COMPARATIVE EFFECTS OF CONSERVATION TILLAGE SYSTEMS ON SELECTED SOIL PROPERTIES AND YIELDS OF GROUNDNUT (*Arachis hypogaea*)

Bisa Chileshe Bwalya

A dissertation submitted to the University of Zambia in partial fulfilment of the requirement of the degree of Master of Science in Agronomy.

SCHOOL OF AGRICULTURAL SCIENCES

DEPARTMENT OF PLANT SCIENCES

THE UNIVERSITY OF ZAMBIA

LUSAKA

2017

DECLARATION

I, Bisa Chileshe Bwalya, hereby declare that the work presented in this dissertation is my own and has never been submitted for a degree at this or any other university.

Signature _____

Date _____

APPROVAL

This dissertation of Bisa Chileshe Bwalya was approved as fulfilling part of the requirements of the award of degree of Master of Science in Agronomy by the University of Zambia.

Examiner's Name	**Signature**	**Date**
.....	.....	.....
.....	.....	.....
.....	.....	.....

ABSTRACT

Conservation Agriculture has been recommended as a sustainable farming system for many crops in Zambia based on reported improvements in soil infiltration, moisture, soil carbon, microbial activity and reduced bulk density over time. However, the effects in groundnuts such as plant development, agronomic aspects such as biological nitrogen fixation and yields under conservation systems remain scanty. A study was carried out during the 2014/15 cropping season at Msekera research station in Chipata, Eastern Zambia to determine effects different conservation practices on the soil and groundnuts development and productivity. Three tillage systems namely Conventional tillage (CV), Conservation tillage (CT) (minimum tillage + soil cover) and Conservation farming (CF) (CT + legume in rotation), were evaluated to determine their effect on selected soil properties and yields in groundnut (*Arachis hypogaea*). The tillage systems were arranged in a split plot design. All parameters except soil chemical properties, nodule weight and biological nitrogen fixation were affected by tillage, with CV yielding better results. The lowest bulk density was 1.29 g/cm^3 under CV, while the highest bulk density was 1.52 g/cm^3 under CT. The crop under CV had more above and below ground biomass. The 100 seed weight was highest under CV, with a mean of 56.81, while CF and CT it was 55.08 and 54.24 g/100 seeds, respectively. The crops under CV had the highest number of pods per plant at 24.63, with the lowest being CT with 18.43. Yields ranged from 1.42 for CF to 2.13 t/ha under CV. The results indicated that for groundnuts conventional farming systems are better than conservation farming or tillage. The superior performance of groundnut under CV could be attributed to lower bulk density, higher porosity and the soil nitrogen dynamics.

DEDICATION

I dedicate this piece of work to my daughter, Nkole Natasha Daka.

ACKNOWLEDGEMENT

.

I would like to thank my supervisors Dr. Mebelo Mataa and Dr. Alice Mutiti Mweetwa, as well as Dr. Moses Siambi for their invaluable support, advice and guidance.

I'm also thankful for the support received from the lecturers and staff from School of Agricultural Sciences, UNZA, staff at ICRISAT Malawi, PACO Chipata and Msekera Research Station particularly Mr. Mwila Mulundu and Kennedy Kanenga.

I would like to thank my parents, Dr. And Mrs Bwalya, Mr. D. C Mvula and all family and friends who stood by my side and lightened my burden throughout my study period.

My sincere gratitude to ICRISAT led IFINITE Project for financially and technically supporting my graduate study program.

Above all, all praise and glory to God almighty.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1. INTRODUCTION

1.1. Introduction

The agriculture sector in Zambia is one of the most important economic sectors in the country (Mtonga, 2012; National Mid-Term Investment Plan, 2014). In the year 2013, the sector was estimated to contribute 19.8 % to the country's Gross Domestic Product (Index Mundi, 2015). Agriculture supports the livelihoods of over 66% of the population in the country (Tembo and Sitco, 2013). The major crops grown in Zambia include maize, soybean, sunflower, wheat, sugar cane, tobacco, cotton and groundnut.

Groundnut (*Arachis hypogea*) is an important crop in Zambia. The value of groundnut lies both as an income generating commodity and an important nutrient source providing dietary carbohydrates, vitamins and proteins for many rural and urban households. Groundnut is consumed raw, boiled, roasted or fried, or processed into either a powder which is added to vegetables/meat, or into peanut butter. The multiple uses of groundnut make it an excellent cash crop for domestic markets as well as foreign trade (Okello et al., 2015). The crop is an important income source for growers and many other players in the groundnut value chain. As a cash crop, groundnut assures moderately high returns per unit of land area. They are adapted to a wide range of soil and climatic conditions ranging from hot semi-arid conditions to high rainfall regions (Okello et al., 2015). According to the Zambian Crop Forecast Survey (CFS) for 2014/2015 agricultural season (CFS, 2015), groundnut were the second most important crop grown in Zambia after maize in terms of area cultivated accounting for 9.92 % of total cultivated land in Zambia. The crop is grown mainly by small and medium scale rural farmers throughout the country.

Eastern province is the largest producer of groundnut in Zambia. In the 2014/15 farming season, Zambia produced 111,429 tons of groundnut, of which 23,792 tons were grown in Eastern province (CFS, 2015). This accounted for 21.4 % of the country's production. A total

of 168,862 small and medium scale farmers in Eastern Province grew groundnut, accounting for 23.8 % of the country's 709,140 farmers that grew groundnut (CFS, 2015).

Groundnut productivity still remains very low in Zambia. Over the last 15 years, yield has ranged from 0.38 to 0.62 t/ha (CFS 2000-2015). During the 2014/15 farming season, the country's average yield stood at 0.46 t/ha while that of Eastern Province at 0.36 t/ha (CFS 15). This fell far below the optimum productivity of the improved varieties, which under good management would give a yield of 1-3 t/ha (Siamasonta et al., 2000). The main improved varieties are mainly MGV4, Chishango, Luena, Katete, Chalimbana and MGV5. A number of local landraces such as Kanjute and Kadononga are grown. The local landraces are grown mostly by small scale farmers who lack access to improved varieties (Ross and De Klerk, 2012)

Groundnut production and productivity is highly constrained by a number of factors such as poor agronomic practices- late planting, high weed, pests and diseases infestation (particularly rosette), high labour demand, soil fertility problems (pops), late onset of rains, and long dry spells (Ross and De Klerk., 2012). The low use and access to improved seed and extensive recycling of open pollinated varieties have also been cited as critical factors affecting productivity (Mukuka and Shipekesa, 2013). The low use of improved seed is attributed to lack of availability of the seed. Commercial seed companies produce very little certified groundnut seed as its production is not as profitable as many other crops because the multiplication factor is low. Groundnut seed can be recycled up to five years, thereafter it loses viability quickly and the demand for seed is unstable (Ross and De Klerk, 2012). Other constraints arise from the declining capacity of agricultural land to provide adequate growth conditions especially in view of climate change and variability.

Since the mid-1990s, there has been a lot work in developing and promotion of climate resilient agricultural tillage systems that can support sustained high productivity of crops as well as enhance the use of alternative ecologically safe nutrient sources like biological nitrogen fixation. Invariably, all cultivation systems involve some degree of soil tillage. Tillage is important because it loosens the soil in seedbed, reduces weed density, enhances the release of nutrients through mineralization and oxidation after exposure of soil organic matter to air, incorporates crop residues along with any soil amendments and helps to control soil borne diseases and pests (Hobbs et al., 2008). In addition to conventional tillage several tillage systems are currently used in the production of groundnut including Conservation tillage and Conservation Farming.

Conventional tillage is a tillage system using cultivation as the major means of seedbed preparation and weed control (OECD, 2001). The Conservation Farming Unit in Zambia (CFU) has described Conventional tillage as the act of disturbing the soil using an implement powered by animals or by tractors.

Conservation Farming (CF) is a tillage system characterized by three linked principles, namely: 1. Continuous minimum mechanical soil disturbance. 2. Permanent organic soil cover. 3. diversification of crop species grown in sequences and/or associations (FAO, 2014).

Conservation farming systems generally lead to higher rainfall infiltration, soil moisture retention, a gradual increase of soil carbon and improvements in crop yields in comparison with conventional systems over time (Thierfelder et al., 2012). The increased soil carbon, moisture and infiltration in the soil are essential for the enhancement of soil microbial activity and diversity (Muchabi et al., 2014).

Conservation tillage (CT) has been defined as minimum tillage plus the retention of crop residues to the extent possible (CFU, 2011). It excludes the third component of conservation

agriculture which is the diversification of crop species grown in sequences and/or associations. The conservation objectives of CT include conservation of fuel, soil fauna-earthworms, soil water, soil structure and nutrients (Baker et al., 2002).

A number of studies have been done to assess the performance of maize under different tillage systems, (Thierfelder et al., 2012; Kabamba et al., 2009; Rockstrom et al., 2009: Thierfelder and Wall 2009; 2010), but no study has been undertaken to assess the performance of different tillage systems in groundnut production.

In their review on CA in small holder farming in Africa, Giller et al (2009) raise concerns over lack of clear and consistent empirical evidence to support the said benefits of CA. They further question lack of clear information on which of the principles of CA contribute to the desired positive effects. In Zambia, despite the potentially high economic value of groundnut, there is a paucity of information on effects of conservation practices. Information on the development of groundnut plant, physiological aspects such as biological nitrogen fixation, and yields under various tillage systems is limited in Zambia.

1.2. Statement of the Problem

Several institutions and organizations are currently giving blanket recommendations for the use of conservation farming for a wide range of crops including groundnut, even when no research has been undertaken to assess the impact on crop production. To date no studies have been undertaken in Zambia to ascertain whether the positive impacts observed in crops like maize as a result of use of CF and CT can also be realized in other crops particularly groundnut. There is inadequate information on the benefits of growing groundnuts under conservation farming or conservation tillage compared to conventional tillage.

1.3. Objectives

The overall objective of the current study was to determine the effects of different tillage systems on selected soil properties and yield in groundnut

The specific objectives were

1. To determine the effect of tillage system on selected soil physical and chemical properties
2. To determine yield response of selected groundnut varieties to different tillage systems.

The research hypotheses were that 1) Conservation tillage systems have an effect on soil physical and chemical characteristics. 2) Conservation tillage systems have effects on the development and yield of groundnuts.

Chapter 2: LITERATURE REVIEW

2.1. Botanical aspects of groundnut

Cultivated Groundnut (*Arachis hypogaea L.*) belongs to the genus *Arachis* in subtribe *Stylosanthinae* of tribe *Aeschynomenea* of family Leguminosae (Ntare et al., 2008). Also known as peanuts, the annual herbaceous plant bears pods with seeds that mature within a peg underground. The plants are self-pollinating, indeterminate, annual herbaceous legumes (Putnam et al., 1991; Okello et al., 2015).

The genus is morphologically well defined and distinguished from other genera by having a peg and geocarpic reproductive growth (Prasad et al., 2010). After pollination, fertilized ovaries derived from above ground flowers develop into gynophores commonly known as pegs (Haro et al., 2011). Proembryo development is essential for initiating geotropic embryo elongation, because it controls the production of required hormones and meristem activity at the base of the ovary (Brennan, 1969; Periasamy and Sampoornam, 1984). Peg extension is slow at first but at about 3 mm long they become positively geotropic and start to grow towards the soil after which elongation increases rapidly (Prasad et al., 2010).

One characteristic of tropical food legumes including groundnut is their association with Rhizobium bacteria to form root nodules, the site of biological nitrogen fixation (Woomer, 2010). *Arachis* is usually nodulated by slow growing forms of the *Bradyrhizobium* sp. (Cowpea type), which generally have a wide host range and occur abundantly in most tropical soils (Smartt, 1994). Nitrogen fixation in groundnut is about 150 kg N per ha and offers strong residual benefits to subsequent crops while cowpea, common bean and soya bean have Biological Nitrogen Fixation (BNF) of up to 125, 200 and 120 kg N per ha respectively (Woomer, 2010). Groundnuts are also able to form symbiotic relationships with mycorrhizae (Doley and Jite, 2012). Arbuscular mycorrhizal association is considered to be a symbiotic association between specific soil fungi and a plant root (Schüßler et al., 2001).

Studies by Doley and Jite (2012) have shown significant increase in number of shoots and root length, fresh and dry weight of plant, as well as leaf, pod and nodule numbers as a result of inoculation with mycorrhizae (*Glomus fasciculatum*).

2.2. Origin and taxonomy

Groundnut is believed to have originated from South America most likely around the Brazilian - Paraguayan region (Marlikarjuna et al., 2014). Southern Bolivia and Northern Argentina is thought to be the center of origin of this crop (Gregory et al., 1980; Kochert et al., 1996). The center of diversity of the genus includes western Brazil, Bolivia, Paraguay and Northern Argentina (Gregory et al., 1980). This crop was grown widely by the native people of the new world before the coming of the Europeans; it was subsequently taken to Europe, Africa, Asia, and the Pacific islands (Putnam et al., 1991). In the 16th century, the Portuguese took groundnut from Brazil to West Africa and the Spaniards took it across the Pacific to the Philippines from where it spread to China, Japan, Malaysia, India and as far as Madagascar (Purseglove, 1974). It is now found and grown in tropical and subtropical, and warm temperate zones (Smartt, 1994).

Genus *Arachis* includes 37 named species that are divided into nine sections including *Arachis, Caulorrhizae, Erectoides, Extrannervosae, Heteranthae, Procumentes, Rhizomatosae, Trierectoides* and *Triseminalae (*Prasad et al., 2010). Subdivision of *Arachis hypogaea* L. holds two subspecies: *Arachis hypogaea* sub specie *hypogaea* and *Arachis hypogaea* sub specie *fastigiata* (Prasad et al., 2010). This distinction is based on the vegetative and reproductive structures and is important not only for taxonomic purposes but has production implications.

2.3. Agronomic classification

The sub species *hypogaea* has no floral axes or branches on the main stem; it exhibits alternating pairs of vegetative and reproductive axes on branches; simple inflorescence with seed size being medium to large. The Virginia market type of groundnut belong to this class of groundnut (Ntare et al., 2008). Seeds show dormancy, and plants are late maturing. Generally, the plants branch profusely having a runner or spreading bunch habit (Prasad et al., 2010). The testa colour is generally tan although red, white, purple and variegated seeds also exist (Okello et al., 2015).

The *fastigiata* sub species produce floral axes on the main stems, with irregular pattern in the sequence of reproductive and vegetative branching. The inflorescence may be simple, with smaller seeds which are concentrated around the central axis. They have lower water requirements, are early maturing and the seeds do not show any dormancy compared to the *hypogaea* group. (Ntare et al., 2008). The plants are always erect, with a sparsely branched growth habit (Prasad et al., 2010). Spanish and Valencia market type of groundnut belong to the *fastigiata* sub species, with the Spanish having smaller round seed and the Valencia intermediate in size and shape (Putnam et al., 1991).

2.4. Utilization of Groundnut

All parts of the groundnut plant can be used for different purposes (Putnam et al., 1991). With the increasing cost of animal protein, groundnuts are becoming an even more important source of protein (Kalule et al., 2015). One kilogram of groundnut provides approximately the same energy value as 2 kg of beef, 1.5 kg of cheddar cheese, 9 litres of milk or 36 medium sized eggs (Woodroof, 1983). Jambunathan (1991) reported the percentage contents

of groundnut seed as being: 25.2 % protein, 48.2 % Oil, 11.5 % Starch, 4.5% Soluble sugar, 2.1 % Crude fibre and 6 % Moisture.

Domestic Utilization

In many African societies, the flour obtained from groundnut is added to vegetables and stews, or used to make porridge. Peanut butter is also produced from groundnut. In Zambia, on-farm processing and utilization of groundnut include shelling, oil pressing, grinding into peanut powder, and peanut butter making, with the peanut butter and peanut powder being primarily for consumption (Mukuka and Shipekesa, 2013). Groundnut are typically used for preparing relish since many people in rural households do not use cooking oil, or mixed with maize to prepare food for weaning (Farnworth et al., 2011).

Commercial Utilization

Groundnut is a highly nutritious food. The Virginia types containing 38 to 47 % oil and the Spanish type 47 to 50 % oil (Purseglove, 1968). Groundnut is particularly valued for its high protein content of about 26% (Burn et al., 1975). Due to the high protein content, groundnut is used in nutritional supplements for infants, aged or ill persons (Smartt, 1994). Groundnut also possesses vitamin E, niacin, calcium, phosphorus, magnesium, zinc, iron, riboflavin, thiamine and potassium (Pandey et al., 2012). The nut can further be processed to extract oil and the remaining pressed cake containing between 40- 50% protein is used mainly as a high protein livestock feed or as a fertilizer (Prasad et al., 2010). The oil extracted from groundnut is a very important cooking medium in India and many Asian countries were the bulk of groundnut produced are used for the extraction of oil which is also used to make vegetable gee and margarine (Singh and Diwakar, 1993). About two thirds of the world production of

groundnut is utilized as edible oil, making it one of the world's leading oil seed crops (Smartt, 1994).

Non-food items such as soaps, medicines, cosmetics and lubricants are made from groundnuts, with the leaves and vines being an excellent high protein hay for horses and ruminant livestock, and the shells serving as high fiber roughage in livestock feed, fuel, mulch, particle board manufacture and fertilizer production (Putnam et al., 1991). Ardil, a synthetic textile fibre, is also manufactured from the protein in groundnut (Purselglove, 1974). Groundnut oil is used to extract glycerin, is a substitute for olive oil in medicine as it contains an anti-inflammatory compound and its emulsion is a useful insecticide (Singh and Diwakar, 1993).

2.5. Global Groundnut Production

Groundnut is the second most important oil crop globally after soybean (*Glycine max*) (Upadhaya et al., 2015). The global production as at 2013 stood at approximately 45 million metric tons (FAOSTAT, 2013). The global average productivity is 1.62 t/ha, with countries like China having productivity of 3.35 t/ha, America at 3 t/ha and India at 1.22 t/ha (Upadhyaya and Dwivedi, 2015). The major groundnut producing countries in the world are China, India, Nigeria, Senegal, Sudan, Burma and USA (Madhusudhana, 2013). China is the world's largest groundnut producer, with 40 % of world's production, followed by India with 23 %, a group of Sub-Saharan African (SSA) countries at 8.4 % and the United States with 5.6 % (Akolgo et al., 2014).

2.6. Zambian groundnut industry

Groundnut is grown throughout the country. The major production areas are Eastern, Northern, Central, Southern and Luapula provinces. The crop is grown mainly by small scale farmers who account for 99.4 % of the country's area under production (CFS, 2015). Figure 1 shows production figures of groundnut in comparison to other legumes and oil crops during the 2014/15 farming season in Zambia

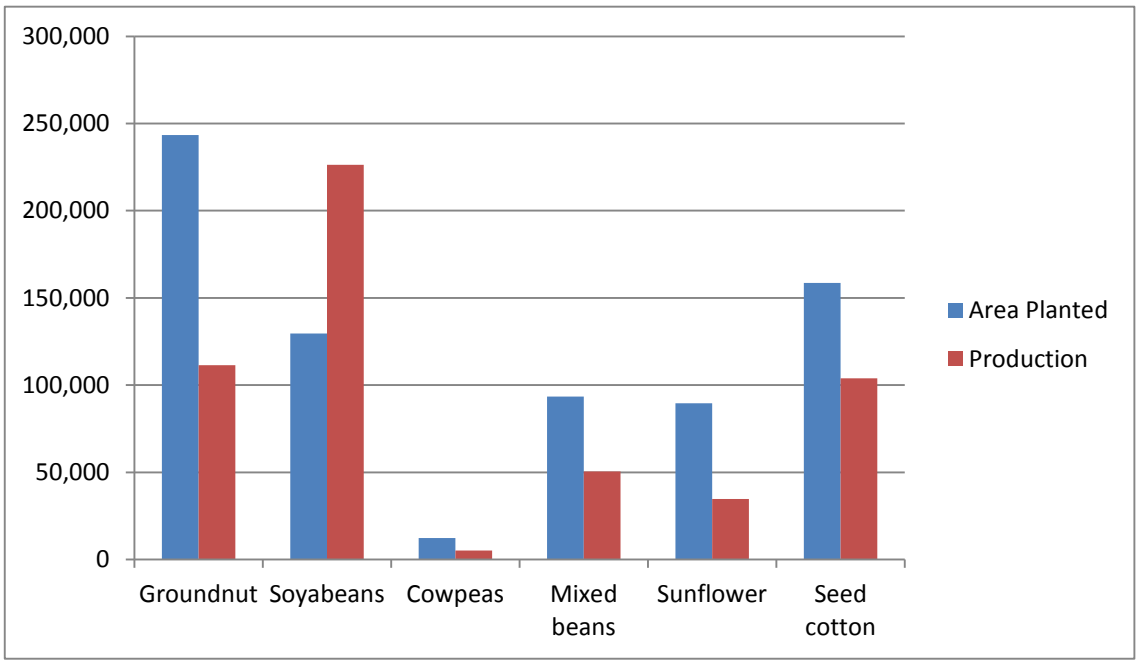

Figure 1: Production figures (MT) for legumes and oil crops in Zambia (2014/15 season)

Source: Crop Forecast Survey 2015 (MAL/CSO 2015)

Figure 1 shows that the area under groundnut production is higher than all the other legume and oil crops, although its yield is second to soybean because of the low productivity of groundnut. Production of groundnut in Zambia has been steadily increasing over the past 13 years, with the highest production being during the 2009/10 season (Figure 2).

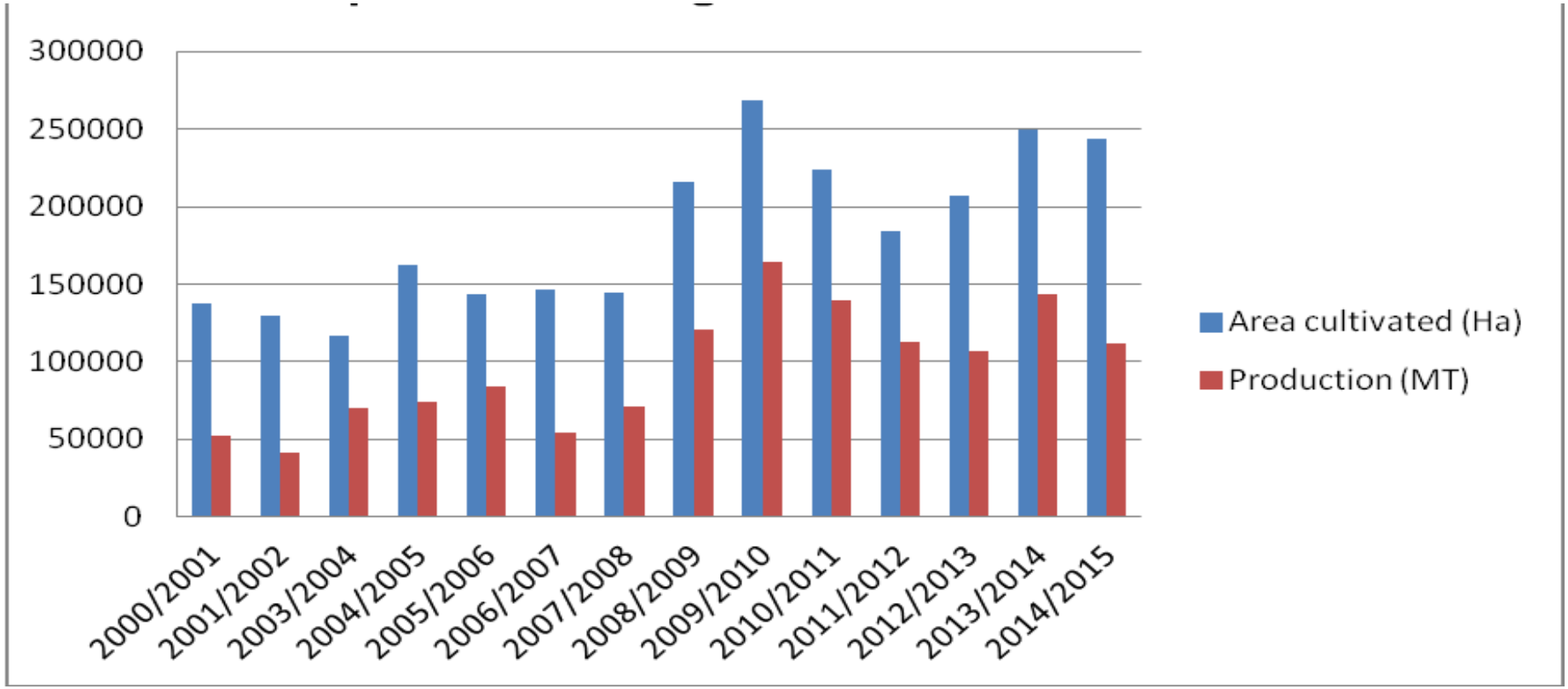

Figure 2: Production trends for groundnut in Zambia between 2001 and 2014.

Source: Crop Forecast Surveys 2001-2015 (CSO/MAL 2001-2014)

During the 2014/15 farming season, 402 large scale and 709,140 small scale farmers grew groundnut. During the same season, a total of 111,428.54 tons of groundnut were produced (CFS, 2015). Eastern province is currently the highest producer of groundnuts in the country accounting for 21% of the country's production as is shown in figure 3.

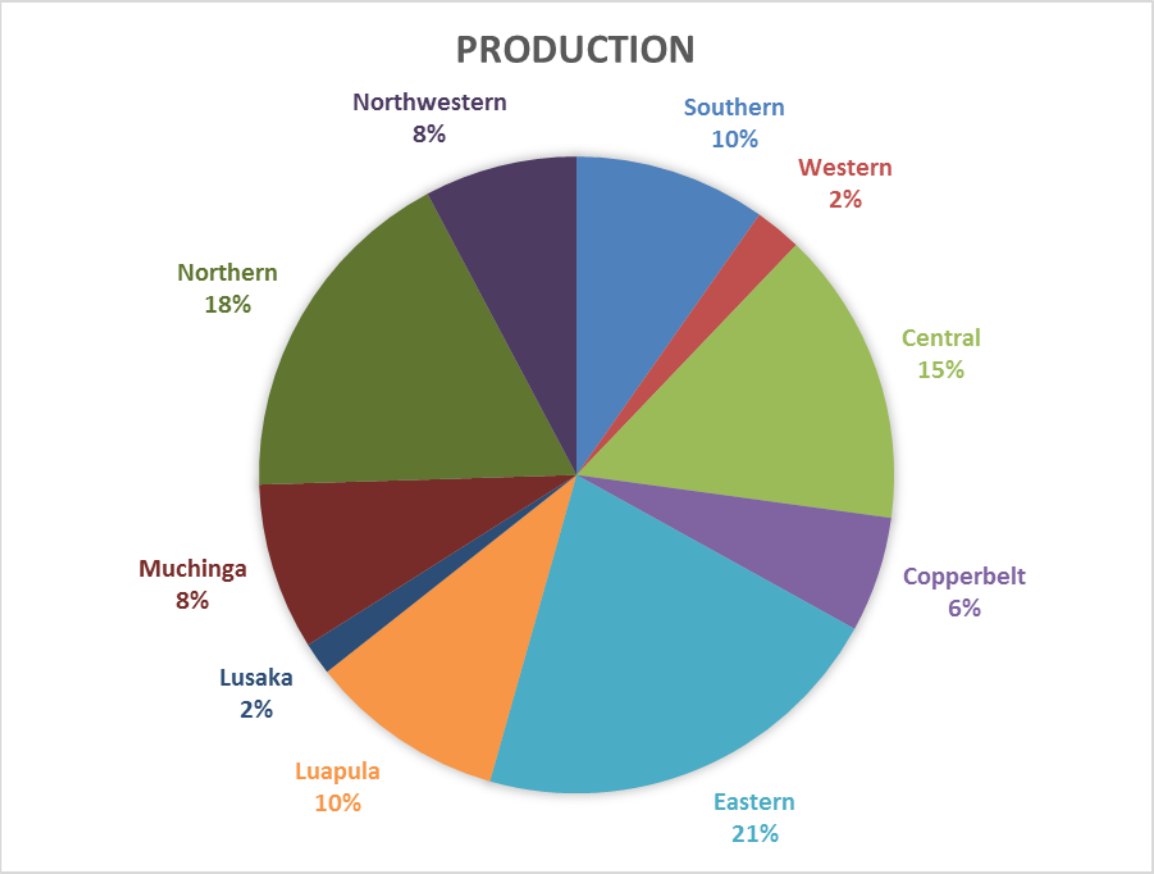

Figure 3: Groundnut production by province (%) during 2014/15 growing season

Source: Crop Forecast Survey, 2015 (MAL/CSO, 2015)

Groundnut productivity is still very low in Zambia as is shown in Figure 4. The national average productivity for small scale farmers stands at 0.45 t/ha, with Eastern Province at 0.36 t/ha (CFS, 2014/15). This is low compared to the world average of 1.62 t/ha (Upadhyaya and Dwivedi, 2015).

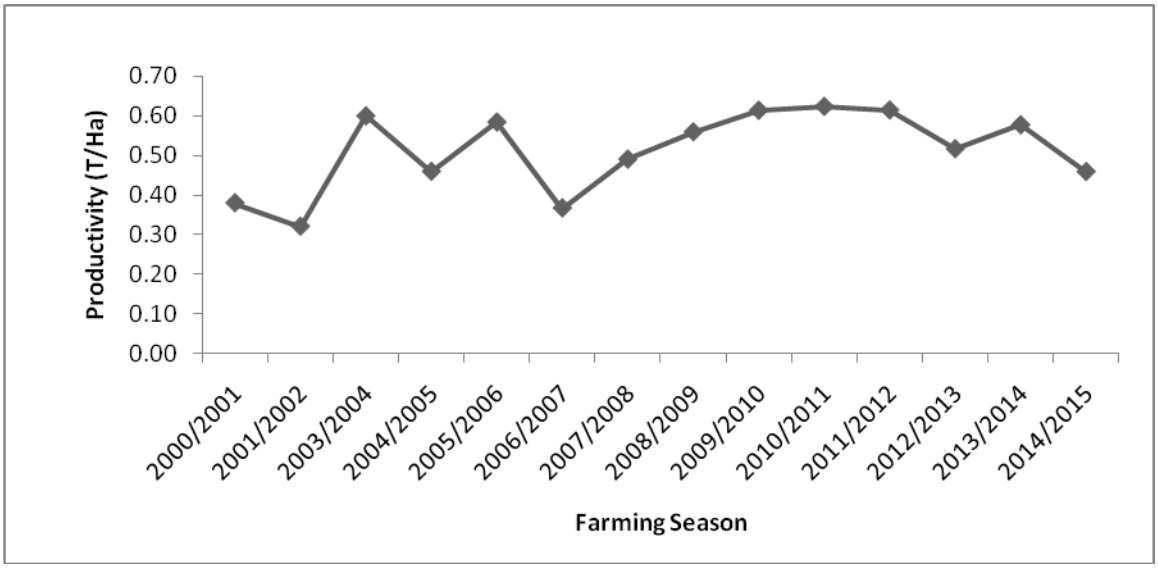

Figure 4: Groundnut productivity in Zambia (2001-2015).

Source: Crop Forecast Surveys 2001-2015

The majority of groundnut produced pass through the informal market system (Sitko et al., 2011). During the 2014/15 season, only 40.2% of groundnuts in Zambia were produced for sale (CFS 2015). As is the case with other agricultural commodities, national and international groundnut prices vary among years and seasons depending on supply and demand for the commodity. According to Index mundi (2016), the world price of groundnut stood at $1806.89/t in January 2016. A spot check for groundnut prices at major traders in Chipata during the same period gave an average of $909/t, while in January 2015, it stood at $550/t. This price variability has made it difficult for producers to plan their production, as well as for domestic traders, processors and exporters to forecast their profits and eventually their income levels (Mukuka and Shipekesa, 2013).

2.7. Crop improvement

Currently in Zambia, most of the groundnut breeding is directed towards yield improvement, disease tolerance and aflatoxin resistance. Msekera research station in Chipata is the government research station that carries out research in groundnuts, pigeon pea, cowpeas and Bambara nut. To date, 12 ICRISAT bred varieties have been released by Msekera research station (ICRISAT, 2015). Various varieties of groundnut have been released by Msekera research station as well as independent seed companies. Table 1 shows a list of varieties that have been released locally.

Table 1: List of recommended released groundnut varieties in Zambia

Variety	Year released	Yield (t/ha)	Market type	Kennel description
Makulu red	1964	2.0 – 2.5	Virginia (B)[z]	Small, red
Chalimbana	1966	0.8 – 1.5	Virginia (R)	Large, tan
Comet	1970	0.5 -1.5	Spanish (B)	Small, tan
Natal common	1976	0.5 – 1.5	Spanish (B)	Small, tan
MGS-2	1988	1.5 – 2.5	Virginia (R)	Large, tan
MGV4	1992	2.0 – 3.0	Virginia (B)	Medium, red
Chipego	1995	1.0 – 1.5	Spanish (B)	Small, tan
Champion	1998	2.5 – 3.0	Virginia (B)	Large, pink
Luena	1998	1.0 – 2.0	Spanish (B)	Small, tan
Chishango	2005	2.0	Virginia (B)	Medium, tan-pink
MGV5	2008	2.5 – 3.0	Virginia (B)	Large, tan
Katete	2008	1.0 – 2.0	Spanish (B)	Small, tan-pink
MGV6	2015	2.5 – 3.0	Virginia (B)	Medium, red
MGV7	2015	2.5 – 3.0	Virginia (B)	medium, red
Lupande	2015	1.5 – 1.8	Spanish (B)	Medium, tan
Wazitatu	2015	1.5 – 2.0	Valencia (B)	Small, red
Wamusanga	2015	1.5 – 1.8	Spanish (B)	Medium, tan

[z]R – Runner type, B – Bunch type.

Source: Msekera Research Station (2015)

2.8. Constraints to Groundnut Production

Groundnut is mainly grown in the semi-arid tropics region by resource poor farmers (Pandey et al., 2012). This is because it is a low input crop, grown mainly grown by women among medium and small scale farmers, which unlike crops like maize and cotton, lacks a stable market (Ross and De Klerk, 2012). Like all crops, groundnut has defined levels of essential nutrients for optimum growth. Crop productivity is adversely affected by many biotic and abiotic stresses. Many of these stresses often occur in combinations and their severity and extent of distribution vary with cropping systems, growing seasons and regions (Upadhyaya et al., 2015).

Biotic factors

A report on the groundnut value chain analysis in Zambia identified some of the constraints to production as poor cultural practices; pest, disease and weed stress (Stepman, 2013).

Groundnut is susceptible to a number of diseases such as Early Leaf Spot (ELS), Late Leaf Spot (LLS), Rust, and Groundnut Rosette Disease (GRD) (Siamasonta et al., 2000). The crop is reasonably free from insect attack, but some insects including thrips (*Megalurothrips sjostedti and Frankliniella schultzei*), jassids (*Empoasca terminalis*), white gubs (*Schyzonycha spp*) and termites (*Isoptera spp*) can cause economic damage in some parts of Zambia (Siamasonta et al., 2000). Sucking pests such as aphids are not themselves considered economically important but are carriers of virus diseases such as GRD (Dwivedi et al., 2003).

Aflatoxin contamination is a major post harvest risk in many groundnut producing areas (Prasad et al., 2010). In addition to health risks, aflatoxin contamination has serious economic implications resulting from lost international trade opportunities (Mukuka and Shipekesa,

2013). Depending on the market, groundnut export can be severely curtailed by aflatoxin contamination. For example in the European Union (EU) legislation sets maximum aflatoxin levels for groundnut sold within the EU at 10 parts per billion (ppb) for groundnut destined for processing and 4 ppb for those destined for direct human consumption (Otsuki et al., 2001). Aflatoxin contamination in selected districts of Eastern Province ranged from 4 to 4,980 ppb (ICRISAT/ZARI 2013).

Weeds cause significant losses in groundnut production. Weeding is the most critical labour-demanding activity in groundnut production as it involves making ridges to ensure the pods do not grow on the surface (Mukuka and Shipekesa, 2013). In their analysis of the groundnut value chain in Eastern Province, Ross and De Klerk (2012), found that 67 % of farmers they interviewed cited weed control as their major constraint to production.

Abiotic factors

The major abiotic factors affecting production include inadequate rainfall, low availability of phosphorus especially under acidic soil conditions, salinity and temperature stress (Upadhyaya et al., 2015). Drought is the major abiotic stress, as 70 % of the crop is under semi-arid tropics which are characterized by low and erratic rainfall (Pandey et al., 2012).

2.9. Groundnut Tillage Systems

Conventional Tillage

Conventional tillage has been described as the physical turning of a soil surface to prepare a seedbed for crop germination and growth (Sprague, 1986). It typically includes a sequence of

practices such as ploughing and harrowing to produce a fine seedbed and also the removal or incorporation of most of the plant residue from the previous crop (OECD, 2001). Conventional tillage is defined by the Conservation Tillage Information Center (West Lafayette, Indiana, USA (CTIC, 2004)) as any tillage and planting system that leaves less than 15 % residue cover after planting, or less than 560 kilograms per hectare of small grain residue equivalent throughout the critical wind erosion period.

Hobbs et al (2008) summarized the uses of cultivation to include loosening the soil and preparation of seedbeds, control of weeds and help to release soil nutrients needed for crop growth through mineralization and oxidation after exposure of soil organic matter to air. Ploughing also incorporates fertilizer nutrients into the root zone, resulting in increased nutrient availability and generally increased crop yield (Coolman and Hoyt, 1993). In groundnut the use of ridges can prevent water logging, and improve weed control and harvesting (Okello, 2015). Studies carried out on soils to examine the effects of tillage on bulk density found that bulk density and penetration resistance of surface soil decreased with intensity of soil loosening by tillage operation (Osunbitan et al., 2005, Malecka et al., 2011, Thomas et al., 2007).

However, agricultural intensification by use of intensive tillage-based production systems generally has had a negative effect on the quality of many of the essential natural resources such as soil, water, terrain, biodiversity and the associated ecosystem services provided by nature (Friedrich et al., 2012). Most soils degrade under prolonged and intensive arable agriculture resulting in the formation of crusts and compaction (below the plough layer), and leads to increased soil erosion. The process is dramatic under tropical climatic situations but occurs all over the world (FAO, 2014).

Conservation Farming

Conservation Agriculture in general and conservation farming (CF) in particular is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. CF is characterized by three linked principles namely (FAO, 2014):

1) Continuous minimum mechanical soil disturbance
2) Permanent soil cover
3) Diversification of crop species grown in sequence and/or associations.

Conservation farming is an agricultural practice that started in the USA as a result of the effects of the American dust bowl of 1930's, which resulted from excessive tillage and exposure of soil to wind (Hobbs et al., 2008). This experience led to the gradual emergence of principles and practices of conservation agriculture. Conservation farming is defined as a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment (FAO, 2007).

Conservation farming has 5 component technologies that should be applied simultaneously (Aagaard, 2003):

1. Retention of biomass (no burning) of at least 30 % of crop residue.
2. Land tillage of only 10 to 15 % of the surface area without soil inversion
3. Land preparation immediately after harvest to break the hard pan
4. Precise and permanent grid of planting stations, furrows, pits, trenches or ridges on the contour
5. Rotation with nitrogen fixing legume of at least 30% of the cropped area.

Farmers who apply only principles 1- 4 are said to be practicing conservation tillage, while those that practice all 5 principles are practicing conservation farming in its real sense (Baudron et al., 2007).

Conservation farming systems as practiced in Zambia is generally considered to lead to higher rainfall infiltration, increased soil moisture, a gradual increase of soil carbon and improvements in crop yields in comparison with conventional systems over time. (Thierfelder et al., 2012). It is commonly assumed that these improvements in the soil physical and chemical composition can help to alleviate the challenges to growing diverse crops including groundnut production faced by many small holder farmers.

Studies carried out in Brazil on an oxisol showed an increased amount of organic carbon in soils under no- tillage than those under conventional tillage (Balota et al., 2004). It is known that carbon is a key factor governing soil microorganism growth (Grayston et al., 1993). The increased soil carbon levels have been shown to result in increased biotic activity. Grantina et al., (2011) studied the impact of a six- year -long organic cropping on soil microorganisms and crop diseases suppresiveness. The study showed that on average, significantly higher numbers of all groups of analyzed cultivable microorganisms were observed in organic agriculture fields in comparison to conventional fields. These effects may enhance numbers and activity of microbes responsible for activities such as mineralization, decomposition and biological nitrogen fixation.

A study carried out in western Kenya showed that the amount of nitrogen fixed was higher under no tillage compared to conventional tillage (Okoth et al., 2014). Studies in Brazil also show that the use of agronomic practices such as no tillage with legume crop rotations contribute to agricultural sustainability and maintain *Bradyrhizobia* spp population and diversity (Ferreira et al., 2000). *Bradyrhizobia* can infect, nodulate and symbiotically fix

nitrogen in legumes leading to higher yields, and even when yield responses are not evident, inoculation may still have benefits by increasing seed N levels and N levels in plant residues (Vessey, 2004). Regi et al., (2012) studied the effects of long term conventional and no tillage practice and found an abundance of phospholipid fatty acid (PLFA) biomarkers indicative of fungi, bacteria, arbuscular mycorrhizal fungi, and *Actinobacteria* spp was consistently higher in the no-till surface soil. They also found that soil organic carbon was positively correlated with most of the PLFA biomarkers. These results indicated that tillage practice and soil depth were two important factors affecting soil microbial community structure and activity, and conservation tillage practices improve both physicochemical and microbiological properties of soil. Apart from this, a reduction in physical disturbance may slow organic matter decomposition and thereby contribute to longevity of microbes (Yang et al. 2012).

Higher soil pH, soil organic carbon, nodulation and biological nitrogen fixation were found under CF compared to conventional farming in a soybean crop after seven years of practice in Zambia (Muchabi et al., 2014). Several years of practicing CF technologies are required before benefits begin to be noted. Umar, (2012) found no evidence of CF associated improvements in soil fertility after five years of CA practice in Southern, Eastern and Central provinces of Zambia in fields with mixed crops. Short term benefits are important, because they determine to a large extent the attractiveness of CF to farmers (Giller et al., 2009). This may affect the adoption of technologies such as CF.

Many challenges are encountered by farmers using CF. Results from a study undertaken by Umar et al., (2011) showed that weed management, crop residue retention, timely planting and soil fertility management were the most challenging for CF farmers especially those without reliable access to oxen. Crop residue retention conflicted with the socio-cultural practices of the communities and was hardly practiced while crop rotation seemed difficult in

light of the dominance of maize cultivation and the lack of markets for crop legumes. Several studies have also been undertaken to determine which tillage system produces higher yields. Results have been inconsistent with some studies having higher yields under CF (Rockström et al., 2009) while others have had no significant yield differences (Mikanová et al., 2012, Omondi et al., 2014). In certain studies, the yields under CF have even been lower than those under CT (Sessiz et al., 2010, Gatere et al., 2013).

Conservation Tillage

Conservation tillage is defined as any minimal tillage system that leaves the soil surface covered with at least 30% crop residue (CTIC, 2004; Awada et al., 2014).

Conservation tillage therefore has 4 of the 5 components that constitute Conservation farming. Umar and others (2011) have indicated that it is very difficult to determine the number of adopters of CA as some farmers only adopt some of the recommended practices of CA. Farmers will only adopt technologies that suit them, and studies undertaken to access CF should take this critical factor into account to ensure that the different components of CF are assessed independently to observe their effects. Several socio-cultural factors determine the choice of which tillage practice a farmer will adopt. CFU recommends that 30% of cultivated land be planted with a nitrogen fixing crop to be rotated with maize or cotton but this may prove to be too inflexible when outside factors such as markets and demand for produce are taken into account (Baudron et al., 2007). The majority of farmers just practice some of the components of CF. Figure 5 shows a breakdown of the farmers utilizing various tillage practices in 2015, with only 2% of the farmers are using zero tillage system

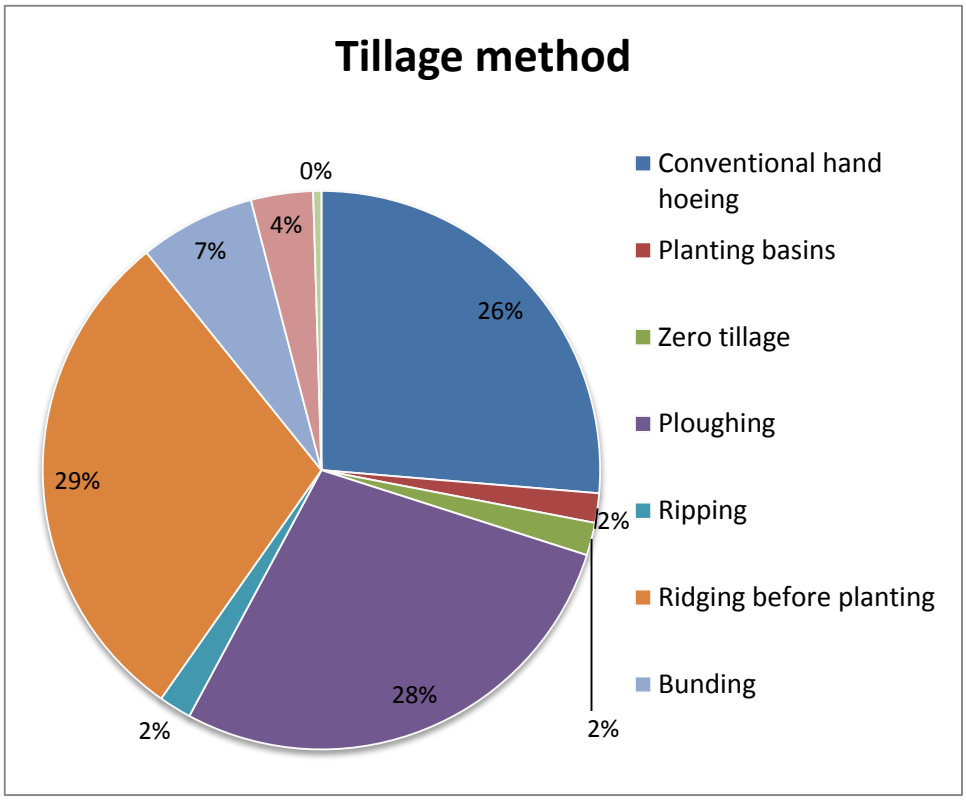

Figure 5: Distribution (%) of farmers utilizing the various tillage methods in Eastern province.

Source: 2015 CSO/MAL/IAPRI Rural Livelihoods Survey

Chapter 3. MATERIALS AND METHODS

3.1. Experimental design

This study was carried out at Msekera research station in Chipata District during the 2014/15 growing season. The site (S13º39´06.3″ and E32º33´54.0″) is located in the Zambian Agro - ecological zone II with medium rainfall that ranges from 800 to 1000 mm per annum. The annual mean temperature for Msekera ranges from 15 to 30 ºC. During the 2014/15 growing season, maximum temperatures ranged from 27.6 to 35˚ C with a total of 906.6 mm of rainfall and 60 days of rainfall as shown in Figure 6a and 6b. The soils at the research site are Chromi- haplic Alisols, which are well drained, moderately deep to deep, red to strong brown, friable, gravelly, moderately weathered loamy to clay soils (Exploratory soil map, 1991).

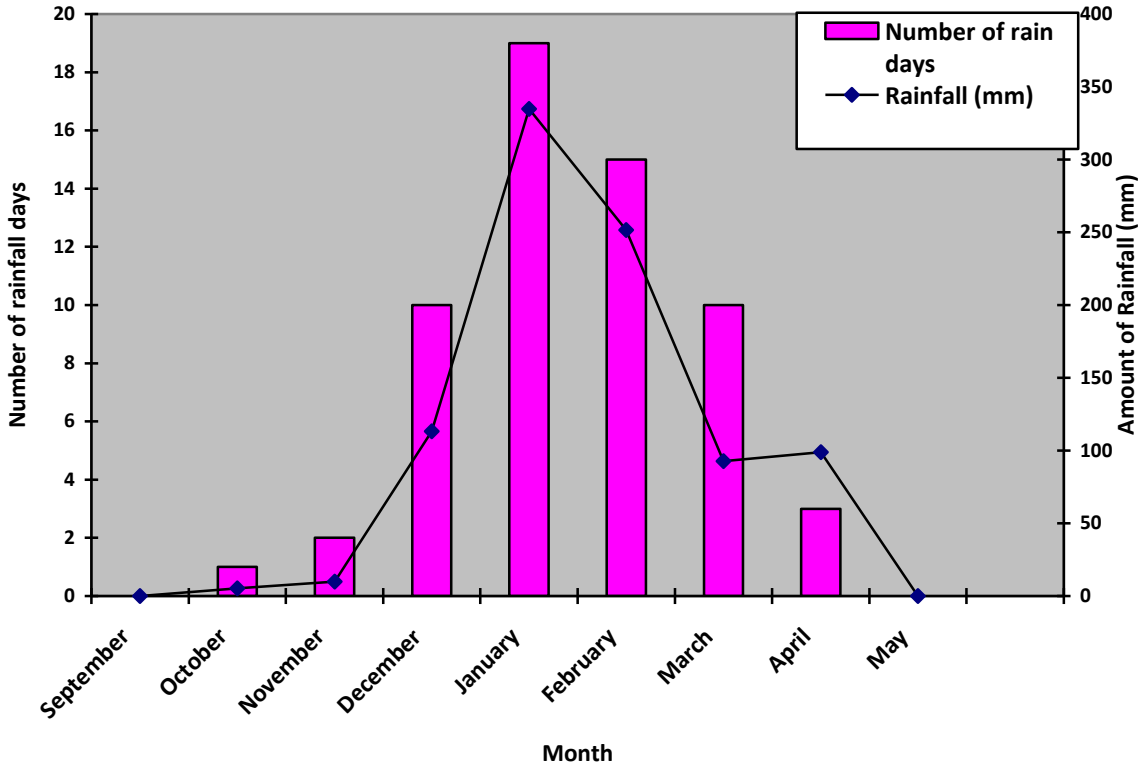

Figure 6a: Number of rain days and monthly rainfall at Msekera Research station during the 2014/15 growing season

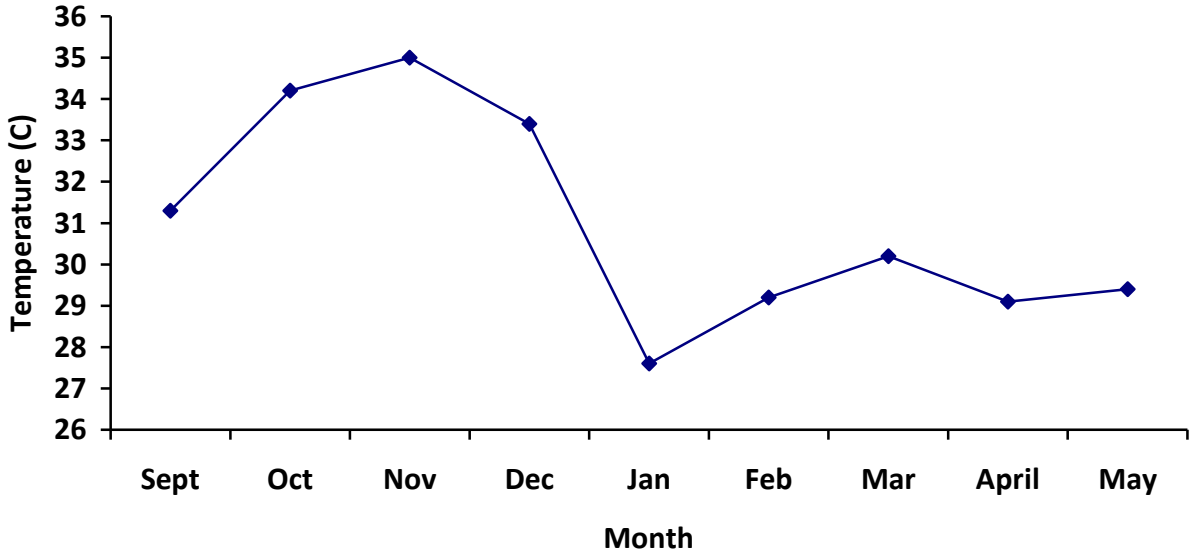

Figure 7: Maximum daily temperature (˚C) at Msekera Research station during the 2014/15 growing season.

This study compared the performance of different groundnut varieties grown under three different tillage systems namely; Conventional Tillage (CV), Conservation Tillage (CT) and Conservation Farming (CF).

It is anticipated that the information generated will contribute to further understanding of the effects of conservation and provide a scientific basis for more realistic targeting of promotion of conservation tillage systems for the production of different genotypes of groundnut.

The site had been subjected to conservation farming, conservation tillage and conventional tillage systems under cultivation since the year 2007 under a maize trial. This study made use of this site in order to take advantage of the residual benefits of the treatments that had been

running for 7 years. In this new experiment the groundnut trial was therefore superimposed on the plots that had been under the respective tillage practices. The conventional and minimum tillage plots had had maize as a sole crop grown while the conservation tillage had maize/ cowpea intercrop for the same 7 years.

3.2. Experimental Design

The study used a Split plot experimental design with three replications. The treatments were as follows: the main plot comprised the tillage system, while the subplot was the groundnut genotype. Three tillage systems were used: Conventional tillage (CV), Conservation Tillage (CT), and Conservation Farming (CF). Among the five groundnut genotypes four were improved Katete, Chishango, and MGV4 the fifth Kanjute was a local landrace. Luena and Katete were bunch type Spanish varieties, while Chishango and MGV4 are bunch type Virginia varieties. Kanjute was a local bunch type Virginia groundnut. The Spanish varieties were early varieties with a maturity period of between 90-100 days while the Virginia varieties were medium maturing varieties with maturity period of 120-140 days as is shown in Table 2 and Figure 7. A sub-plot of Pearl millet (*Pennisetum* spp) was also randomly planted in each main plot to serve as a reference crop for the determination of Biological Nitrogen Fixation (BNF). This resulted in six sub-plots per main plot (five with groundnut and one with pearl millet).

Table 2: General characteristics of the groundnut (*Arachis hypogea*) genotypes used in the study

Variety	Days to Maturity	Variety type	Oil (%)	Yield (t/ha)
Luena	90-100	Spanish	40	1-2
Katete	90-100	Spanish	43	1-2
Chishango	130-140	Virginia	47	2
MGV4	120-140	Virginia	49	2-3
Kanjute	-	Virginia		-

Figure 8: Groundnut (*Arachis hypogaea*) varieties used in the study.

A. Katete, **B**. Chishango, **C.** Luena, **D**. Kanjute , **E**. MGV4

3.3. Planting and Cultural Practices

Land Preparation

Each field was separated into three tillage systems: Conventional tillage, Conservation tillage and Conservation farming. The main plots were 13 x 17 m, while the sub plots were 6 x 5 m. Each replication therefore had 3 main plots and 18 subplots, giving a total of 54 subplots. Ridges were made for the conventional plot while a ripper was used to prepare the land for the conservation plots. In all groundnut plots, a planting spacing of 6 x 10 cm was used. Planting was done on 22nd December, 2014. One seed was sown per station at approximately 5 cm deep for the groundnut. The pearl millet was sown at a depth of about 2 cm. Fertilizer was not applied to any of the sub-plots in order to mimic small holder farmers who do not apply fertilizer to their groundnut fields.

Weed Management

Post emergence herbicides were applied at; 14 days after planting and 30 days after planting. These were Panther and Zephyr, which were against grasses and broad leaved weeds (*Corchorus spp, Acanthospermum hispidum, Nicandra physalodes, and Amaranthus hybridus*) respectively. Manual weeding (hand pulling) was also carried out at 45 days after sowing, taking care not to injure the plants.

Harvesting

Katete and Luena which were the early maturing varieties were harvested on 10th April, 2015 while the late maturing varieties- Chishango, MGV4 and Kanjute- were harvested on 15th May, 2015. A 4 x 4 m area net plot was harvested from each subplot. The nuts were sun dried for one week after harvest and shelled thereafter. This period was slightly shorter than the one used by farmers because the nuts were not meant for long term storage.

3.4. Determination of Soil Physical, Chemical and Biological parameters

In order to determine the physical, chemical and biological parameters, soil sampling was carried out before planting. A total of 54 soil samples were collected for the chemical assessments, with each treatment having three (3) sub samples collected to come up with a composite sample. Soils were collected from depth of 0- 20 cm in a radial sampling scheme using an auger (Wilding, 1985). Sampling to determine bulk density was also carried out before sowing. Bulk density and porosity were selected for analysis because groundnut is a crop that places its yield under the ground and is affected by the degree of compactness and infiltration of moisture in the soil.

3.5. Soil Physical Analysis

Bulk density

The method of Blake and Hartge (1986) was used to determine bulk density. Bulk density measurements were done at four (4) levels: 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm, with 3 samples taken in each of the plots. Undisturbed soil samples were collected using a 5 cm diameter steel ring (2.5 cm radius) which was gently hammered into the soil and removed without disturbing or loosening the soil. The ring with the soil was placed in an oven at 90˚C overnight to dry. The weight of the soil sample was determined after drying by subtracting the weight of the steel ring from the total weight of the ring and the dry soil.

The volume of the ring was determined by the equation below.

$$Volume = \pi r^2 h,$$

Where: $\pi = 3.14$, r^2(radius ^{2}) = 2.5^2, and h (height) = 5 cm

Bulk density was determined with the equation below.

$$Bulk\ density\ (g/cm^3) = Dry\ soil\ weight\ (g) / Soil\ volume\ (cm^3)$$

The mean of the 3 bulk densities per plot was calculated to give the average bulk density per plot.

Porosity

Porosity was determined using the bulk and particle density (Brady and Weil, 1996). Porosity was calculated as:

$$Porosity = 1- (Bulk\ density/particle\ density)$$

This was based on assumption of a particle density of 2.65 g/cm^3.

3.6. Soil Chemical Analysis

Soil reaction

The pH of the soil was determined in a Calcium chloride suspension (Van Reewijk, 1992) by weighing 10 g of 2 mm air dried soil putting it into a beaker to which 25 ml of $CaCl_2$ solution was added. The suspension was stirred thoroughly every 10 minutes for 20 minutes and then allowed to settle for 10 minutes. The pH was then measured using a pH meter which was standardized using buffer solutions of pH 4.0 and 7.0 before taking readings.

Total nitrogen

The Kjeldahl digestion method according to Black (1965) was used. The method involves weighing 1 g of air dry soil into digestion tubes to which 3 g of mixed catalyst was added followed by 10 ml of concentrated H_2SO_4. The samples were digested for 45 minutes in a

digestion block set at 410º C. After cooling for 15 minutes, the samples were distilled with 25 ml of boric acid indicator solution. Fifteen (15 ml) of 10 M sodium hydroxide (NaOH) solution was added into the distillation flask and filtered for the distillation. Sufficient flow of cold water was utilized to keep the condenser cool, regulate flow back and minimize frothing. The distillate collected was then titrated with 0.01 M HCl and a blank was prepared using 0.03 g of pure starch. Total nitrogen percentage was calculated as:

$$\textit{Total N (\%)} = \frac{\textit{Volume of sample} - \textit{Volume of blank x normality of acid x 1.4 x 10}}{\textit{mass of sample (g)}}$$

Organic carbon

The Walkey and Black method (1934) was used to determine organic carbon. For analysis, 1 g of soil was put into a beaker to which 10 ml of 1N $K_2Cr_2O_7$ and 20 ml H_2SO_4 was added, swirled and allowed to stand in a fume hood for 30 minutes. Thereafter, 150 ml of distilled water, 10 ml of phosphoric acid (H_3PO_4) and 1 ml of diphenylamine indicator were added. The solution was then titrated with Iron II Sulphate (Fe_2SO_4). A blank titration containing only dichromate was also made to standardize the Fe_2SO_4. The results gave the amount of organic matter in the soil. To determine the amount of organic carbon, the following formula was used:

$$\%C = (a - b) \times 0.4$$

Where a = Fe_2SO_4 added to the blank, b = Fe_2SO_4 added to the sample multiplied by a conversion factor of 1.724. The factor was based on the assumption that the organic matter is composed of 50 % carbon.

Exchangeable Bases

The exchangeable bases Calcium, Magnesium, Potassium, and Sodium were determined using the method of Rowell (1994). For analysis, 5 g of air dried soil was passed through a sieve and put into a plastic bottle to which 25 ml of ammonium acetate solution at pH 7.0 was added. The bottles were shaken for 30 minutes in an orbital shaker before filtering. Ca, Mg and Na were analyzed using The Atomic Absorption Spectrophotometer (Perkin Elmer; Analyst 400 model; 2005) while K was analyzed by the flame photometer (Chapman, 1965). In determining Ca, Mg and Na, 1 ml of the filtrate was added to 5 ml of strontium solution and diluted to 25 ml and read on the AAS which had prior to this been calibrated using standard solutions. The amount of exchangeable bases was calculated using the formula below and expressed in cmol/kg soil:

$$\frac{\textit{Base = Reading (mg/l) x volume of extract (L) x dilution factor}}{\textit{Equivalent weight of ion x mass of sample (kg)}}$$

Available Phosphorus

To determine soil phosphorus content, the Olsen et al. (1954) procedure was used in which 3 g of soil was placed in a 15 ml beaker to which 21 ml of extraction solution are added and shaken for a minute. Five millilitres (5.0 ml) of supernatant was then pipetted into a 25 ml volumetric flask and 10 ml distilled water 4 ml of reagent B (1.056 g Ascorbic acid dissolved in 200 cm^3 of a mixture of 12 g Ammonium molybdate in 250 cm^3 distilled water, 0.2908 g potassium antimony tartrate in 100 cm^3 distilled water and 2.5 M sulphuric acid) was added and filled to the mark with distilled water. The solution was equilibrated for 15 minutes for colour development and the P content read on the spectrophotometer at 882 nm. The available phosphorus was calculated as follows:

$$\underline{P(mg/kg) = Reading(mg/L) \times dilution\ factor}$$
$$Mass\ of\ sample$$

3.7. Determination of Nodulation and Biological Nitrogen Fixation (BNF)

Nodulation

The number of nodules and nodule fresh weight per plant were determined. At 8 weeks after planting, 5 plants were randomly selected from each plot. These plants were used for assessing nodulation as well as biological nitrogen fixation. The plants were dug to a depth of 30 cm and the plants cleaned on a sieve under running water. Immediately after, nodules were removed from the roots, counted and weighed and their mean determined to give nodule number and fresh nodule weight per plant.

Biological Nitrogen Fixation (BNF)

To determine biological nitrogen fixation, the modified nitrogen difference method was used (Unkovich et al., 2008). Pearl millet (*Pennisetum glaucum*) was used as the reference crop as it was a non-nitrogen fixing crop. The leaves of the millet were collected at 8 weeks after germination from 5 randomly selected plants in the different tillage systems. The leaves of the groundnut plants used in the nodule assessments were used for the determination of BNF. The leaves of pearl millet and groundnut were placed in individual paper bags and oven - dried at 65˚ C for 24 hrs. The samples were then ground to a powder.

One gram of the oven-dried plant material was put into a digestion tube to which 7 ml of Salicyclic acid mixture was added. After 30 minutes, 1 g of $Na_2S_2O_3.5H_2O$ was added, and

after 15 minutes, 3 ml of H_2SO_4 and 1 g of catalyst mixture. The digested sample was then distilled into 25 ml of boric acid indicator solution and distillate titrated with 0.01 M HCL

The amount of nitrogen was calculated using the formula:

$$Total\ N\ (\%) = \frac{Volume\ of\ sample - Volume\ of\ blank \times normality\ of\ acid \times 1.4 \times 10}{mass\ of\ sample\ (g)}$$

BNF was then calculated as shown below:

$$BNF = Groundnut\text{-}N - Pearl\ millet\text{-}N$$

In determining BNF using this method, three assumptions were made:

1. N_2 – fixing plant (groundnut) and non N_2-fixing plant (pearl millet) use similar amounts of soil mineral nitrogen.
2. N content of the non N_2-fixing plant represent the amount of soil mineral N available for plant growth and
3. Total N in the N_2-fixing plants is never less than that of the non N_2-fixing plants.

3.8. Groundnut plant development parameters

Days to 50 % emergence and flowering

This was determined by counting the number of days from the date of sowing to the date when 50% of the seedlings emerged and flowered from each of the plots.

Days to 50 % peg initiation

This was determined by counting the number of days from the date of sowing to the date when 50% of the pegs have developed in each of the plots.

Plant height, and root and shoot biomass

Five randomly sampled plants in each plot were measured from the ground to the top of the main axis, and the mean height calculated. Plant height was recorded at 32 and 64 days after sowing. The plants were then uprooted and cleaned on a sieve under running water. The plant was cut at the point where the root axis starts. The root and shoot biomass was then measured.

Number of pods per plant

Immediately after harvest, five plants were selected per plot. The pods from each plot were counted to determine the mean pods plant in each plot.

Determination of 100 seed weight

A random sample of 100 seeds was taken from the harvested bulked seed per plot and weighed to give 100 seed weight per plot.

Groundnut yield

The sun dried nuts from each plot were shelled and weighed to give the yield per plot.

3.9. Data Analysis

To determine the effect of tillage system, variety and their interaction an analysis of variance was done and where significant differences were discernible. Means were separated using the Least Significant Difference (LSD) and considered significant at $p \leq 0.05$. Data analysis was done using GENSTAT edition 17.1.

Chapter 4. RESULTS AND DISCUSSION

4.1. Physical Properties

4.1.1. Bulk Density

The bulk densities ranged from 0.87 – 1.68 g/cm^3, with the highest bulk density being under CT. Analyses of variance for bulk density showed significant differences for the tillage method at all the soil depths analysed. The bulk density was lowest at the 0-5 cm soil depth but gradually increased down the profile, with the highest density at the 10-15 cm depth after which it started to reduce as shown in Table 3. Conventional tillage had the lowest bulk density. At the 0-5 cm depth, CA had the lowest bulk density of 1.287 g/cm^3 followed by CV with 1.291 g/cm^3. CA and CV were not different but they differed from CT which had a bulk density of 1.390 g/cm^3. Table 3 further showed that at 5-10 cm depth, CV differed from CT, but not from CF. CT and CF were not statistically different. Bulk density under CV had the lowest bulk density of 1.39 g/cm^3 followed by CF and CT with 1.49 and 1.44 g/cm^3 respectively. At 10-15 cm, CV with 1.39 had the lowest bulk density followed by CF and CT at 1.53 g/cm^3. In the 15-20 cm depth, the bulk densities for CV, CT and CF were 1.41, 1.52, and 1.47 g/cm^3 respectively. CV was different from CT but not CF. CT and CF were not different. Generally for CF and CT bulk density increased with soil depth.

Table 3: Effects of tillage methods on bulk density at different soil depths

	Bulk density (g/cm^3)			
	Soil depth (cm)			
Tillage Method	0-5	5-10	10-15	15-20
Conventional Tillage	1.29a	1.39a	1.39a	1.41a
Conservation Tillage	1.39b	1.49b	1.53b	1.52b
Conservation Farming	1.29a	1.44ab	1.47b	1.47ab
LSD	0.0863	0.097	0.0647	0.0673
P-value	0.033*	0.014*	<0.001**	0.006**

The highest bulk density was 1.68 g/cm^3 under conservation tillage. According to Smith (1988) bulk densities in excess of 1.6 g/cm^3 can restrict root growth and result in low levels of water movement into and within the soil. High silt and clay soils have growth limiting bulk densities ranging from 1.45 to 1.40 g/cm^3, while values for sandy soils were as high as 1.65 to 1.75 g/cm^3, and a plant already shows significant growth reduction before the soil reaches these points of severe compaction (Stevenson et al, 1991). The high bulk density levels under conservation tillage and conservation farming could have affected root development and penetration of roots down the soil profile. This is further supported by the lower root biomass in the groundnut grown under conservation tillage and conservation farming compared to those grown under conventional tillage (Table 6). The above ground biomass was also higher under CV than CT and CF and may have been as a result of reduced ability by the crop to take up nutrients required for crop growth. Conventional tillage had the lowest bulk density and the highest yield. These results are similar to those of Osunbitan et al (2005) who

examined the effects of tillage on bulk density on a loamy sand soil and found that the bulk density decreased with increase in the intensity of soil loosening by tillage operation. Aikins et al (2012) and Kombiok et al (2005) also found that no- till plots had the highest bulk densities than tilled plots.

4.1.2. Porosity

The porosity ranged from 36.7 to 67.2 %, with CV having the highest porosity and CT the lowest. Table 4 showed that tillage system affected porosity at all the soil depths. The 0-5 cm depth had the highest porosity under CA with 51.4% followed by CV at 51.3% and CT had the lowest at 47.6%. CV and CA were not different but they both differed from CT. At 5-10cm, CV had the highest porosity of 47.7 %, followed by CF and CT with 43.7 and 45.6% respectively. In 10-15cm depth, CV had a porosity of 47.4, while CF had the lowest at 42.5%. At 15-20cm, CV was different from CT but not CF. CT and CF did not show any difference. The porosity for the three tillage systems ranged from 42.6% under CT to 47% under CV. The 0-5cm soil depth had the highest porosity, while the 10-15cm depth had the lowest porosity. Porosity reduced gradually up to the 10-15cm depth after which it reduced as is shown in table 4 below. Most agricultural soils have a porosity of about 50%, but if they become compacted, porosity may decrease limiting the space available for water, air and restricting root development (Rogers et al, 2015). The reduced porosity under the conservation systems especially at the 5 – 15cm depths may have been responsible for poor root development observed (figure 8). This coupled with the high bulk densities may have also been responsible for the lower biomass and number of root nodules as the plant roots may not have been able to access adequate amounts of nutrients necessary for growth.

Table 4: Effects of tillage practices on porosity at different soil depth

Tillage method	Porosity (%)			
	Soil depth (cm)			
	0-5	5-10	10-15	15-20
Conventional tillage	51.3a	47.7a	47.4a	47.0a
Conservation tillage	47.6b	43.7b	42.5b	42.6ab
Conservation farming	51.4a	45.6ab	44.4b	44.5b
LSD	3.28	2.61	2.45	2.55
P-value	0.038*	0.013*	<0.001**	0.005**

4.2. Soil chemical characteristics

Results for the soil chemical properties are presented in Table 5. No significant effects of tillage were discernible after 7 years of practice. These results corroborate with earlier findings that suggest that the practice of conservation tillage do not always result in changes in soil chemical properties and that where changes are observed, these take a certain minimum number of years to appear. For example, in their study of soils under conservation farming, Umar et al., (2011), reported no significant differences between the levels of total N in conventional and conservation tillage soils after 5 years of CA practice while Muchabi et al., (2014) suggested that some soils may take as long as 16 years to show improvements in physical and chemical properties.

Table 5: Effect of tillage practices on soil reaction, organic carbon, total nitrogen and exchangeable bases

Tillage system	pH	Organic C (%)	Total N (%)	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)
Conventional Tillage	5.15	1.75	0.13	0.35	0.20	0.19
Conservation Tillage	5.13	1.58	0.12	0.35	0.17	0.21
Conservation Farming	5.09	1.54	0.12	0.33	0.17	0.20
P-value	0.34ns	0.60ns	0.61ns	0.51ns	0.1ns	0.61ns

The soils in this study were all acidic with pH ranging from 5.0 to 5.4, but within the range that still promote plants growth of crops such as maize, cowpea, groundnut and soybean (Fairhurst, 2012). Soil organic carbon ranged from 1.54 to 1.75 % which was also within the critical limit of 1.5 % for optimum crop productivity (Fairhurst, 2012). Total N levels ranged between 0.12 and 0.13, which was below levels recommended for optimum growth of 0.15 % (Fairhurst, 2012). Average P levels of above 10 mg/kg are required for good plant growth (Shitumbanuma and Banda, 2004), and these soils all fell below the critical limit as they were all < 1 mg/kg. The recommended levels for optimum growth for Ca, Mg and K were 0.50, 0.20 and 0.20 cmol/kg respectively (Fairhurst, 2012). The soils in this study had optimum amounts of K, but below optimum amounts of Ca and Mg.

In order to mitigate against deficiencies as a result of inadequate levels of total nitrogen, phosphorus, calcium and magnesium, fertilizers such as di ammonium phosphate (DAP) and manure need to be added to the soil to increase levels of the soil. Addition of lime to the soil aids in reduction of the acidity of the soil and make available, calcium and magnesium which are necessary for plant growth.

4.3. Biological analysis

4.3.1. Days to 50 % Germination, Plant height and, above and below ground biomass.

Germination measured by Days to 50 % germination, varied significantly among varieties and not tillage systems. Early maturing varieties, Luena and Katete germinated earlier than the medium maturing varieties, Chishango, MGV4 and Kanjute as shown in Table 6. The rate of germination seemed to be related to crop maturity, with the early maturing varieties germinating earlier than the medium maturing varieties as is evident in Table 6. The effects of tillage and tillage-variety interaction on days to 50 % germination were not significant as shown in Tables 7 and 8.

Plant height was significantly affected by both tillage and variety (Tables 6 and 7). However the tillage-variety interaction was not significant for plant height. Plants grown in conventional tillage plots were taller than those from conservation farming fields. Heights of plants in CV fields were 13.4 and 36.4cm, compared to CT and CF with 11.9 and 24.9, and 11.4 and 28.4cm at both growth stages (table 6). CT and CF were not significantly different. At 32 days after sowing, Kanjute had the tallest plants and Chishango the shortest, but at 66 days after sowing, Katete had the tallest plants and Chishango and MGV4 the shortest (Table 7).

Groundnut plants under conventional tillage were taller and more vigorous in comparison to the conservation systems which also showed chlorosis between the second and fourth weeks after germination. This could be attributed to nitrogen stress. When tillage is minimized, mineralization and nitrification are reduced, coupled with increased N immobilization and a higher potential for denitrification lead to a decrease in available N (Doran, 1980; Giller et al., 1997; Abiven and Recous, 2007). The previous crop's residue was maize which had a high C:N of 57:1, and when added to soil will result in a temporary nitrogen deficit (USDA NRCS, 2011). The N stress commonly observed in CA systems may result in depressed plant vigor and growth during the early stages of plant growth (Verhulst et al., 2010).

The lower growth under CT and CF could also be as a result of the higher bulk densities and lower infiltration observed in these systems. Duruoha et al (2008) showed that increases in bulk density substantially reduced peanut root volume. This greatly affected nutrient and water uptake.

Plants under CV had the highest amount of both below and above ground biomass with the interaction of Kanjute under CV producing the highest amount of above ground biomass. Kanjute is a local variety which may be adapted to the local soil and climatic conditions, and cultivation under conventional systems, and was thus able to outperform the other varieties with regard to above ground biomass. At 55 days after sowing, the early maturing varieties had the highest below ground biomass as they were already producing pods, compared to the medium maturing varieties which had not yet started production and filling of pods as is evident in figure 8. This can also be supported by the earlier flowering exhibited by Luena and Katete, which flowered a week earlier than the medium maturing varieties (table 13). Further, uniformly density greatly reduce the incidence of groundnut rosette virus disease as the vector of the disease often alight preferentially on widely spaced plants (Naidu et al., 1999). Plant cover under the conventional system was denser than the conservation systems.

The canopy to root ratio was not significant for the tillage methods as is shown in Table 6. Table 7 and 8 showed that the variety and variety-tillage interaction were significant, with the early maturing varieties having lower ratios than the medium maturing varieties.

Table 6: Effect of different tillage system on germination, plant height and biomass in groundnut (*Arachis hypogea*)

Tillage system		Plant height (cm)		Biomass at 55 days		
	Days to 50% Germination	32 days after sowing	64 days after sowing	Above Ground	Below Ground	Canopy; root
Conventional tillage	8a	13.4a	36.4a	32.09a	2.97a	14.38
Conservation tillage	8a	11.9b	29.8b	16.56b	1.84b	13.01
Conservation farming	9a	11.4b	28.4b	13.80c	1.88b	10.44
LSD	0.923	0.535	2.000	0.978	0.472	
P-value	0.828ns	<0.001**	<0.001**	<0.001**	<0.001**	0.023ns

Table 7: Differences in groundnut (*Arachis hypogea*) varieties development when grown under different tillage systems

Variety		Plant height (cm)		Biomass at 55 days		
	Days to 50% Germination	32 days after sowing	64 days after sowing	Above ground (canopy)	Below ground	Canopy: Root
Chishango	9a	11a	28a	17.72 a	1.13 a	14.87b
Katete	7b	12b	36b	19.48 b	3.70 b	5.09c
MGV4	10a	12bc	28a	20.15 b	1.22 a	19.24a
Luena	7b	13c	33c	19.88 b	3.56 b	6.61c
Kanjute	10a	14d	33cd	26.86 c	1.53 a	17.24ab
LSD	1.191	0.690	2.582	1.262	0.609	3.587
P-value	< 0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**

Table 8: Effects of tillage system on germination and plant height in five groundnut varieties (*Arachis hypogea*) grown under different tillage systems

Tillage system	Variety	Days to 50% Germination	Plant height (cm) at 32 DAS	Plant height (cm) at 64 DAS	Biomass at 55 days Canopy	Biomass at 55 days Root	Canopy: Root
Conventional tillage	Chishango	9	11.40	33.42	30.13	1.43	21.24
	Katete	7	12.93	41.50	31.27	5.27	5.95
	MGV4	9	12.80	31.42	26.95	1.90	14.18
	Luena	7	13.87	38.58	32.95	4.22	11.25
	Kanjute	10	16.00	36.83	39.17	2.03	19.27
Conservation tillage	Chishango	10	12.53	25.58	16.13	1.37	11.80
	Katete	7	11.13	33.33	14.10	2.83	4.98
	MGV4	10	11.60	28.58	14.10	0.55	27.06
	Luena	7	12.20	29.67	15.90	3.00	5.41
	Kanjute	9	13.93	31.58	22.57	1.43	15.80
Conservation farming	Chishango	10	10.00	35.33	16.90	0.60	11.57
	Katete	7	10.73	32.58	13.07	3.00	4.35
	MGV4	10	11.47	23.67	19.40	1.20	16.48
	Luena	7	11.73	30.67	10.80	3.45	3.16
	Kanjute	10	13.27	29.50	18.83	1.13	16.63
LSD %		2.064	1.195	4.472	2.186	1.056	6.213
P-value		0.945 ns	0.765ns	0.590ns	<0.001**	0.091ns	0.002*

Figure 9: Above and below ground biomass in groundnut varieties at 55 days after sowing.

A: Chishango, B. Luena. Left to right: Conventional tillage, Conservation tillage and Conservation farming.

4.3.2. Nodulation and Biological Nitrogen Fixation

Nodules in all the treatments were active when analyzed. They all had the characteristic pink/reddish colour inside indicating active nodules as shown in Figure 9 below.

Figure 10: Groundnut root nodule effectiveness at 55 days after sowing.

Left to right: Conventional tillage, Conservation tillage and Conservation farming.

Results presented in Tables 9, 10 and 11 showed that nodule number varied significantly due to tillage, while variety and tillage-variety interaction had no significant effect. Nodule number under CV was significantly higher with 122 nodules per plant, than CT and CV which had 95 and 83 nodules per plant, respectively. Number of nodules per plant under CT and CV were not different. Albeit small, the higher number of nodules resulted in the highest yield under CV and can be attributed to the higher root biomass, giving a larger root area for nodule initiation and function. Tajima et al (2007) in their study on nitrogen fixing activity of root nodules in relation to their size in groundnut found that the activity of nodules was closely related to their size, and that medium sized nodules were the most active. On the other hand, Mweetwa et al (2014) suggested that nodule efficiency maybe more important in determining the amount of nitrogen fixed than nodule number or fresh weight. Nodule weight and BNF did not differ significantly among tillage systems, varieties and their interaction.

Table 9: Effects of tillage system on nodule number, nodule weight and BNF in groundnut

Tillage System	Parameter		
	Nodule Number/plant	Nodule Weight (g)	Biological Nitrogen Fixation (%)
CV	122a	0.44a	3.80a
CT	95b	0.44a	5.13a
CF	83b	0.41a	3.00a
LSD	19.60	0.09	3.03
P-value	0.001**	0.776ns	0.359ns

Table 10: Nodule number, nodule fresh weight and biological nitrogen fixation of groundnut varieties (*Arachis hypogea*) pooled for different tillage systems

Variety	Nodule Number/plant	Nodule Weight (g/plant)	Biological Nitrogen Fixation (%)
Chishango	89	0.38	7.11
Katete	98	0.43	2.44
MGV4	96	0.38	3.33
Luena	110	0.45	3.44
Kanjute	107	0.55	3.56
P-value	0.445ns	0.103ns	0.159ns

Table 11: Effect of tillage system on nodule number per plant, nodule fresh weight per plant and biological nitrogen fixation (%) in five groundnut (Arachis hypogea) varieties

Tillage system	Variety	Parameter		
		Nodule number	Nodule weight	Biological nitrogen fixation
Conventional tillage	Chishango	11	0.40	7.33
	Katete	124	0.51	5.00
	MGV4	114	0.37	3.33
	Luena	127	0.36	2.33
	Kajute	128	0.58	1.00
Conservation tillage	Chishango	93	0.43	7.33
	Katete	98	0.42	2.00
	MGV4	96	0.42	5.67
	Luena	96	0.48	7.00
	Kajute	92	0.46	7.00
Conservation farming	Chishango	58	0.30	6.67
	Katete	72	0.36	0.33
	MGV4	78	0.34	1.00
	Luena	106	0.53	4.33
	Kajute	100	0.53	2.67
P-value		0.844ns	0.463ns	0.662ns

4.3.3. Growth and yield characteristics

Table 12 showed effects of tillage systems on reproductive parameters. Conventional had highest number of pods per plant, and 100- seed weight and consequently it had significantly higher yield compared to the other two. Number of days to flowering and pegging were not significantly affected by tillage system. These results are similar to a study by Sessiz et al (2010), which compared Conventional tillage and conservation tillage in maize that did not find any significant differences in germination date. Analysis of variance for 100 seed weight showed significant differences between tillage methods with weights of 56.81 g under CV and, 55.08 g and 54.24g from CT and CF respectively. CV and CF were not different. The conventional tillage treatment had the highest number of pods per plant (24.63 pods per plant) compared to Conservation tillage (19.85 pods per plant) and Conservation farming (18.43 pods per plant). CT did not differ from CF. Ridges under conventional farming loosen the soil, making it easier for pod penetration and groundnut growth and development; hence the higher number of pods under conventional tillage. Groundnut yield was highest under conventional farming, with conservation tillage and conservation farming not having any difference in yield. The main reasons for these differences in yield were due to number of pods per plant and the 100- seed weight. CV had the highest reading for these two parameters. This higher yield under conventional tillage can be attributed to the lower bulk density and higher porosity as well as the higher number of root nodules on the groundnut plants. Previous researches on legume growth and yield influenced by tillage system have shown varying results. Lasisi and Aluko, 2009, and Woznaik 2013 have both found higher yields under Conventional tillage compared to minimum tillage in a variety of legume crops, while Omondi et al 2014 found lower yields under conventional farming compared to minimum tillage. Studies in which groundnut crop was used showed higher yields under Conservation farming than the conventional systems (Rabo et al., 2013; Grichar, 1998)

All the varieties showed significant differences in terms of number of days to flowering and pegging, number of pods per plant and 100 seed weight as is evident in table 13. This was because Virginia and Spanish variety classes were used in this study and these are medium and early maturing respectively. Katete and Luena varieties flowered and produced pegs earlier than Chishango, Kanjute and MGV4. MGV4 and Kanjute were different from the other varieties, with the two varieties having the highest seed weights and Katete, the lowest. This is as a result of varietal differences as Kanjute, MGV4 and Chishango are large seeded Virginia types and Katete and Luena are small seeded Spanish types. Katete and Kanjute were different from all the other varieties, with Katete having the highest number of pods and Kanjute the lowest. Although Kanjute grew faster at the beginning of the season, it had the lowest number of pods per plant but highest seed weight. The variety seems to have invested more of its resources in biomass production at the expense of pod production, although the seed weight was highest.

Table 12 showed the effects of tillage method on the reproductive parameters. The only parameter that showed significant difference was the number of pods per plant, with the interaction of Katete under conventional tillage producing the highest number of pods per plant. Kanjute had the worst interactions, and produced the lowest number of pods per plant under all the tillage methods.

Table 12: Number of days to flowering, number of days to peg formation, grain yield and 100- seed weight in groundnuts *(Arachis hypogea*) grown under different tillage methods

Tillage method	Parameter					
	Days to 50 % Flowering	Days to 50 % Pegging	Number of pods per plant	100 seed weight (g)	Yield (t/ha)	Total Biomass (kg)
Conventional	40a	47a	25a	56.8a	2.13a	43.4a
Conservation T	42a	48a	20b	55.1b	1.55b	35.1b
Conservation F	41a	47a	18b	54.2b	1.42b	37.7ab
LSD (0..05)	1.043	1.188	2.552	1.592	0.227	5.93
P-value	0.084ns	0.232ns	<0.001**	0.008**	<0.001**	0.010*

Table 13: Differences in groundnut (*Arachis hypogea*) varieties growth and yield characteristics when grown under different tillage systems

Variety	Parameter					
	Days to 50 % Flowering	Days to 50 % Pegging	Number of pods per plant	100 seed weight (g)	Yield (t/ha)	Total Biomass (kg)
Chishango	45b	51b	21b	54.6b	1.52b	45.7b
Katete	36a	42a	27a	36.5d	1.80ab	23.9c
MGV4	44b	50b	21b	67.9a	1.86a	48.3ab
Luena	36a	41a	21b	50.0c	1.52b	21.7c
Kanjute	45b	52b	15c	67.9a	1.79ab	54.1a
P-value	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**
LSD (0.05)	1.346	1.534	3.295	2.056	0.293	7.66

Table 14: Effects of tillage system on yield parameters in five groundnut varieties (*Arachis hypogea*) grown under different tillage systems

Tillage system	Variety	Parameters					
		Days to Flowering	Days to peg Formation	100- seed weight (g)	Number of pods per plant	Yield (t/ha)	Total biomass (kg)
Conventional tillage	Chishango	45	51	57.03	21.53	1.91	47.9
	Katete	35	41	37.37	35.73	2.39	30.9
	MGV4	42	48	68.73	25.07	2.52	51.3
	Luena	36	42	51.53	26.60	1.66	27.3
	Kanjute	45	51	69.40	14.20	2.12	59.5
Conservation tillage	Chishango	45	52	54.93	20.87	1.39	44.2
	Katete	36	42	36.73	24.60	1.60	20.8
	MGV4	45	51	68.17	18.93	1.55	40.2
	Luena	36	41	48.07	19.80	1.33	17.6
	Kanjute	46	53	67.50	15.80	1.88	52.8
Conservation farming	Chishango	45	51	51.87	21.87	1.24	45.1
	Katete	36	42	35.27	20.73	1.40	20.1
	MGV4	45	51	66.70	17.73	1.51	53.5
	Luena	36	41	50.50	16.67	1.57	20.1
	Kanjute	45	51	66.87	15.13	1.37	50.0
P-value		0.502ns	0.631ns	0.546ns	0.010*	0.152ns	0.762ns
LSD		2.331	2.656	3.561	5.706	0.50	13.26

Chapter 5. CONCLUSION AND RECOMMENDATIONS

The primary objective of this study was to determine the effect of tillage systems on selected soil properties and yields in different groundnut germplasm. The study therefore tried to determine whether these responses to different tillage systems were genotypic specific or general. Under the soil and climatic conditions where this study was undertaken, the conventional practice outperformed the conservation tillage and conservation farming systems. Porosity, plant height, 100- seed weight, number of pods per plant, and yield were highest and bulk density lowest under conventional tillage. Thus the main effect of the tillage method was on soil bulk density, which was high in the CF and CT. Differences in yield were transduced by impact on number of pods per plant and weight of the seeds.

The study demonstrated variable effects of different tillage systems on soil physical properties and ultimately effects on crop yields. The results indicated that for groundnuts conventional farming systems is still better than conservation farming or tillage. In order to further validate these results, more research needs to be done in various agro-ecological zones, under different soil types and over several years.

6.0 REFERENCES

Aagaard P., 2003. Conservation Farming Handbook for hoe farmers in agro-ecological zone I and II flat culture, Lusaka: Conservation Farming Unit.

Abiven S., and S. Recous, 2007. Mineralization of crop residues on the soil surface or incorporated in the soil under controlled conditions. Biology Fertility Soils 43: 849 – 852. Accessed from http://www.icrisat.org/newsroom/latest-news/happenings

Aikins S.H.N., and J.J Afuakwa, 2012. Effect of four different tillage practices on soil physical properties under cowpea, Agriculture and Biological Journal of North America, 3: 17-24

Akolgo J.A., G.T. Kwadzo and D.P.K. Amegashie, 2014. Comparison of the profitability of groundnut production in west mamprusi and bunkpurugu-yuyoo districts in northern Ghana, Global Journal of Biological, Agriculture and Health Sciences, Vol 3:144-151.

Awada L., C.W. Lindwall and B. Sonntag, 2014. The development and adoption of conservation tillage systems on the Canadian prairies, International soil and water research Vol. 2:47-65.

Baker C.J., K.E. Saxton and W.R. Ritchie, 2002. No-tillage seeding: science and practice. In CAB International 2nd edn, Oxford, UK.

Balota E.L., A.C. Filho, D.S. Andrade, and R.P. Dick, 2004. Longterm tillage and crop rotation effects on microbial biomass and C and N mineralization in Brazilian oxisol. Soil and tillage research 77: 137-145.

Baudeon F., H.M. Mwanza, B. Triomphe, and M. Bwalya, 2007. Conservation Agriculture in Zambia: a case study of Southern Province. Nairobi African Conservation Tillage Network, FAO, CIRAD.

Black C.A., 1965. Methods of soil analysis, Part I, American Society of Agronomy, Madison, Wisconsin, USA.

Blake G.R., and K.H. Hartge, 1986. Methods of soil analysis part 1, Bulk density (2nd ed.), Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Brady N.C., and R.R. Weil, 1996. The nature and properties of soils (11th ed.), Prentice hall, New York.

Brennan J.R., 1969. The Peanut gynophore, Biologist 51:71 – 82.

CFS/MAL, Annual reports for 2002-2015 Crop Forecast Survey (CFS) Data, Lusaka, Zambia: CFS/MAL

Chapman H.D., 1965. Cation exchange capacity. In: Black C.A., Ensminger L.E., Clark F.E., (Eds). Methods of Soil Analysis. Agronomy 9: pp. 891-901. American Society of Agronomy, Inc., Madison, Wisconsin.

Conservation Farming Unit, 2011. The practice of conventional and conservation agriculture in east and southern Africa. Conservation Farming Unit, ZNFU.

Conservation Tillage Information Center, 2004. 'National crop residue management survey.' (Conservation Technology Information Center: West Lafayette, IN)

Coolman R.M., and G.D. Hoyt, 1993. The Effects of Reduced Tillage on the Soil Environment, HortTechnology: 3:143-145

Doley K., and P.K. Jite, 2012. Response of groundnut (JL-24) cultivar to mychorrizae inoculation and phosphorus application, Not Sci Bio 4:118-125.

Doran J.W., 1980. Soil Microbial and biochemical changes associated with reduced tillage, Soil Sci. Soc. Am. Journal 44:765-771

Duruoha C., C.R. Piffer, and P.R.A. Silva, 2008. Root volume and dry matter of peanut plants as a function of soil bulk density and soil water stress, Irriga, Botucatu V.13, P. 170-181.

Dwivedi S. L., J.H. Crouch, S.N. Nigam, M.E. Ferguson and A. Paterson, 2003. Molecular breeding of groundnut for enhanced productivity of security of food security in the semi-arid tropics: opportunities and challenges. *Adv. Agron.* 80: 221

Fairhurst T., (Ed.), 2012. Handbook for Integrated Soil Fertility Management, Africa Soil Health Consortium, Nairobi.

Exploratory soil map of Zambia, 1991. Soil survey section, Ministry of Agriculture, Zambia.

FAO, 2007. What is conservation Agriculture? Assessed from www.fao.org

FAO, 2014. Agriculture and Consumer Protection Department. What is conservation agriculture? Accessed from http://www.fao.org/ag/ca.html

FAO, 2014. What is conservation Agriculture? Assessed from www.fao.org

FAOSTAT, 2013. Crop productivity Accessed from http//www.faostat.fao.org

Farnworth C.R., V.M. Akamandisa, and M. Hichambwa, (2011). Zambia Feed the Future Gender Assessment Report.

Ferreiraa C. M, D. Andradeb, L.M. Chueirea, S.M. Takemura and M. Hungriaa, 2000. Tillage method and crop rotation effects on the population sizes and diversity of bradyrhizobia nodulating soybean, Soil Biology and Biochemistry, Elsevier Science ltd, 32: p627 – 637.

Friedrick T., R. Derpsch and A. Kassam, 2012. Overview of the global spread of Conservation Agriculture, Reconciling Poverty eradication and Protection of the Environment – Special Issue 6.

Garreston C, 1999. Soil water content determination. Environmental monitoring branch, California department of pesticide regulation, Sacramento. Accessed from: www.cdpr.ca.gov./docs/empm/pubs/sop.htm

Gatere L., J. Lehmann, S. DeGloria, P. Hobbs, R. Delve, and A. Travis, 2013. One Size does not fit all: Conservation farming success in Africa more dependent on management than on location, Agriculture, Ecosystems and Environment 179: 200 – 207.

Giller K. E., G. Cadisch, C. Ehaliotis, E. Adams, W.D. Sakala, and P.L. Mafongoya, 1997. Building soil nitrogen capital in Africa. Replenishing soil fertility in Africa, Special edition No. 51:151-192.

Giller K.E., E. Witter, M. Corbeels and P. Tittonell, 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view, Field crops research 114:23-34

Grantina L., K. Kenigsvalde1, D. Eze, P. Zaiga, I. Skrabule, N. Rostoks, and V. Nikolajeva, 2011. Impact of six-year-long organic cropping on soil microorganisms and crop disease suppressiveness, Žemdirbystė=Agriculture, 98:399–408.

Grayston S.J., W. Shenquiang, and C. Campbell, 1993. Selective influence of plant species on microbial diversity in the rhizosphere. Soil Biol. and Biochem, 3: 369-378.

Grichar W.J., 1998. Long term effects of three tillage systems on Peanut grade, yield and stem rot development, Peanut Science 25:27

Haro R. J., A. Mantee, and M.E. Otegui, 2011. Peg viability and pod set in peanut: Response to impaired pegging and water deficit. Flora 206(2011)865-871.

Hobbs P.R., K. Sayre, and R. Gupta, 2008. The role of conservation agriculture in sustainable agriculture, Royal Society Publishing, Phil.Trans.R.Soc.B 363:543-555.

IAPRI, 2015. Rural agriculture livelihoods survey report

ICRISAT, 2015. Zambia releases five new groundnut varieties after seven years, ICRISAT Happenings No. 1698

ICRISAT-ZARI. 2013. Aflatoxin, Health Effects and Detection in Human Blood and in Crops. Power point presentation at the USAID partners meeting, 19-20 March. Chipata, Zambia.

IndexMundi, 2015. Zambia's GDP: Composition by Sector. Accessed from www.indexmundi.com/factbook/zambia

Jambunathan R., 1991. Groundnut quality characteristics. In: Uses of tropical grain legumes, Proceedings of consultants meeting, Patancheru, 27-30 March, 1989 pp 267-275, ICRISAT.

Kabamba H. and A. Muimba-Kankolongo. 2009. Adoption and Impact of Conservation. Farming on Crop Productivity among Smallholder Farmers in Kapiri Mposhi District of Zambia. Journal of Animal and Plant Sciences 3.2: 205–214.

Kochert G., H.T. Stalker, M. Gimenes, L. Galgaro, C.R. Lopes, and K. Moore, 1996. RFLP and cytogenetic evidence on the origin and evolution of allotetraploid domesticated peanut, *Arachis hypogaea* (Leguminosae) American Journal of Botany, 83:1282–1291.

Kombiok, J.M., E.Y. Safo, and C. Quansah, 2005. Yield and Nitrogen Fixation of Cowpea as affected by tillage and Cropping Systems in the Northern Savanna Zone of Ghana, West African J. Appl. Ecol., 7: 95-108.

Lasisi D., and O.B. Aluko, 2009. Effects of tillage methods on soybean growth and yield in a tropical sandy loam soil, International Agrophysics Journal 23nr. 2.

Madhusudhana B., 2013. A survey on area, production and productivity of groundnut crop in India, IOSR Journal of Economics and Finance, 3: 1-7.

Malecka I., A. Blecharczyk, Z. Sawinska, and T. Dobrzeniecki, 2012. The effect of various long-term tillage systems on soil properties and spring barley yield, Turk J Agric 36: 217 – 226

Mallikarjuna N., and R.K. Varshney, 2014. Genetics, genomics and breeding of peanut: An introduction.

Mikanová O., T. Šimon, M. Javůrek, and M. Vach, 2012. Relationships between winter wheat yields and soil carbon under various tillage systems, Plant Soil Environment 58, 2012 (12): 540–544

Mtonga E.M., 2012. Discussion paper on Cooperatives and Market access in Zambia. Accessed from www.fes-zambia.org

Muchabi J., O. Lungu, and A.M. Mweetwa 2014. Conservation Agriculture in Zambia: Effects on selected soil properties and biological nitrogen fixation in soya beans, Sustainable Agricultural Research, Vol 3.

Mukuka R. M., and A.M. Shipekesa, 2013. Value Chain Analysis of the groundnut sector in the Eastern Province of Zambia. The Indaba Agricultural Policy Research Institute (IAPRI), Working Paper number 78.

Mweetwa A.M., M. Mulenga, X. Mulilo, M. Ngulube, J.S.K. Banda, N. Kapulu, and S.H. N'gandu, 2014. Response of cowpea, soyabeans and groundnut to non-indegenous legume innoculants. Sustainable Agricultural Research; Vol 3 No. 4.

Naidu R.A., F.M. Kimmins, C.M Doem, P. Subrahmanyam, A.J. Chiyemnekeza, and P.J.A. Van der Merwe, 1999. Groundnut Rosette: A virus disease affecting groundnut production in Sub-Saharan Africa, Plant Diseases vol.83 no. 8, American Phytopathological Society.

National Medium Term Investment Programme, 2004. Support to NEPARD-CAADP implementation, Vol I.

Ntare B. R., A.T. Diallo, J. Ndjeunga, and F. Waliyar, 2008. Groundnut Seed Production Manual, ICRISAT/CFC/FAO.

OECD, 2001. Environmental indicators of Agriculture – Vol 3: Methods and results pages 389-391.

Okello D.K., P. Okori, P. Naveen, B.U. Boris, C.M. Deom, J. Ininda, P. Anguria, M. Biruma, and C. Asekenye, 2015. Groundnut Seed Production for Uganda, National Agriculture Research Organisation.

Okoth O. J., N.W. Mungai, J.P. Ouma, and P.F. Baijukya, 2014. Effect of tillage on biological nitrogen fixation and yield of soybean varieties, Australian Journal of crop science

Olsen S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean, 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate, USDA circular.

Omondi J. O., N.W. Mungai, J.P. Ouma, and F.P. Baijukya, 2014. Effect of tillage on biological nitrogen fixation and yield of soybean (Glycine max L. Merril) varieties, Australian Journal of Crop Sciences 8(8):1140-1146

Osunbitan, J. A., J.D. Oyedele, and K.O. Adekalu, 2005. Tillage effects on bulk density hydraulic conductivity and strength of a loam sand soil in Southwestern Nigeria. *Soil & Tillage Research*, 82: 57-64.

Otsuki T., J.S. Wilson, and M. Sewadah, 2001. What price precaution? European harmonization of aflatoxin regulations and African groundnut exports. European review of agricultural economics vol. 28: 263-283.

Pandey M.K., E. Monyo, P. Ozias-Akins, X. Liang, P. Guimarães, S.N. Nigam, H.D. Upadhyaya, P. Janila, X. Zhang, B. Guo, D.R. Cook, D.J. Bertioli, R. Michelmore, and R.K. Varshney, 2012. Advances in Arachis Genomics for peanut improvement, Biotechnical Advances, Vol 30, Issue3: 639-651

Periasamy K., and C. Sampoornam, 1984. The morphology and anatomy of ovule and fruit development in *Arachis hypogeae* L., Annals of Botany 53:399-411.

Prasad P.V.V., G.V. Kakani and H.D. Upadhyaya, 2010. Growth and Reproduction of groundnut – Soils, Plant growth and Crop production vol. II, Encyclopedia of Life Support systems.

Purselglove J.W., 1974. Tropical Crops – Dicotyledons, John Wiley and Sons Publishing.

Putnam D. H., Oplinger E.S., Teynor T.M., Oelke E.A., Kelling K.A., Doll J.D., (1991). Peanut, Alternative Field Crops Manual, University of Minnesota.

Rabo A.S., and H.G. Ahmed, 2013. Effects of tillage practice on the growth and yield of groundnut at Dambatta, Nigeria, International journal of science and technology, Vol2:7.

Rockström, J., P. Kaumbutho, J. Mwalley, A. Nzabi, M. Temesgen, L. Mawenya, J. Barron, J. Mutua and S. Damgaard-Larsen, 2009. Conservation farming strategies in east and southern Africa: Yields and rainwater productivity from on-farm action research, Soil and Tillage Research, 103: 23-32.

Rogers D. H., J. Aguilar, I. Kisekka, P.L. Barnes and F.R. Lamm, 2015. Important agricultural soil properties, Ogallala aquifer program grant. Assessed from: https://www.ksre.k-state.edu/irrigate/reports/r15/L935.pdf

Ross, S., and M. De Klerk, 2012. Groundnut value chain and marketing assessment in Eastern Province, Zambia, Prepared for Eastern Province

Rowell D.L., 1994. Soil Science: Methods and Applications. Addison Wesley Longman Singapore Publishers (pte) Ltd., UK.

Schüßler A., D. Schwarzott and C. Walker 2001. A new fungal phylum, the Glomeromycota, phylogeny and evolution. Mycol Res 105:1413-1421.

Sessiz A., A. Alp and S. Gursoy, 2010. Conservation and Conventional Tillage Methods on Selected Soil Physical Properties and Corn (Zea Mays L.): Yield and Quality

under Cropping System in Turkey, Bulgarian Journal of Agricultural Science, 16: 597-608

Shitumbanuma V., and D. Banda, 2004. Soil changes associated with conservation farming under small scale farming conditions in Monze and Mumbwa districts of Zambia (unpublished report). Department of soil science, School of Agricultural Sciences, University of Zambia, Lusaka.

Siamasonta B.M., K. Kanenga, J.C. Musanya and P.M. Hamazakaza, 2000. Recommendations for improved groundnut production in Zambia, Ministry of Agriculture, Food and Fisheries.

Singh F., and B. Diwakar, 1993. Nutritive value and uses of pigeonpea and groundnut, HRDP: 302-324

Sitko N.J., A. Chapoto, S. Kabwe, S. Tembo, M. Hichaambwa, R. Lubinda, H. Chiwawa, M. Mataa, S. Heckand D. Nthani, 2011. Technical Compendium: Descriptive Agricultural Statistics and Analysis for Zambian Support of the USAID Mission's Feed the Future Strategic Review. Working Paper no. 52, Food Security Research Project.

Smartt J., 1994. The Groundnut Crop – A Scientific Basis for Improvement, Chapman and Hall.

Stepman F., 2013. A report on the Groundnut value chain analysis in Zambia, Agriculture Consultative Forum.

Stevenson C. K., and G.S. Lier, 1991. The effects of soil compaction the production of vegetables and field crops: a review, Ontario land stewardship program.

Tajima R., O.N. Lee, J. Abe, A. Lux, and S. Morita, 2007. Nitrogen –Fixing activity of root nodules in relation to their size in peanut (*Arachis Hypogaea L.*), Plant Production Science 10 (4): 423 – 429.

Tembo S., and N. Sitko, 2013. Technical compendium: Descriptive Agricultural statistics and analysis for Zambia, Working paper 76, Indaba Agricultural Policy Research Institute.

Thierfelder C., and P. Wall, 2009. 'Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe', Soil and Tillage Research, 105(2): 217-27.

Thierfelder C., and P. Wall, 2010. 'Investigating conservation agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change', Journal of Crop Improvement, 24: 113-21

Thierfelder C., M. Mwila and L. Rusinamhodzi, 2012. Conservation agriculture in eastern and southern provinces of Zambia: Long-term effects on soil quality and maize productivity, Soil & Tillage Research 126: 246–258.

Thomas G. A., R.C. Dalal and J. Standley, 2007. No-till effect on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. Soil Till Res 94: 295-304.

Umar B. B., 2012. Reversing Agro-Based Land Degradation through Conservation Agriculture: Emerging Experiences from Zambia's Smallholder Farming Sector, Sustainable Agriculture Research; Vol 1:72-87

Umar B. B., J.B. Aune, F.H. Johnsen and O.I Lungu, 2011. Options for Improving Small holder Conservtion Agriculture in Zambia, Journal of Agricultural Science 3(3):50.

Umar, B. B., H.N. Progress, and B.A. Jens, 2011. Conservation agriculture: an innovation for increasing food security among small holders in Zambia. Department for International Environment and Development Studies, Norwegian University of Life Sciences, Norway.

United States Development Agency, 2011. Carbon to Nitrogen ratios in Cropping systems, 2011. USDA Natural Resources Conservation Service, soils.usda.gov

Unkovich M., D. Herridge, M. Peoples, G. Cadisch, B. Boddey, K. Giller, B. Alvis and P. Chalk, 2008. Measuring plant associated nitrogen fixation in agricultural systems, ACIAR Monograph 136:258pp

Upadhyaya H.D., and S.L. Dwivedi, 2015. Global Perspectives on Groundnut Production, Trade, and Utilization: Constraints and Opportunities, In: Lead Papers at National Seminar on Technologies for Enhancing Oilseeds Production through NMOOP, January 18-19, 2015, India.

Van Reeuwijk, L.P., 1992. Proceedings for soil analysis, (3rd Ed.), International soil Reference and Information Center (ISRIC), Wageningen, Netherlands

Verhulst, N., and B. Govaerts, 2010. The Normalized Difference Vegetative Index (NDVI) greenseeker handheld sensor: Towards the integrated evaluation of Crop Management. Part A: Concepts and case studies, CYMMT Mexico.

Vessey, J. K., K. Powlowski and B. Bergman, 2004. Root based N_2 fixing symbiosis: Legumes, actinorhizal plants, parasponia sp. and cycads. Plant and Soil 266: 205-230.

Walkley, A., and I.A. Black, 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil science journal.

Woodroof, J. G., 1983. Peanuts Production, Processing, Products. 3th ed. Avi Publishing Company Inc. Westport, Connecticut.

Woomer, P. L. 2010. Biological Nitrogen Fixation and Grain Legume Enterprise: Guidelines for N2Africa Master Farmers. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture. Nairobi. 17 pp

Woznaik A., 2013. Yielding of Pea (*Pisum sativum L.)* under different tillage systems, Acta Sci. Pol., Hortorium Cultus 12(2) 2013.

Yang S. K., M.K. Kim, Y.W. Seo, K.J. Choi, S.T. Lee, Y.S. Kwak and Y.H. Lee, 2012. Soil microbial community analysis of between no-till and tillage in a controlled horticultural field. World Journal of Microbiology and Biotechnology, 28: 1797–1801.

7.0 APPENDIX I – ANALYSIS OF VARIANCE TABLES

Variate: Groundnut Yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	1.11051	0.55525	6.02	
rep.*Units* stratum					
tillage	2	4.25325	2.12662	23.06	<.001
variety	4	0.95560	0.23890	2.59	0.058
tillage.variety	8	1.22768	0.15346	1.66	0.152
Residual	28	2.58165	0.09220		
Total	44	10.12868			

Table	tillage	variety	tillage/variety
l.s.d.	0.227	0.293	0.508

Variate: Total_biomass_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	733.93	366.97	5.83	
rep.*Units* stratum					
tillage	2	536.19	268.10	4.26	0.024
variety	4	7970.81	1992.70	31.68	<.001
tillage.variety	8	307.07	38.38	0.61	0.762
Residual	28	1761.23	62.90		
Total	44	11309.23			

Table	tillage	variety	tillage/variety
l.s.d.	5.93	7.66	13.26

Variate: Plant Height (cm) at 32 days after sowing

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	14.1813	7.0907	13.89	
rep.*Units* stratum					
tillage	2	31.7280	15.8640	31.07	<.001
variety	4	70.4836	17.6209	34.51	<.001
tillage.variety	8	2.4764	0.3096	0.61	0.765
Residual	28	14.2987	0.5107		

Total	44	133.1680	
Table	tillage	variety	tillage/variety
l.s.d.	0.535	0.690	1.195

Variate: Plant Height (cm) at 64 days after sowing

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	14.1813	7.0907	13.89	
rep.*Units* stratum					
tillage	2	31.7280	15.8640	31.07	<.001
variety	4	70.4836	17.6209	34.51	<.001
tillage.variety	8	2.4764	0.3096	0.61	0.765
Residual	28	14.2987	0.5107		
Total	44	133.1680			

Table	tillage	variety	tillage/variety
l.s.d.	0.535	0.690	1.195

Variate: nodule weight (g)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.37436	0.18718	11.79	
rep.*Units* stratum					
tillage	2	0.00811	0.00406	0.26	0.776
variety	4	0.13569	0.03392	2.14	0.103
tillage.variety	8	0.12606	0.01576	0.99	0.463
Residual	28	0.44439	0.01587		
Total	44	1.08861			

Table	tillage	variety	tillage/variety
l.s.d.	0.0942	0.1217	0.2107

Variate: nodule number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	3972.3	1986.2	2.89	
rep.*Units* stratum					
tillage	2	11714.9	5857.5	8.53	0.001
variety	4	2636.8	659.2	0.96	0.445
tillage.variety	8	2757.3	344.7	0.50	0.844
Residual	28	19230.5	686.8		
Total	44	40311.9			

Table	tillage	variety	tillage/variety
l.s.d.	19.60	25.31	43.83

Variate: BNF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	32.40	16.20	0.99	
rep.*Units* stratum					
tillage	2	34.84	17.42	1.06	0.359
variety	4	117.42	29.36	1.79	0.159
tillage.variety	8	96.04	12.01	0.73	0.662
Residual	28	458.93	16.39		
Total	44	739.64			

Table	tillage	variety	tillage/variety
l.s.d.	3.028	3.909	6.771

Variate: Below ground biomass at 55 days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.6072	0.3036	0.76	
rep.*Units* stratum					
tillage	2	12.4071	6.2036	15.56	<.001
variety	4	59.6956	14.9239	37.43	<.001
tillage.variety	8	6.2318	0.7790	1.95	0.091
Residual	28	11.1626	0.3987		
Total	44	90.1042			

Table	tillage	variety	tillage/variety
l.s.d.	0.4723	0.6097	1.0560

Variate: Above ground biomass at 55 days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	2.757	1.378	0.81	
rep.*Units* stratum					
tillage	2	2917.740	1458.870	853.85	<.001
variety	4	442.367	110.592	64.73	<.001
tillage.variety	8	290.796	36.350	21.27	<.001
Residual	28	47.840	1.709		
Total	44	3701.501			

Table	tillage	variety	tillage/variety
l.s.d.	0.978	1.262	2.186

Variate: Number of pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	11.06	5.53	0.48	
rep.*Units* stratum					
tillage	2	316.30	158.15	13.59	<.001
variety	4	675.53	168.88	14.51	<.001
tillage.variety	8	298.35	37.29	3.20	0.010
Residual	28	325.95	11.64		
Total	44	1627.20			

Table	tillage	variety	tillage/variety
l.s.d.	2.552	3.295	5.706

Variate: days to 50% pegging

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	5.378	2.689	1.07	
rep.*Units* stratum					
tillage	2	7.778	3.889	1.54	0.232
variety	4	970.578	242.644	96.20	<.001
tillage.variety	8	15.556	1.944	0.77	0.631
Residual	28	70.622	2.522		
Total	44	1069.911			

Table	tillage	variety	tillage/variety
l.s.d.	1.188	1.534	2.656

Variate: % porosity 0-5cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	46.31	23.15	1.20	
rep.*Units* stratum					
tillage	2	141.70	70.85	3.69	0.038
variety	4	35.05	8.76	0.46	0.767
tillage.variety	8	380.69	47.59	2.48	0.036
Residual	28	538.27	19.22		
Total	44	1142.02			

Table	tillage	variety	tillage/variety
l.s.d.	3.28	4.23	7.33

Variate: % Porosity 5-10cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	75.86	37.93	2.69	
rep.*Units* stratum					
tillage	2	120.83	60.41	4.29	0.024
variety	4	32.57	8.14	0.58	0.681
tillage.variety	8	75.05	9.38	0.67	0.716
Residual	28	394.10	14.08		
Total	44	698.41			

Table	tillage	variety	tillage/variety
l.s.d.	2.81	3.62	6.27

Variate: % Porosity 10-15cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	53.55	26.77	2.10	
rep.*Units* stratum					
tillage	2	181.89	90.94	7.13	0.003
variety	4	44.49	11.12	0.87	0.493
tillage.variety	8	39.06	4.88	0.38	0.921
Residual	28	357.12	12.75		
Total	44	676.11			

Table	tillage	variety	tillage
l.s.d.	2.67	3.45	5.97

Variate: % Porosity 15-20cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	159.81	79.91	6.22	
rep.*Units* stratum					
tillage	2	143.39	71.70	5.58	0.009
variety	4	31.72	7.93	0.62	0.654
tillage.variety	8	84.42	10.55	0.82	0.591
Residual	28	359.95	12.86		
Total	44	779.30			

Table	tillage	variety	tillage
l.s.d.	2.68	3.46	6.00

Variate: 100 seed weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	18.968	9.484	2.09	
rep.*Units* stratum					
tillage	2	51.660	25.830	5.70	0.008
variety	4	6304.831	1576.208	347.77	<.001
tillage.variety	8	31.853	3.982	0.88	0.546
Residual	28	126.905	4.532		
Total	44	6534.218			

Table	tillage	variety	tillage/variety
l.s.d.	1.592	2.056	3.561

Variate: bulk density 0-5 cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.03315	0.01658	1.24	
rep.*Units* stratum					
tillage	2	0.10280	0.05140	3.86	0.033
variety	4	0.02403	0.00601	0.45	0.771
tillage.variety	8	0.26326	0.03291	2.47	0.036
Residual	28	0.37298	0.01332		
Total	44	0.79623			

Table	tillage	variety	tillage/variety
l.s.d.	0.0863	0.1114	0.1930

Variate: bulk density 5-10cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.05232	0.02616	2.60	
rep.*Units* stratum					
tillage	2	0.08427	0.04214	4.18	0.026
variety	4	0.02503	0.00626	0.62	0.651
tillage.variety	8	0.05013	0.00627	0.62	0.752
Residual	28	0.28214	0.01008		
Total	44	0.49390			

Table	tillage	variety	tillage/variety

l.s.d.	0.0751	0.0969	0.1679

Variate: bulk density 10-15 cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.038773	0.019387	2.15	
rep.*Units* stratum					
tillage	2	0.130013	0.065007	7.21	0.003
variety	4	0.031013	0.007753	0.86	0.500
tillage.variety	8	0.024053	0.003007	0.33	0.946
Residual	28	0.252427	0.009015		
Total	44	0.476280			

Table	tillage	variety	tillage
l.s.d.	0.0710	0.0917	0.158

Variate: bulk density 15-20 cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	0.109960	0.054980	6.15	
rep.*Units* stratum					
tillage	2	0.098280	0.049140	5.49	0.010
variety	4	0.023231	0.005808	0.65	0.632
tillage.variety	8	0.058742	0.007343	0.82	0.591
Residual	28	0.250507	0.008947		
Total	44	0.540720			

Table	tillage	variety	tillage/variety
l.s.d.	0.0707	0.0913	0.1582

RESEARCH FIELD LAYOUT