12
Tillage method error	1	(2)394.43	12385	1.85	533.76	(2)153363
Split plot error	7	167.78	(6)6469.61	(6)7.97	248.73	(4)68502
Corrected total	16	(16)362.03	(15)18203.51	(15)7.39	(15)348.21	(13)142372.1

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)

Annex 11: Mean squares of treatments at Rarieda in season one

Source of variation	DF	Root biomass (kg ha^{-1})	Shoot biomass (kg ha^{-1})	Dry nodule weight (kg ha^{-1})	% active nodule	Dry grain yield (kg ha^{-1})
Block	2	115.94	2085.53	2.42	203.63	7411.89
Tillage method	1	2.84	40.37	0.11	18.30	12881.79
Block*tillage method	2	52.17	519.57	0.66	48.37	2952.22
Variety	2	37.95	842.92	1.43	436.26	11371.00
Tillage method*variety	2	41.30	220.18	0.01	667.21	15258.64
Tillage method error	1	(2)53.10	(3)549.25	(2)0.66	(2)48.37	2952.22
Split plot error	7	(5)23.75	(5)720.17	(2)0.50	(8)318.83	(4)5040.88
Corrected total	17	(14)48.30	(14)991.98	(11)1.25	310.58	(12)7732.69

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)

Annex 12: Mean squares of treatments at Rarieda in season two

Source of variation	DF	Root biomass (kg ha^{-1})	Shoot biomass (kg ha^{-1})	Dry nodule weight (kg ha^{-1})	% active nodule	Dry grain yield (kg ha^{-1})
Block	2	49.54	293.09	10.79	55.89	32027.10
Tillage method	1	680.49	35399.27	0.32	4.47	1262922.69
Block*tillage method	2	20.50	697.31	1.20	79.97	188248.28
Variety	2	184.31	13875.34	3.87	97.80	27359.15
Tillage method*variety	2	515.23	11549.59	3.43	161.54	96356.23
Tillage method error	1	(2)22.77	427.95	(2)1.26	(2)79.97	(2)189004
Split plot error	7	204.26	(6)5366.21	(6)6.45	(8)211.30	249473
Corrected total	16	241.44	(15)9267.63	(15)5.57	146.19	229734.5

* indicates significance at $p<0.05$() indicates different degrees of freedom (df)

Annex 13: Mean squares of N-fixed (kg ha^{-1}) at Alupe, Bungoma, Ugunja and Rarieda

Source of variation	DF	Bungoma	Ugunja	Alupe	Rarieda
Block	2	12.5	59.8	0.4	239.1
Tillage method	1	157.5*	122.3	250.4*	17.0
Block*tillage method	2	8.3	97.5	105.1	41.5
Variety	2	188.1*	346.2*	741.0*	405.0*
Tillage method*variety	2	46.1	81.1	(1)272.5	345.6
Tillage method error	1	172.3	270.0	(6)115.7	361.6
Split plot error	8	114.3	158.8	287.9	199.5
Corrected total	17	397.8	578.3	1011	985.1

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)

Annex 14: Mean squares of chlorophyll content index and plant height (cm) in season one

Source of variation	DF	Alupe		Bungoma		Ugunja		Rarieda	
		Chlorophyll content index	Plant height (cm)	Chlorophyll content index	Plant height (cm)	Chlorophyll content index	Plant height (cm)	Chlorophyll content index	Plant height (cm)
Block	2	3.32	24.48	0.09	0.24	2.76	0.64	4.55	1.46
Tillage method	1	1.39	61.61	0.50	441.05*	120.64*	51.34	24.73*	0.76
Block*tillage method	2	2.74	9.13	16.20	7.70	4.32	0.47	0.62	0.88
Variety	2	115.75*	42.69	23.22	23.38	6.84	1.82	47.78*	11.98
Tillage method*variety	2	0.70	4.67	2.34	44.63*	2.59	0.32	10.57	1.22
Tillage method error	2	2.74	9.13	16.20	7.70	4.32	0.47	0.62	0.88
Split plot error	8	1.00	14.53	6.26	7.35	18.64	6.19	1.74	3.89
Corrected total	17	14.97	19.99	7.90	38.34	17.81	6.31	9.75	3.71

* indicates significance at $p<0.05$

Annex 15: Mean squares of chlorophyll content index and plant height (cm) in season two

Source of variation	DF	Alupe		Bungoma		Ugunja		Rarieda	
		Chlorophyll content index	Plant height (cm)	Chlorophyll content index	Plant height (cm)	Chlorophyll content index	Plant height (cm)	Chlorophyll content index	Plant height (cm)
Block	2	90.89	25.94	7.89	80.72	1.93	82.75	30.26	31.2
Tillage method	1	8.00	2.42	2.07	16.06	0.50	40.20	57.60*	0.44
Block*tillage method	2	1.24	11.43	9.16*	19.49	35.56	5.16	8.69	8.37
Variety	2	8.28	106.78	158.48*	124.17*	84.28*	51.53	6.63	7.64
Tillage method*variety	2	8.57	3.31	5.24	4.34	0.49	3.87	1.31	3.09
Tillage method error	2	1.24	11.43	9.16	19.50	35.56	5.16	8.68	8.37
Split plot error	8	5.55	6.42	1.72	14.13	12.65	13.61	8.19	11.32
Corrected total	17	15.90	20.51	22.20	34.50	20.37	25.63	12.76	11.27

* indicates significance at $p<0.05$

Annex 16: Mean squares of dry haulms (kg ha^{-1}), dry husks (kg ha^{-1}) and weight of 100 seeds (g) in season one

Source of variation	DF	Bungoma			Ugunja		
		Dry haulms weight (Kg ha^{-1})	Husks dry weight (Kg ha^{-1})	Weight of 100 seeds (g)	Dry haulms weight (Kg ha^{-1})	Husks dry weight (Kg ha^{-1})	Weight of 100 seeds (g)
Block	2	262970.74	0.01	0.53	174453.18	0.01	1.18
Tillage method	1	21.34	0.02	3.31*	759096.89	0.21	8.46
Block*tillage method	2	128022.87	0.14	1.54	61523.17	0.06	4.58
Variety	2	3561023.26*	0.38*	17.69*	497829.34	0.07	1.44
Tillage method*variety	2	42885.18	0.02	0.69	224550.56	0.02	0.41
Tillage method error	2	128023	0.07	1.54	63159	0.06	4.55
Split plot error	8	191941	0.02	0.58	(7)194011	(7)0.06	(7)1.90
Corrected total	17	560314.9	0.07	2.87	(16)253513.1	(16)0.06	(16)2.41

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)

Annex 17: Mean squares of dry haulms (kg ha^{-1}), dry husks (kg ha^{-1}) and weight of 100 seeds (g) in season one

Source of variation	DF	Alupe			Rarieda		
		Dry haulms weight (Kg ha^{-1})	Husks dry weight (Kg ha^{-1})	Weight of 100 seeds (g)	Dry haulms weight (Kg ha^{-1})	Husks dry weight (Kg ha^{-1})	Weight of 100 seeds (g)
Block	2	13789.87	0.01	0.12	957.92	0.02	0.15
Tillage method	1	105925.77	0.01	1.10	0.17	0.02	0.10
Block*tillage method	2	8105.06	0.02	1.96	5698.61	0.01	1.30
Variety	2	607154.34*	0.02	36.98*	4987.10	0.10	23.17*
Tillage method*variety	2	3872.81	0.00	0.60	189.06	0.00	0.22
Tillage method error	2	8105.06	0.02	1.96	(1)5698.61	0.01	1.22
Split plot error	8	27723	0.01	0.78	(4)3595.48	(6)0.02	(5)0.80
Corrected total	17	93738.4	0.01	5.10	(12)2831.26	(15)0.03	(14)4.43

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)

Annex 18: Mean squares of dry haulms (kg ha^{-1}), dry husks (kg ha^{-1}) and weight of 100 seeds (g) in season two

Source of variation	DF	Bungoma			Ugunja		
		Dry haulms weight (Kg ha^{-1})	Husks dry weight (Kg ha^{-1})	Weight of 100 seeds (g)	Dry haulms weight (Kg ha^{-1})	Husks dry weight (Kg ha^{-1})	Weight of 100 seeds (g)
Block	2	499132.00	0.40	7.96	525128.85	0.12	1.33
Tillage method	1	190817.83	0.07	2.41	893620.07	0.44	1.19
Block*tillage method	2	155691.54	0.03	1.19	285549.14	0.13	1.36
Variety	2	357274.03	0.39	25.59	4536049.79*	0.24	54.02*
Tillage method*variety	2	726716.44*	0.38	0.75	960541.67	0.44	0.02
Tillage method error	2	155692	(1)0.01	1.26	279465	0.12	1.38
Split plot error	8	123641	(6)0.38	(7)6.91	(5)471204	(5)0.36	(5)0.69
Corrected total	17	273974.8	(15)0.36	(16)7.75	(14)1174523	(14)0.27	(14)9.19

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)

Annex 19: Mean squares of dry haulms (kg ha^{-1}), dry husks (kg ha^{-1}) and weight of 100 seeds (g) in season two

Source of variation	DF	Alupe			Rarieda		
		Dry haulms weight (Kg ha^{-1})	Husks dry weight (Kg ha^{-1})	Weight of 100 seeds (g)	Dry haulms weight (Kg ha^{-1})	Husks dry weight (Kg ha^{-1})	Weight of 100 seeds (g)
Block	2	58875.68	0.34	4.38	71172.25	0.52	1.40
Tillage method	1	119153.83	0.60	0.12	361148.25	12.30*	3.34
Block*tillage method	2	278776.31	0.28	4.17	29118.05	0.14	0.09
Variety	2	405848.55	8.09*	17.03	331720.09	0.75	10.17*
Tillage method*variety	2	389746.63	0.19	0.36	13360.54	1.16	0.99
Tillage method error	2	277811	0.28	4.14	30639	0.15	0.09
Split plot error	7	200610	0.19	1.48	152318	0.99	(8)0.72
Corrected total	16	258821	1.30	4.12	159550.2	1.56	(17)2.03

* indicates significance at $p<0.05$

() indicates different degrees of freedom (df)