A COMPARISON OF THE PERFORMANCE OF NAMIBIA-SPECIFIC CONSERVATION AND CONVENTIONAL TILLAGE TECHNOLOGIES AS USED FOR PEARL MILLET PRODUCTION IN NORTHERN NAMIBIA

A DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY OF THE UNIVERSITY OF NAMIBIA

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ABSTRACT

Studies were conducted over a period of three years (2011 to 2013) at the Ogongo Campus of the University of Namibia (UNAM), to compare the differences between tractors and animal-drawn implements both using conventional and Namibia Specific Conservation Tillage (NSCT) technologies. Two conventional tillage (CV) treatments (i.e. tractor-drawn disc harrow (TDH) and animal-drawn mouldboard plough (AMP) were compared to two NSCT treatments (tractor-drawn ripper furrower (TRF) and animal-drawn ripper furrower (ARF).

There were four specific objectives. The first objective is to compare the field performances of the two technologies each for the NSCT and CV on (i) depth of cut, (ii) width of cut, (iii) draught of the power source (iv) efficiency and (v) effective field capacity under Ogongo conditions. NSCT technologies (TRF and ARF) performed better than CV technologies (TDH and AMP) on depth of cut in all the three years. Though the NSCT technologies also resulted in higher draught forces than the CV technologies, however, the specific draught of NSCT technologies were better across the three seasons showing that they were more energy efficient than CV technologies. Tractor drawn tillage methods resulted in lower specific draught than animal-drawn tillage methods across the three years. ARF performed better than AMP in the last two years.

None of the tractor-drawn implements in the study met the ASAE Standards of Efficiency (70-90%). The on-station field efficiencies fell short by 16% for TDH and by 8% for TRF. Across the three years, the effective field capacities for tractor-drawn tillage methods were:

TDH = 0.68 ha hr^{-1}, TRF = 0.74 ha hr^{-1}. For animal-drawn tillage methods, the effective field capacities for AMP = 0.03 ha hr^{-1} and for ARF = 0.15 ha hr^{-1}, 80% better than AMP.

The second objective was to compare the field performances of the NSCT animal-drawn ripper-furrower techniques using single and double ripping methods with two and three donkeys on the same parameters as highlighted above. There were no significant differences in means of draught, effective field capacity, time per run and efficiency for all implements among ripping techniques. There were, however, significant differences for depth, width, speed and turn time among ripping techniques. There were also significant differences in depth and width between double ripping with three donkeys and single ripping with three donkeys showing that double ripping with three donkeys can achieve increased depth and width of cut. Moreover, double ripping with two donkeys can contribute to reduced turning time thereby improving on the time the animals take to do actual work.

The third objective, to compare the effects of the NSCT and CV technologies on soil moisture content, soil compaction (as measured by the penetration resistance), root development and yield of pearl millet under Ogongo conditions, showed significant differences ($p<0.001$) in penetration resistance (PR) among the tillage methods and a significant positive linear relationship between penetration resistance (PR) and depth in 2012 at planting and at harvesting for various depths for the four tillage technologies ($p<0.001$). In the farmers' fields, 31% (n=13) had PR values that were less than 2 MPa meaning that the fields for the rest of the farmers (69%) could have problems of soil compaction. For moisture results, there were significant ($p<0.003$) differences in moisture among tillage methods and interaction between time and tillage ($p<0.001$), with soil moisture peaks in February for every year. TRF resulted in the highest percentage increase in moisture content with 8.1%, whilst TDH

increased by 3.9%, ARF increased by 3.1%, AMP actually decreased by 3.1% over the two year period.

Yields were not significantly influenced by tillage technologies ($p = 0.410$ in 2011 and 0.078 in 2012) but root lengths were significantly influenced by tillage technologies in the second year ($p<0.005$). There were no significant differences in yield among mulch levels for all the tillage treatments. Both NSCT methods (TRFmulch and ARFmulch) achieved longer root lengths than CV methods (TDH and AMP) by 24.5% and 8.5% respectively. Tractor ripper furrower (TRF) achieved highest values of depth, wide furrows, increase in moisture and highest mean root length and yields in 2012. NSCT methods TRF and ARF achieved higher yields than CV methods TDH and AMP by 10% and 11% respectively.

Finally, for the fourth objective was to investigate whether the farmers in two Constituencies (Ogongo and Omuntele) who were introduced to the NSCT technology had the knowledge, attitude to practice (KAP) and adopt the technology. The farmers showed that they had some knowledge and positive attitudes towards NSCT but only practiced it when the implements were made available to them. NSCT technologies in this study showed more positive attributes throughout and therefore the NSCT production system holds promise and has the potential to significantly transform Namibian small-holder agriculture into a sustainable and productive crop production option.

Keywords: Namibia, Namibia specific conservation tillage, ripper furrower, Implement performance, soil moisture, penetration resistance, root length, yield, KAP, adoption.

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LIST OF ABBREVIATIONS

ACT	African Conservation Tillage Network
ASAE	American Association of Agricultural Engineering
ASABE	American Society of Agricultural and Biological Engineers
CEM	Cardno Emerging Markets
CV	Conventional tillage
CT	Conservation Tillage
CA	Conservation Agriculture
CES	Creative Entrepreneurs Solutions
CLUSA	Cooperation League of the United States of America
CONTILL (LIMA NAWA)	Conservation Tillage Project
DAP	Draught Animal Power
DAPAP	Draught Animal Power Acceleration Programme
FAO	Food and Agriculture Organisation
GEF	Global Environment Facility
GDP	Gross Domestic Product
GRN	Government of the Republic of Namibia
IFAD	International Fund for Agricultural Development
MAWF	Ministry of Agriculture, Water and Forestry
MDG	Millennium Development Goal
MSTT	Mahangu Sorghum Task Team
NAB	Namibian Agronomic Board
NCA	Northern Communal Area
NCAP	Namibia Conservation Agriculture Project
NCBA	National Cooperative Business Association

NCR	North Central Regions
NDP	National Development Plan
NEWFIU	Namibia Early Warning and Food Information Unit
NEWFIS	Namibia Early Warning and Food Information System
NEWU	National Early Warning Unit
NGO	Non-Governmental Organisation
NNFU	Namibia National Farmers' Union
NPC	National Planning Commission
NRC	Namibia Resource Consultants
NSA	Namibia Statistical Agency
NSCT	Namibia Specific Conservation Tillage Method as developed by the CONTILL (LIMA NAWA) project
SADC	Southern African Development Community
SGP	Small Grants Programme under GEF
SSA	Sub Saharan Africa
UN	United Nations
UNAM	University of Namibia
NCD	North Central Division
SADC	Southern African Development Community
SSA	Sub-Saharan Africa
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development

LIST OF SYMBOLS

Notation	Description	Dimension
Pd.B.	Drawbar power required for an implement	kW
D	implement draught	KN
S	average forward speed of implement	km hr^{-1}
T	implement depth of cut	m
Ds	specific draught	kN m^{-2}
W	implement width of cut	m
TFC	theoretical field capacity	ha hr^{-1}
C_a	Effective field capacity	ha hr^{-1}
E_f	field efficiency	%

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DEDICATION

This dissertation is dedicated to my Lord Jesus Christ, my late sister Jeneth and my family.

I can do all things through Jesus Christ who gives me strength. Philippians 4:13

DECLARATIONS

I, Bertha Mudamburi, hereby declare that this study is a true reflection of my own research, and that this work, or part thereof has not been submitted for a degree in any other institution of higher education. No part of this dissertation may be reproduced, stored in any retrieval system, or transmitted in any form, or by means (e.g. electronic, mechanical, photocopying, recording or otherwise) without the prior permission of the author, or The University of Namibia in that behalf.

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1. INTRODUCTION

1.1 Background

More than 70% of Namibia's population of two million humans depend on agriculture for their livelihood (Iijima, Niitembu, Nojima, & Kato, 2003; Tjaronda, 2009; AGRI Views, 2010; Shifeta, 2015) and approximately 23% of the population derive their income from subsistence agriculture (NSA, 2012). According to McDonagh and Hillyer (2003), more than 90% of the farmers in the Northern Communal Area (NCA) (Fig 1.1) of Namibia cultivate pearl millet (*Pennisetum glaucum*) as a staple food. Pearl millet or 'mahangu' as it is called in the Oshiwambo language, is a cereal crop that can survive high temperatures, has good drought resistance characteristics, does well in sandy soils (Uno, 2005) and can survive under normal rainfall conditions in the semi-arid environment of Namibia. Pearl millet yields in the NCA of Namibia are reported to be declining over the years (Davis & Lenhardt, 2009). Various authors claim that the pearl millet yields of Namibian smallholder farmers are extremely low at around 250 to 400 kg ha^{-1} per annum (Mallet & Rigoud, 2004; Vigne and Associates, 2004; Davis & Lenhardt, 2009; MSTT, 2009; von Hase, 2013). The problem of low mahangu yields in the NCA is said to be caused mainly by the frequent disturbance of top soil by ploughing among other things (NRC, 2003; Davis & Lenhardt, 2009; MSTT, 2009; NAB, 2009; von Hase, 2013).

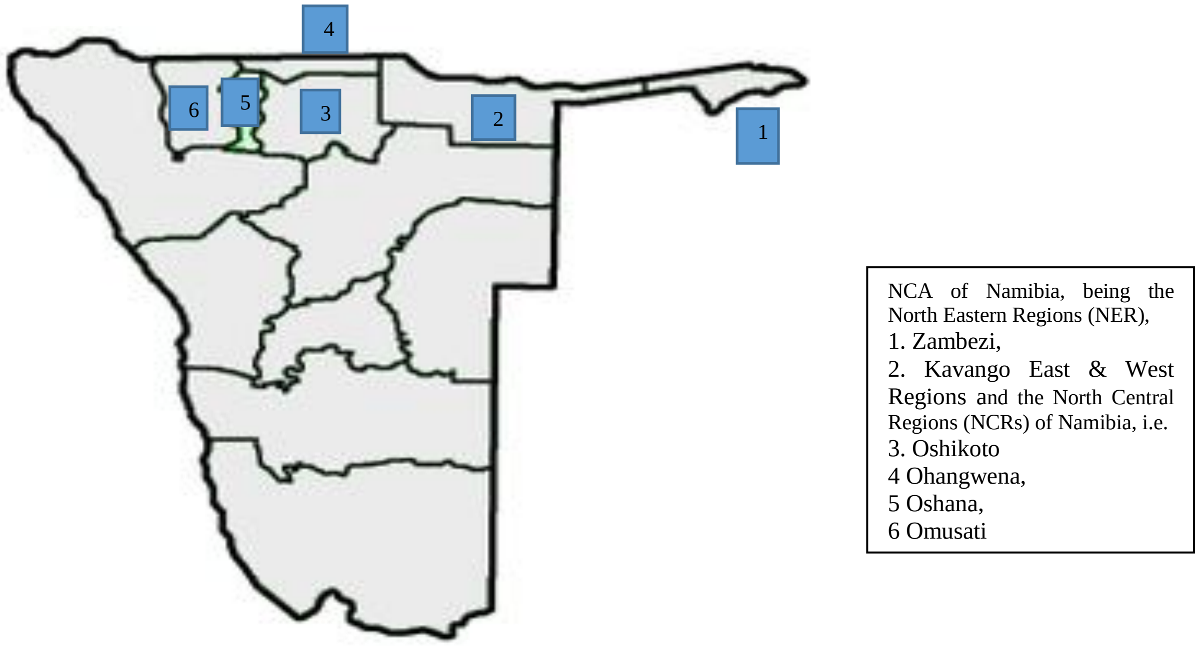

Fig 1.1: Map of Namibia showing the Northern Communal Areas

The NCA is characterised by sandy soils that are highly susceptible to many forms of degradation which manifest in the form of soil erosion, decline in soil fertility, deforestation, flash flooding, declining water tables and river flows (FAO, 2009; 2014). Farmers in these areas practise Conventional Tillage (CV) i.e. mouldboard ploughing, disc ploughing and harrowing. These practices, especially when high-speed disc harrows are used, pulverise the soil thereby destroying the soil structure. They also destroy vital organic matter and create hardpans and plough lines. This leads to soil degradation resulting from erosion, both biological and mechanical. As a result, there occurs a rapid decrease in crop yields (NRC, 2003; Davis & Lenhardt, 2009; MSTT, 2009; NAB, 2009; von Hase, 2013). Derpsch, Franzluebbers, Duiker, Reicosky and Koeller, (2014) and Reicosky, (2015) also pointed out that CV generally leads to soil degradation and loss of crop productivity. Several authors have concluded that the high penetration resistance of soils tilled with Conventional Tillage systems has resulted in reduced root growth (Atwell, 1993; Reichert, da Silva & Reinert, 2004; So, Grabski & Desborough, 2009), thereby affecting water and nutrient uptake by crops and thus resulting in lower yields.

Burning or removal of crop residues is another cause of low crop yields in the NCA. Crop residues are either grazed by livestock or removed for domestic use e.g. stalks are used to fence the homestead. The general practices of mono-cropping without adequate soil nutrient replenishment by most farmers is deemed to be another cause of low yields that further exacerbates the problem (NAB, 2009; Davis & Lenhardt, 2009).

Bruinsma (2009) and UN (2014) stated that, in the coming decade, the whole world might have to produce more food. This has to be achieved through sustainable farming methods using technologies that are more efficient and which minimise the negative impact on the environment. Populations continue to grow in many countries and soon new land for farming will not be available. It is of utmost importance that food production should keep pace with or exceed population growth. Bruinsma (2009) estimates that a 70% increase in food production is needed by 2050 to keep pace with population growth in the world.

The United Nations' Millennium Development Goals (MDGs) also focused on the need to increase food production as the expanding population is expected to reach 9.5 billion by 2050 (UN, 2014). It is reported that the proportion of undernourished people in developing regions decreased from 24% in 1990–1992 to 14% in 2011–2013. Meeting the target of actually halving the percentage of people suffering from hunger by 2015 was going to require immediate additional effort, especially in countries which had made little headway (UN, 2014). Yields still need to be significantly increased and this means that Sub Saharan African countries have to find ways of increasing crop yields per unit area. This posed, and still poses, a significant challenge for agricultural engineers, scientists, extension personnel and farmers in all the affected countries, with Namibia being no exception. Farmers in Namibia, like all farmers in other countries, have to find ways of increasing their yields in order to meet the required target. For this reason agriculture continues to be a priority focus under Namibia's National Development Plan 4 (NDP4).

Technologies to increase crop yields also need to be sustainable if they are to have any meaning for the future. The idea of 'conservation' is thus crucial in the formulation of such technologies. In trying to address some of the problems in the NCA, a Conservation Tillage (CONTILL) 'Lima Nawa' project was implemented in Northern Namibia between 2005 and 2011. 'Lima Nawa' in the Oshiwambo language means "cultivate well". This project was run by the Namibian Agronomic Board (NAB), Namibia Resource Consultants (NRC), Namibia National Farmers Union (NNFU), Ministry of Agriculture, Water and Forestry (MAWF) and the Golden Valley Agricultural Research Trust of Zambia. The project involved setting up demonstration plots in farmers' fields across the NCA, based on what was termed the Namibia Specific Conservation Tillage (NSCT) method. The method makes use of the animal-drawn and tractor-drawn ripper-furrowers to rip and make furrows in one operation. Apart from that, the technology emphasizes the use of mulch, manure and crop rotations. The NSCT was reported to have a great potential for increasing yields (Davis & Lenhardt, 2009) as it improved some farmers' pearl millet yield of 225-400 kg ha^{-1} to a range of 1500 kg ha^{-1} to 3063 kg ha^{-1} which is 5 to 8 times higher than the national average (Davis & Lenhardt, 2009; NCBA, 2012, von Hase, 2013).

In 2011, the Namibia Conservation Agriculture Project (NCAP) was initiated to continue with the NSCT as from 2012. The NCAP is now implemented in the north central and

Kunene regions by the Cooperative League of the United States of America (CLUSA), in collaboration with Creative Entrepreneurs Solutions (CES). The Government of the Republic of Namibia (GRN) also included the promotion of Conservation Agriculture (CA) in a number of policies such as the National Policy on Climate Change for Namibia, and openly encouraged the implementation of NSCT by providing ripping services in various crop growing regions (GRN, 2011). In 2015, the GRN launched the Comprehensive Conservation Agriculture Programme for Namibia, 2015-2019.

1.2 Draught Animal and Tractor Power in Namibia

There are no latest numbers for tractors in Namibia. Vigne and Associates (2004) estimated that in 2004 there were 400–500 tractors involved in land preparation in the six crop-growing northern regions, including approximately 200 operational former GRN tractors that are now privatized. From 2010 onwards, the GRN intensified its agricultural mechanisation programme to boost productivity and food security by making tractors available to the farmers at 50% subsidy (AGRI Views, 2010; Masawi, 2011; Ashipala, 2012; MAWF, 2014). These tractors were used for land preparation in the NCA. As reported by CEM (2011) during the 2010 to 2011 season, MAWF purchased 44 tractors (Appendix 2) for the NCA.

In April 2014, MAWF had 75 tractors that were providing land preparation services to all the communal farmers. (Namalambo, personal communication; MAWF, April, 2014). This indicates that very few tractors are purchased for the communal farmers in the NCA.

There is, however, a large number of farmers who still use draught animal power (DAP) alone or in combination with tractor power. One might ask why farmers should use draught animals when tractors can work much faster. Indicative estimates are that 60-89% of farmers in the NCA use DAP (Mudamburi, Chigariro, Namalambo & Chitsiko, 2003) while those who can afford to do so use tractor power (Mudamburi & Namalambo, 2010).

The use of draught animals for agricultural work by smallholder farmers is widespread in the NCA of Namibia, When the then Ministry of Agriculture, Water and Rural Development (MAWRD) realized the importance of DAP, they established the DAP programme at Mashare Agricultural Development Institute (MADI) near Rundu in 1995. In 1998, the Draught Animal Power Acceleration Programme (DAPAP) was conceived at the time when the privatization of the MAWRD tractor-ploughing services started. The purpose was to accelerate and promote use of DAP for ploughing and weeding in NCA and to complement the MAWRD tractor-ploughing services where they were not affordable or cost effective. The MAWF and NAB implemented the DAPAP project and the Productivity Upliftment Micro Project (PUMP) between 2003 and 2006. The two projects, DAPAP and PUMP, provided training to about 4000 communal farmers in the use of draught animals and provided loan guarantees for the purchase of draught animals, harnesses and implements through the Agribank of Namibia. After that, MAWF and NAB jointly implemented the DAPAP 2, a project that continued from 2007 to early 2010. The project was implemented in ten regions: Ohangwena, Omusati, Oshana, Oshikoto, Kavango, Zambezi, Otjozondjupa (Communal areas), Omaheke (Communal areas), Erongo and Kunene. The project made an impact in the small holder farming areas of Namibia, and trained 4500 farmers in ten regions to use draught animals for power and found that 89% of the trained farmers continued to farm with draught animals in the following years (NAB, 2010). This shows how much work has been put into use of draught animals in Namibia and further reinforces that there needs to be more work done in order to establish more effective and sustainable DAP tillage options.

1.3 Use of tillage implements in the NCA

Since the inception of the National Development Plans (NDPs), Namibian national agricultural policy documents have repeatedly emphasized the need to conserve soils, but the farmers continue to practise Conventional Tillage. The degree to which the disc harrow and plough are damaging these soils is not widely acknowledged by the local farmers. This is exacerbated by the Ministry of Agriculture, Water and Forestry (MAWF), which continues to subsidize Conventional Tillage through its ploughing services programme (AGRI Views, 2010; Ashipala, 2012; MAWF, 2014).

Globally, it is recognized that the ill-effects of Conventional Tillage can be reversed by the application of the techniques of Conservation Agriculture (CA) (FAO, 2004; 2009; 2014; Deprsch, 2008). CA embraces three key principles which are: reduced or minimum soil disturbance, provision of permanent soil cover and the use of crop rotations (Holland, 2004; Derpsch, 2008; FAO, 2014). Dumanski, Peiretti, Benetis, McGarry and Pieri (2006) also added that the principles and activities to be supported in CA should also be: enhancing soil and water conservation, use of integrated pest management (IPM) technologies and promoting the application of fertilizers in balance with crop requirements.

1.4 Conservation Tillage

Conservation Tillage (CT) is a concept that includes a broad set of practices with a goal of leaving some crop residues on the soil surface the object of which is to increase water infiltration, reduce the loss of soil and water. The concept also embraces all practices that minimise soil disturbance and use crop residues. Therefore CT is operationally defined as "any tillage or tillage and planting combination which leaves 30% or more mulch or crop cover on the surface" (ACT, 2005; ASABE Standards, 2005, Derpsch *et al*. 2014; Reicosky, 2015). CT is also the collective umbrella term commonly given to no-tillage, direct-drilling, minimum-tillage and/or ridge-tillage, thus conveying that the specific practice has a conservation goal of some nature. Other conservation objectives for the CT practice as described by Baker, Saxton and Ritchie (2002) include conservation of time, fuel, earthworms, soil water, soil structure and nutrients. The Namibia Specific Conservation Tillage (NSCT) method, makes use of the animal-drawn and tractor-drawn ripper-furrowers to rip and make furrows in one operation. Apart from that, the technology emphasizes use of mulch and crop rotations.

In the Southern African region, the value of conservation tillage in sustaining or increasing crop productivity through conservation of soil and water is well recognised. It has been proven by many researchers in Southern Africa to have an enormous potential for contributing to sustainable food production at a relatively low cost (Elwell, 1993; Oldrieve, 1993; Vogel, Nyagumbo & Olsen, 1994;Nyagumbo, 1998; Nyagumbo, 1999; Haggblade & Tembo, 2003; Baker, Southard & Mitchell 2005; Twomlow, Hove, Mupangwa, Masikati & Mashingaidze, 2008;Mupangwa, Twomlow, Hove & Walker, 2007; Giller, Witter, Corbeels & Tittonell, 2009; Thierfelder & Wall 2009; Rusinamhodzi, 2013). They have shown that the effects of CT will vary depending on soil type as well as climate and other conditions. According to Fowler and Rockstrom (2001) CT offers an opportunity to reverse the land degradation that prevails in many parts of sub-Saharan Africa. It has also been reported that minimizing tillage operations by adopting conservation tillage can provide significant energy and cost production savings (Hobbs, Sayre & Gupta, 2008). In addition to all this, reduced or no-tillage can provide opportunities for farmers to adopt good management practices as advocated by the Food and Agriculture Organization of the United Nations (FAO).

Olatunji (2007) reported that three things are involved in soil tillage: the power source, the soil and the implement. Tillage demands some form of energy, due to the large amount of soil mass that must be moved. It is therefore important for agricultural engineers, farm machinery practitioners, farmers and operators to understand which implements contribute to improved energy efficiency and conservation objectives especially with the introduction of the NSCT technology in Namibia.

1.5 Important knowledge gaps and Problem statement

Even though Namibia has recognized the damage and problems associated with conventional tillage (CV), no scientific studies have been conducted in the NCA to provide information on the use of NSCT technology for sustainable crop production. There is no known published data currently available on the draught requirements of agricultural implements operating in the soils of Namibia, whether powered by animals or tractors for CT or CV.

Most of the implement field performance data used in Namibia is based on American standards and none are based on information from Africa. All the draught data presented by the American Society of Agricultural Engineers (ASAE, Standards D497.5, 2002; 2003; 2006) are mostly based on USA soils. The only available information on draught requirements of implements in Namibia is for animal-drawn cultivators mainly used for weed control (Chigariro, Mudamburi, Namalambo, Mavetera, & Keib, 2005). Research in this area of soil tillage dynamics in Namibia is also necessary as a basis for specific Namibian planning. Moreover, there is no known field performance study on the draught requirements of the current agricultural implements such as the animal- and tractor-drawn ripper-furrowers operating on sandy soils predominant in NCA. Because there is a large number of smallholder farmers using draught animals in Namibia, any studies focusing on tillage technologies must therefore consider including both tractor-drawn and animal-drawn implements. A few studies have been carried out on both animal-drawn and tractor-drawn conservation tillage implements to find the best sustainable solutions to CT in Namibia (Chigariro, Mudamburi, Namalambo, Mavetera, & Keib, (2005); NAB, 2009; Davis & Lenhardt, 2009; von Hase, 2013). In these studies, however, there was no evaluation of the draught and other power requirements of the NSCT technologies. The animal- and tractor-drawn ripper-furrowers are also peculiar in that they differ in design and manufacture specifications from one country to another and in Namibia are designed to perform under Namibian conditions. It is thus important to study their performance under Namibian conditions. It is thus obvious that there is a knowledge gap to be filled by studying the field performance of some implements (animal- and tractor-drawn) available in Namibia, particularly those used by the NSCT technology.

Despite large numbers of farmers using draught animals in Namibia and in spite of the Namibian Government putting a lot of resources for training farmers to use draught animals and related implements, not much work has been done and no scientific studies have been conducted on animal-drawn NSCT technologies. Good as the technology may be, there are concerns that using the animal-drawn NSCT riper furrower does not result in deep and wide furrows.There is therefore a need to find the most suitable and effective NSCT animal – drawn practice that can achieve maximum depth, width and result in reduced soil compaction.

Information is also lacking in the smallholder farming areas of Namibia with regard to the performance of animal- and tractor-drawn NSCT implements and how they affect soil moisture, soil compaction, root length and yield of pearl millet. There is therefore a need to find the most suitable tillage practice that can conserve the most amount of soil moisture and result in reduced soil compaction particularly with the introduction of the NSCT technology. Also, no study has been done to compare the NSCT and CV technologies, as the former has not been sufficiently tested in the NCA. If Namibian farmers could improve their yield of pearl millet, they could reduce the pearl millet deficit and thereby reduce import costs.

A knowledge gap also exists concerning the extent to which the NSCT technology that is promoted by various organisations was being practised in the NCA. The *Republikein* (2013) reported that, by the end of 2011, approximately 800 NCA farmers (0.34% of the total 233 522 who derive their income from subsistence agriculture) were using "CA". Despite the claims of the *Republikein*, little information existed on why so few farmers were adopting or practising NSCT and how many farmers had been exposed to or had the knowledge of NSCT.

If smallholder farmers are being slow to adopt recommended CT technologies, there is a need to find out why. Especially as the recommended technology is intended to help such farmers improve their crop yields, slowness of adoption has implications for the sustainability of Namibian agriculture. It needs to be known whether the problem lies in the performance of the technology/implements, the lack of knowledge and exposure of NCA farmers to new technologies, or something else entirely.

With the promotion of CT and 'CA' in Africa, and Namibia in particular, especially by various NGOs and donor agencies, it is important to investigate the farmer behaviour concerning such technology. In the NCA it is important to find out what the farmers know about NSCT (Knowledge), how the farmers feel about NSCT (Attitude) and what the farmers do about NSCT (Practice). The approach through separately exploring knowledge, attitude and practice, known as KAP is used to investigate human behaviour concerning a certain technology (IDAF, 1994). In this present study the farmers' interest and willingness to adopt the NSCT Technology in two constituencies of the NCA was investigated to find out whether the farmers who were introduced to the NSCT technology have the knowledge, attitude to practice and adopt the technologies.

1.6 Objectives

The general objective of the study was to compare the performances of Namibia-Specific Conservation and Conventional tillage technologies for pearl millet production in Northern Namibia.

The specific objectives of the study were:

a. To compare the field performances of two technologies each for the NSCT and CV technologies on (i) depth of cut, (ii) width of cut, (iii) draught of the power source (iv) efficiency and (v) effective field capacity under Ogongo, Namibia conditions. The tillage implements are a tractor-drawn disc harrow and an animal-drawn mouldboard plough, representing the CV technology and a tractor-drawn ripper-furrower and an animal-drawn ripper-furrower representing NSCT technology.
b. To compare the effects of the two technologies each for the NSCT and CV technologies on soil moisture content, soil compaction (as measured by the penetration resistance), root development and yield of pearl millet at Ogongo in Namibia.

c. To compare the field performances of two techniques applied with the NSCT animal-drawn ripper-furrower implement using single and double ripping with two and three donkeys on (i) depth of cut, (ii) width of cut, (iii) draught of the power source (iv) efficiency (v) effective field capacity, and (vi) soil compaction.

d. To investigate whether the farmers in two Constituencies (Ogongo and Omuntele) of the NCA who were introduced to the NSCT technology had the knowledge, attitude to practice and adopt the technologies. The ‘Knowledge, Attitude and Practice’ (KAP) method was used to identify what farmers know (Knowledge), how they feel (Attitude) and what they do (Practice) in relation to the NSCT technologies.

1.7 Hypotheses and research question

In order to achieve the objectives as stated in section 1.6, the following hypotheses were tested in this study:

- Field performance characteristics (depth, width, draught force, specific draught, efficiency and effective field capacity) of the animal and tractor drawn NSCT technologies are significantly different to the field performance characteristics of the CV technologies at the 95% CI.
- Use of NSCT technologies can result in significantly:
  - reduced soil compaction when compared to CV implements.
  - higher soil moisture storage when compared to CV technologies.
  - increased root development and yield of pearl millet when compared to use of CV Technologies at the 95% CI.
- Field performance characteristics (depth, width, draught force, specific draught, efficiency and effective field capacity) of the two or three combinations of donkey

numbers in a span, using single ripping of the NSCT technologies are significantly different to the field performance characteristics of the two or three combinations of donkey numbers in a span, using double ripping of the NSCT technologies at the 95% CI.

- The research question that guided objective d was: Do farmers have the knowledge and attitude to practice and adopt the NSCT technologies?

1.8 Significance of study

It is hoped that the findings of this research will add to the knowledge and understanding of the subject of NSCT technologies and their application in the NCA, and may contribute to the successful adoption of NSCT technologies by farmers and the various organizations promoting NSCT. The results may help to educate the practitioners about the field performance of NSCT technologies during crop production and may also highlight the challenges and complexities that farmers face in trying to increase pearl millet yields using the NSCT technologies. The work may, therefore, also contribute in assisting MAWF and NGOs like CES and NCAP- CLUSA in designing capacity-building programs for farming communities adopting NSCT. In addition, it may lead to the designing of programs that can enhance change among various stakeholders at individual, community and institutional level with regards to NSCT and CA in general.

1.9 Organisation of the Dissertation

This dissertation comprises of eight chapters. Chapter 1 discusses the background to the study, which includes the problem, knowledge gaps, objectives, justification and organisation of the dissertation. Chapter 2 discusses the literature review on tillage, factors affecting the performance of various tillage practices, effect of tillage on moisture, soil compaction, root lengths and yield. It also reviews the concepts of adoption, knowledge, attitude and practice of technologies. Chapter 3 discusses the methodology of the study. Chapter 4 tackles the field performances of tillage technologies on fields without crop – results, analysis and discussion. Part of chapter 4 was published in the Journal of the International Conference on Environmental and Agriculture Engineering IPCBEE (Appendix 16). Chapter 5 is about the field performances of tillage technologies on fields without crop – results, analysis and discussion. Part of chapter 5 was peer reviewed and is found in the Book of condensed papers, African Congress on Conservation Agriculture, 1ACCA conference in Lusaka, Zambia (Appendix 16). Chapter 6 compares the performance of ripping techniques of Animal - Drawn Ripper Furrower in Ogongo, Namibia. This chapter was presented at the 3rd Annual Science Research Conference "Innovation: the Heart of Development". UNAM, November 18-19, 2015 (Appendix 16). Chapter 7, discusses the adoption of NSCT technologies by farmers in two Constituencies of the NCA using the 'Knowledge, Attitude and Practice' (KAP) method. Lastly, Chapter 8 discusses the major conclusions drawn from the study and recommendations for future research.

2. LITERATURE REVIEW

2.1 Introduction

The aim of this review is to identify and assess the factors that inform the principal hypotheses of the dissertation. This chapter starts off by introducing tillage in general. The focus, however, is on Conventional (CV) and Conservation tillage (CT). The use of draught animals and tractor power are also discussed. The chapter goes on to review the literature on animal- and tractor-drawn tillage implements and then reviews literature relevant to some of the factors that affect the field performances of the implements used in various tillage technologies. The chapter continues to review the effects of tillage and also mulch and tillage on soil moisture, soil compaction, root length and yield. Lastly the role of knowledge, practices and attitudes of farmers on the adoption of various technologies is reviewed.

2.2 The Concept of Tillage

Tillage of agricultural soils is defined as the manipulation, generally mechanical, of soil properties to modify soil conditions for crop production (SSA, 1987; Adel, 2000; Hunt, 2001; ASAE, 2004). Tillage operations involve an interaction between an implement and the soil. Olatunji (2007) further explains that three things that are involved in soil tillage are: power source, soil and implement. Ahaneku, Oyelade and Faleye (2011) also specify that agricultural tillage includes soil cutting, soil turning, and soil pulverization. Tillage therefore demands a high energy input, not just due to the large amount of soil mass that must be moved, but also to deal with the inefficient methods of energy transfer to the soil. According to Manian, Kathirvel and Rao (2000) tillage is a major event in crop production and it consumes nearly 30 to 35 % of the total energy requirement for production. There are various reasons for soil tillage, but the overall objective of tillage is to develop a desirable soil structure that promotes seed germination, plant emergence and root growth. Tilling the soil thus also includes water and soil conservation and weed control.

Tillage has various effects on soil that can be either beneficial or degrading, depending on the appropriateness or otherwise of the methods used. Physical attributes particularly soil and water conservation, have a direct influence on soil productivity and sustainability. Adamu, Ezeaku and Mshelia (2004) and Nkakini, Akor, Fila and Chukwumati (2008) have pointed out the very important role that soil tillage plays in soil productivity when it functions to create optimum soil conditions for crop growth. Some of the desired effects like improved soil aeration, infiltration and nutrient availability, reduced soil erosion and root system proliferation are to a large extent influenced by tillage practices. Rashidi and Keshavazpour (2007) also mention that soil tillage is among the important factors affecting soil physical properties and crop yield. With a growing world population needing to be fed, understanding the impact of tillage on soil quality and hence agricultural sustainability are now more important than ever before.

There are various tillage systems that can be used in crop production, but each of them has advantages and disadvantages. The two broad categories used are Conventional (CV) and Conservation Tillage (CT). These tillage practices both carry out their functions in modifying soil structure by changing its properties, but there is increasing awareness worldwide and in

Namibia of the negative effects that conventional tillage may have on soils, altering their properties for the worse and not for the better.

2.2.1 Conventional Tillage (CV)

Conventional tillage describes the system where the characterizing feature is the incorporation of crop residues into the tilled soil layer (Hunt, 2001). It involves inversion of the soil, normally with a mouldboard plough as the primary tillage implement, followed by secondary tillage with the same implement. In this system, the main objective of the primary tillage is weed control by means of ploughing, and the main objective of the secondary tillage is seedbed preparation. Conventional tillage uses tools and implements that are most commonly used in a given geographical area to produce a given crop (ASAE, 2004).

Several researchers have identified the disadvantages of conventional tillage (Dillalesa, 2006; Temesgen, 2007; Worku, 2006; Rusinamhodzi, 2013; Derpsch *et al*. 2014; Reicosky, 2015). Kaumbutho, Gebresenbet and Simalenga (1999) reported that many farms in East and Southern Africa have lost large amounts of soil through erosion due to the continued use of traditional manual, animal-drawn and tractor-drawn mouldboard ploughing. Where disc and mouldboard ploughing, both animal- and tractor-drawn, has been used consistently, hardpans have formed and soils no longer have the capacity to allow the easy percolation of rain or irrigation water. These researchers mention that the situation is as bad for humid as it is for semi-arid areas. In another study (Elwell & Stocking 1988), high erosive effects of the mouldboard plough were recorded on crop fields. It was shown that the mouldboard plough induced erosion rates of 50 t $ha^{-1}year^{-1}$ compared to only 2 t $ha^{-1}year^{-1}$ for ‘no-till’ tied ridging (CT).

Nyagumbo (2002) however, reported that average annual measurements recorded at Domboshawa in Zimbabwe, showed soil losses for conventional mouldboard ploughing at 8.4 t ha^{-1} compared to clean ripping at 3.7 t ha-^{1}, hand hoeing at 2.8 t ha^{-1}, no-till tied ridging at 1.9 t ha^{-1} and mulch ripping at 0.9 t ha-$^{\cdot 1}$. Regardless of the lower loss values measured by Nyagumbo (2002) both studies confirm that Conservation Tillage methods reduced soil loss more than conventional mouldboard ploughing.

In Namibia, it is predicted that ploughing results in a steady decrease in yields over time as a result of plough pan formation (NRC, 2003; Vigne & Associates, 2004; MSTT, 2009; NAB, 2009). This is because, where ploughing has been done year after year, a hardpan layer or ‘plough pan’ will restrict root penetration and as a result crops can be expected to wilt during dry spells. According to the Soil Quality Institute (2003) a plough pan is a dense layer (often 5-10 cm thick) beneath the normal tillage depth that forms when the tillage depth does not change from year to year. It is possible to break a plough plan with appropriately-timed deep ripping. Pulverising the soil, particularly with the use of a disc harrow, also leads to the destruction of macropores which are important for aeration and water infiltration, and this accelerates the loss of soil organic matter and fauna (Kishor, Ghosh & Claramma, 2013). It is worth noting that the sandy soils in the Namibian NCA have a low level of particle aggregation that is likely to be further reduced by tillage, especially by disk harrowing.

In the NCA, tractor-drawn ploughs are less common than tractor-drawn disc harrows, although the ploughs are important in areas with heavier soils (Mudamburi & Namalambo, 2010). The tractor disc harrow is thus the main tractor-drawn tillage implement used in the NCA. It tends to pulverize soils, especially when used at high speed, leading – in the same manner as the plough, but much faster – to biological and physical erosion and also to hardpan formation. Several authors have predicted that these soil-pulverising and hardpan effects of disc harrows will lead to soil degradation (Rigourd & Sappe, 1999; Strohbach, 1999; NRC, 2001; 2003; Vigne & Associates, 2004; MSTT, 2009; NAB, 2009; von Hase, 2013). They also predicted that disc harrowing will very likely lead to sharper yield declines than ploughing, mainly due to soil pulverization and hardpan formation, destruction of the soil structure and other negative effects on organic matter and soil fauna of harrowing.

Apart from both the animal-drawn ploughs and tractor-drawn discs and ploughs being highly suspect in pulverizing the unstable NCA sandy soils and creating hard plough pans that restrict moisture and crop root penetration and consequently depress crop yields, quickly reduce soil organic matter, they send large volumes of CO_2 into the atmosphere, thus intensifying climate change (Reicosky, 2008).

Kassam, Friedrich, Shaxson and Pretty (2009) acknowledge that CV methods provide short term benefits for growing crops by loosening the soil, making a seedbed and controlling weeds. Over time, however, this practice compacts the soil, releases stored carbon into the atmosphere and speeds up the oxidation of organic soil matter. They also confirm that the consequences of this are decreased water absorption, soil erosion, loss of soil structure and nutrients, reduced organic soil matter, less biodiversity and ultimately falling crop yields.

While the need to conserve the fragile NCA sandy soils is repeatedly emphasized in all national policy documents, the degree to which the plough and disc harrow are damaging these soils is not widely acknowledged, since the highly destructive ploughing service continues to be subsidized. It is believed that the animal or tractor drawn plough is not only damaging the soil (structure) but is also damaging the environment. Because of this it is important for Namibia to explore options that can offer sustainable solutions on tillage like use of conservation tillage. Further research is justified to specify draught requirements of the tillage implements and the effect of tillage performance in different soils especially with the introduction of the NSCT technology.

2.2.2 Conservation Tillage

The alternative to CV is Conservation Tillage (CT). It is operationally defined as any tillage or tillage and planting combination which leaves 30% or more mulch or crop cover on the surface (Baker, Saxton & Ritchie, 2002; ACT, 2005; ASABE Standards, 2005; Derpsch *et al*. 2014; Reicosky, 2015). Other researchers (Rockstrom, Kaumbutho, Mwalley and Temesgen, 2001) defined CT as any tillage system that conserves water and soil while saving labour and traction needs. Hunt (2001) defined CT as a system that places a premium on reducing soil loss. The Food and Agriculture Organization of the United Nations (FAO, 2008a) defines CT as a general term which refers to a tillage system that does not invert the soil and which retains crop residues on the surface. In general, CT is the collective umbrella term under which the practices known as no-tillage, direct-drilling, minimum-tillage and/or ridge-tillage are grouped to denote that these specific practices have conservation goals of some nature. Baker *et al*. (2002) further specify that the retention of 30% surface cover by residues characterizes the lower limit of classification for Conservation Tillage, but other conservation objectives for the practice include the conservation of time, fuel, soil organisms soil water, soil structure and nutrients.

Opara-Nadi (1993) stated that CT, as defined by the Conservation Tillage Information Centre (CTIC), excludes all CV tillage operations that invert the soil and bury crop residues. The CTIC identified five types of conservation tillage systems: no-till, mulch tillage, strip or zonal tillage, ridge till (including no-till on ridges) and reduced or minimum tillage. Derpsch (2008) also identified more or less the same types of CT systems as CTIC, and defines a variety of Conservation Tillage systems as follows:

- **Direct drilling** (no-till) refers to planting the seed into the stubble of the previous crop without any previous tillage or soil disturbance, except that which is necessary to place the seed at the desired depth. Herbicides have to be used for weed control, at least initially.
- **Strip tillage or zonal tillage** refers to a system where strips of 5 to 20 cm in width are prepared to receive the seed whilst the soil along the intervening bands is not disturbed and remains covered with residues. The system provides less cover along the rows and causes more soil disturbance than direct drilling.
- **Tined tillage** agriculture refers to a system where the land is prepared with implements which cause little soil compaction and do not invert the soil. The surface normally remains with a good cover of residues in excess of 30% on the surface.
- **Ridge tillage** is a system where the crops are grown on ridges and in furrows. The ridges may be narrow or wide and the furrows can be parallel to the contour lines or constructed with a slight slope, depending on whether the objective is to conserve water or to drain excess water. The ridges can be semi-permanent or be constructed again each year, which determines the amount of residue material that remains on the surface.
- **Reduced tillage** refers to tilling the whole soil surface but eliminating one or more of the operations that would be used in a conventional system. The type of implement

> and the number of passes also vary. The result is that some systems leave very little residue on the surface. In others, this may be in excess of 30%. The approach does not use either mouldboard or disc ploughs. Owing to the great variation in the reduced systems, it is difficult to generalize about the advantages and limitations. However, all the reduced tillage systems have the advantage over conventional (CV) systems of also reducing fuel consumption, work time and the equipment required.

Barber (2000) and Derpsch, Franzluebbers, Duiker, Reicosky & Koeller (2014) have specified that there was a need to standardize no-till research, as many researchers and practitioners all over the world were using different terminologies and methodologies and this makes it very difficult to compare research results. This current study is concerned mainly with Conservation Tillage.

It is reported that no-till is experiencing a steady and persistent growth worldwide. Approximately 47% of the no-till technology is practised in Latin America. According to Derpsch (2008) the USA regularly conducts surveys and has ascertained the extent of adoption of different forms of CT in that country to be 39%, in Australia to be 9% and in the rest of the world to be 3.9%. However, for other parts of the world information is very scarce or non-existent and in some countries statistics for CT are based on estimates (Derpsch, 2008).

In South America (Argentina, Bolivia, Brazil and Paraguay), more than 60% of crop land is under no-till. In Brazil, 500 000-600 000 ha of that land is estimated to be farmed by about 100 000 smallholder farmers using animal power (Derpsch, 2008). This shows that animal power is still widely used even in other countries where no-till is highly practised. Moreover it is reported that no-till has reversed soil degradation, allowed the expansion of cropping into marginal lands, boosted farmers' profits and increased the sustainability of cropping systems (Derpsch, 2008).

As described above, CT involves minimum soil disturbance and the use of mulch or crop residues on the soil surface. It can therefore improve agricultural production by increasing water infiltration and minimizing evaporative losses (Hobbs, Sayre & Gupta, 2008) at the same time as reducing erosion, improving soil surface aggregates, reducing compaction through promotion of biological tillage, increasing surface soil organic matter and carbon content, moderating soil temperatures, and suppressing weeds. CT also helps reduce costs of production, saves time, increases yield through timelier planting, reduces diseases and pests through stimulation of biological diversity, and reduces greenhouse gas emissions (Hobbs, 2006).

In Africa, the greatest progress in no-till has been made in Ghana where 300 000–350 000 ha is reported to be under no-till agriculture involving about 650 000 smallholder farmers (CEM, 2011). The biggest limitation experienced by smallholder farming systems is lack of soil cover, because the relevant vegetation is used as forage. Therefore, the practice is more of minimum soil disturbance and less of soil cover. Nevertheless farmers persist with it because of demonstrated increases in the efficiency of water and nutrient use, guaranteeing increased crop productivity (CEM, 2011).

In the Southern African region, the value of CT practices in sustaining or increasing crop productivity through conservation of soil, water, nutrients and/ or draught power is well recognised and has been reported by various authors to have an enormous potential for contributing to sustainable food production at a relatively low cost (Elwell, 1993; Oldrieve, 1993; Vogel, Nyagumbo & Olsen, 1994; Nyagumbo, 1998; 1999; Baker, Southard & Mitchell, 2005; Twomlow, Hove, Mupangwa, Masikati & Mashingaidze, 2008; Mupangwa, Twomlow & Walker, 2007; Giller, Witter, Corbeels & Tittonell, 2009; Rusinamhodzi, 2013). In Zambia, the productivity of over 182,000 smallholder farmers has reportedly been transformed from below subsistence to commercial farming. Most of them used hand hoe-basins (CEM, 2011). In Zimbabwe, CT techniques that include hand hoe basins and precision application of small doses of nitrogen have demonstrated grain yield increases of 15.75% in the fields of more than 300,000 households (Mazvimavi & Twomlow, 2008). The benefits of CT were reported to be more evident in years of severe drought. The benefits of CT are therefore multi-fold: it will sequester soil carbon and improve soil water-holding capacity and structure, which will all boost crop growth and create a larger atmospheric carbon sink (McCauley, Jones & Jacobsen, , 2009).

Despite the many advantages of Conservation Tillage there are also some disadvantages. These include a large number of different weed species which may receive encouragement (Carter & Ivany, 2006). Vogel (1994) reported weed pressure as one of the challenges of adopting ‘no-till’ systems. According to Opara-Nadi (1993) no-till requires significant inputs of chemical herbicides. The cost of these chemicals can be quite significant, rendering the whole approach non-viable, especially as chemicals used could cause considerable harm to the environment.

Opara-Nadi (1993) also criticized CT method namely ‘mulch tillage’ (leaving plant residues in the field) as creating conditions which harbour pests and diseases. Also, in the poor farming regions of the world, there are many alternative uses for the mulch such as animal feed, thatching materials and fuel. This would in any case reduce its availability for use in NSCT as most farmers use mulch for more or less the same purposes.

2.3 Power Sources for Tillage Technologies

According to Pearson (2005) draught animals and humans are estimated to provide 80% of the power input on farms in developing countries. Rijk (1989) has pointed out that high levels of tractorization are generally associated with relatively well developed economies, and that this goes along with the production of cash crops, profitable agriculture, operator skills, appropriate equipment and timely and cost effective repair and maintenance services. However, animals and motor power both help to reduce human drudgery and allow people to achieve more with their time. Motor power, where available and affordable, can achieve the greatest savings in time and labour. Whilst many smallholder farmers would like to benefit from tractor power, such aspirations are often unrealistic. Motor power tends to be most appropriate for large-scale farming (Starkey, 2010).

Wilson (2003) accordingly maintains that more than half of the world's population depends on animal power as its main energy source. Other studies emphasised that although there will continue to be contributions from tractor power to land preparation, much of the Eastern and Southern African region will continue to be cultivated using hand and animal power (FAO, 2003; Starkey, 2010).

In any agricultural crop production system, humans, draught animals and engines or motors provide the power in various proportions for crop establishment, harvesting, transport and processing (FAO, 2003; Pearson, 2005, Starkey, 2010) and tractors, draught animals and related implements constitute a major adjunct to crop production. The proper operation of these is essential for a profitable agricultural operation. Performance data for tractors, animals and implements under different soil conditions is therefore important information for agricultural engineers, farmers, machinery operators and tractor and equipment manufacturers. The importance of knowing the performance of tractors, animals and implements as used in Namibian crop production can help to improve the effectiveness and efficient use of implements and power sources.

2.3.1 Draught Animal Power (DAP)

Despite the production advantages of motor power, there are nonetheless a lot of advantages in using DAP, as it allows farmers to cultivate a larger area than they could do by hand, thereby increasing yields and incomes. It is economical and, compared to hand hoeing; it also reduces labour inputs and general drudgery of farm operations, which is particularly important in view of the impact of HIV and AIDS.

Despite the faster speed of operation of tractors, the need to share them in tractor schemes and the high incidence of mechanical failure means that DAP allows improved timeliness of planting and weeding operations, especially in semi-arid areas, and so may lead to risk reduction and yield increases. Also because it is faster than hand labour, animal power can lead to yield increases due to improved timeliness in cultivation, planting and weeding in this context as well.

In semi-arid areas, a delay of even one day in cultivation, weeding or planting after rain has fallen can reduce yields. Research conducted in Zimbabwe found that 5-10 % of cereal potential grain yield is lost for every week of delay in planting (Nyagumbo, 2008). This is very important in semi-arid areas like Namibia, where the time of planting after the first rains is critical. In theory, greater timeliness can come from tractors, but in practice with regard to public and private land preparation services, this is only true for the first in the tractor queue. According to Starkey (2010) when many smallholder farmers own animals, they can all plough their fields at the same optimum time. Assuming that everything else goes well, then farmers can expect good yields.

DAP can also relieve the burden of women by contributing to the transport of water, wood, fertiliser, manure, seed, tillage implements and produce, which would otherwise be head loaded by women, reducing their availability for other tasks. Compared to motorized transport, DAP is also less damaging to the broader environment in its non-reliance on fossil fuels.

2.3.1.1 Use of Donkeys as Draught Animals in Namibia

The on-station trials of this study used donkeys as draught animals in the implement trials. It is therefore important to look at literature specifically concerning donkeys in Namibia. Unlike other draught animals such as oxen and horses, there is very little literature about donkeys and their use in Namibia. Some information on the comparative economics of donkey use has been published in South Africa (Naudé-Moseley & Jones, 2002), but by and large, the agricultural literature does not dwell much about donkeys, even where donkeys have been used extensively for rural transport. This neglect may be because of the bad name the donkey has among some ethnic groups. The users of donkeys, especially farmers, often do value their donkeys' work although their use on farms has been limited mainly to transport and ploughing. Donkeys are in fact used for a number of purposes in Namibia.

Issues of livestock management, particularly those of donkeys, are given very little attention, if at all, in the NCR. There is, generally, a lack of concern about the well-being of donkeys. Donkeys are left to roam freely without anyone caring for them. It seems they are only remembered when the farmers want to use them, either for tillage or transport purposes. As soon as their services have been rendered the donkeys are left on their own again to fend for themselves – which they generally do quite well. Most farmers keep more donkeys than they need for replacement purposes as they claim that donkeys die due to internal parasites and other diseases, which are often the consequence of poor husbandry (Mudamburi *et al*., 2003). Table 2.1 gives general advantages and disadvantages of donkeys.

Table 2.1: Advantages and disadvantages of donkeys

Advantages	Disadvantages
Friendly towards humans	Suffer from being alone
Willing to work	Noisy when frustrated or lonely
Can turn in a small space	Friends not easily separated
Easy to train	Uncastrated males aggressive towards other donkeys
Need little supervision in work	Skin easily wounded
Can utilize poor feed well	Wander long distances if not supervised
Not affected much by external parasites	Do not move out of the way of traffic
Need little water	Need shelter from cold and damp
Can survive well in tsetse-infested areas	Meat not generally eaten
Can survive droughts better than cattle	Comparatively small in size
Comparatively cheap to buy	Mature slowly
Strong relative to size	Breed slowly
Live and work many years in good care	Manure more fibrous than nutrient-rich
Useful for calming and guarding other kinds of animals	
Fast walking speed	

Source: (Jones, 1997)

2.3.1.2 Work Performance of Donkeys

Understanding work performances of draught animals is important as it helps to understand what sizes of animals and implements contribute to improved efficiencies. Live weight influences both pulling and packing capacities. Goe (1983) reported that a donkey could pull 16-20 % of its live-weight at a speed of 2.5–2.8 km hr^{-1} for 3–3.5 hours per day. Starkey (1985) reported that donkeys could pull 17–25% of their body weight while ploughing. These capacities depend on the animal's physical condition, food and oxygen consumption capacity, health status, climatic factors, sex of species, implement and type of harness used. On a per kg body weight basis, donkeys can potentially produce twice as much work as cattle. Two donkeys of about 160 kg each were able to develop a draught force of 800 N for four hours per day at a speed of 3.6 km hr^{-1} (Dibbits, 1991).

Studies in Zimbabwe have shown that well-fed, well-trained donkeys teamed in fours are capable of sustaining a combined draught force of over 1 kN for a 4-hour working period, sufficient to plough relatively deep soil with a mouldboard plough and complete most other agricultural tasks associated with crop production in an acceptable time (Pearson *et al.*, 1989). Some of the results obtained by Nengomasha (1997) on the performance of donkeys are given in Table 2.2.

Table 2.2: Results of the performance of a team of donkeys and a team of oxen on clay, red soil, sandy and sandy clay soils with an ox-drawn plough at Matopos Research Station

Performance parameter	Value per team of 4 donkeys
Mean live weight (kg)	169
Draught force (N)	867
Speed (ms^{-1})	0.87
Power output (W)	689
Area ploughed (m^2)	770
Ploughing depth (cm)	13.5
Ploughing width (cm)	26.5
Effective field capacity (hr/ha)	14.2 (0.07 ha hr^{-1})

Source: Nengomasha, (1997)

Makki and Manzool (2013) reported that donkeys in Adilling, Sudan, could work for 4 to 7 hrs per day at a speed of 0.6 to 2.7 km hr^{-1}. The same donkeys could also achieve work rates of 0.004–0.13 ha hr^{-1} with efficiencies of 66.7–83.3 %.

Light implements and the proper attachment of harness and implement play an important role in the welfare of donkeys and other draught animals. According to Inns (1996) draught and therefore working depth can be controlled by selecting a suitable combination of angle of pull and implement weight. In order to reduce draught of tillage implements it is therefore important to choose light implements. MAWF, through the Draught Animal Power Acceleration Programme (DAPAP) and Productivity Upliftment Micro Project (PUMP) projects, made deliberate efforts to bring from other countries light implements that are specifically designed for donkeys, including ploughs, cultivators and planters.

It has been reported that the draught force that animals exert to draw an implement constantly changes due to numerous interacting variations attributable to the animals, the operator, the soil and the orientation of the implements. For instance, Lawrence and Pearson (1985) reported that, the draught measurements ranged from 589 to 2160 N for the same plough in the same field in the same two-week period at the end of a rainy season. Also O'Neill and Kemp (1989) gave examples of the great variation in draught forces associated with soil conditions and previous tillage history. Pearson *et al.*, (1989) provided values to illustrate how much effect individual operators can have on the draught force of an implement, even one with fixed settings. In one particular trial (cited by Starkey, 1989), ploughing on terraces with a traditional ard in Nepal, a mean draught force of 704 N was measured with one ploughman, and 492 N with a different ploughman. In this case the animals, soil, environmental conditions and apparent working practices were the same, so that the differences in draught could only be ascribed to the way the two operators used the ploughs. Different manufacturers, too, will not necessarily make exactly the same implement. The foregoing discussion justifies checking the performance of the implements predominantly operating in the NCA of Namibia.

2.3.2 Tractor Power

Many Sub-Saharan African (SSA) governments have at various times introduced schemes, development projects and incentives designed to encourage farmers to make more use of agricultural machinery, in particular tractors. According to Ashburner and Kienzle (2009) most of these efforts did not meet expectations. In fact many of them failed due to financial and operational disasters. The projects had little or no effect on the adoption rate of mechanisation. By 2011, the rate of use of agricultural machinery was still below that which is considered necessary to meet the rising demand for food (Mrema, 2011).

Between 1960 and early 1980s, large numbers of tractors were supplied as gifts from donors or on advantageous loan terms to developing countries. However, the public sector tractor-hire schemes collapsed because of the distorted cost of capital as compared to labour and draught animals. There was also a lot of mismanagement and the inefficiencies of Government-run machinery services (FAO, undated). Compared to draught animals, tractors nonetheless achieve the greatest savings in time and labour, but at such great initial expense with regard to the capital investment required to buy a tractor (FAO, 2008b) that they tend to be more appropriate for large-scale commercial farming (Bishop-Sambrook, 2005). The FAO (2008b) reported that individual tractor ownership is in most cases particularly difficult for farmers with small areas of land for cultivation because of the high initial capital investment needed in order to purchase the tractors. Table 2.3 shows the numbers of tractors in African countries minus Egypt and Mauritius and nine other countries in the world per 1000 hectares. The table shows that Africa is far behind in terms of tractor use. Mrema, Baker, and Kahan (2008) also reported that tractors were used about nine times more per unit of land in Asia compared to Africa.

Table 2.3: Average number of tractors in African countries and nine others.

Region	Tractors per 1000 ha
Africa (minus Egypt and Mauritius)	28
Average of nine countries (Bangladesh, Brazil, China, India, Korean Rep., Pakistan, Philippines, Thailand, Viet Nam.)	241

Source: The World Bank (2007) as cited by FAO and UNIDO (2008)

2.4 Field Performance of Tractor and Animal Tillage Implements

The performance of tillage implements involves the power source, the amount of soil manipulation by the implement and the amount of force required to cause the manipulation. In order to measure implement field performance, these factors must be assessed. Tillage implement performance parameters with regard to tractors and animal power comprise the following: draught force, speed of power source and implement, depth of cut, width of cut, width of implement, specific draught, effective field capacity and field efficiency. These parameters can assist the farmer or operators in choosing what type of tillage implement to use. ASAE Standard D497.4 (2003) provides some information on typical agricultural machinery management data.

The performance of an implement sometimes depends on the skill of the operator or on the weather and soil conditions (Edwards, 2001). Nevertheless, differences among implements can be evaluated through research reports, field trials and personal experience. Performance rates for field machines depend upon achievable field speeds and upon the efficient use of time (ASAE, 2004). Field speeds may be limited by rough ground, and inadequacy of operator control. Small or irregularly shaped fields and raised capacity machines may cause a substantial reduction in field efficiency.

2.4.1 Draught Force and Factors affecting Draught

Draught is defined as the force required to pull an implement in the horizontal direction of travel. Draught and power requirements are important parameters for measuring and evaluating field performance of tillage implements so that implements can be matched to the right sizes of animals, tractors and also operation.

The factors that affect draught are generally seen as: soil texture, tillage depth, geometry of implement/tools (Upadhyay, Williams, Kemble & Collins, 1984; Grisso, Yasin & Kocher, 1994; Naderloo, Alimadani, Akram, Javadikia & Zeinali Khanghah, 2009; Olatunji & Davies, 2009), speed, working width, weight, and moisture content of soil (Serrano & Peça, 2008 Olatunji & Davies, 2009). All these are important for measuring and evaluating the performance of tillage implements (Serrano & Peça, 2008; Naderloo *et al*., 2009; Olatunji & Davies, 2009). Various studies have been conducted to measure draught and power requirements of tillage implements under various soil conditions (Gebresenbet, 1989; Grisso *et al.,* 1994; Al-Janobi & Al-Suhaibani, 1998; Manian, Rao & Kathirvel , 2000; Shrestha, Singh, & Gebresenbet., 2001; Gratton, Chen & Tessier, 2003; Arvidsson, Keller & Gustafsson, 2004; Shoji, 2004; McLaughlin & Campbell, 2004; Serrano & Peça, 2008; Al-Suhaibani, Al-Janobi & Al-Majhadi, 2010). They all reported and observed that draught varies with variations in soil conditions, tool design and operational parameters.

2.4.1.1 Speed

It has been widely reported that the draught forces on implements increase significantly with forward speed and the relationship varies from linear to quadratic (Grisso *et al.*, 1994). It has been shown (ASAE, 2002) that performance rates for field machines depend upon achievable forward speeds and upon the efficient use of time. Naderloo *et al*., (2009) also showed that, for three tillage implements, a significant increase in draught was observed with an increase in forward speed.

Serrano and Peça (2008) studied the effect of forward speed on the draught force required to pull trailed disc harrows, and they found that draught force increased with forward speed and that this relationship is almost linear at speeds between 3 and 9 km hr^{-1}. They measured draught values to range between 12.46 and 27.02 kN for offset disc harrows with 20 discs. They also found that the forward speed directly affects the required draught of trailed disc harrows. Hunt (2001) also mentions forward speed as a factor which affects draught of a tillage implement.

Draught measurements were also taken by Al-Janobi and Al-Suhaibani (1998) for major primary tillage implements operating on sandy loam soil. The implements were three tractor drawn chisel ploughs of different shanks, an offset disk harrow, a mouldboard plough and a disk plough. An increase in horizontal and vertical forces was observed for all tillage implements with an increase in the forward speed.

Several researchers reported that draught forces increased with an increase in forward speed. (Chandon & Kushwaha, 2002; Mamman & Oni 2005; Alimardani, Fazel, Akram, Mahmoudi & Varnamkhasti, 2008; Al-Suhaibani and Ghaly, 2010). Al-Janobi, Kabeel and Aboukarima (2000) evaluated three mathematical models which predicted horizontal and vertical forces of the plough with different tools or attachments when operating on sandy loam soil, comparing these with field measurements. They found that the forces varied according to tool shape and forward speed. Keller (2004) also reported that the draught force of a tillage implement is a direct measure of the energy requirement; the draught requirement for pulling a tillage implement through soil is in turn dependent on implement parameters, tillage forward speed.

All the draught data presented in the ASAE Standards and ASAE Standard D497.4 (ASAE, 2002; 2003; cited by Manuwa & Ademosun, 2007) were based mostly on soils found in United States of America. In Namibia, there are no published data available concerning the draught requirements of agricultural implements operating on local soils. Typical tractor speeds are given in Hunt (2001) and in ASAE standards, D497.4 (ASAE, 2003). Ranges of typical forward speeds for most of the field machines given in the ASAE Standards (ASAE, 2003) are 6.5 to 11 km hr^{-1}.

2.4.1.2 Width of Cut

The width of cut also affects draught, as it has to do with the amount of soil that can be pushed by the implement. The width of cut also affects how long the implement is going to take per given distance or unit of land. Width of cut has been reported (Hunt, 2001; Godwin (2003); Serrano and Peça, 2008) as a factor which affects draught of a tillage implement.

2.4.1.3 Depth of Cut

Depth of cut has been cited by several researchers (Hunt, 2001; Serano & Peca, 2008; Naderloo *et al*., 2009; Al-Suhaibani and Ghaly, 2010) as a factor that most affects implement draught. Results from Al-Janobi and Al-Suhaibani (1998) on the draught of primary tillage implements in sandy loam soils show a significant increase in draught in all the treatments with an increase in tillage depth of cut. The offset disc harrow showed draught forces of 5.62 kN and 11.37 kN whilst the chisel plough showed draught forces of between 8.33 kN and 18.31 kN for depths between 70 mm and 230 mm. Arvidsson *et al*., *(*2004) calculated draught force from measurements of fuel and speed, and concluded that draught was related to depth of ploughing. Moeenifar, Mousavi-Seyedi and Kalantari (2014) studied the influence of tillage depth and forward speed on the draught force of a thin blade. Their results indicate the stronger influence of tillage depth as compared to forward speed. Mamman and Oni (2005) likewise investigated the draught performance of a range of models of chisel furrowers. The results showed that tillage depth had significant effects on the draught of the model tools. Godwin (2003) reported that the draught of a mouldboard plough and the depth (working depth) has a much greater influence than the furrow width and the implement velocity. This therefore suggests that depth has a greater effect on draught than does width of cut.

Adewoyin (2013) conducted a fuel consumption evaluation of some commonly-used farm tractors for ploughing operations on the sandy-loam soil of Oyo State, Nigeria. He reported that fuel consumption values significantly increased with ploughing depth. This study shows that, in order to reduce both draught and fuel consumption, one has to compromise on the depth of cut. It concluded that the depth of crop roots should determine the appropriate ploughing depth in order to minimize expense on fuel. Since various researchers reported that depth affects draught, it was concluded that it would be essential to investigate the effect of depth as well on the NSCT technologies used in the NCA as this has not been done.

2.4.2 Methods of measuring draught requirements of tillage implements.

There are various methods of measuring the draught requirements of tillage implements. Mostly they use dynamometers, which can be grouped into two major categories: drawbar dynamometers and three-point hitch dynamometers. Field measurement methods include three-point hitch dynamometers, instrumented strain gauges and instrumented toolbars for the attachment of different tillage tools and drawbar transducers for trailed implements (Askari, Komarizade, Nikbakht, Nobakht, & Teimourlou, 2011).

Various researchers have used drawbar dynamometers with two tractors. (Narayanarao and Verma 1982; Vozka 2007; Ahaneku *et al.,* 2011). Use of a drawbar dynamometer or digital dynamometer involves attaching the dynamometer to the front of the tractor on which the implement is mounted. Another auxiliary tractor is used to pull the implement-operating tractor through the dynamometer, but with the implement removed. The auxiliary tractor then pulls the implement-operating tractor with the latter in neutral gear, but with the implement mounted and in operating position. The difference between the two readings, gives the draught requirement of the implement.

2.4.3 Specific Draught

Several researchers have pointed out that, to assess differences between different implements accurately, the draught requirement must be related to the volume of soil tilled (Al-Janobi & Al-Suhaibani, 1998; Serrano & Peça, 2008). This is called the 'Specific Draught Requirement' (force per cross-section of tilled area, kN m^{-2}). Serrano and Peça (2008) refer to Al-Janobi and Al-Suhaibani (1998) in recommending the Specific Draught per unit implement width as a convenient measure of disc draught. Both studies measured disc draught as the Specific Draught per unit implement width, whilst Sommer, Chen and Bieri (1983) defined Specific Draught as the projected Specific Draught per cross-sectional unit area of the tilled zone, corresponding to implement draught divided by the rectangular area. In their study the rectangular area is defined by the cutting width and depth of disc penetration. This definition was also used by Khaffaf and Khadr (2008). For the present study, the Specific Draught in kN m^{-2} is defined as the implement draught divided by the rectangular area because it explains all the soil that is moved by the implement.

According to Manuwa and Ademosun (2007) the Specific Draught of agricultural tools and implements varies widely under different conditions, being affected – predictably – by such factors as soil type and condition, ploughing speed, plough type, shape, friction characteristics of the soil-engaging surfaces, share sharpness, and shape, depth of ploughing, width of furrow slice, type of attachments, and adjustment of the tool and attachments. This merely reminds us that there are a number of factors that can affect Specific Draught.

Al-Janobi and Al-Suhaibani (1998) observed increases in the Specific Draught proportional to an increase in tillage depth and speed for several implements (offset disk harrow, mouldboard plough, disk plough and chisel plough) tested on sandy loam soil. Arvidsson, Keller and Gustafson (2004) measured the Specific Draught requirement for mouldboard plough, chisel plough and disc under different moisture conditions and at different working depths. They found that the Specific Draught requirement was lowest for the mouldboard plough and highest for the chisel plough, especially under dry conditions. The actual tillage depth has a great effect on the total draught requirement. Arvidsson *et al.*, (2004) further reported a 19.5% increase in Specific Draught with increased working depth from 17 cm to 21 cm for a chisel plough. Arvidsson and Hillerstrom (2010) also reported a 20% increase in Specific Draught with increased tine width from 50 to 120 mm. This shows that Specific Draught is affected by tillage depth and width.

Al-Suhaibani and Ghaly (2010) measured the draught of a heavy duty chisel plough in a sandy soil over wide ranges of ploughing speeds and depths, and evaluated the effects of these on draught, vertical Specific Draught and horizontal Specific Draught. The results indicated that increasing the ploughing depth and/or the forward speed increased the draught, and vertical Specific Draught. It was shown that doubling the ploughing depth increased the vertical Specific Draught by 44.2% while doubling the forward speed increased the Specific Draught by 14.4%. This suggests that depth has the greater effect on Specific Draught and that forward speed is less important.

2.4.4 Field Efficiency (Ef)

Field Efficiency refers to the time and width utilization of machines – in simple terms, the time a machine actually spends in the field doing exactly what it is supposed to do as compared to the total time the machine spends in the field (Hunt, 2001; Lands, (2002). It is important for an operator to become aware of those factors associated with machine use that contribute to wasted or lost time. This will help the operator to do something about the time losses and other unproductive machine activities. Field Efficiency (Ef) can also be referred to as the ratio of the effective field capacity of a machine to the theoretical field capacity. Field Efficiency is determined by comparing the theoretical time required to cover an area against the actual time taken to do so. It has been shown (ASAE, 2002) that performance rates for field machines depend upon achievable field speeds and upon the efficient use of time.

Field Efficiency takes into account failure to utilize the theoretical operating width of the machine, time lost because of operator capability and habits and operating policy, and field characteristics. Travel to and from a field, major repairs, preventive maintenance, and daily service activities are not included in field time or Field Efficiency. Field Efficiency is thus not a constant for a particular machine, but varies with the size and shape of the field, pattern of field operation, crop yield, moisture, and crop conditions.

Al Hamed (2005) studied the Field Efficiency and the Effective Field Capacity during tillage operations in sandy loam soil for three chisel ploughs with different shank shapes. The three ploughs showed an inverse relationship between Field Efficiency and forward speed, and Field Efficiency values were close at each of the four forward speeds. Typical ranges of Field Efficiencies, i.e. of 70–90% for most of the field machines, can be found in ASAE (2003, 2006). A gap, however, exists in establishing the field efficiencies of NSCT technologies that are used in the NCA as this has not been done.

2.4.5 Effective Field Capacity

Effective Field Capacity is another parameter that will help to establish the actual output that an implement achieves. According to Buckingham (1984) three factors are important for Effective Field Capacity: machine width or size, operating speed, and time spent in operation. Field speed may be limited by rough ground and adequacy of operator control. Time lost includes time taken up when turning at headlands, stopping for adjustments or filling up with fuel. As a time-dependent parameter, Field Efficiency is affected by irregularly shaped fields and high capacity machines. Effective Field Capacity is the actual rate of field coverage, and this is important because it enables one to estimate how much time is needed in order to finish a certain area of field. This parameter is therefore important to Namibian farmers, as it can be used to predict what area of land can be covered in a given time, especially when this concerns the introduction of new implements like the ripper-furrower.

The performance of agricultural machines is measured by the quality achieved and the rate at which the operations are completed. Rate is an important measure, and for most agricultural field machines it is reported in terms of area per hour. This is thus a measure of the actual amount of work done by the machine. Vozka (2007) evaluated the performance of tractor-drawn ploughs and showed that increasing the width of the implement increases the work rate and decreases the operating costs.

A study from Western Kenya comparing different types of land preparation (Bishop-Sambrook, 2003) showed that hand power required 62 days per hectare (0.001 ha hr^{-1} assuming 12 hours a day as for Chigariro) as compared to 7 to 10 days (0.008 ha hr^{-1} for animal draught power and about half a day (0.17 ha hr^{-1}) for tractor power (Bishop-Sambrook, 2005). In another study, Simalenga, Belete, Mzeleni, and Jongisa (2000) concluded that oxen can plough about five times more land than humans can do manually, while donkeys can plough about 2.5 times more. Chigariro, Sheehama and Chiremba (2008) estimated that work rates for ploughing in Namibia could be 0.02 ha hr^{-1} for manual power, 0.07 ha hr^{-1} with donkeys, 0.08 ha hr^{-1} with oxen and 0.43 ha hr^{-1} with tractors.

Because there are no known field performance studies on the draught requirements of the current agricultural implements such as the animal- and tractor-drawn ripper-furrowers operating on the sandy soils predominant in NCA, there is therefore a gap in our knowledge and a need to study the performance and draught requirements of some implements available in Namibia, particularly those used in the NSCT technology.

2.5 Soil Compaction

2.5.1 Definition of Soil Compaction

Soil compaction is the process by which a stress applied to a soil causes densification as air is displaced from the pores between the grains (Guerrero, 2004; Ziyaee & Roshani 2012; Umeghalu & Ngini, 2013). It can also be defined as a decrease in soil volume and porosity, or an increase in soil bulk density, due to mechanical stress on soil, for example from the traffic of agricultural machinery. Compaction can also occur naturally. Natural processes occur mostly in soils with high clay content because individual clay particles are so small that they are more susceptible to being pressed together tightly (Ziyaee & Roshani, 2012).

According to Hamza and Anderson (2005) the main cause of soil compaction is axle load of farm machinery. They reported that over 30% of field area is affected by tyres of heavy machinery. Ziyaee and Roshani (2012) reported more generally that common causes of soil compaction are vehicle and foot traffic, and rain on bare soils.

Another form of compaction is the subsoil compaction that occurs below the plough layer due to a surface load (Soil Quality Institute, 2003). Subsoil compaction refers to any type of compaction deeper in the soil profile than the surface horizon. Examples are plough pans as mentioned above, deep compaction, and inherent hardpans. Ziyaee and Roshani (2012) found that excessive tillage accelerates the breakdown of organic materials that inhibit compaction. It can also damage soil structure, the arrangement of mineral particles in relation to pore space, especially if soil is tilled when it is wet. Over the years, repeated tillage aligns all of the soil particles in the same direction, causing a layer of compacted soil (a plough pan) to form directly beneath the area being tilled. Plough pans are mainly a problem on farm fields where the soil is consistently tilled at the same depth. Ramzan, Khan, Hanif & Ali (2012) also reported that compaction is caused by the use of agricultural machinery, pressure from tyres, continuous ploughing at the same depth for many years, grazing of animals and less use of organic matter.

In Namibia, Rigourd and Sappe (1999) investigated soil fertility in the North Central Regions and found that soils tend to form hard pans, in some cases due to the inherent nature of the soil and in other cases due to repeated ploughing at the same depth. Strohbach (1999) also reported soil degradation in Namibia as manifesting itself as nutrient depletion, hardpan formation and surface sealing. Several other studies reported that ploughs and disc harrows being used in the North Central Regions (NCRs) were creating hardpans and this contributes to the rapid decrease in crop yields (MSTT, 2009; NAB, 2009; von Hase, 2013). However, no actual measurements or studies of soil compaction under tillage were undertaken.

The effects of tillage on soil compaction have been studied by many. For instance studies by Birkas, Jolankai, Gyuricza and Percze (2004) showed that annual shallow disking and ploughing caused subsoil compaction at the depth of tillage. The surfaces of such tillage pans are often smeared by the passage of the implement, which drastically reduces the pore continuity between the topsoil and the subsoil. This may have a major negative effect on soil quality. Andrade-Sánchez, Upadhyaya and Jenkins (2007) remarked that studies had shown that an increased level of soil compaction leads to a reduction in the infiltration characteristics of the soil, which in turn leads to low soil moisture.

Borghei, Taghenejad, Minaei, Karimi and Varnamkhasti (2008) evaluated the effect of sub soiling on soil bulk density, soil compaction (as measured by penetration resistance) and cotton yield in the northwest of Iran. They concluded that sub soiling not only increased the yield of cotton but also reduced soil compaction to ensure root aeration and propagation.

In this context, Małecka, Blecharczyk, Sawinska and Dobrzeniecki (2012) evaluated 3 tillage systems i.e. conventional tillage, reduced tillage, and no-till. Continuous cultivation for 7 consecutive years by reduced tillage and no-till led to changes in the physical properties of the surface soil layer (0–5 cm). Conservation tillage (CT) where no tillage was used resulted in decreased penetration resistance compared to conventional (CV) tillage.

Mosaddeghi, Mahboubi and Safadoust (2009) investigated the short term effects of tillage and manure on some soil physical properties and maize root growth in a sandy loam soil in western Iran. They found that soil conditions in arid and semi-arid environments under a no-till conservation system were better than those under a conventional system.

Other researchers (Osunbitan, Oyedele & Adekalu 2005) studied the effects of tillage on the strength of a loam sand soil. They found that the penetration resistance of surface soil decreased with the increase in the intensity of soil loosening by tillage operations. Also in apparent contradiction, when Cavalaris and Gemtos (2002) evaluated four conservation tillage methods in a sugar beet crop, they found and reported that reduced tillage methods caused a higher penetration resistance in the soil as compared to conventional tillage methods. Other contradictory results were reported by Fabrizzi, Gorcia, Costa and Picone (2005) and Bayhan, Kayisoglu, Gonulol, Yalcin and Sungur (2006) who showed increases of penetration resistance (PR) values under no-till compared with those in conventional tillage. All these contradictions could be because there is no standardisation worldwide on no-till research. It could also be that the effects vary depending on soil type as well as climate conditions.

In another study, Altuntas and Dede (2009) evaluated the effects of conservation tillage and ridge planting systems on the physical properties of soil and plant characteristics of second crop silage maize in Turkey. They found that penetration resistance was higher in conservation tillage systems using chisel and toothed harrow compared to those under a conventional system which used mouldboard plough, cultivator and toothed harrow. They went on to specify that it is important to measure the long-term impact on soil quality, crop growth and yield in order properly to evaluate different tillage systems and planting systems.

2.5.2 Effect of Soil Compaction on Root penetration

The inability of plant roots to penetrate compacted soil is reported by Laker (2001). Several authors (Petersen, Ayers & Westfall, 2004; Wells, Stombaugh & Sheraer, 2005; Raper, 2006) have also reported that soil compaction, apart from hindering root penetration; can also reduce yields of crops by hindering root development as well as air and water movement in the soil. (Petersen *et al.*, 2004; Wells *et al*., 2005; Raper, 2006).

Several authors likewise concluded that a high penetration resistance in conventional systems resulted in a lower root growth, (Atwell, 1993; Reichert, da Silva & Reinert, 2004; So, Grabski & Desborough 2009) affecting water and nutrient uptake by crops. Shaxson and Barber (2003) reported that Saturnino and Landers (1997) measured the number of maize roots in 10 cm layers of soil to 1 m depth after 15 years of constant no-till and conventional tillage treatments. The results showed marked differences. No-till and crop rotation favoured recycling of nutrients and better soil structure, resulting in better root development and higher production. Derpsch et al. (1991) also reported that the total number of roots was more evenly distributed down the profile with no-till than with conventional tillage. This shows the importance of long term trials.

Several researchers have reported different critical values for root growth reduction as a result of soil compaction or high penetration resistance. Kees (2005) stated that soil compaction begins to inhibit the root growth of most plants when the soil's strength is about 1, 5 MPa and went further to say that the roots of many plants stop growing when the soil's strength reaches about 2.5 MPa. According to Atwell (1993); Reichert *et al*., (2004); So *et al.*, (2009) penetration values greater than 2 MPa are generally reported to reduce root growth significantly. Aase, Bjorneberg and Sojka (2001) also reported that, as soil pressures exceeded 2 MPa, root growth had been shown to be restricted to varying degrees. A measure of 2 MPa was, therefore, considered as determinant of soil hardpan layer. Other researchers also reported different critical values that limit root growth for penetration resistance (PR). Sinnett, Morgan, Williams and Hutchings (2008) reported that a PR value larger than 3 MPa caused a major hindrance to the root penetration of four tree species in sandy loam soils. Hermawan and Cameron (1993) likewise reported that rooting depth is restricted in cases where PR exceeds 3.0 MPa. Lampurlanes and Cantero-Martinez (2003) chose to be more flexible, reporting that a PR value between 2 MPa and 5 MPa is the critical upper value above which root growth is severely impeded.

Several researchers (Cavalaris & Gemtos, 2002: Kumar, Chen, Sadek, and Rahman 2012) studied effect of depth on penetration resistance for various tillage practices. They reported that penetration resistances increased with soil depth regardless of tillage practices.

2.5.3 Methods of measuring compaction

There are various methods of measuring soil compaction. The most commonly used is that which looks at bulk density. An alternative method, also common, is that which uses a soil penetrometer. Soil penetration resistance (PR) is one of the common variables used to assess soil strength in tillage (Kumar *et al*., 2012). It is a measure of 'soil strength' and an indicator of how easily roots can penetrate into soil, and thus something of a measure of plant growth and crop yield. Whilst Lampurlanes and Cantero-Martizez (2003) have pointed out that the most common variables used to assess soil strength in tillage studies are bulk density and soil penetration resistance, Kees (2005) also stated that penetrometers can help identify soil compaction faster and easier than standard bulk density tests. Duiker (2004) also reported that penetration resistance was a better indicator of the effects of soil compaction on root growth than bulk density, because its results can be interpreted independent of soil texture.

The force required to press the cone through the soil, is an index of soil strength expressed in kilopascals and is also called the Cone Index. The cone is a part of the penetrometer. The diameter of the cone is 20.27 mm for soft soils or 12.83 mm for hard soils (Kees, 2005). The Cone Index of any soil is mostly affected by factors like soil water content and bulk density. The higher the Cone Index, the greater is the amount of energy that must be expended by the roots to widen the soil pores (Chen, Cavers, Tessier, Monero & Lobb, 2005). As specified by Isaac, Taylor, Staggenborg, Schrock and Leikam (2002), the Cone Index must have at least three consecutive data points that exceed 1 MPa to be classified as hardpan layer. Within a soil type, penetration resistance is affected by the water content and structure of the soil (Bengough *et al.*, 2002 cited in Vanags, Minasny & McBratney *et al.*, 2006; Andrade-Sánchez, Upadhyaya & Jenkins *et al.*, 2007; Mupangwa *et al*., 2008).

Different types of penetrometers that operate on static or dynamic principles have been developed to measure soil penetrability (Bengough, Campbell & O'Sullivan, 2001; Lowery & Morrison, 2002). The static penetrometer is pushed into the soil at a constant rate. The most common standards for hand-held penetrometers in agriculture are given in ASABE (2004). The penetrometer measures the resistance to penetration by a cone and has been designed to mimic a crop root. The resistance to a cone is believed to be similar to what a root experiences as it grows through the soil.

2.6 Soil moisture

2.6.1 Effect of tillage without mulch on soil moisture

Several researchers have reported that conservation tillage brings about positive changes in the physical, chemical and biological properties of a soil (Bescansa, Imaz, Virto, Enrique & Hoogmoed. 2006; Dumanski *et al*., 2006). One of the physical properties of the soil is soil moisture. The major objective of soil and water management systems is to encourage water to infiltrate rather than run off the surface. According to Mupangwa *et al*. (2007), conservation tillage (CT) leads to positive changes in soil physical properties such as water infiltration and water retention. Good soil water storage depends not only upon tillage management but also upon the previous crop.

Other researchers reported that water content affects penetration resistance within a soil type because of reduced water infiltration which in turn leads to low soil moisture content (Bengough *et al*., 2002; Andrade-Sanchez *et al*., 2007; Mupangwa *et al*., 2008). Andrade-

Sanchez *et al.* (2007) also explain that increased levels of soil compaction lead to reduction in the infiltration capacity of the soil, which in turn leads to low soil moisture. According to Lipiec, Kus´, Słowinska-Jurkiewicz and Nosalewiczl (2006) improved infiltration of rainwater into the soil not only increases water availability to plants and reduces surface runoff, it also improves groundwater recharge.

Cavalaris and Gemtos (2002) evaluated four conservation tillage methods in the sugar beet crop and reported that reduced tillage methods resulted in higher moisture content in the soil as compared to conventional tillage methods**.** In another study, Altuntas and Dede (2009) evaluated the effects of conservation tillage and ridge planting systems on the physical properties of soil and the plant characteristics of second crop silage maize in Turkey, and found out that soil moisture content was higher in conservation tillage systems using chisel and toothed harrow applications than in those under a conventional system using mouldboard plough, cultivator and toothed harrow applications. Małecka, Blecharczyk, Sawinska and Dobrzeniecki (2012) evaluated 3 tillage systems i.e. conventional tillage, reduced tillage, and no-till. Continuous cultivation for 7 consecutive years using reduced tillage and no-till led to changes in the physical properties of the surface soil layer (0–5 cm). At the stem elongation growth stage of spring barley, conservation tillage systems resulted in higher soil water content compared to that measured for conventional tillage. Dangolani and Narob (2013) examined the effect of four types of tillage operations on the performance of three varieties of cotton and observed the highest soil moisture level in the no-till treatment and the lowest moisture level in the mouldboard/disk treatment. They mentioned that the reason for such a difference in soil moisture could have been the residual cover provided by no-till treatment which prevented direct exposure to sunlight.

There are some contradictory evidences on the effect of tillage on soil moisture, however. Kováč, Macák & Švančárková (2005) studied the effect of conventional tillage, reduced till, mulch till and no-till technologies on soil moisture, but their results showed that conventional tillage performed better in soil moisture than all the other CT methods. The soil under conventional tillage had significantly higher moisture content than the tested reduced till, mulch till and no-till treatments. Licht and Al-Kaisi (2005) studied the effect of strip tillage on soil moisture content, and compared it to chisel ploughing and no-till. Their results showed no significant differences in soil moisture status among the three tillage systems, although the strip-tillage soil profile had slightly higher moisture content than the chisel ploughed soil. However, the changes in soil moisture storage from post-emergence to pre-harvest at 0–30 and 0–120 cm were much greater with strip-tillage and chisel ploughing, than with no-till. The contradictory results reported here could be due to lack of standardisation in tillage research rather than as a result of the different treatments. The other reason could also be that the mulch levels were different in the various treatments, different soil conditions, weed control regimes and the soil type as well as climate.

2.6.2 Effect of tillage and Mulch on soil moisture

Researchers (Scopel *et al*., 2004; Fuentes *et al*., 2009) have reported that the presence of crop residue mulch at the soil-atmosphere interface, i.e. on the surface of the soil, has a direct influence on infiltration of rainwater into the soil and evaporation from the soil. Infiltration and soil evaporation are among the key processes that determine soil water availability to crops in semi-arid agriculture. Fuentes *et al*. (2009) reported that retention of residues improved infiltration and reduced evaporation and also resulted in lower resistance to water penetration and higher moisture retention regardless of tillage system. Mulches thus play an important role in conservation of soil water through reduced soil evaporation in semi-arid conditions (Scopel *et al*., 2004). Mulch cover reduces surface runoff and holds rainwater at the soil surface, thereby giving it more time to infiltrate into the soil. Crop residues remaining to decompose on the surface under conservation tillage improve the soil's physical and biological characteristics which results in increased soil fertility and soil quality (Köller, 2003).

A common agricultural practice in many parts of the world is the removal of crop residues after harvest through burning, grazing or removal for use as fodder. This may result in the soil surface remaining exposed for up to six months each year during the FALLOW periods (Govaerts *et al*., 2008). According to Giller, Witter, Corbeels and Tittonell, (2009) a lot of challenges are faced when trying to implement conservation agriculture in Africa, especially in the semi-arid regions where the successful implementation of conservation tillage depends on the ability of farmers to retain crop residues and to ensure adequate weed control. Farmers in Namibia are known to remove or burn all crop residues (stover) without adequate soil nutrient replenishment (NAB, 2009).

A soil surface residue cover of 30% or more decreases the amount of water evaporated from the soil surface and increases water infiltration rates, leading to more water stored in the soil (Simmons, Williams & Nafziger, 2009). Since CT tillage systems offer the possibility of covering more than 30% of the soil surface by plant residues (ACT, 2005), this could be expected to greatly reduce runoff, increase the infiltration rate and decrease the evaporation of the soil water under such a system (Dumanski *et al*., 2006).

Erenstein (2003) reported positive effects of the application of crop residue as mulch on yield He pointed out that crop residues shield the soil from solar radiation, thereby reducing evaporation from soil, increasing soil organic content, keeping the soil surface cool and providing a microclimate conducive to beneficial soil biota. Trials conducted in the higher agricultural potential areas of Zimbabwe between 1988 and 1995 indicated that mulching significantly reduced surface runoff and hence soil loss (Erenstein, 2002).

Other studies conducted in Zimbabwe measured topsoil moisture contents in 'mulch ripping' (CT) and results were 5–10% higher than under conventional mouldboard ploughing (Nyagumbo, 2002). Results showed that mulch ripping (CT) resulted in significantly ($p<0.05$) better soil water storage than conventional mouldboard ploughing in the top 45 cm, corresponding to an increase of about 5%. In trials conducted in Zimbabwe on a sandy soil, direct seeded CT treatments had a 49% and 45% greater infiltration rate than the conventionally tilled plots after a simulated rainfall in two seasons. In Zambia, on a finer textured soil, the same treatment as the one in Zimbabwe had 57% and 87% greater infiltration rates than the conventionally tilled control treatment in two seasons. (Thierfelder & Wall 2009).

Combining reduced tillage with surface residue has been shown to improve crop performance (Woyesa & Bennie, 2004; Dam, Mehdi, Burgess, Madramootoo, Mehuys & Callum, 2005). The effect of crop residues and management practices on soil quality, soil nitrogen dynamics and crop yield was also reviewed by Kumar and Goh (2000). They concluded that residues of cultivated crops are a significant factor for crop production. Vogel (1993) went so far as to suggest that mulching could be the best conservation tillage technique for the semi-arid regions because of the reduced topsoil water losses.

However, Mupangwa, Dimes, Walker, and Twomlow (2011) studied the effect of mulching and minimum tillage specifically on maize. They showed that maize yield was not significantly influenced by mulching or minimum tillage, individually or in combination. Maize yields for conventional ploughing were better than the yields under minimum tillage practices in heavier soils. Planting basins performed better on sandy soil. The study showed that no additional soil water benefits were derived from applying mulch cover beyond 4 t ha^{-1} on both clayey and sandy soils. The researchers concluded that minimum tillage methods, even in combination with mulching, gave only small yield benefits especially on sandy soils. Mulching helps conserve soil water, but the benefits level off at fairly low levels of mulch application. Further research is justified to study the effect of CV and NSCT technologies and mulch that are used in the NCA on soil moisture.

2.7 Crop Yields under Different Tillage Systems

Yield is a major factor in farm-level profitability, and the most documented in literature. Generally, crop yields in SSA are very low when compared with other regions in the world. For example, average cereal yields of about 1000 kg ha^{-1} in SSA are only about one third of the average cereal yields in countries in Asia and Latin America (World Bank, 2007 as cited by FAO & UNIDO, 2008).

In the Eastern and Southern Africa Regions, yields of staple food crops such as maize, millet and sorghum remain in the order of 0.5 to 1.5 t ha^{-1} under smallholder rain-fed farming systems, yet yields of 4 to 6 t ha^{-1} are attainable under improved crop management systems in similar agro-ecological zones (Rockstrom, 2002).

Food production must keep pace with or exceed the population growth, as many countries would soon have insufficient new land for farming, leaving no option but to increase yield per unit area (Bruinsma, 2009). However, conservation tillage and improved soil management can play a role in increasing crop yields and productivity on a sustainable basis. Chambers and Conway (1991) defined sustainable livelihoods as “those that can cope and recover from stress and shock, maintain and enhance its capabilities and assets and provide sustainable livelihood opportunities for the next generation and which contributes to the net benefit to other livelihoods”.

Researchers have also reported increased yields from conservation tillage (Scopel et al., 2001; Diaz-Zorita, Duarte, & Grove, 2002). Diaz-Zorita *et al*., 2002; Rashidi & Abbassi, 2011). Mazvimavi (2011) also reported that in 2008/09 cropping season maize yield gains for basin tillage were 42 and 105 % higher than conventional tillage for Zambia and Zimbabwe, respectively. Mupangwa, Twomlow and Walker (2007) also reported that for ripper and basin tillage systems in Zimbabwe, maize grain yield increased with mulch cover in seasons that had below average rainfall with 2–4 t ha^{-1} mulch treatments, giving an optimum yield. In the wettest growing season (2005/06) the ripper and basin systems yielded 3% and 9% more maize grain than the conventional system. In the driest growing season (2006/07) the ripper and basin systems yielded 8% and 2% more maize grain than the conventional system.

In another study, Dillalessa (2006) evaluated three tillage systems: minimum tillage with residue retention, minimum tillage with residue removal and conventional tillage. Results showed that minimum tillage with residue retention significantly increased the grain yield by 6.6% and 12.2% compared to minimum tillage with residue removal and conventional tillage, respectively. De Vita, Di Paolo, Fecondo, Di Fonzo and Pisante (2007) also studied the effects of conventional tillage and No Till on wheat yield. They, too, showed that No Till (CT) achieved greater yields than conventional (CV) tillage.

Cavalaris and Gemtos (2002) evaluated four conservation tillage methods in a sugar beet crop. They reported, by contrast, yields of sugar beet reduced between 26.1% and 46.6% under reduced tillage methods as compared to conventional tillage methods. Contradictory results could be due to lack of standardisation, soil conditions, mulch levels, weed control measures as well as climate conditions.

Likewise, in yet another study, Rusinamhodzi *et al*. (2011) conducted a meta-analysis using worldwide maize grain yield data from rain-fed long-term studies on tillage and residue management from semi-arid to sub-humid environments. There was no change in weighted mean differences in maize grain yield over time, and it was therefore concluded that no-till had no positive effect on maize yield compared with conventional tillage. Results from Rusinamhodzi *et al.* (2011) showed that in the first 10 years, crop yields under no–till were lower than under conventional tillage practice. Dam *et al.* (2005) also reported that, after 11 years, maize yields were not affected by tillage and residue practices but that climate-related differences seemed to have a greater influence on the variation in yields. Małecka *et al.* (2012) evaluated 3 tillage systems: conventional tillage, reduced tillage, and no-till, and their results also showed no effect of the tillage system on yield. The no-till system alone had a negative effect on yield of spring barley, by 6.8% in comparison with conventional tillage. Results from the Laikipia conservation agriculture project in Kenya (Kaumbutho & Kienzle, 2007) showed that maize yields were virtually the same for plots managed under conventional tillage and those managed under conservation agriculture. All this suggests that there are no significant differences between CT and CV when it comes to yield.

On the other hand, Rashidi, Gholami and Abbassi (2010) studied the effect of different tillage methods on yield in the sandy loam soils. The tillage treatments included: conventional tillage (mouldboard ploughing + two passes of disk harrowing), minimum tillage (MT: one pass of disk harrowing) and no-till (NT). The results indicated that tillage methods significantly ($P \leq 0.05$) influenced the yield of tomatoes.

2.8. Pearl Millet Production in the NCA

According to Mendelsohn (2006) cereals contributed 14% to Namibia's Gross Agricultural Production of which pearl millet grown in the NCA accounted for 64% of this contribution. In the second quarter of 2014, agriculture contributed 4.4% to Namibia's Gross Domestic Product (GDP) (NSA, 2014).

The Namibian climate can be described as semi-arid to arid. Dry land agriculture in Namibia is highly dependent on the availability of rain. Namibia is one of the driest countries in sub-Saharan Africa, and rainfall is a significant constraint on agriculture over most of the country (Kuvare, Maharero & Kamupingene, 2008; Kerdiles, Rembold, & Pérez-Hoyos (2015). Reliable crop production under rain-fed conditions is only possible in areas receiving an average of over 400 mm rainfall annually, representing 34% of the country. Soils, particularly where crop production is practised, are generally sandy with low water-retention capacity. Sweet and Burke (2006) reported that 97% of the soils in these areas have a clay content of less than 5%. These soils also have very low organic matter content, poor water-holding capacity, and are generally poor in several nutrients except calcium. As well as being deficient in most of the major nutrients, they are also deficient in micro-nutrients such as manganese iron and zinc (Sweet & Burke 2006).

The interaction between rainfall and soil type in the NCA dictates the type of cereal grown in each locality. When the length of the rainy season is shorter than 100 days, maize cannot be grown economically. Due to the short growing seasons in Kavango and the North-Central regions (<100 days) and the predominant sandy soils, the cereal choice is thus limited to pearl millet (*Pennisetum glaucum*). It is therefore important to note that farmers in Kavango and the North-Central Regions grow pearl millet because there is no other cereal they can grow economically under the available rainfall conditions (Matanyaire, 1996).

Pearl millet as a result is widely grown for food in the northern regions of the country by the majority of small-scale resource-poor farmers. There is also a market where there is a high demand for pearl millet, in particular amongst workers in mining and fishery sectors (NEPRU, 2000 as cited by Thomas & Mpofu, 2013) as well as in the informal urban settlements of the country. Pearl millet grains and the by-products such as straw and chaff can be used variously as food, beer, animal feeds, fuel, thatching, manure, fencing materials and building materials for many rural houses (Onwueme & Sinha, 1991 as cited by Thomas & Mpofu, 2013). According to NAB (2012), research has established that *mahangu* (pearl millet) is highly nutritious, gluten-free and does not form acid, so it is soothing and easy to digest, making it a viable commodity and highly marketable. The disadvantages are however its vulnerability to bird attack.

In Namibia, three improved varieties of pearl millet – namely Okashana 1, Okashana 2 and Kangara – were introduced between 1990 and 1998 and are now available to farmers. They are early maturing (in <90 days), open-pollinated varieties that are drought-tolerant with quick grain-filling capability, which is a useful terminal drought escape mechanism. Farmers have adopted these varieties for their yield stability rather than their yield potential. Results from research show that, in good seasons, the yields of the local varieties that mature in 120 days, developed by indigenous farmers, are just as good as or even better than the 3 improved varieties, although they take longer to mature (Uno, 2005).

2.8.1Yields of Pearl Millet

Since 1996, the Namibian Agronomic Board (NAB) has collected data on national pearl millet production which indicate that production has fluctuated wildly from one year to the next, with average national production at 65 800 tonnes (median 63 200 tonnes) per annum (NAB, 2012). The Crop, Livestock and Food Supply Assessment Mission fielded by the FAO/World Food Programme (WFP) in 2009 estimated that the Namibian national production of cereals in the 2008/09 season was 138 797 tonnes, including 63 324 tonnes of millet. National cereal production between 2008 and 2013 is also shown in Table 2.4.

Table 2.4: Namibia Cereal Production

	2008–2012 average (000 tonnes)	2012 (000 tonnes)	2013 estimate (000 tonnes)
Maize	62	88	43
Millet	48	56	33
Wheat	14	14	14
Others	6	8	6

Source: FAO/GIEWS, (2014)

Menges (2004) reported that according to Christof Brock, Chief Executive Officer of the Namibian Agronomic Board, Namibia needed about 185 000 tons of *mahangu* and maize each year. As judged from Table 2.4, the totals for maize and millet from 2008 to 2013 fell short of the estimated 185 000 tons that was needed. This means that Namibia would have had to import the balance, and in 2012, Namibia did import 42 800 tonnes of pearl millet (NEWFIU, 2012). These values for cereal production, shows that farmers in Namibia need to produce more in order to cut down on imports.

Klaij and Serafini (1988) undertook a long-term experiment to evaluate the effects of primary tillage, fertilization and the maintenance of crop residues on yields of pearl millet. Their results indicate that, when fertiliser and residues were used, yields of pearl millet were as high as 5680 kg ha^{-1} for ploughing, 5850 kg ha^{-1} for ridging and 5430 kg ha^{-1} for no-till treatments. Yields were higher when residues were maintained compared to when they were removed i.e. 5480 kg ha^{-1} for ploughing, 4690 kg ha^{-1} for ridging and 4720 kg ha^{-1} for no-till treatments. This suggests that it is beneficial to use residues and fertilisers in order to increase yields.

In the NCA, the introduction of the NSCT has shown that yields can be improved through use of residues and fertilisers as well. Table 2.5 shows tractor ripper-furrower yield results from CONTILL farmer plots in Namibia. The table shows a vast improvement in yields from 250 to 400 kg ha^{-1} produced by most farmers in the NCA that were reported by (NEWFIS, 1993; 2010; Mallet & Rigoud, 2004; Vigne and Associates, 2004; Davis & Lenhardt, 2009; MSTT, 2009; von Hase, 2013).

Table 2.5: Tractor ripper-furrower yields from CONTILL project for 2010/2011

Area	kg ha^{-1}
Omusati mahangu yields – highest	3 063

Omusati mahangu yields – lowest	1 213
Omusati mahangu yields – average	1 738
Kavango, mahangu average yield	1 321

Source: NRC, NNFU and LIMA NAWA, (2012)

2.9 Adoption of Tillage Technologies by Farmers

2.9.1 Adoption

Wilkinson (1989) defines adoption as a continuous process that may occur in a gradual or stepwise manner. From this definition adoption seems to be that it's a process rather than an event and information about the new technology is essential. According to Pannell and Zilberman (2001) adoption is the extent to which an individual farmer uses a new technology. The triad of knowledge, attitude, and practice in combination governs all aspects of life in human societies, and all together determine the adoption or non-adoption of the technology. Rogers (2003: 168) further explains that the decision to adopt is a process that does not happen spontaneously, but happens over time and that there are 5 stages that a farmer might go through before he or she adopts a technology. At first, farmers learn about various technologies that are available through information workshops and training programmes. This is knowledge. They then form attitudes about the technology, and finally use the technology.

The five stages Rogers (2003) states are that, in general, successful adoption of a particular innovation should result from high scores in terms of (1) its relative advantage over existing practices, (2) compatibility to users' needs, (3) trialability (4) observability, and (5) simplicity of use. Such characteristics of innovations can explain their rate of adoption.

1. Relative advantage of one technology over another is a key determinant in the adoption of a new technology, in this case NSCT technology versus the CV technologies. The notion of relative advantage is a reflection of how the innovation is subjectively perceived as being superior to the previous practice.
2. Compatibility of the innovation reflects how the innovation is perceived based on the existing values, past experiences, and needs of potential adopters.
3. Trialability is the characteristic which enables users, i.e. farmers, to be given a chance to try out the technology themselves.
4. Observability is degree to which the innovation's use and effects are visible to others. Observability reflects how the results of an innovation are seen, as when neighbours can see the application of technology in their neighbour's field.
5. Simplicity reflects the perceived lack of difficulty in understanding and using the innovation. The complexity of the technology will also impact on adoption.

Various studies (Khoram, Shariat, Azar, Moharamnejad and Mahjub, 2006; Grace *et al.*, 2009; Grahn, 2013) have been conducted using the KAP approach and have shown that, where farmers had been exposed or trained in a certain technology, they were found to possess the necessary knowledge. Grace *et al.* (2009) conducted a KAP survey to characterize and validate farmers' knowledge and practice in the management of cattle trypanosomiasis in the cotton zone of West Africa. Their study found that farmers had the necessary knowledge and played a major role in successfully managing trypanosomiasis, and thus recommended recognition and support for community-based treatment of the disease.

Farmers can also hear and learn about new technologies from their neighbours, NGOs and extension staff. According to Oster and Thorton (2009) in any technology adoption process, peer effects work in three major ways: (1) individuals profit from acting like friends/neighbours; (2) individuals gain knowledge of the benefits of the technology from their friends; and (3) individuals learn about how to use a new approach from peers. When farmers hear about new technologies, their attitudes may change for these reasons and they may therefore become more interested in knowing more about the technology, how it works and what it can do for them. This is very important, as it plays a major role in influencing their decision whether or not to continue practising current technologies and subsequently influencing them in deciding whether or not to adopt or reject a new technology.

Farmers can also make their decisions based on any expected impacts on the wellbeing of their households, particularly on household income. Quisumbing (2003) argues that the chances of adoption could be higher if there are prospects for higher profitability and greater yields. Straub (2009) explained that, historically, adoption was understood in terms of behavioural change. This implies that adoption happens over time, and only when an innovation has been accepted will it be used and integrated into a farmer's system. According to Bhattarai (2009) a farmer makes his or her own choice to adopt or not to adopt a particular technology depending on various factors such as his or her socio-economic characteristics, perceptions and also the particular technical features of any new methodology.

A survey was conducted by Khoram *et al.* (2006) on the knowledge, attitude and practice (KAP) of sustainable agriculture among rural farmers in the Hamadan province of Iran. They showed that those farmers had a very good knowledge of and a good attitude towards the fundamentals of sustainable agriculture. The farmers also practised sustainable agriculture to a fair level. This was mainly due to the education provided by agricultural extension, expansion of communications and also the expansion of modern information technology.

They concluded that it was very important for agents of change to promote the knowledge, improve attitudes and also to increase the practice of farmers where sustainable agriculture was concerned.

In another study, Grahn (2013) investigated the knowledge, attitude and practices (KAP) of brucellosis among smallholder farmers in Tajikistan. Results showed that there was a widespread lack of adequate knowledge among the participating smallholder farmers, accompanied by low values for attitude and practice. They concluded that better education of farmers was needed in order for them to protect their livestock from exposure as well as reduce the risk of the transmission and spread of brucellosis.

In yet another study, Godtland, Sadoulet, de Janvry, Murgai and Ortiz (2004) evaluated the impact of Farmer Field Schools (FFS) on the knowledge and productivity of potato farmers in the Peruvian Andes. They found that farmers who participated in the programme had significantly more knowledge about integrated pest management practices than those in the comparison group not participating in the FFS programme. They also found suggestive evidence that improved knowledge about IPM practices had the potential to significantly improve productivity in potato production. This study also highlighted the importance of conducting a baseline study before conducting KAP studies.

NSCT has become very important in Namibia and has been introduced to small holder farmers in some parts of the NCA. However, within the theory of technology adoption there was a gap where the establishment of farmers' knowledge was concerned, as well as knowledge of, their attitudes and practices concerning NSCT. Therefore it was found important to find out whether farmers have knowledge, attitude to practice and to adopt the NSCT as this has not been sufficiently studied.

2.10 Conclusions

Various researchers have reported different results on field performances of the tillage methods and their effects on moisture, compaction, roots and yield in crop production. This could be due to climate, soil conditions, no standardization in CT research studies and maybe other reasons. Few farmers in Namibia have also adopted the NSCT technology since its inception, making one wonder what the reasons could be. Little has been done in the NCA about comparing the field performances of animal- and tractor- drawn tillage technologies and how they affect soil moisture, soil compaction, root length and yield of pearl millet. For farmers to adopt a technology, they need to have knowledge about it and also to practice or use it. If they have a good attitude towards it, they will most likely use or practice the technology. A gap exists in the study of the NSCT technology and its adoption, as it has not been sufficiently tested in the NCA.

3. MATERIALS AND METHODS

3.1 Introduction

In order to be able to compare CV and NSCT technologies in Namibia, on-station trials were carried out at the Ogongo Campus of the University of Namibia (UNAM) between 2010 and 2013. Another study on the adoption of NSCT technology by farmers who were exposed to the technology was carried out in Ogongo and Omuntele Constituencies of Omusati and Oshikoto Regions between 2012 and 2013. The studies were divided into four parts based on the objectives of each part. A full description of the methods used to achieve the aims of each part are hereby presented in the following sections.

3.2. PART 1 – Field Performances of Tillage Technologies on fields without crop

3.2.1 Research design

The first part of the research involved testing the field performance of two CV and two NSCT technologies. The technologies tested were: (1) animal - drawn mouldboard plough (AMP); (2) animal - drawn ripper furrower (ARF), (3) tractor - drawn disc harrow (TDH) and (4) tractor - drawn ripper furrower (TRF). The tractor-drawn disc harrow and an animal-drawn mouldboard plough, represented the CV technology and a tractor-drawn ripper-furrower and an animal-drawn ripper-furrower represented the NSCT technology.

The research was set up in a randomized complete block design. Each block was given a total of 4 tillage treatments over a total of 16 plots, as shown in the experimental layout (Fig 3.1). The randomization of treatments in blocks was carried out using the Randomized Complete Block Design module of Genstat 4th Edition. The plots measured 10m x 10m, and 5m borders between blocks and 2m between plots to allow proper turning and movement of tractors and animals.

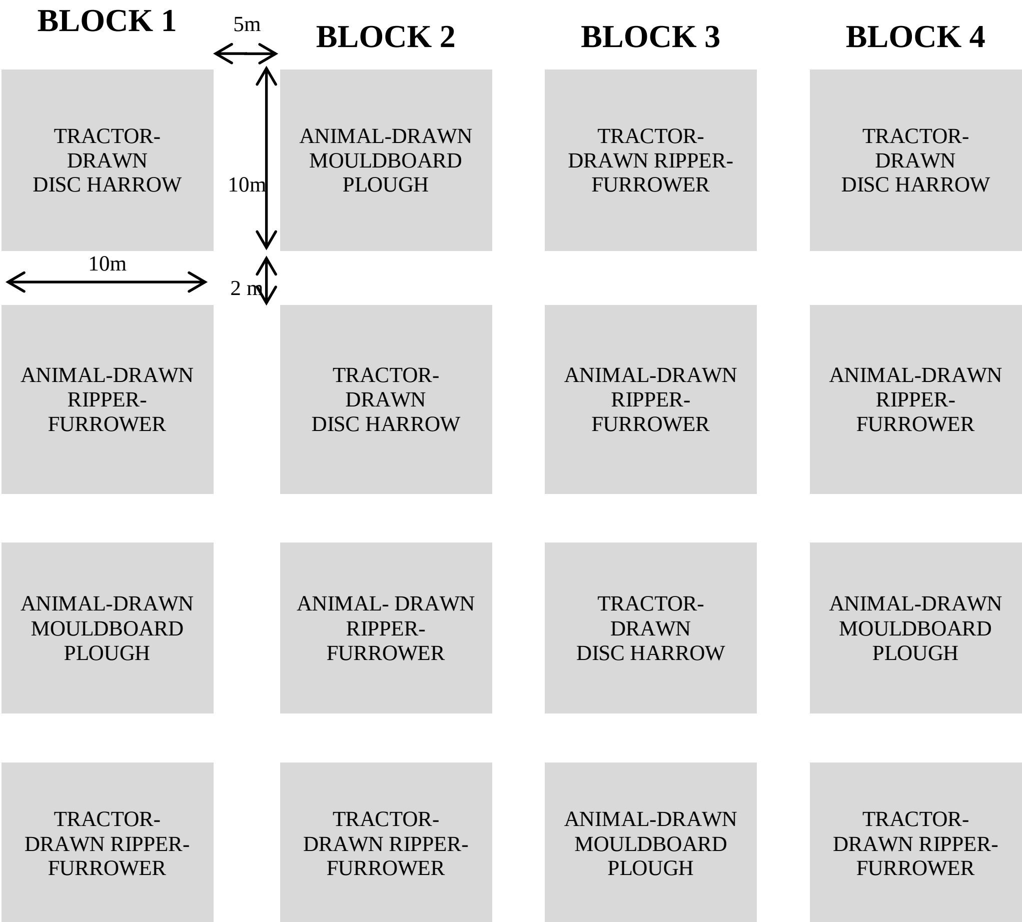

Fig 3.1: Experimental layout for Field Performances of Tillage Technologies on fields without crop

3.2.2 Materials Used

The specifications of the power sources (tractors and donkeys) are outlined in Tables 3.1 and 3.2 respectively. The specifications for the CV and NSCT implements are also given in the same tables. The technologies used in the present study are shown in Figs 3.2 to 3.5.

Table 3.1: Specification of the power sources and tillage implements

Power source	Implement	Tillage system	Implement Specifications	Width of Implement
3 Donkeys Total mass 673.2 kg	Animal-drawn ripper furrower (ARF) Fig 3.2	Namibia Specific Conservation Tillage	Baufis ripper-furrower	1m
3 Donkeys Total mass 673.2 kg	Standard animal-drawn single furrow plough (AMP) Fig 3.3	Conventional tillage	Standard V8 mouldboard plough	0.2 m
Tractors John Deer 5415 (65kW) and 2351 (55kW)	Tractor-drawn ripper furrower (TRF) Fig 3.4	Namibia Specific Conservation tillage	Baufis 2-tine	1.85m
Tractors John Deer 5415 (65kW) and 2351 (55kW)	Tractor-drawn offset disc harrow (TDH) Fig 3.5	Conventional tillage	Offset .20 discs	2.2 m

Fig 3.2: Animal-drawn ripper-furrower

Fig 3.3: Animal-drawn mouldboard plough

Fig 3.4: Tractor-drawn ripper-furrower

Fig 3.5: Tractor-drawn offset disc harrow

3.2.3. Draught Capabilities for the Donkeys Used in the Trials

Based on the normal practice of local farmers, a team of 3 donkeys was used for pulling the animal-drawn implements. The animal-drawn plough weighed 30kg (300N) and the animal-drawn ripper-furrower was 34 kg (340N). Table 3.2 shows the draught capabilities of the three donkeys.

Table 3.2: Specifications for the donkeys

Animals	Girth (cm)	Length (cm)	Mass of donkey (kg)*	Draught Capabilities of the donkeys
Donkey 1	130	125	218.6	218.6 x 0.21x 10 = 459 N
Donkey 2	136	128	242.0	242 x 0.21 x 10 = 508 N
Donkey 3	128	125	212.6	212.6 x 0.21 x 10= 446.5 N
Total live weight of the 3 donkeys			673.2	1414 N

*** mass of donkey =** $\frac{\text{girth}^2\text{ (cm) x length (cm)}}{10800} + 23$

Calculations of the draught capabilities of the donkeys were based on the estimated average of the 17–25% given by Starkey (1985). The mass of draught animals was also calculated using the length and girth measurements of the animals (AETC, 1986). A scale was used to measure the mass of the animal-drawn implements.

3.2.4 Research Site

On-station tests and trials to compare the implements were conducted at the UNAM Ogongo Campus in the Omusati region as shown in Fig 3.6. The rainfall is seasonal, falling mostly between the months of November and April. Normally the wetter period of the season stretches between January and March of each year (Mendelsohn, Obeid & Roberts, 2000).

The Ogongo Campus receives a mean annual rainfall of between 300 and 500 mm (Kuvare *et al.*, 2008; Kerdiles, *et al.* (2015). However, a total of 621.6 mm of rainfall was recorded at Ogongo from December 2010 to May 2011. In the following year, from December 2011 to May 2012, 377.4 mm was recorded and during December 2012 to May 2013, 332.3 mm was recorded. Rainfall therefore decreased from 2011 to 2013.

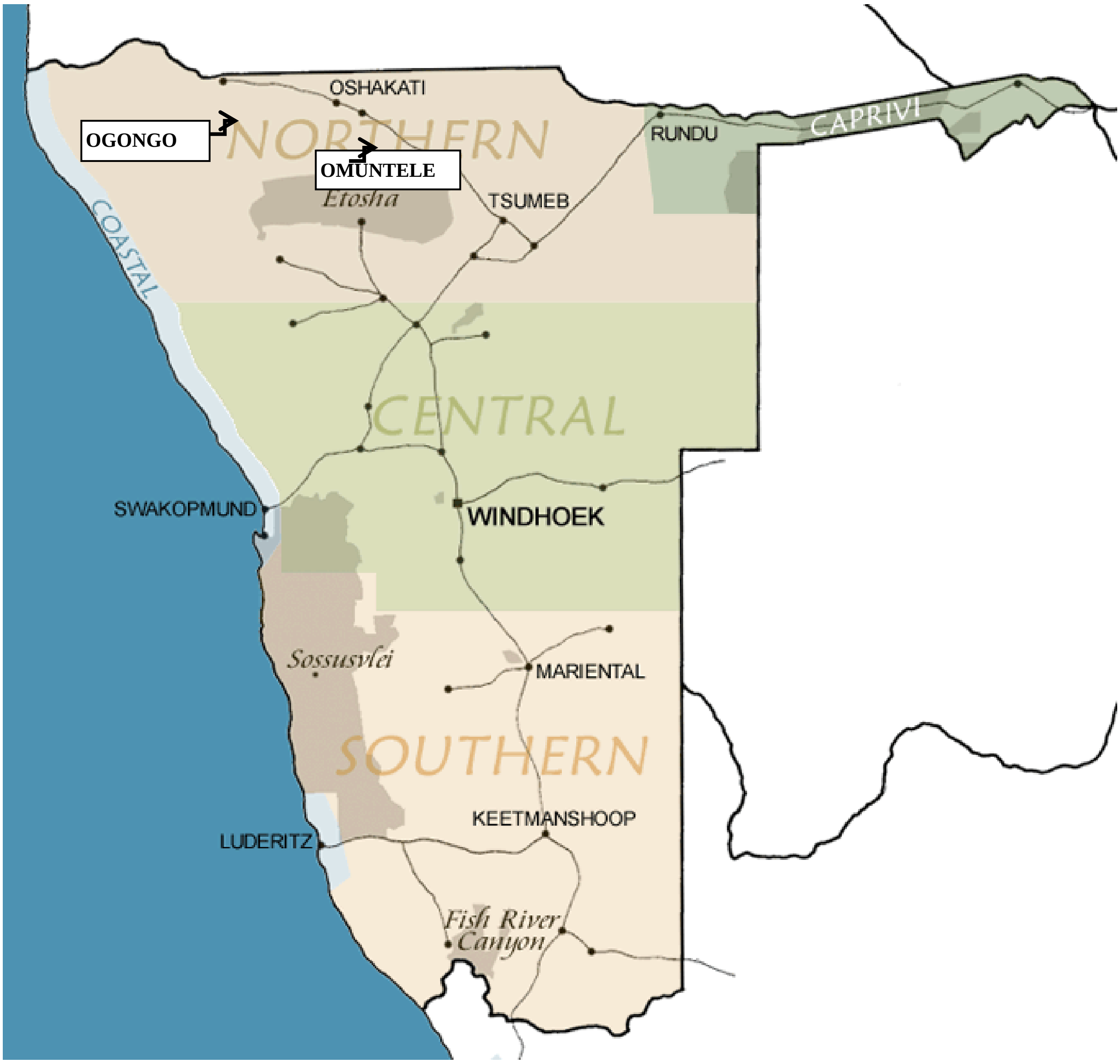

Fig 3.6: Map of Namibia showing Omuntele in Oshikoto Region and Ogongo in Omusati Region

In order to establish the soil type for the Ogongo Campus, samples of soils were taken at five randomly selected places and sent to the Analytical Laboratory Services in Windhoek. The soils at the research site are sandy with particle size analysis indicating 92.7 % sand, with 4.8 % silt and 2.6 % clay. (Appendix 1).

3.2.5. Experimental Procedure

An animal-drawn Baufis ripper-furrower (Fig 3.2) and tractor-drawn Baufis ripper-furrower (Fig 3.4) were used for ripping and making furrows whilst an animal-drawn mouldboard plough (Fig 3.3) and tractor-drawn disc harrow (Fig 3.5) were used to conventionally till the land. The tractor- and animal-drawn ripper-furrowers were used to rip and make a furrow in one operation. Only the soil in the furrow was thus disturbed. The ripped furrows were 1m apart. The mouldboard plough and the disc harrow disturbed the whole area and the mouldboard further inverted the soil and buried the weeds, crop residues and manure.

During the trials to compare the field performances of the tillage technologies, test runs were conducted before the actual experiments were conducted to ensure smooth running of the operations. Trained operators and animals were used both in the test run and in the experimental runs. Farmers in the NCA normally use torn harnesses that sometimes have wires protruding and damaging the animals' skin. In some cases, farmers use yokes on donkeys (Mudamburi & Keib, 2007). The best available designs for donkey harnesses were instead used in this study, and they were sourced from Baufis/Leather Connections to ensure the donkeys would be as comfortable as possible.

The 'Principle of Constant Traffic' was used for all treatments. 'Constant Traffic' is a system that reduces compaction by limiting it to designated areas of the field or controlled traffic lanes, such as the wheel tracks or furrow.

3.2.5.1 Tractor and implement draught measurements

Implement draught measurements followed the method described by Narayanarao and Verma (1982); Vozka (2007) and Ahaneku *et al.* (2011). Two tractors, a John Deere 5415 (65kW) and a John Deere 2351 (55kW) were used. A Novatech F 256 Axial Compensated Load cell (10kN) in combination with a TR150 portable load meter was used to measure both tractor and donkey draught force. Draught was measured using the load cell with the portable load meter attached to the front of the 55 kW tractor on which the implement was mounted. Another tractor (65kW) was then used to pull the 55kW implement mounted tractor through the load cell. The (65kW) tractor pulled the implement-mounted tractor with the latter in neutral gear but with the implement in the operating position. Draught was recorded in the measured distance (10 m) as well as the time taken to traverse the distance. On the same field, the implement was lifted out of the ground and the draught recorded without the implement. The difference between the two readings i.e. loaded minus unloaded, gives the draught of the implement. This procedure was repeated for each of the implements evaluated. Fig 3.7 shows the Novatech F 256 Axial Compensated Load cell and a TR150 portable load meter whilst Fig 3.8 shows their use for tractors. Five readings were taken from the digital display on the TR150 portable load meter attached to the load cell at ten randomly selected places in the four middle rows per plot. Five readings for each of the variables i.e. depth of cut, width of cut, draught, time per run, time for turning were measured at ten randomly selected places in the four middle rows per plot following the methods recommended by RNAM (1983 & 1995).

Fig 3.7: Novatech F 256 Axial Compensated Load cell and a TR150 portable load meter

Fig 3.8: Use of Novatech F26 Axial Compensated Load cell together with a TR 150 portable load meter for tractors

3.2.5.2 Animal and implement draught measurements

For donkeys, the draught force was also measured using the Novatech F 256 Axial Compensated Load cell (10kN) and a TR150 portable load meter attached to the front of the implement between the harnesses swingle tree and implement in draught chain as shown in

Figs 3.9. Five readings were taken from a digital display on the TR150 portable load meter attached to the load cell at ten randomly selected places in the four middle rows per plot

.

Fig 3.9: Use of Novatech F 256 Axial compensated Load cell together with a TR 150 portable load meter for donkeys

3.2.5.3 Speed Measurements

The tractor-drawn ripper furrower and the tractor drawn disc harrow were operated at 6.5 to 6.7 km hr^{-1}. The speed of the animals pulling the animal-drawn implements was calculated at the end of the row and the speeds ranged from 1.75 to 2.4 km hr^{-1}. A stop watch was used to measure time taken per run and for turning from one row to the next.

3.2.5.4 Depth of cut

Loose soil was carefully removed from the bottom and edges of each furrow, and a steel tape was used to determine the furrow depth. Depth was measured vertically from the top of the undisturbed soil surface to the bottom of the furrow (deepest point disturbed by the implement). Measurements for depth of cut were taken at ten randomly selected places in four middle rows.

3.2.5.5. Width of cut

A steel rule was used to measure tillage width of cut which was taken to be the horizontal distance from the one side of the furrow to the next of the disturbed soil in the furrow as visually inspected without removing loose soils. Measurements for width of cut were taken at ten randomly selected places in four middle rows.

3.2.6 Determination of Specific Draught, Drawbar Power, EFC and Field Efficiency

The measured variables mentioned in section 3.2.5 were used in establishing specific draught, drawbar power, EFC and Field Efficiency.

3.2.6.1 Specific draught

For this study, the specific draught in kN m^{-2} was calculated using equation 1:

$$D_s = \frac{D}{WT} \tag{1}$$

Where:

D_s = specific draught (kN m^{-2})

D = implement draught, kN

T = implement depth of cut in m

W is implement working width m

3.2.6.2 Drawbar power

The drawbar power can be related to draught or pull and speed, by using the equation 2 provided by Ajit, Srivastava, Goering, Rohrbach & Buckmaster, (2006).

$$P_{db} = \frac{DS}{3.6} \quad (2)$$

where:

P_{db} is drawbar power required for the implement, kW

D is implement draught, kN

S is travel speed, km hr^{-1}

3.2.6.3 Field Efficiency

Field Efficiency, E, is the ratio of the effective field capacity of a machine to the theoretical field capacity (Hunt, 2001). Determining field efficiency is to determine the theoretical time required to cover an area and comparing this with the actual time taken and this can be calculated using the equation 3:

$$E_f = C_a/TFC \times 100 \quad (3)$$

Where:

E_f = % Field efficiency

TFC = theoretical field capacity (ha hr^{-1})

C_a = Effective field capacity (Area capacity) (ha hr^{-1})

3.2.6.4 Effective Field Capacity (area capacity)

The Effective Field Capacity or area capacity is the actual rate of field coverage and is more important than the field efficiency. According to Hunt (2001), the effective field capacity can be calculated using the equation 4:

$$C_a = SWE_f / 10 \tag{4}$$

where:

C_a = area capacity, ha hr^{-1}

S = average speed of implement expressed in km hr^{-1}

W = implement working width in m

E_f is field efficiency, decimal form (NOT as a percent)

3.2.7 Data Analysis for Field Performances of Tillage technologies on Field Without Crop

The need for covariance parameters arises quite frequently in applications, the following being the two most typical scenarios:

- The experimental units on which the data are measured can be grouped into clusters and the data from a common cluster are correlated
- Repeated measurements are taken on the same experimental unit, and these repeated measurements are correlated or exhibit variability that changes.

The Proc Mixed analysis (SAS, 2003) was applied to the data for this part of the study. The Univariate Procedure (SAS, 2003) was used to obtain univariate statistics (means, standard deviation, CV) for the different variables. Mixed model methodology was used to analyse the depth of cut, width of cut, draught force, specific draught, efficiency, and effective field capacity data. Since the experiments were conducted on each plot for the 2011 to 2013 land preparation years, the outcome measurements (e.g. draught force, depth of cut and width of cut) were correlated over years. Responses measured on the same plot are correlated because they contain a common contribution from the plot. Variances of repeated measures often change with time. These potential patterns of correlation and variation may combine to produce a complicated covariance structure of repeated measures (Littell, Milliken, Stroup, & Wolfinger, 1996).

This procedure implements random effects in the statistical model and permits modelling the covariance structure of the data. Therefore, Proc Mixed (SAS, 2003) was used to compute efficient estimates of fixed effects and valid standard errors of the estimates. Modelling the covariance structure is especially important for the analysis of repeated measures because measurements taken close in time are potentially more highly correlated than those taken far apart in time (Littell *et al.*, 1996). Hence in the analysis of repeated measures using Proc Mixed (SAS, 2003), alternative covariance structures were compared using goodness of fit criteria.

The Mixed procedure fits a variety of mixed linear models to data and enables one to use these fitted models to make statistical inferences about the data. A mixed linear model is a generalization of the standard linear model used in the GLM procedure, the generalization being that the data are permitted to exhibit correlation and non-constant variability. The

Mixed linear model, therefore, provides a flexibility of modelling, using not only the means of the data (as in the standard linear model) but their variances and covariances as well.

Traditional mixed linear models contain both fixed-effects and random-effects parameters, and in fact it is the combination of these two types of effects that led to the name mixed model. Proc Mixed fits not only these traditional variance component models but numerous other covariance structures as well. The covariance parameters are what distinguish the mixed linear model from the standard linear model.

Once a model has been fit to one’s data, one can use it to draw statistical inferences via both the fixed-effects and covariance parameters. Proc Mixed software computes several different statistics suitable for generating tests of hypothesis and confidence intervals. The validity of these statistics depends upon the mean and variance-covariance model you select, so it is important to choose the model carefully. Some of the output from Proc Mixed helps one to assess one’s model and compare it with others.

3.2.7.1 Comparison of models

Alternative models were compared by running the Proc Mixed (SAS, 2003) with various covariance structures. The covariant structures were:

CS = compound symmetry: specifies the compound-symmetry structure, which has constant variance and constant covariance.

UN = Unstructured: Unstructured does not assume homogenous variances. It requires fitting the most parameters and, therefore, requires the most observations. It is also less generalizable given the complexity of the model.

TOEP =Toeplitz : this assumes that measurements taken next to each other have the same correlation, but do not necessarily have the same pattern as in AR(1).

AR (1) = First order auto regressive: This is a special case of TOEP where the variances are assumed to be homogeneous and the covariance or correlation decline exponentially with time. That is, variability in a measurement is constant regardless of when it is measured and two measurements taken closer together are more correlated than those taken farther apart.

And HF = Huynh-Feldt: specifies the Huynh-Feldt covariance structure (Huynh & Feldt, 1970). This structure has the same number of parameters and heterogeneity along the main diagonal. However, it constructs the off-diagonal elements by taking arithmetic rather than geometric means.

Covariance structures can be objectively computed using goodness of fit criteria (Littell *et al*., 1996) by Proc Mixed, including the REML log likelihood (RELM Log L), Average Information criteria (AIC) and the Schwarz's Bayesian Information Criteria (BIC). The value of information criteria closest to zero indicates a better model fit to the data (SAS Institute, 1999).

The statistical model used for this analysis is defined by equation 5 and it was used across all covariance structures to allow for easy comparisons.

$$Y_{ijt} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijt} \qquad (5)$$

Where:

Y_{ijt} = is the t^{th} measurement (depth of cut; width of cut; draught force; specific draught, efficiency, effective field capacity) on a plot under the i^{th} tillage method in the j^{th} year

α_i = the effect of the i^{th} year (i = 1, 2, 3)

β_j = is the effect of the j^{th} tillage method (j = 1, 2, 3, 4)

$(\alpha\beta)_{ij}$= is the interaction effect between i^{th} tillage method and j^{th} year

ε_{ijt} = is the random error associated with the t^{th} (all variables) measurements on a plot under the i^{th} tillage method in the j^{th} year.

3.3 Determination of Soil Moisture Content

The gravimetric method was used to determine soil moisture content. In the course of land preparation, soil samples for gravimetric moisture content determination were collected from ten randomly selected places in the four middle rows from each plot in all four replications. An auger was used to collect soil samples between 0 and 30 cm depth. The wet soil samples were weighed and then put in an oven at 105°C for 48 hours, after which the mass of each dry sample was weighed. Results were reported as % soil water on a dry-mass basis, using the equation 6:

$$\%\ SM = (Mw\ (g) - Md\ (g) / (Md\ (g) * 100 \qquad (6)$$

Where: SM = soil moisture in %, Mw = mass of wet soil in g and Md is mass of dry soil in g.

3.4 Determination of Soil Compaction

A cone penetrometer (hand-held, Eijelkamp) was used to measure penetration resistance following the recommendation of ASABE (2004; 2006). The cone penetrometer has a base area of 2 cm^2 and a diameter of 15.96 mm. Penetration resistances were measured in 10 cm increments starting at 10 cm up to greater than 20cm. The resistance was read in N (Newtons) and noted for the appropriate depth.

Measurements for cone resistance were taken at ten randomly selected places in four middle rows of the plots. The penetration resistance was calculated using equation 7:

$$PR = \frac{\text{Manometer reading (N)}}{\text{Base area of cone } (m^2)} \qquad (7)$$

Where: PR = penetration resistance in MPa

3.5. PART 2 - Tractor and Animal-drawn CV and NSCT Technology Performances under cropped land

3.5.1 Research design

Part 2 research was not set up in quite the same way as Part 1 because of the addition of crop and mulch. It was set up in a 'split plot randomized complete block design' with tillage method as the main plot factor, and two mulch rates (0 and 3 t ha^{-1}) as the subplot factor in 4 blocks, totalling 40 plots. Research trials comprised five treatments comprising of cultivating with four tillage methods – five, including FALLOW – namely: (1) Animal-drawn mouldboard plough (AMP), (2) Animal-drawn ripper-furrower (ARF), (3) Tractor-drawn disc harrow (TDH), (4) Tractor-drawn ripper furrower (TRF), and (5) FALLOW i.e. No tillage No crop (NTNC).

The randomizations were carried out using Genstat. The plots were 10m x 10m, with 5 m borders between blocks and 2 m between plots to allow proper turning and movement of tractors and animals.

3.5.2. Procedure

Some of the plots were conventionally tilled (CV) using an animal-drawn mouldboard plough and a tractor-drawn disc harrow, whilst the land preparation for NSCT plots used an animal-drawn ripper furrower and a tractor-drawn ripper furrower. In the ploughed and disked CV plots, seeds were dropped into the straight lines and covered with soil, and in the NSCT plots, seeds were likewise dropped into the ripped furrows and covered with soil. One meter inter-row spacing and in-row spacing of 25 cm was used. The recommended plant population for pearl millet is 80 000 plants per hectare, with seed rates of 3 to 4 kg per hectare. The target of 80 000 plants was achieved by thinning to 2 plants per planting station. This agrees with the CONTIL project and thus with what the farmers were using.

In the first year, the crops were planted in December 2010, and in the second year in December 2011. For all treatments, at planting, Mono-ammonium phosphate fertiliser was applied at 150 kg per ha, i.e. 4 g per planting station. Manure was also applied at planting at 5 t per ha, translating into 0.125 kg per planting station. When the crops were at about 50 to 60 cm high, ammonium nitrate was also applied at 150 kg per ha.

Two levels of mulch were tested on the split plots. One part of plot per treatment had no mulch, i.e. 0 t ha^{-1}, while the other set had 3 tons ha^{-1}. This agrees with what the farmers were using. The 'Principle of Constant Traffic' was also used for all treatments whereby the same planting lines were used for both seasons. The plots were hand-weeded two to three times during the growing season, depending on weed intensities.

Ten soil samples were collected for gravimetric determination of moisture content before crop establishment and every two weeks during the crop growing period at ten randomly selected places along two middle rip and plough lines for each subplot. Concurrently, the DSM moisture meter was used to collect moisture data at the same points, making it also ten sampled places. The outer rows were avoided for all measurements as they are subject to 'edge effects'. Equation 6 was used for calculating the soil moisture content.

Soil compaction, in the form of penetration resistance, was measured at three depths (<10, 11-20 cm and >20 cm) at planting and at harvest at ten randomly selected places in the two middle rows of each plot. The cone penetrometer was used and penetration resistance was calculated by the method explained in section 3.3. Apart from taking PR in the fields on-station, penetration resistance measurements were also taken from farmer's fields that were conventionally tilled and those where the NSCT was practiced. The plots were monitored and any changes in soil characteristics and field conditions were noted every week. Planting and harvesting dates were noted, and rainfall amounts were recorded during the growing period.

3.5.3 Pearl Millet Root Length

Root lengths were measured at the time of harvesting the pearl millet. Ten plants were randomly selected from the two middle rows of each plot. The outer rows were avoided for all measurements as they are subject to ‘edge effects’. The selected plants were watered and thereafter hand-held Eijelkamp root augers were used to get root samples. Subsequently, the roots were rinsed in water (Bohm, 1979, Fehrenbacher & Alexander, 1955) and then separated carefully from the whole plant and measured from the base of the stem to the tip of the root.

3.5.4 Pearl Millet Yield

Panicles of ten pearl millet plants were randomly harvested from the two middle rows of each plot. The outer rows were avoided for all measurements as they are subject to ‘edge effects’. After harvesting, the pearl millet panicles were threshed and winnowed. All the kernels from the sampled plants in each plot were weighed using an electrical balance and recorded as kg yield/ha. The yields for whole plots were also measured and compared to the sample yields.

3.5.5 Validity and Reliability

Validity and reliability were dealt with by replicating the treatments four times in order to obtain a measure of experimental error and improve the precision of the estimates. Replication reduces variability in experimental results, increasing their precision and the confidence level with which a researcher can draw conclusions about an experimental factor (Reynolds, Pask & Mullan, 2012). Randomization, standardization of all other variables, inclusion of the control and taking more samples were measures taken to ensure validity and reliability.

3.5.6 Data Analysis

Analysis of variance (ANOVA) using Genstat was used to test for any significant differences in moisture content, penetration resistance, yield, root length among all treatments, being AMP, ARF, TDH, TRF and FALLOW (NTNC), as described in Section 3.5.1. Analysis of variance was used to test for interaction between tillage and mulching, and the main effects of tillage and mulching on soil moisture, penetration resistance, root length and yield. The data were subjected to normality and variance tests during the ANOVA. Probability levels of 0.05 were used to determine the level of significance among the means. Repeated Measures Analysis was used to determine the changes in moisture content and penetration resistance between the seasons (2011 and 2012) among the five methods and the two mulch application levels. Repeated measures is used to investigate either (1) changes in means over three or more time points, or (2) differences in means under three or more different conditions.

3.6 PART 3: Comparison of the Performance of NSCT Ripping Techniques of the Animal-Drawn Ripper Furrower

3.6.1 Research Design

In order to establish which animal-drawn ripping technique would be able to achieve deeper depth of cut and wider width of cut, this trial tested combinations of donkey numbers in a span, using single and double ripping. The tested treatments were: Double ripping with 2 donkeys (DRIP2), Double ripping with 3 donkeys (DRIP3), Single ripping with 2 donkeys (SRIP2), Single ripping with 3 donkeys (SRIP3) and FALLOW (as the control).

The trial was carried out in a Randomized Complete Block design with the above 5 treatments in 4 blocks, thus totalling 20 plots. Randomization was done using Genstat. The plot dimensions were 3m x 20m, and 5 m borders were made between blocks with 2 m between plots to allow proper turning for the animals. For each treatment, samples were collected at ten randomly selected places for tillage depth, working width, draught forces, effective working and turning time per run, soil compaction and soil moisture content.

3.6.2 Procedure and Data Analysis

All measurements of depth, width, draught, speed, time per run, turning time, moisture content and penetration resistance were taken for the different animal-drawn implements as described in Part 1 section 3.2.5. Excel and GenStat computer packages were used for data management and statistical analyses. Analysis of variance (ANOVA) was used to test for any significant differences among the ARF ripping techniques. A probability level at 0.05 was used to test the significance of the differences between the means.

3.7 PART 4 – Adoption of Tillage Technologies by Farmers

3.7.1 Theoretical Framework

The theoretical framework of this part of the study is based on the assumption that a number of factors influence acceptance and adoption of any new technology such as the NSCT. These include socio- economic factors, knowledge about the technology, attitude towards the technology and eventually practice of the technology. The KAP concept, with its three key pillars (knowledge, attitude and practice), was used as a suitable framework be it qualitative or quantitative, to analyse and understand specific human behaviour in this case adoption of NSCT technology. Apart from KAP a different focus compared to the famous Rogers's Diffusion Model (2003) that states five stages for successful adoption of a particular innovation as (1) its relative advantage over existing practices, (2) compatibility to users' needs, (3) trialability (4) observability, and (5) simplicity of use, is the technology acceptance model (TAM) (Davis, 1993) that focuses not just the specific type of adoption environment but it focuses on a specific type of innovation. In addition the innovation should be easy to use (similar to Roger's complexity characteristic), whereby the innovation should be easy to learn and not too complex that it negates it usefulness. Fig 3.10 shows TAM model. It illustrates the linkages between technology knowledge, attitude and practice thereby leading to adoption and the various factors that influence the adoption.

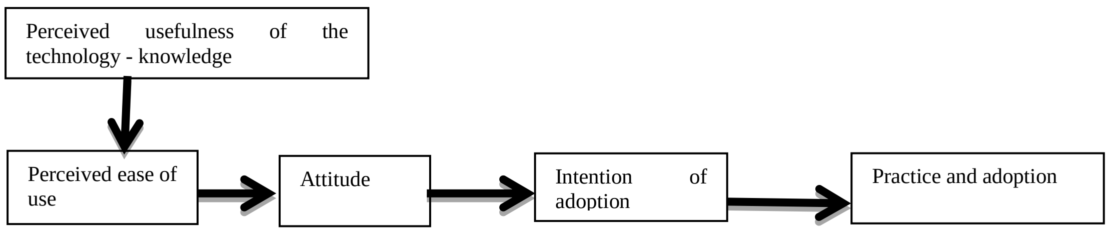

Fig 3.10. From Technology Acceptance Model (Davis, 1993)

Whilst no statistical analysis was done using the KAP nor the Davies and Rogers models, qualitative analysis was done by grouping the answers from the farmers into themes of knowledge, attitude, practice and adoption.

3.7.2 Choice of Study Area

The study was conducted in the Ogongo Constituency of the Omusati Region and the Omuntele Constituency of the Oshikoto Region. The Ogongo Constituency was selected because it is near to the University of Namibia, Ogongo Campus where on-station trials were conducted, making it easier and cheaper to access the constituency. It is also one of the areas with farmers who had implemented the NSCT technology. The Omuntele Constituency was likewise selected because it has a number of farmers who are experienced in NSCT. Projects under MAWF, CLUSA and CES are also working with the farmers on NSCT in that constituency. Fig 3.11 shows one of the interviews conducted at an interviewee's house in the Omuntele Constituency.

Fig 3.11: Interviewing an NSCT farmer at his house in Omuntele, Oshikoto Region

3.7.3 Research Design

This part of the study was qualitative, and the researcher chose it because Best and Kahn (2006) assert that qualitative designs provide rich descriptions of a phenomenon that can occur without the intervention of an experiment. Also, a qualitative design was chosen because of its flexibility and the fact that it allows for a systematic collection of data by penetrating into the realities of the situation of this specific group of farmers who used the NSCT.

3.7.4 Procedure for the Interviews for the Adoption of Tillage Technologies by Farmers

Some factors were considered when trying to decide what method to use for the Knowledge, Attitude, Practice and adoption study. The first factor to be considered was the sample size, and for this study it was very small i.e. 13 interviewees in both constituencies. Zucker (2009) maintained that small number of interviewees is adequate for in-depth interviews with participants and key informants to obtain the correct information about the issues being investigated. Secondly, multiple sources of evidence according to Yin (1994) helps to counter the shortcoming of relying on a few interviewees. He also suggested that, it also was important to use other data sources in order to explain and validate the findings of such studies. For this study, therefore, literature, key informant interviews and observations were used as secondary sources of data.

Three methods were used to collect information from the farmers. The first method involved collecting data by interviewing the farmers face to face. The interviews were designed to collect information about use of the NSCT technology, and were conducted through research assistants who could speak the local language and could assist in translating questions for the farmers and their answers back to the researcher. Different research assistants were used at different places. Mcmillan and Schumacher (2006) and Denscombe (2010) argue that interviews are good because, when there is direct contact, an interviewer can actually check on the accuracy of data which is not possible when the researcher uses questionnaires that are sent by mail or post. It is, however, recognized that the major disadvantage of an interview is its potential for subjectivity and bias (Mcmillan & Schumacher, 2006). An interviewer may actually ask leading questions to support a particular viewpoint, or the interviewer's perceptions may not necessarily be accurate. The researcher in this study made use of an interview guide, so that the questions were framed beforehand, thus minimizing the risk of asking leading questions. Open-ended questions were used, as these allow for a greater variety of responses from participants – but they are difficult to analyse statistically because the data must be coded or reduced in some manner (Jackson, 2009). However, for this study qualitative analytical methods such as the interpretation and explanation of various opinions, views and concepts, were summarized, categorized, and presented in convenient forms related to KAP.

The second method used was interviewing key informants, mainly from MAWF, CES and CLUSA. These interviews were conducted to verify and validate information collected from farmers. The third method used was observation, whereby the farmers' fields were observed to check evidence of use of the ripper furrower, the status of the crop, evidence of mulch and if the field had furrows. Apart from the qualitative study, Fig 3.12 shows a picture of the researcher and research assistant taking PR measurements using a penetrometer in a farmer's field in Omuntele Constituency. The PR study is reported in chapter 5.

Fig 3.12: Taking PR measurements in a farmer's field in Omuntele Constituency

3.7.4.1 Sampling

A purposive sampling technique was used to identify farmers in the two constituencies. In purposive sampling, the sample is determined by the information sought. According to Bernard (2002) and Denscombe (2010) purposive sampling is used to get the information through focusing on a relatively small number of instances deliberately selected on the basis of their known attributes. Denscombe (2010) further said that purposive sampling works where the researcher already knows something about the specific people because they are seen to give the most valuable information. The inclusion criteria for selection were that the farmers must have used the NSCT technology, reside either in Ogongo Constituency or Omuntele Constituency and have homesteads and fields that are easily accessible.

Based on the criteria above, interviewees were selected with the help of the MAWF Extension Technician for Ogongo and Omuntele, and staff of CES and the NCAP, CLUSA projects also helped. In the Ogongo Constituency, five farmers had used the ripper-furrower technology, so all five farmers were selected. However, only four farmers were interviewed due to the inaccessibility of the fifth farmer's homestead because of floods. In the Omuntele Constituency, a total of nine farmers were selected.

3.7.5 Validity

In order to address the accuracy and the appropriateness of the data collected, the researcher tried to triangulate data by using information from all the interviews and the information related to NSCT obtained by other means. In order to increase the validity of the data collection methods, the researcher made sure that feedback given during interviews was fully considered so as to allow less room for ambiguity. This was achieved through proper and thorough planning of the interviews, which the researcher rehearsed together with the research assistants who assisted with the farmers in Oshiwambo, and this was cross-checked before the interviews were conducted. Key informants were also used to verify the information given by the interviewees.

3.7.6 Ethical Issues

Before the interviews were conducted, the researcher visited the projects and MAWF offices working in the two constituencies for the purpose of seeking permission to go around the villages and carry out the interviews. The farmers were also asked at the beginning of each interview if they were willing to participate, and they were also told that they were free to agree to participate or not to participate. All the farmers agreed to participate and were also assured that the information that they gave was going to be used for study purposes only.

3.8 Limitations of The Study

The trials in this study were designed to run for three seasons, resulting in an annual consecutive collection of data on the tractor and animal-drawn CV and NSCT technologies field performances under land without crops. However, on tractor and animal-drawn CV and NSCT technology performances under cropped land, crops and soil data were collected for the first two years only, because in the third year a severe drought occurred. This hindered the timely implementation of trials, and crops could only be established after the rains commenced. As a consequence, no harvest could be collected in the third year due to late and patchy rains. The data that were collected in the first two years were, however, adequate and of good quality.

Although it would have been ideal to use a 3-point hitch linkage dynamometer to collect data on draught measurements, this was not possible due to funding constraints. The drawbar dynamometer was therefore used as an alternative. In a way, using the drawbar dynamometer afforded the researcher the opportunity to learn if the results obtained are comparable to those of a 3-point hitch dynamometer used by other researchers and as documented in the American Society of Agricultural Engineering (ASAE) standards. Thus, although it constituted a limitation to the study, its use and the results obtained therefore made it possible to recommend it to researchers in developing countries as part of cost-saving alternative.

For the adoption part of the study, the initial plan was to interview as many farmers as possible in four regions of the NCA. However, because of limited funds, the researcher ended up only interviewing farmers in two constituencies i.e. Ogongo and Omuntele, respectively of

Omusati and Oshikoto Regions. The researcher found that it took a very long time to interview farmers because of the need to engage research assistants who could speak the local language so as to assist in interpreting between farmer and researcher. Different interpreters were used in different places, and the resulting different interpretations and style of translation may have introduced unreliability into the data. However the data collected was verified with the key informants and found to be of good quality.

4. PERFORMANCE OF TILLAGE TECHNOLOGIES UNDER FIELD WITHOUT CROP

4.1 Introduction

This chapter presents the results for the field performances of tillage technologies on depth of cut, width of cut, draught force, specific draught, efficiency and effective field capacity at land preparation. These are characterized as: TRF: tractor-drawn ripper-furrower (NSCT), ARF: animal-drawn ripper-furrower (NSCT), TDH: tractor-drawn disc harrow (CV) and AMP: animal-drawn mouldboard plough (CV). The results are presented for three agricultural seasons, i.e. 2010 -2011, 2011-2012 and 2012-2013.

4.2 Univariate Statistics for Field Performances of CV and NSCT Technologies.

Table 4.1 summarizes the univariate statistics for all the variables for the two CV and the two NSCT technologies in the three years. The different variables are presented in the following sections.

Table 4.1: Univariate statistics for field performances of CV and NSCT technologies.

Statistic	Depth (m)	Width (m)	Draught force (kN)	Efficiency (%)	Tractor Effective Field Capacity (ha hr^{-1})	Animal Effective Field Capacity (ha hr^{-1})	Specific draught (kN m^{-2})
N	136	144	144	144	72	72	141
Mean	0.154	1.002	3.004	60.290	0.715	0.089	25.890
Median	0.130	0.825	0.960	60.500	0.695	0.078	27.950
Mode	0.130	0.200	0.800	60.000	0.690	0.030	33.330
Std. Deviation	0.078	0.833	3.12320	0.4877	0.091	0.061	15.650

Variance	0.006	0.693	9.75438	0.0238	0.008	0.004	244.929

4.3 Analysis of Depth of Cut, Width of Cut, Draught Force, Draught Power, Specific Draught, Efficiency, and Effective Field Capacity

Mixed model methodology as implemented in (SAS, 2003) was used to analyse the depth of cut, width of cut, draught force, draught power, specific draught, efficiency, and effective field capacity data. The statistical model used for this analysis is defined in equation (5). The same model below was used across all covariance structures for easy comparisons.

$$Y_{ijt} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijt} \quad (5)$$

Where

Y is the depth of cut; width of cut; draught force; specific draught, efficiency, effective field capacity

Y_{ijt} = is the t^{th} measurement on a plot under the i^{th} tillage method in the j^{th} year

α_i = the effect of the i^{th} tillage (i= 1, 2, 3, 4)

β_j = is the effect of the j^{th} year (j= 1, 2, 3)

$(\alpha\beta)_{ij}$= is the interaction effect between tillage and year

ε_{ijt} = is the random error associated with the t^{th} various variables measurements on a plot under the i^{th} tillage method in the j^{th} year.

4.3.1 Depth of cut analysis

The fit statistics for the five covariance structure are presented in Table 4.2. A smaller model fit statistic value indicates a better fit to the data. Based on the BIC the TOEP structure was selected.

Table 4.2: Fit criteria for depth of cut

	Covariance structure	BIC	REML log L
1	CS	-536-5	-544-2
2	UN	-540-0	-563-2
3	AR (1)	-536-8	-544-6
4	TOEP	-533-1	-544-7
5	SIMPLE	-538-7	-542-6
6	HF	-542-5	-558-0
7	ANTE (1)	-543-7	-563-1

CS = compound symmetry; UN = Unstructured; AR (1) = First order auto regressive; TOEP = Toeplitz; HF = Huynh-Feldt; ANTE= First order Ante- dependence

The ANOVA results for depth of cut are shown in Table 4.3. The analysis shows that all factors were highly significant (p< 0.001). Tillage method (p <0.0001), year (p 0.0012) and tillage vs year interactions were also highly significant (p <0.0001).

Table 4.3: ANOVA table for depth of cut

Effect	Num DF	Den DF	F Value	Pr > F
Tillage	3	44	307.12	<.0001
Year	2	80	7.32	0.0012
Tillage vs year	6	80	11.71	<.0001

Num DF = the degrees of freedom of the numerator; Den DF = the degrees of freedom of the denominator

Table 4.4 shows the least square means and their standard error for depth of cut outputs of the model analysis. Statistical analysis using Proc Mixed (SAS, 2003) shows that there was a significant interaction between tillage method, year, and tillage vs years for depth of cut (p<0.001).

Table 4.4: Least square means (± s.e) for depth of cut

Effect	Tillage Method	Year	Depth Estimate (m)	Standard Error
Tillage method	AMP		0.095	0.005
Tillage method	ARF		0.137	0.005
Tillage method	TDH		0.124	0.005
Tillage method	TRF		0.292	0.005
Year		2011	0.151	0.004
Year		2012	0.167	0.004
Year		2013	0.168	0.004
Tillage vs year	AMP	2011	0.079	0.007
Tillage vs year	AMP	2012	0.091	0.007
Tillage vs year	AMP	2013	0.114	0.007
Tillage vs year	ARF	2011	0.130	0.007
Tillage vs year	ARF	2012	0.132	0.007
Tillage vs year	ARF	2013	0.149	0.007
Tillage vs year	TDH	2011	0.142	0.007
Tillage vs year	TDH	2012	0.128	0.007
Tillage vs year	TDH	2013	0.101	0.007
Tillage vs year	TRF	2011	0.255	0.008
Tillage vs year	TRF	2012	0.315	0.007
Tillage vs year	TRF	2013	0.307	0.009

Comparing depth of cut for the four tillage methods, TRF had the deepest cut over the 3 years whilst the shallowest depth of cut was found in AMP. Depth of cut was significant ($p<0.001$), with TRF having an average highest depth over the 3 years, whilst there was not much difference among the remaining three methods. This shows that TRF is the tillage method that can achieve greatest depth.

Fig 4.1 shows variation of depth of cut over the three years. Comparing the variation of depth of cut over time for the four tillage methods showed that there is a significant ($p<0.001$)

interaction between tillage and years. There is a gradual increase in depth of cut over time for two tillage methods i.e. ARF and AMP whereas TDH showed a decrease in depth of cut. TRF showed an increase in 2012 and then decreased in 2013.

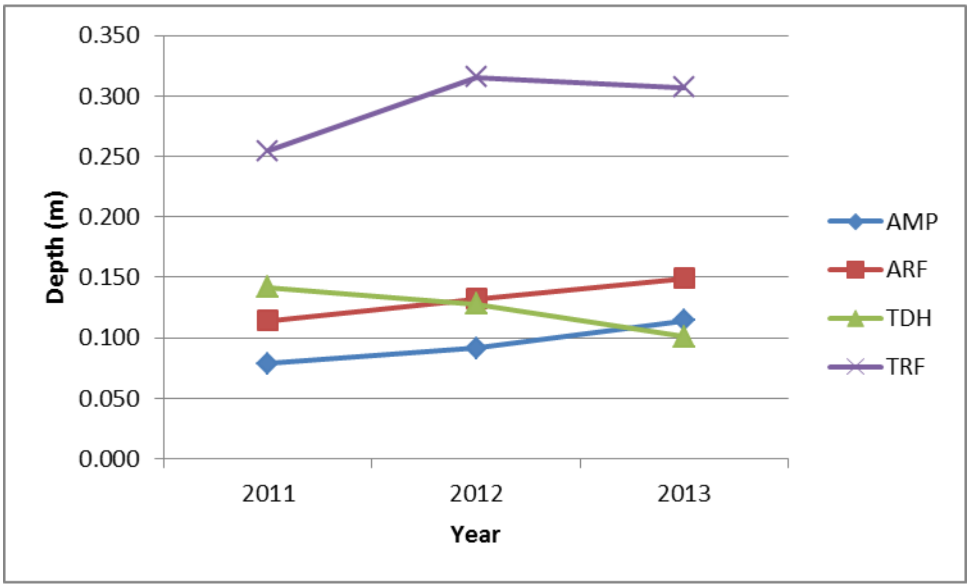

Fig 4.1: Comparison of depth of cut among tillage methods and across years (p <0001)

In 2011, comparing the tractor group, TRF cut the soil by 44.32 % deeper than TDH, and in the animal group ARF cut the soil by 30.82% deeper than AMP. In 2012, within the tractor group TRF again performed better, by going 59.45% deeper than TDH. In the animal group ARF cut the soil by 30.92% deeper than AMP. Cultivating with a tractor disc harrow is a waste of energy as it does not result in any significant depth of cut when compared to the animal-drawn implements.

In 2013 the same trend appears in both the animal and tractor groups. TRF outperformed TDH by 67.17%, and ARF outperformed AMP by 23.46%. There was, however, also an increase in depth of cut for all the animal-drawn implements. It could be that the effect of continuously working on the soil from 2011 to the beginning of 2013 could have caused some increase in depth of cut.

Comparing TRF and TDH (the tractor group) on depth of cut, TRF performed better than TDH, and in the animal group, ARF performed better than AMP. Overall, this suggests that NSCT methods were superior to CV methods in terms of depth of cut, regardless of power source. TRF, however, achieved the greatest depth. This suggests that, in cases where there is soil compaction and reduced root penetration; the tractor-drawn ripper-furrower can be used to achieve greater depths.

As among the animal-drawn implements the ARF cut deeper than AMP in the on-station results, this also suggests that the NSCT implements can achieve greater depths than the CV ones. Where animal-powered tillage methods are concerned, Nengomasha (1997) obtained greater depths of cut for ploughing compared to what was obtained in the present study i.e. 13.5 cm as compared to 9.5 cm.

4.3.2 Width of cut analysis

Following the model comparison as given in equation (5), section 4.3**, t**he fit statistics for the five covariance structures is presented in Table 4.5. A smaller model fit statistic value indicates a better fit to the data. Based on the BIC, the simple covariance structure was selected.

Table 4.5: Fit criteria for width of cut

	Covariance structure	BIC	REML log L
1	CS	-282-1	-289-9
2	UN	-385-2	-408-5
3	AR (1)	-303-7	-311-4
4	TOEP	-335-7	-347-3
5	SIMPLE	-273-0	-276-9
6	HF	-316-3	-331-8
7	ANTE (1)	-383-8	-403-2

CS = compound symmetry; UN = Unstructured; AR (1) = First order auto regressive; TOEP = Toeplitz; HF = Huynh-Feldt; ANTE = First order Ante- dependence

The ANOVA results for width of cut are shown in Table 4.6. The analysis shows that all factors were highly significant.

Table 4.6: ANOVA table for Width of Cut

Effect	Num DF	Den DF	F Value	Pr > F
Tillage	3	44	5585.18	<.0001
Year	2	88	79.69	0.0012
Tillage vs year	6	88	40.47	<.0001

Num DF = the degrees of freedom of the numerator; Den DF = the degrees of freedom of the denominator

Table 4.7 shows least mean squares for width of cut over the three years for the four tillage methods. Statistical analysis using Proc Mixed (SAS, 2003) shows that there was a significant interaction between tillage method and years for width of cut ($p<0.001$). Fig 4.2 shows a comparison of width of cut among tillage methods and across years. The results are shown for three years.

Table 4.7: Least square means (± s.e) for width of cut

Effect	Tillage	Year	Width Estimate (m)	Standard Error
Tillage method	AMP		0.211	0.013
Tillage method	ARF		0.161	0.013
Tillage method	TDH		1.871	0.013
Tillage method	TRF		1.764	0.013
Year		2011	1.115	0.011
Year		2012	0.949	0.011
Year		2013	0.942	0.011
Tillage vs year	AMP	2011	0.203	0.022
Tillage vs year	AMP	2012	0.213	0.022
Tillage vs year	AMP	2013	0.218	0.022
Tillage vs year	ARF	2011	0.126	0.022
Tillage vs year	ARF	2012	0.178	0.022
Tillage vs year	ARF	2013	0.179	0.022
Tillage vs year	TDH	2011	2.167	0.022
Tillage vs year	TDH	2012	1.725	0.022
Tillage vs year	TDH	2013	1.723	0.022
Tillage vs year	TRF	2011	1.963	0.022
Tillage vs year	TRF	2012	1.680	0.022
Tillage vs year	TRF	2013	1.650	0.022

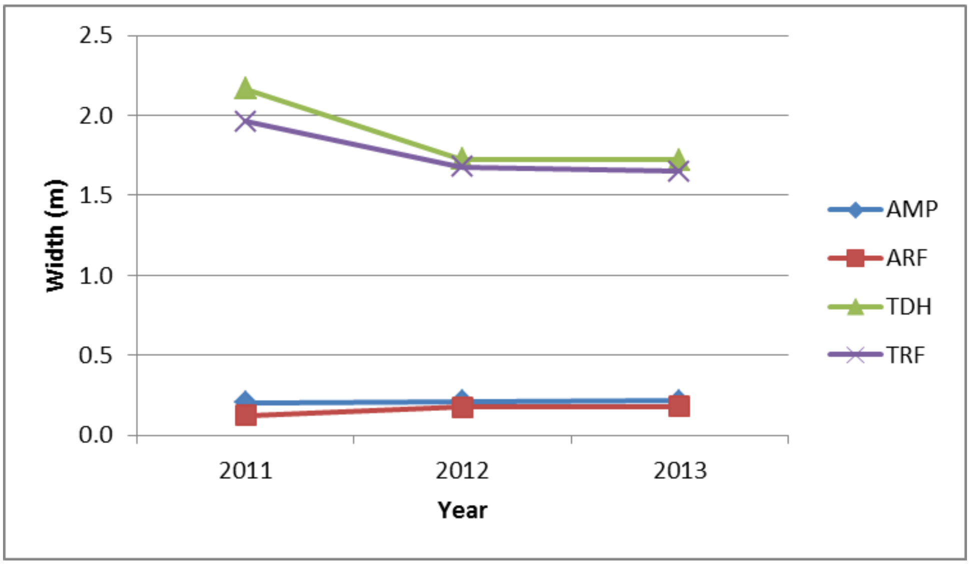

Fig 4.2: Comparison of width of cut among tillage methods (p <0. 0001) and across years (p= 0.0012)

Within the tractor group, in 2011, TDH had a wider width of cut than TRF by 9.4%, in 2012 by 2.6 % and in 2013 by 4.2%. In the animal group, in 2011, AMP has a wider width of cut than ARF by 38.12%, in 2012 by 16.25% and 2013 by 17.61 %. The same trend is shown in both 2012 and 2013: AMP and ARF showed increases in width of cut over the years whereas TRF and TDH showed decreases in width of cut over those years. This could be attributed to dry soil conditions and lower rainfall as it decreased from 2011 to 2013. A total of 621.6 mm of rainfall was recorded at Ogongo from December 2010 to May 2011. In the following year, from December 2011 to May 2012, 377.4 mm was recorded and during December 2012 to May 2013, 332.3 mm was recorded.

For tractor drawn-technologies, TDH had greater width of cut than TRF across all the three years whilst for animal-drawn methods there was wider cut for AMP than ARF. Concerning width of cut, therefore, CV methods performed better than the NSCT methods regardless of power source. For tractor-drawn tillage (TDH and TRF), the width of cut was wider than for animal-drawn tillage (AMP and ARF) across the three years. This was more or less as was expected as the specifications for TDH and TRF were 2.2m and 1.85m wide as compared to 0.2m and 1m for AMP and ARF.

Observations on the formation of furrows by the NSCT implements showed that TRF made wider and deeper furrows, whereas ARF did not. Both NSCT implements were expected to make furrows that could potentially harvest water. TRF achieved satisfactory deep and wide furrows whilst these were not achieved by ARF, although these ripper-furrowers were expected to facilitate the harvesting of water. The operators of the ARF tried their best, but the furrows were not as good as the TRF ones. This means that TRF is the best method for making furrows that can harvest water. From observing and comparing the work done by the four implements, it can be concluded that ARF might not be very effective in harvesting water if used alone. The on-station moisture results showed that TRF harvested more water than ARF and was the best among the four treatments. It might be necessary to start by using the tractor-drawn ripper-furrower in the first year and then use the animal-drawn ripper-furrower in subsequent years. The two implements can thus complement each other.

Comparing some of the performance values for ARF and AMP in this study with those from Nengomasha (1997), the width for AMP was better than ARF in both experimental results and Nengomasha (1997). This shows that ARF could not achieve a wider width of cut. Nengomasha also showed a greater width of cut when used for ploughing, 0.265 m as compared to 0.218 m for AMP in the present study. However, for this study the animal-drawn ripper furrower is the implement that was expected to have a large width of cut and also to provide large furrows, thereby being able to harvest moisture. This suggests that ARF cannot be used alone in the first year of land preparation if one's objective is to make furrows that would harvest water. However, if the objective is to achieve better depth of cut for increased root penetration, then ARF could be used alone.

4.3.3 Draught Force Analysis

The model described in section 4.3 was also used for determination of draught force. The fit statistics for the five covariance structures for draught force are presented in Table 4.8. A smaller model fit statistic value indicates a better fit to the data. Whilst UN had the smallest model fit value, it had many parameters to estimate. The ANTE (1) had BIC close to that of UN. The ANTE (1) structure was therefore selected because it is more parsimonious (fewer parameters to estimate) than the UN.

Table 4.8: Fit criteria for draught force

	Covariance structure	BIC	REML log L
1	CS	234.3	226.6

2	UN	179.9	156.7
3	AR(1)	222.4	214.7
4	TOEP	219.4	207.8
5	SIMPLE	237.3	233.5
6	HF	240.0	224.5
7	ANTE(1)	182.2	162.8

CS = compound symmetry; UN = Unstructured; AR (1) = First order auto regressive; TOEP = Toeplitz; HF = Huynh-Feldt; ANTE (1) = First order Ante- dependence

Table 4.9 shows the ANOVA results for draught force. The analysis shows that all factors were highly significant.

Table 4.9: ANOVA table for draught force

Effect	Num DF	Den DF	F Value	Pr > F
Tillage	3	44	615.61	<0.0001
Year	2	88	1217.21	0.0001
Tillage vs year	6	88	379.11	<0.0001

Num DF = the degrees of freedom of the numerator; Den DF = the degrees of freedom of the denominator

Table 4.10 shows the least square means and their standard error for draught force outputs of the model analysis. Statistical analysis using Proc Mixed (SAS, 2003) shows that for draught force there was a significant interaction between tillage method ($p<0.001$) and years ($p = 0.001$).

Table 4.10: Least square means (± s.e) for draught force

Effect	Tillage	Year	Draught Force Estimate	Standard Error

Tillage method	AMP		0.706	0.110
Tillage method	ARF		0.831	0.110
Tillage method	TDH		4.135	0.110
Tillage method	TRF		6.344	0.110
Year		2011	1.199	0.084
Year		2012	3.167	0.069
Year		2013	4.645	0.073
Tillage vs year	AMP	2011	0.502	0.169
Tillage vs year	AMP	2012	0.770	0.138
Tillage vs year	AMP	2013	0.848	0.145
Tillage vs year	ARF	2011	0.736	0.169
Tillage vs year	ARF	2012	0.868	0.138
Tillage vs year	ARF	2013	0.888	0.145
Tillage vs year	TDH	2011	1.377	0.169
Tillage vs year	TDH	2012	4.113	0.138
Tillage vs year	TDH	2013	6.915	0.145
Tillage vs year	TRF	2011	2.183	0.169
Tillage vs year	TRF	2012	6.918	0.138
Tillage vs year	TRF	2013	9.930	0.145

Across the three years, for tractor-drawn tillage methods, draught force is, as expected, significantly higher than the animal-drawn tillage methods. For tractor-drawn implements and AMP, draught increased over the years.

For animal-drawn implements, AMP (CV) seemed on the whole to require less draught force than ARF (NSCT). The draught force for AMP (CV) in 2011 was 31.8% less than ARF. In 2012, on the other hand, ARF used a 4.4% less draught force and in 2013 AMP (CV) used a 4.6% less draught force than ARF.

Among the tractor drawn implements, TDH (CV) resulted in less draught than TRF (NSCT). For tractor-drawn implements in 2011, the draught force used for TDH was 36.9%, less than TRF, in 2012, 40.6% and in 2013, 30.4%. Although the draught force increased for all tillage methods from 2011 to 2013, the increase was much greater for tractor-based tillage methods compared to animal-based tillage. For example, under TRF the increase was times 4.5, compared to times 1.7 for AMP.

Overall, the NSCT implements required higher draught forces than the CV ones, probably because they had to push large volumes of soil in order to make furrows. As reflected in Table 4.4., the depth of cut for TDH was also less than for TRF. Similar trend was observed for AMP, which achieved less depth than ARF. This also explains the lower draught forces required for CV methods. TRF and ARF achieved greater depth of cut than CV methods, thereby explaining the higher draught forces as compared to TDH and AMP. This is also supported by other researchers, who have indicated that depth of cut was the greatest factor affecting draught force (Mamman & Oni, 2005; Abbaspour-Gilandeh, Khalilian, Alimardani, Keyhani & Sadati, 2006; Naderloo *et al.*, 2009; Al-Suhaibani & Ghaly, 2010 and Vozka, 2011).

Another reason for draught increases for tractor-drawn implements over the years could be the weight of the implement (Olatunji & Davies 2009), as the weight of tractor disc harrow could have contributed to an increase in depth. On the tractor-drawn ripper-furrower, the increased depth as well as the moving of a high volume of soil could have also greatly increased the draught force required. As for the animal-drawn tillage methods, especially the ARF, the operators tried hard to make furrows, and this could have contributed to the increased draught force employed.

The draught forces in 2013 were possibly much higher because of the lower soil moisture due to the drought experienced in 2013. Soil moisture content also decreased over the years, and this could have contributed to increased draught requirements and the implements working in harder soils than before. The rainfall records for Ogongo showed a total of 621.6 mm from

December 2010 to May 2011. In the following year, December 2011 to April 2012, 377.4 mm was recorded and for 2012 to 2013, 332.3 mm. As the rainfall became less, the soil tended to harden and this could also have contributed to increased draught requirement. The implements could also have reached a hard soil pan created by previous tillage in the field, which required higher draught forces than expected.

Fig 4.3 shows a comparison of draught forces among tillage methods across the years. In 2011, within the tractor group, TRF (NSCT) showed the use of greater draught force than TDH (CV), and within the animal group ARF (NSCT) showed the use of greater draught force than AMP (CV). In 2012 and 2013, however, although TRF again showed greater draught forces than TDH, within the animal group there was not much difference between ARF and AMP.

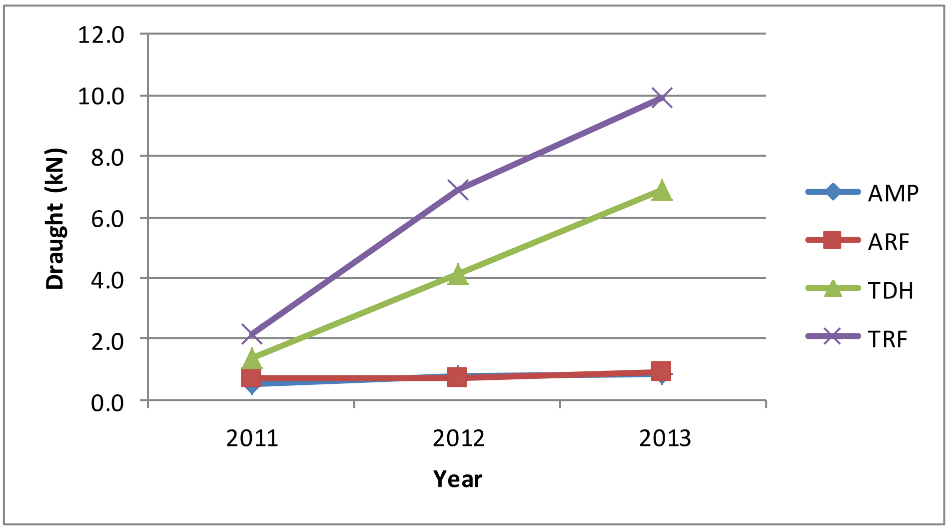

Fig 4.3: Comparison of draught force among tillage methods and across years (p <0.0001)

4.3.3.1 Draught force and depth

Depth also increased from 2011 to 2013 as shown in Fig 4.1. This is consistent with the finding of Al-Janobi and Al-Suhaibani (1998); Al-Janobi, Kabeel and Aboukarima (2000);

Arvidsson *et al.,* (2004); Shoji, 2004; Mamman and Oni (2005); Naderloo *et al.,* (2009); Abbaspour- Gilandeh *et al.,* (2006); Al-Suhaibani and Ghaly (2010) and Vozka (2011) who also measured a significant increase in draught force with increases in depth. Draught requirements also varied with implement type.

4.3.3.2 Draught force and speed

It was reported in Section 3.2.5.3 that the tractor-drawn ripper-furrower and the tractor -drawn disc harrow were operated at 6.5 km hr^{-1} in 2011 and at 6.7 km hr^{-1} in 2013 due to changes in operator. Such a conclusion is supported by the fact that increase in speed has been cited by various researchers as contributing to increased draught force (Al-Janobi, Kabeel & Aboukarima, 2000; Hunt, 2001; Chandon & Kushwaha, 2002; Mamman & Oni, 2005; Alimardani, Fazel, Akram, Mahmoudi & Varnamkhasti, 2008; Serrano & Peça, 2008; Naderloo *et al*.,2009; Al-Suhaibani & Ghaly, 2010).

The draught force was higher for ARF, indicating that the animal-drawn plough (CV) was more efficient, compared to the ARF (NSCT). Results of 823 N for AMP from Nengomasha (1997) were slightly higher than the on-station results in the present study for 2011 and 2012, but lower than those for 2013, being AMP draught 502 to 848 N for AMP. An explanation for these differences could be that the draught force that animals exert to draw an implement constantly changes due to numerous interacting variations attributable to the animals, the operator, the soil and the orientation of the implements. O'Neill and Kemp (1989) gave examples of the great variation in draught forces associated with soil conditions and previous tillage history. Lawrence and Pearson (1985) reported that, in one experiment, draught measurements ranged from 589 to 2160 N for the same plough in the same field in the same two-week period at the end of a rainy season. Pearson, Lawrence and Ghimire (1989) provided values to illustrate how much effect individual operators can have on the draught force of an implement, even one with fixed settings. Starkey (1989) also mentioned that a mean draught force of 704 N was measured with one ploughman and 492 N with a different ploughman whilst ploughing on terraces with a traditional ard in Nepal. The differences in draught could only be ascribed to the way the two operators used the ploughs, suggesting that operators can greatly influence the performance of tillage methods. In this study, tractor-drawn implements, TDH (CV) required a lower draught force than TRF (NSCT) and among the animal-drawn implements AMP (CV) required a lower draught force than ARF (NSCT).

4.3.3.3 Draught force and use of donkeys for NSCT

This study has also shown that donkeys can be used with the ripper–furrower, as three donkeys together could pull 11.29% of their combined body weight on the animal-drawn plough and 13.37% on the animal-drawn ripper-furrower. Goe (1983) reported that a donkey could pull 16.20 % of its live weight at a speed of 2.5–2.8 km hr^{-1} for 3–3.5 hours per day. Starkey (1985) reported that donkeys could pull 17–25% of their body weight while ploughing. This suggests that the donkeys in this study could possibly have pulled more weight than they achieved if they had been given the chance to do so.

4.3.4 Specific Draught Analysis

4.3.4.1 Model Comparison

The statistical model used for this analysis is defined in equation (5). Following model comparison as provided in Section 4.3, the fit statistics for the five covariance structures are presented in Table 4.11. A smaller model fit statistic value indicates a better fit to the data.

Table 4.11: Fit Criteria for Specific Draught

	Covariance Structure	**BIC**	**REML Log L**
1	CS	954.4	946.7
2	UN	930.5	907.2
3	AR(1)	953.7	946.0
4	TOEP	956.0	944.4
5	SIMPLE	950.7	946.8
6	HF	949.3	933.8
7	ANTE(1)	928.4	909.1

CS = compound symmetry; UN = Unstructured; AR (1) = First order auto regressive;
TOEP = Toeplitz; HF = Huynh-Feldt; ANTE (1) = First order Ante- dependence

Based on the BIC, the Ante dependence covariance structure was selected. Table 4.12 shows the ante-dependence estimated covariance and correlation matrices for replicate 37 and plot 1 for the three years of the study; other plots have the same covariance and correlation matrices. The estimated covariance matrix indicates there is considerable variation in specific draught across years. For example, the variance in specific draught in 2011 is about 6 times that for 2012. Table 4.12 also indicates weak correlations in the specific draught measurements across the years of the study.

Table 4.12: Ante-dependence Covariance and Correlation Matrices for Specific Draught

Estimated R Matrix for rep (plot) 37 1			
Row	**Col 1**	**Col 2**	**Col 3**
1	144.69	0.9733	0.4090
2	0.9733	24.1260	10.1386
3	0.4090	10.1386	51.2841
Estimated R Correlation Matrix for rep (plot) 37 `			

Row	Col 1	Col 2	Col 3
1	1.0000	0.01647	0.004748
2	0.01647	1.0000	0.2882
3	0.004748	0.2882	1.0000

The ANOVA results for specific draught are shown in Table 4.13. The analysis shows that all factors were highly significant.

Table 4.13: ANOVA table for Specific Draught

Effect	Num DF	Den DF	F Value	Pr > F
Tillage	3	44	59.59	<0.0001
Year	2	85	24.28	0.0001
Tillage vs year	6	85	18.86	<0.0001

Num DF = the degrees of freedom of the numerator; Den DF = the degrees of freedom of the denominator

Table 4.14 shows the least square means and their standard error for specific draught outputs of the model analysis. Statistical analysis using Proc Mixed (SAS, 2003) shows that there was a significant ($p< 0.001$) difference between tillage method, year and also tillage method vs year for specific draught.

Table 4.14: Least Square Means (± s.e) for Specific Draught

Effect	Tillage Method	Year	Specific Draught Estimate (kN/m^2)	Standard Error
Tillage method	AMP		35.480	1.500
Tillage method	ARF		35.856	1.643
Tillage method	TDH		21.696	1.500
Tillage method	TRF		11.393	1.500

Year		2011	18.628	1.807
Year		2012	27.358	0.709
Year		2013	32.333	1.034
Tillage vs year	AMP	2011	30.219	3.472
Tillage vs year	AMP	2012	40.211	1.418
Tillage vs year	AMP	2013	36.010	2.067
Tillage vs year	ARF	2011	35.852	4.010
Tillage vs year	ARF	2012	37.292	1.418
Tillage vs year	ARF	2013	34.423	2.067
Tillage vs year	TDH	2011	4.323	3.472
Tillage vs year	TDH	2012	19.008	1.418
Tillage vs year	TDH	2013	41.758	2.067
Tillage vs year	TRF	2011	4.116	3.472
Tillage vs year	TRF	2012	12.921	1.418
Tillage vs year	TRF	2013	17.141	2.067

Within the animal group, the specific draught for AMP increased from 30.22 kN m^{-2} in 2011 to 40.21 kN m^{-2} in 2012 but decreased to 36.01 kN m^{-2} in 2013. The specific draught for ARF also followed the same pattern, as reflected in Table 4.14.

Within the tractor group, the specific draught for TDH increased greatly from 2011 to 2013 while that of TRF also increased, but the increases were not as pronounced as those of TDH. In 2011, TRF"s specific draught was less than that of TDH by 4.80 %; 32.02% in 2012 and by 58.95% in 2013. This means that TRF was more energy efficient than TDH.

TDH showed higher specific draught than did TRF in all the three years, probably because of the larger disturbed area, i.e. larger width of cut as compared to TRF which produced a narrower cut. Several researchers have pointed out that, to assess differences between different implements accurately, the draught requirement must be related to the volume of soil tilled (Al-Janobi & Al-Suhaibani, 1998; Khaffaf & Khadr, 2008; Serrano & Peça, 2008).

This means that TRF performed better than TDH in all the three years and ARF only performed better than AMP in the last two years, i.e. 2012 and 2013.

Overall in comparison, NSCT methods performed better than the CV methods on specific draught. The tractor-drawn tillage methods (TDH and TRF) showed lower specific draught than the animal-drawn tillage methods (AMP and ARF) across the three years. Since specific draught is a function of draught, depth and width, gradual increases or decreases in the specific draught can also be attributed to increase or decrease in any one of those parameters. NSCT technologies used higher draught forces than did CV ones. NSCT methods, however, outperformed the CV methods on specific draught. TRF and ARF showed lower specific draught than TDH and AMP across the three years, suggesting that NSCT methods were more energy-efficient than CV methods.

Comparing specific draught among tillage methods across the years showed mean specific draught values also increased from 2011 to 2013 for tractor-drawn tillage methods (see Fig 4.4). The pattern was the same for draught force. There was also a gradual increase in depth of cut over time for all the tillage methods as shown in Table 4.2. Increases in both draught force and specific draught could be attributed to increases in depth. For tractor-drawn tillage methods, this is supported by Al-Janobi & Al-Suhaibani (1998); Arvidsson *et al*., (2004); Al-Suhaibani & Ghaly (2010); Arvidsson & Hillerstrom (2010), who also reported increases in specific draught with an increase in depth of cut.

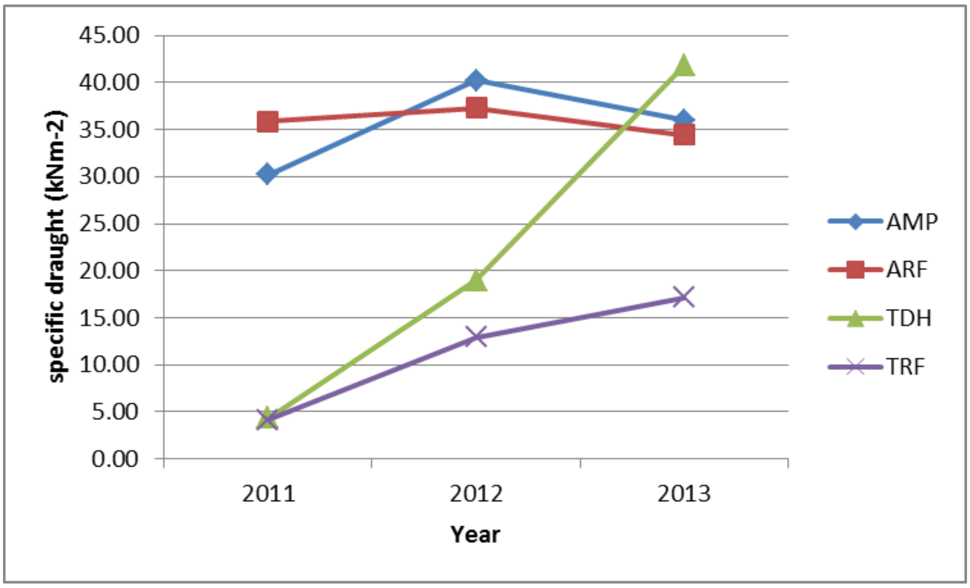

Fig 4.4: Comparison of specific draught among tillage methods and across years (p <0.0001)

Year of measurement was found to have an influence on specific draught (p <0001). The seasonal variability in rainfall and soil moisture appeared to be important determinants in the seasonal dynamics of both draught force and specific draught. Because the soil became drier in the second and third years of land preparation, penetration into the soil by the various tillage implements became more difficult, meaning that, in dry years, high draught requirements could be expected. Fluctuations could also be caused by variations in depth due to soil conditions, surface roughness (Gebresenbet & Kaumbutho 1997) and also due to the use of different operators across the years for both tractor-drawn and animal-drawn tillage methods. Pearson, Lawrence and Ghimire (1989) and Edwards (2001) also reported that the performance of an implement sometimes depends on the skill of the operator as well as soil conditions.

The results for all the four tillage technologies showed gradual increases in depth of cut, draught, draught force and specific draught for tractor-drawn equipment. Comparing TRF and TDH (tractor group) on depth of cut, TRF performed better than TDH, and within the animal group ARF performed better than AMP. NSCT methods thus showed that they were better than CV methods regardless of power source.

Saunders (2002) concluded that depth of cut had the greatest effect on draught force. Others have also shown that, as the depth of cut increases, draught force also increases (Godwin, 2003; Vozka, 2007; Mamman & Oni 2005; Naderloo *et al*., 2009; Al-Suhaibani *et al*., 2010; Adewoyin, 2013; Moeenifar *et al*., 2014). Vozka (2007) cited that the major lessons from this are not to work deeper than necessary and to work at a greater forward speed to increase work rate and achieve better machinery exploitation. Abbaspour-Gilandeh, Khalilian, Alimardani, Keyhani, and Sadati (2006) also reported that draught force increased as the forward speed increased in all soil types, and that tillage depth had a greater effect on the draught and drawbar power than the tractor speed. The results of the present study also showed that, as the depth increased, so did the draught force and specific draught in tractor drawn implements.

Among the animal-drawn implements, AMP showed larger specific draught than ARF. Overall, the high specific draught registered in the animal-drawn implements is very likely due to the small volume of soil which was disturbed, i.e. small depth and width of cut. Comparing the tractor group with the animal group, the low specific draught in the tractor-drawn implements is attributed to high draught, large depth and large width relative to the animal-drawn implements. Depth and draught force gradually increased from 2011 to 2013, and this also might have caused any increase in specific draught.

Other researchers also showed that depth has more effect on draught and that this subsequently affects specific draught. Al-Janobi and Al-Suhaibani (1998) reported that actual tillage depth has more effect on the total draught requirement. Arvidsson *et al*., (2004) also reported an increase of 19.5% in specific draught with a 4 cm increase in working depth (from 17 cm to 21 cm) for a chisel plough. Arvidsson and Hillerstrom (2010) reported a 20%

increase in specific draught with increased tine width from 50-120 mm. In addition, Al-Suhaibani and Ghaly (2010) studied the effects of ploughing depth and forward speeds on draught and vertical specific draught. Their results indicated that increasing the ploughing depth increased the draught, unit draught and vertical specific draught, which suggests that specific draught, is affected by tillage depth, speed and width. They also reported that the recommended ploughing depth should be based on the type of crop and the depth of the root system.

The high specific draught for animal-drawn implements in the present study could also be attributed to the design and configuration of the implements themselves, as this is related to the volume of soil that an implement could essentially push. The ripper-furrower was designed to make furrows, so it tended to push a relatively large amount of soil. The animal-drawn implements also showed high specific draught levels because they had smaller depths and widths of cut. This suggests that specific draught is affected by working depth and implement configuration, as reported by Manuwa and Ademosun (2007).

The results in the present study provided important insight into the variations of depth, draught and specific draught with year. They revealed that, in dry years, high specific draught could be expected. These results need, however, to be supported by large data sets, and more work would need to be done. It would have been easier to model under ‘soil bin’ conditions, where one is able to control certain variables. Al-Janobi and Eldin (1997) developed an indoor soil bin test facility for soil-tillage tool interaction studies on the reasoning that field studies were sometimes meaningless due to the wide variation of soil types and conditions found there. They also pointed out that the chances of getting the same soil at the same condition were very rare if one had to repeat the experiment. Soil bins can also help to minimize capital costs and moderate the manual labour requirements, but might miss out on some of the realities of the field.

Considering the draught values for tractor-drawn implements given by Hunt (2001) the present on-station results as reflected in Table 4.15 are higher than those given by Hunt, with TRF 39% higher and TDH 13% higher, if we choose the largest values. These differences in implement draught suggest that substantial energy savings can readily be obtained by selecting energy-efficient tillage implements. Whilst TDH required less draught force, it gave higher specific draught values compared to TRF, making TDH less efficient. Reduced soil cultivation, in this case with TRF, reduces farm energy requirements and overall farming costs because a smaller area has to be tilled (Monzon *et al*., 2006). The tillage energy data need to be combined with other agronomic and soils data to select the optimum tillage system for a particular soil and climatic region.

Table 4.15: Comparison of field performance of tractor drawn implements on-station with ASAE and Hunt (2001)

	On-station TDH	**On-station TRF**	**Hunt (2001)**	**ASAE**
Speed km hr^{-1}	6.5-6.7	6.5-6.7	6-10	6.5-11
Draught kN	6.9 (2013)	9.9 (2013)	5-6	TRF = 18.03 TDH = 10.35
Efficiency %	52.25 - 56.75	58.75 -64.75	75-90	70- 90

According to Bobobee (2007) camel, horse and cattle are better suited for heavy primary cultivation than are donkeys, which must be in a team of at least four to provide a reasonable draught force. This means that if farmers in the Namibian NCA, who are mainly using 3 donkeys, could add one donkey, they could realize more draught and thereby be more efficient and able to finish their fields much faster. This is also in line with Pearson et al. (1989) who also reported that studies in Zimbabwe had shown that well-fed, well-trained donkeys teamed in fours are capable of sustaining a combined draught force of over 1 kN for a 4-hour working period, sufficient to plough relatively deep soil with a mouldboard plough and complete most other agricultural tasks associated with crop production in an acceptable time. More studies, however, need to be done in this area in Namibian conditions in order to get conclusive results. This is because other researchers (ILCA, 1986; Panin and Ellis-Jones, 1992) have shown that the inclusion of more animals in a team (span) is associated with a loss of efficiency due to co-ordination problems. ILCA (1986) likewise reported that team efficiency is a function of team size, and declines by 7.5% for each extra animal used in a team.

4.3.5 Efficiency Analysis

Following the model comparison as described in section 4.2.1, the fit statistics for the five covariance structure are presented in Table 4.16. A smaller model fit statistic value indicates a better fit to the data. Based on the BIC, the simple structure was selected.

Table 4.16: Fit criteria for Efficiency

	Covariance structure	**BIC**	**REML log l**
1	CS	-591.7	-599.4
2	UN	-608.8	-632.0
3	AR(1)	-603.2	-611.0
4	TOEP	-600.3	-611.9
5	Simple	-575.8	-579.7
6	HF	-583.9	-597.6
7	ANTE(1)	-606.5	-617.9

CS = compound symmetry; UN = Unstructured; AR (1) = First order auto regressive; TOEP = Toeplitz;
HF – Huynh-Feldt; ANTE (1) =First Order Ante- dependence

The ANOVA results for efficiency are shown in Table 4.17. The analysis shows that all factors were highly significant (p< 0.0001).

Table 4.17: ANOVA table for Efficiency

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Tillage	3	44	98.10	<.0001
Year	2	88	28.34	0.0001
Tillage vs year	6	88	17.52	<.0001

Num DF = the degrees of freedom of the numerator; Den DF = the degrees of freedom of the denominator

Table 4.18 shows the least square means and their standard error for efficiency outputs of the model analysis. Statistical analysis using Proc Mixed (SAS, 2003) shows that for efficiency there was a significant interaction between tillage method, year and tillage vs years.

Fig 4.5 shows comparison of efficiency among tillage methods and across the years. In 2011, within the tractor group, TRF was more efficient than TDH. The same trend is shown in both 2012 and 2013. Efficiency for TRF decreased from 2011 through to 2013. TDH however showed an increase in efficiency showing that it improved every year.

Table 4.18: Least square means (± s.e) for Efficiency

Effect	**Tillage**	**Year**	**Estimate (%)**	**Standard Error**
Tillage method	AMP		0.622	0.004
Tillage method	ARF		0.631	0.004
Tillage method	TDH		0.544	0.004
Tillage method	TRF		0.615	0.004
Year		2011	0.621	0.004
Year		2012	0.604	0.004
Year		2013	0.584	0.004

Tillage vs year	AMP	2011	0.665	0.007
Tillage vs year	AMP	2012	0.630	0.007
Tillage vs year	AMP	2013	0.570	0.007
Tillage vs year	ARF	2011	0.648	0.007
Tillage vs year	ARF	2012	0.630	0.007
Tillage vs year	ARF	2013	0.615	0.007
Tillage vs year	TDH	2011	0.523	0.007
Tillage vs year	TDH	2012	0.548	0.007
Tillage vs year	TDH	2013	0.563	0.007
Tillage vs year	TRF	2011	0.648	0.007
Tillage vs year	TRF	2012	0.610	0.007
Tillage vs year	TRF	2013	0.588	0.007

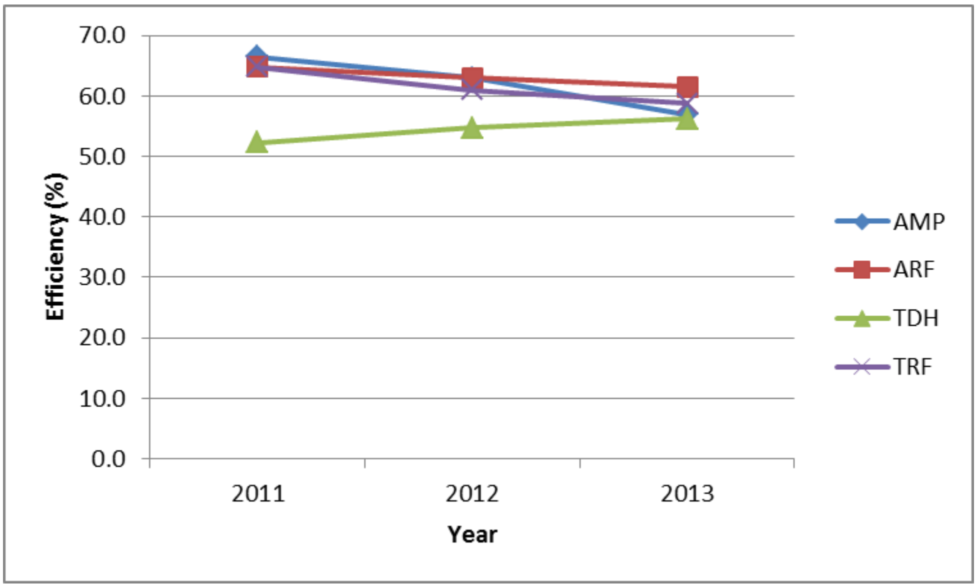

Fig 4.5: Comparison of efficiency among tillage methods and across years (p <0.001).

Within the animal group, in 2011 AMP was more efficient than ARF. AMP was better than ARF by 2.70%; in 2012 they were the same whilst in 2013, ARF was better than AMP by 7.32%. As for the tractor-drawn implements, in 2011 TRF was better than TDH by 19.31%; in 2012 it was better by 10.25% and in 2013 by 4.26%.

Comparing the NSCT with the CV implements, whilst TDH had an improved efficiency over the years, it was nonetheless the least efficient because the tractor had to turn with a larger implement, thereby taking more time to turn than was required with other implements. The plots were also small, so that with bigger plots or fields, the efficiency is bound to improve. Looking at efficiency across the three years, it decreased from 2011 to 2013. Apart from the smallness of the plots, this could also be attributed to changes in operators. Different operators were used in each of the three years.

In comparing the efficiency values, it should be remarked that not all tractor-drawn technologies in the study reached the ASAE Standards of Efficiency, i.e. 70–90%, maybe because of the shorter rows and lack of experience of the operators. According to von Bargen, cited in Hunt (2001, p 85) differences in ability, motivation, alertness, and training of operators can have significant effects on the operator performances. ASAE (2003) standard D497.4 lists field efficiency for tractor-drawn mouldboard plough, tandem disk harrow, roller packer, chisel plough and row crop planter to be all within the range of 70 to 90%. Values for this study fell short of the specified standards by19% for (TDH) and 7% for (TRF).

Whilst TDH was the least efficient, it is used mostly by the tractor service providers in the NCA, and it has been shown to pulverise the soil. This, therefore, reinforces the point that the TDH, which is a conventional tillage implement, should not be the preferred implement for land preparation purposes in the NCA.

Animal-drawn technologies could not achieve high efficiencies because the animals were sometimes difficult and could not move straight all the time. The other reason could be the variation in the performance and alertness of the operators. This is in agreement with Pearson, Lawrence and Ghimire (1989) and Edwards (2001) who mentioned that the performance of an implement sometimes depends on the skill of the operator as well as soil conditions. Another study by Makki and Manzool (2013) also reported that donkeys in Addlling, Sudan could achieve efficiencies of 66.7%–83.3%. In the present study, AMP's efficiencies ranged from 57% to 67% so that AMP only reached the minimum efficiencies established by Makki and Manzool (2013).

4.3.6 Effective Field Capacity Analysis

All the tillage methods together were first analysed for Effective Field Capacity (EFC), and as the distribution was found to be bimodal, they were further analysed separately, i.e. animal group on its own and tractor group also on its own. Following the model comparison as described in section 4.2.1, the fit statistics for the five covariance structures are presented in Table 4.19. A smaller model fit statistic value indicates a better fit to the data. Based on the BIC, the simple structure was selected.

Table 4.19: Fit criteria for Effective Field Capacity

	Covariance structure	BIC	REML log L
1	CS	-237.7	-244.0
2	UN	-308.4	-327.5
3	AR(1)	-249.1	-255.5
4	TOEP	-260.9	-270.4
5	SIMPLE	-228.8	-232.0
6	HF	-280.8	-293.5
7	ANTE(1)	-308.2	-324.1

CS = compound symmetry; UN = Unstructured; AR (1) = First order auto regressive;
TOEP = Toeplitz; HF = Huynh-Feldt; ANTE (1) = First Order Ante- dependence

The ANOVA results for EFC (animal) are shown in Table 4.20. The analysis shows that all factors were highly significant.

Table 4.20: ANOVA table for EFC for animal-drawn implements

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Tillage	1	22	8717.69	<0.0001
Year	2	44	154.69	0.0001
Tillage vs year	2	44	112.86	<0.0001

Num DF = the degrees of freedom of the numerator; Den DF = the degrees of freedom of the denominator

Table 4.21 shows the least square means and their standard error for efficiency outputs of the model analysis for animal-drawn implements. Statistical analysis using Proc Mixed (SAS, 2003) shows that there was a significant interaction between tillage method and years for EFC.

For AMP, EFC decreased from 2011 to 2013, whereas ARF increased from 2011 to 2012 and then decreased again in 2013. Generally both methods decreased by 2013. Efficiency also decreased by 2013 for all tillage methods. This could have contributed to decrease in EFC by 2013. ARF had greater EFC than AMP by 79.42% in 2011. In 2013, ARF had greater EFC than AMP by 81.82% and in 2013 by 77.55%.

Table 4.21: Least square means (± s.e) for EFC for animal-drawn implements

Effect	**Tillage**	**Year**	**Estimate (ha hr^{-1})**	**Standard Error**
Tillage method	AMP		0.030	0.001
Tillage method	ARF		0.148	0.001
Year		2011	0.094	0.001
Year		2012	0.098	0.001
Year		2013	0.075	0.001
Tillage vs year	AMP	2011	0.032	0.001
Tillage vs year	AMP	2012	0.030	0.001
Tillage vs year	AMP	2013	0.028	0.001

Tillage vs year	ARF	2011	0.156	0.001
Tillage vs year	ARF	2012	0.165	0.001
Tillage vs year	ARF	2013	0.123	0.001

For tractor-drawn implements the same model was used as in 4.2.1 above. A smaller model fit statistic value indicates a better fit to the data. Following the model comparison as described in section 4.2.1, the fit statistics for the five covariance structure are presented in Table 4.19. Based on the BIC, the simple structure was selected. The ANOVA results for EFC (tractor) are shown in Table 4.22. The analysis shows that all factors were highly significant ($p< 0.0001$ for tillage, year and $p< 0.0015$ for tillage versus year).

Table 4.22: ANOVA table for EFC for tractor drawn implements

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Tillage	1	22	38.03	<0.0001
Year	2	43	166.38	0.0001
Tillage vs year	2	43	7.61	<0.0015

Num DF = the degrees of freedom of the numerator; Den DF = the degrees of freedom of the denominator

Table 4.23 shows the least square means and their standard error for efficiency outputs of the model analysis for tractor drawn implements. Statistical analysis using Proc Mixed (SAS, 2003) shows that there was a significant ($p<0.001$) interaction between tillage method year and tillage vs year for EFC.

Table 4.23: Least square means (± s.e) for EFC tractor drawn implements

Effect	**Tillage Method**	**Year**	**EFC Estimate (ha hr^{-1})**	**Standard Error**
Tillage method	TDH		0.687	0.006
Tillage method	TRF		0.742	0.006
Year		2011	0.823	0.008
Year		2012	0.647	0.008
Year		2013	0.674	0.009
Tillage vs year	TDH	2011	0.772	0.010

Tillage vs year	TDH	2012	0.616	0.010
Tillage vs year	TDH	2013	0.673	0.011
Tillage vs year	TRF	2011	0.875	0.011
Tillage vs year	TRF	2012	0.678	0.011
Tillage vs year	TRF	2013	0.674	0.015

For TRF, EFC decreased from 2011 to 2013, whereas for TDH, EFC decreased in 2012 and then increased again in 2013. Generally, both tractor-drawn methods showed a decrease of EFC by 2013. In 2011, TRF was better than TDH by 11.78%, in 2012, TRF was better by 9.15% and in 2013 it was also better by 0.24 %. Fig 4.6 shows a comparison of effective field capacity among tillage methods and across years.

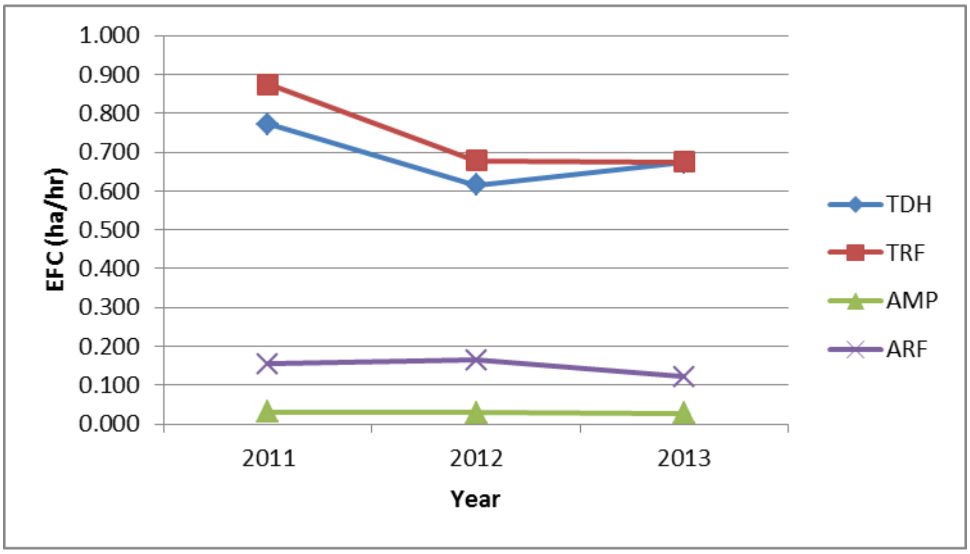

Fig 4.6: Comparison of Effective field capacity among tillage methods and across years (p <001).

The animal-drawn ripper-furrower (NSCT) could do 0.15 ha hr^{-1} compared to the 0.03 ha hr^{-1} for AMP (CV). Working for six hours per day, this would amount to cultivating 0.89 ha per day for ARF and 0.18 ha for AMP. The results show that increasing the width of cut also increases the EFC. This is in line with Vozka (2007) who also showed that increasing the width of the implement increases the work rate, i.e. effective field capacity. It would take about 1.5 hours per hectare with the tractor-drawn tillage treatments, whilst it would take five days per hectare with an animal-drawn plough and one day to complete a hectare with an animal-drawn ripper-furrower with a team of 3 donkeys. Chigariro *et al*. (2008) estimated that donkeys would take 3 days to finish ploughing a hectare whilst working for 12 hours per day, and they estimated that work rates for ploughing in Namibia could be 0.02 ha hr^{-1} with donkeys. Results from the on-station study are better than the above estimates by 7% for AMP and 87% for ARF showing that NSCT was better than CV.

Results from this study showed that it can take five days per hectare to finish ploughing with animal-drawn implements when working six hours per day. If this is increased to eight hours, it can then take about 4 days per hectare. It still means that the animals can get time to rest and feed so as to be fit and able to exert their maximum draught, perform other activities and also to be in good health generally. Considering that the farmers cited by Chigariro *et al.* (2008) used draught animals for much longer periods per day, i.e. 12 hours and sometimes without much rest, the durations could be reduced to 3 days for AMP and 3 hours for ARF as was shown in the present study. This can greatly help the large numbers of farmers who still use draught animals in Namibia (Mudamburi & Namalambo, 2010). This is supported by Starkey, (2010) who acknowledged that, while there will continue to be contributions to land preparation from tractor power, much of the Eastern and Southern African region will continue to be cultivated by hand and animal power.

Considering that the ARF as shown by the width of cut and EFC can finish a field faster than AMP, it is recommended that Namibian farmers should choose ARF. Using ARF (NSCT) instead of AMP (CV) will effectively reduce the amount of time that the animals would need to spend in the field. Reducing energy requirements is crucial for the semi-arid areas of Namibia, where draught animals are often weak during the time of land preparation

(Mudamburi *et al.,* 2003). By implication, this would also lead to yield increases as farmers can plant early. Studies in Zimbabwe (Nyagumbo, 2008) have shown that 5 % of potential cereal grain yield is lost for every week of delay in planting.

'The Republikein' (2013) reported that, by the end of 2011 there were 233 522 farmers who derive their income from subsistence agriculture. In Namibia, the number of tractors as reported by MAWF, April 2014, amounted to only 75 tractors that were providing land preparation services to all the communal farmers. It is doubtful that these would be enough to cover the large number of farmers in the NCA. Assuming that each farmer has 3 ha, then the total area to be covered would be 700 566 ha. If all farmers opt to use TRF, and if 0.67 ha hr^{-1} is chosen (on the basis of the on-station results of TDH 0.67 to 0.77; TRF 0.67 to 0.88), a total of 1 045 620 tractor hours will be needed. Assuming 8 hours per day, this means 130 702 days for each of the 75 tractors available in the NCA. Using the tractor-drawn ripper-furrower, this can be reduced to 1 742 days to cover all the fields. Even then, that would take 4 years to meet the needs of all the farmers. Obviously this means that a great many more tractors are needed for the NCA if all farmers opt to use tractors every season.

Chigariro *et al.* (2008) estimated that work rates for ploughing in Namibia could be 0.43 ha hr^{-1} with tractors. Results from this study are better than those estimates by 36%‒44% for TDH and 36%‒51% for TRF, NSCT being better than CV.

For EFC, generally, both animal-drawn methods decreased by 2013. However, in all the three years ARF had greater EFC than AMP. The tractor-drawn methods also decreased by 2013, although TRF was better than TDH in all the three years. In other words, both NSCT methods performed better than the CV methods regardless of power source.

Fig 4.7 shows another disadvantage of using the disc harrow. It shows a cloud of dust from using the tractor disc harrow and this is detrimental to the environment and the operators. Fig 4.8 in comparison shows the tractor ripper furrower and it does not show as much cloud as seen with the tractor disc harrow.

Fig 4.7: Use of disc harrow at the on-station plots in 2011. Note the cloud of dust.

Fig 4.8: Use of the tractor ripper furrower

4.4 Conclusions

In conclusion, there were significant differences in depth, draught force, specific draught, efficiency and effective field capacity among tillage methods. NSCT methods (TRF and ARF) may have an advantage over CV methods in the Ogongo sandy soils, but justification for implementing the system would be dependent upon site-specific field conditions. ARF will, however, not work alone in the first year and will have to complement TRF as from the second year. Overall NSCT implements had higher draught forces. NSCT methods however performed better than the CV methods on specific draught across the three seasons showing that they were more energy efficient than CV methods. As for efficiency and effective field capacity, NSCT methods performed better than the CV methods regardless of power source. This therefore means that farmers should choose NSCT methods.

5. FIELD PERFORMANCE OF TILLAGE TECHNOLOGIES UNDER CROPPED CONDITIONS

5.1 Introduction

This chapter presents a comparison of the performances of two tillage technologies under cropping conditions for 2011 and 2012. The performances criteria are soil penetration resistance (PR), moisture content, root depth and yield of pearl millet. Since this part involved a split plot design, results are for 'mulched' and 'no mulched' plots.

5.2 Penetration Resistance

The soil penetration resistance measured at planting and harvesting for 2011 and 2012 for the two tillage technologies are shown in Table 5.1. There are no significant differences between mulch levels for both years. TRF and ARF showed PR values of less than 2 MPa whilst the other three methods showed values above 2 MPa.

Table 5.1: Mean PR for 2011 and 2012 at Planting and Harvesting for Different Tillage Methods

Tillage treatment	2011				2012			
	Mean PR (MPa) at Planting		Mean PR (MPa) at Harvesting		Mean PR (MPa) at Planting		Mean PR (MPa) at Harvesting	
	Mulch	No Mulch	Mulch	No Mulch	Mulch	No Mulch	Mulch	No Mulch
AMP	1.978	2.162	1.818	1.755	2.352	2.300	2.355	2.365
ARF	1.926	1.912	1.732	1.630	2.155	2.258	2.240	2.245
FALLOW/CONTROL	2.130	2.317	2.093	1.957	2.338	2.373	2.495	2.518
TDH	2.139	2.150	1.695	1.793	2.405	2.398	2.365	2.234
TRF	1.161	1.350	1.598	1.491	1.642	1.678	1.758	1.787

5.2.1 PR at Planting for 2011

There were significant ($p<0.001$) differences in PR at planting among the tillage methods in 2011. There was a significant ($p=0.002$) interaction between depth and tillage for all soil depths. PR was significant at less than10 cm level but not different for greater than 10 cm. However, for TRF, the PR values were significantly low compared to the other tillage methods, both at less than 10 cm and also above 10 cm, registering less than 2 MPa throughout compared to more than 2 MPa for the other tillage methods.

There were no significant ($p = 0.853$) differences in PR between mulch levels among the tillage methods. However, the PR levels were low and less than 2 MPa for TRF and ARF (all NSCT), as can be seen from Table 5.1. The PR for the two CV methods (TDH and AMP) and the control were all above 2 MPa, except for AMP under mulch treatment.

5.2.2 PR at Harvesting for 2011

There were significant ($p<0.001$) differences in PR among the tillage methods, but no significant ($p=0.663$) differences in PR between mulch treatments within the different tillage methods. A comparison of PR differences across the tillage methods at the two mulch levels at harvesting at 10 cm for 2011 showed that there is no interaction ($p=0.563$) between mulch and tillage. Fig 5.1 shows a comparison of PR at different depths for 2011. There was a significant ($p<0.001$) difference in PR with depth. This shows that PR increased with depth.

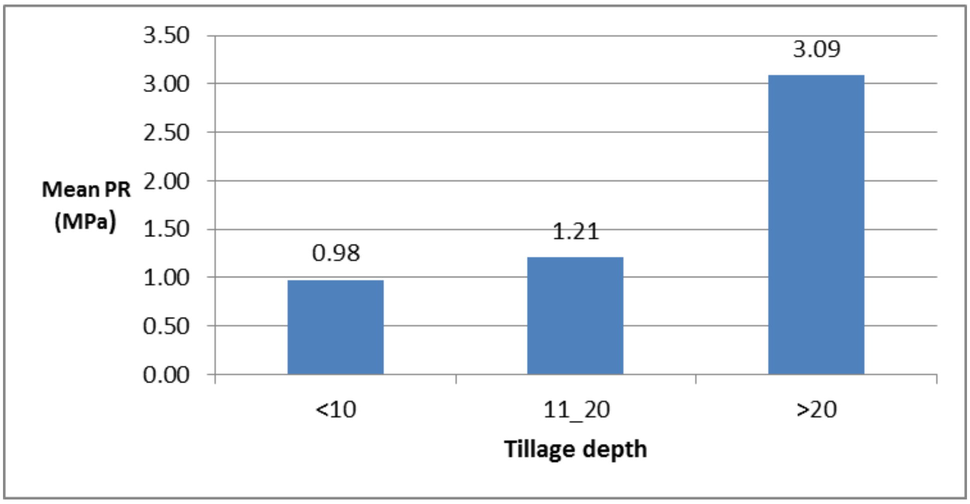

Fig 5.1: Comparison of PR and Depth at harvesting for 2011 ($p<0.001$; lsd = 0.11)

There was no interaction ($p=0.108$) between tillage and depth. At 10 cm and below the PR was significantly low.

5.2.3 Comparison of PR at Planting and at Harvesting for 2011

In 2011 overall, comparing PR at planting and at harvesting, PR values for TRF were low at harvesting, At harvesting in 2011, compared to FALLOW, TRF resulted in lower PR by 30.97 % whilst PR in ARF was lower by 20.83 % than in the FALLOW plot. PR under TDH was lower by 16.67 % whilst for AMP it was lower by 13.41% than in the FALLOW plot. All NSCT methods resulted in lower PR values compared to CV methods, irrespective of power source. TRF resulted in 34% lower PR than TDH; whereas ARF resulted in 6% lower PR than AMP.

5.2.4 PR at Planting for 2012

A comparison of PR across the tillage methods at planting in 2012 shows significant ($p<0.001$) differences in PR among them. TRF had significantly lower PR values than the other methods at all depths, as shown in Fig 5.2. Mulching had no effect on PR (p=0.977) among the tillage methods.

5.2.5 PR and Depth

There was no significant (p=0.086) interaction between depth and tillage. There was, however, a significant (p<0.001) difference in PR with depth. This suggests that PR increased with depth for all tillage methods, as shown in Fig 5.2.

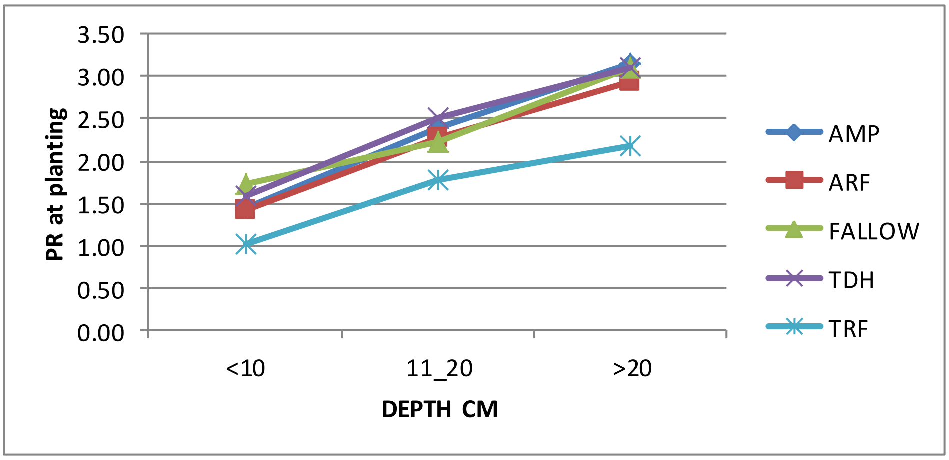

Fig 5.2: Comparison of 2012 PR at Planting at Various Depths for Four Tillage Methods

At planting in 2012, TRF resulted in 42.2 % lower PR than the FALLOW plot, while under ARF the PR was 6.8% lower than the FALLOW plot. The PR for TDH was 1. 7% lower while the PR for AMP was 1.3% lower than the FALLOW plot. All NSCT methods again registered lower PR values compared to CV methods, irrespective of power source. Comparing the tillage methods alone, TRF resulted in 31% lower PR than TDH; while ARF resulted in 5% lower PR than AMP.

5.2.6 PR at Harvesting in 2012 in comparison with PR at Harvesting in 2011

In 2012, there were no differences (p=0.886) in PR between mulch and no mulch within the tillage methods. There were, however, significant (p<0.001) differences in PR among the tillage methods at harvesting. Table 5.2 shows mean PR values for 2012 at harvesting for different tillage methods. The NSCT methods (TRF and ARF) are significantly different from the CV methods (TDH and AMP) in 2011. In 2012 TRF is significantly different from the other three methods including FALLOW. The PR for all tillage methods are significantly different and less than for FALLOW in both years indicating that tillage helps in reducing compaction of soil.

Table 5.2: Mean PR for 2012 at Harvesting for Different Tillage Methods

Tillage Method	Mean PR (MPa) at harvesting 2011*	Mean PR (MPa) at harvesting 2012*
TRF	1.15^{a}	1.772^{a}
ARF	1.68^{a}	2.242^{b}
TDH	1.74^{b}	2.300^{bc}
AMP	1.79^{b}	2.360^{c}
FALLOW (Control)	2.03^{c}	2.507^{d}

*Values with different letters are significantly different at p < 0.05.

Fig 5.3 shows the relationship (p<0.001) between PR and depth at harvesting in 2012, showing that PR increased with depth. Overall PR values increased at harvesting for 2012. The general trend reflects an increase of PR with depth for all tillage methods although TRF again registered low values at harvest.

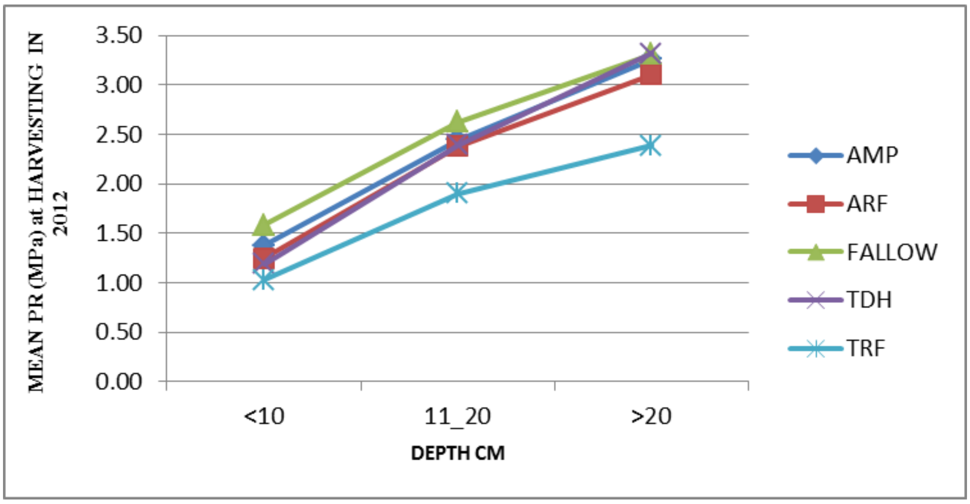

Fig 5.3: PR in 2012 at harvesting for various depths of the tillage methods

PR values at harvesting increased from 2011 to 2012, because the soils could have become harder. This could be due to a probability of hard pan being formed by using the tillage methods. Less rainfall was also recorded in 2012 (377.4 mm) compared to 2011 (621.6 mm), and this could have contributed to hardening of the soils. Depth for all the three technologies under uncropped land also increased in the second year. This also suggests that, as tillage implements go deeper, the chance becomes greater that they will encounter high soil compaction thereby hindering root penetration. When implements operate deep in the soil, draught and specific draught also increase, thereby making any land preparation exercise costly and inefficient. This has also been discussed in chapter 4, where draught force and specific draught results also increased in 2012.

At harvest in 2012, TRF resulted in 41.8% lower PR than the FALLOW plot whilst the PR for ARF was 12.0% lower. PR for TDH was 9.1% lower than the FALLOW plot, whilst the PR for AMP was 6.4% lower. Again this showed lower values for PR under NSCT methods than under CV methods, irrespective of power source. Comparing the tillage methods alone, TRF resulted in 23% lower PR than TDH; whilst ARF resulted in 5% lower PR than AMP.

5.2.7 Combined PR at Three Depths

Results were combined for PR at planting and at harvesting for 2011 and 2012 for the 3 depths, i.e. < 10 cm, 11-20 cm, and > 20 cm. The trend shows that PR increased with depth, as shown in Figs 5.4 and 5.5.

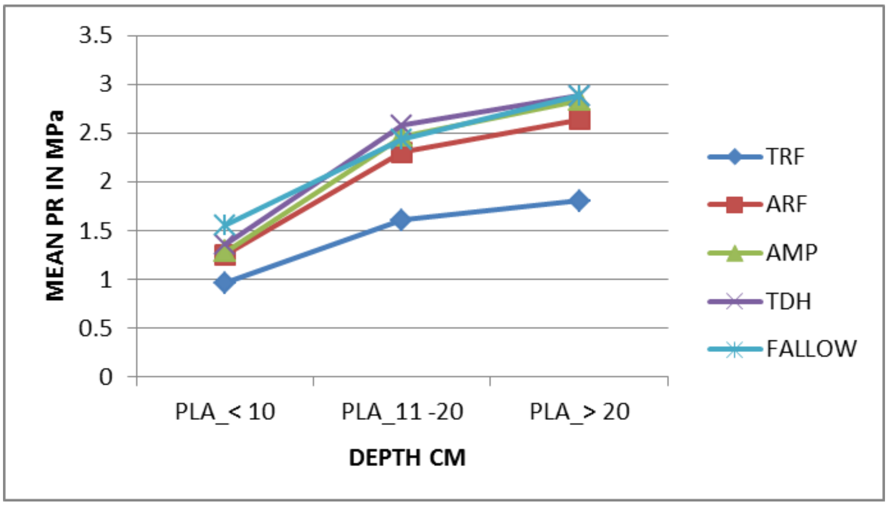

Fig 5.4: Comparison of combined PR and depth at planting

There were significant (p<0.001) differences in PR among the tillage methods, both at planting and at harvesting for all the depths. PR values increased to greater than 2 MPa after 10 cm as shown in Fig 5.4 for planting, but at harvesting PR values only increased to more than 2 MPa at depths greater than 20 cm. There are, however, no significant (p<0.482) differences between the years at time of planting, but significant (p<0.048) at harvesting.

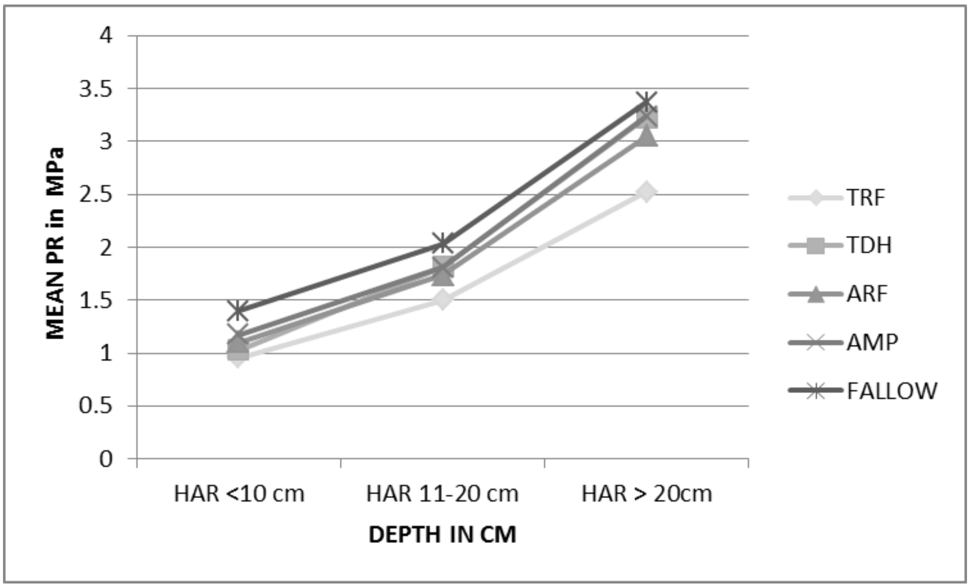

Fig 5.5: Comparison of Combined PR and Depth at Harvesting

Fig 5.6 shows a comparison of PR for tillage methods at planting and at harvesting for 2011 and 2012.

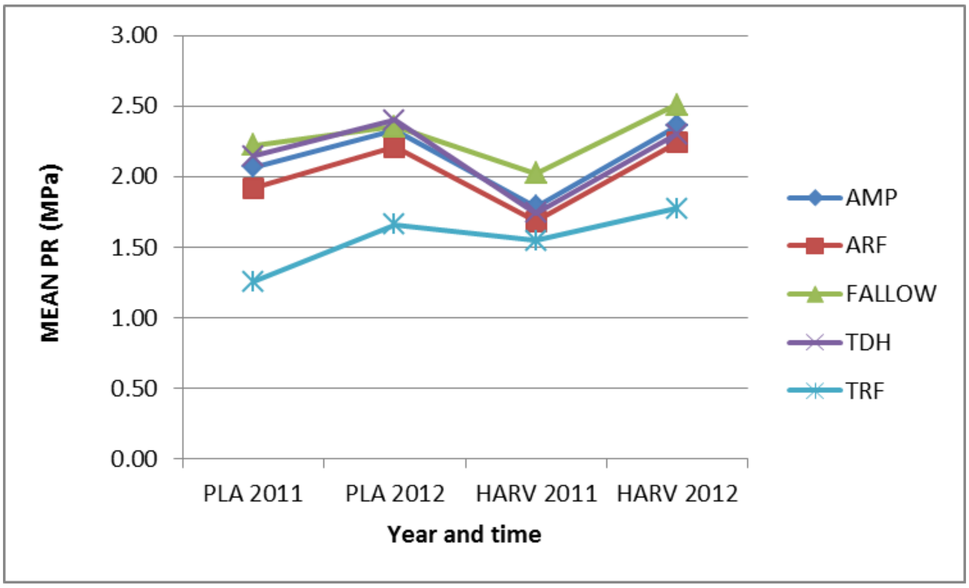

Fig 5.6: Comparison of PR for Tillage Methods at Planting and at Harvesting for 2011 and 2012

5.2.8 Regression Analysis for PR in 2012 at Planting

Regression analysis was done for PR in 2012 at planting and at harvesting. The analysis shows a significant ($p<0.001$) positive linear relationship between PR and depth at planting in 2012 for various depths for the four tillage methods. This shows that depth influences PR. The regression equation for penetration resistance is based on depth and gave a good fit with an R^2 of 0.9968. The regression equation for PR on sandy soils of Ogongo college was therefore PR = 0.731depth + 0.728. The high R^2 value of 0.9968 would make the model suitable for prediction under similar soil conditions.

5.2.9 Regression Analysis for PR in 2012 at Harvesting

Regression analysis shows that there is also a significant ($p<0.001$) positive linear relationship between PR and depth in 2012 for various depths at harvesting. Depth was also found to have an influence on PR at harvesting. It should be noted that the regression equation for penetration resistance is also based on depth.

The regression equation gave a good fit with R^2 at 0.9886. This equation for PR on sandy soils of Ogongo college was PR = 0.896depth + 0.445. The high value of 0.9886 for R^2 would make the model suitable for prediction under similar soil conditions.

In theory, one can estimate the PR required if the depth is known. This equation provided an important insight into the variations of penetration resistance with depth, but needs to be supported by large data, and more work would need to be done. The results are also consistent with those of Cavalaris and Gemtos (2002) and Kumar *et al.* (2012) who reported that penetration resistances had a general tendency to increase with soil depth regardless of tillage practice. For both the 2011 and 2012 seasons PR values increased with depth across all the tillage methods at planting and at harvesting. A positive linear relationship between PR values and depth was shown at both planting and harvesting. That means that there is no justification for tilling at greater depths unless the roots of the crop have to go to those greater depths. In Chapter 4 it was also shown that, as the depth increases, so does the draught and specific draught, thereby making deeper penetration energy-inefficient. This confirms that, as the ripper goes deeper, more force is required to pull the implement.

Overall, the general trend is an increase in PR with depth for all tillage methods, with TRF having the lower values. This could be because TRF harvested more water, making the soil softer than was achieved with the other methods, and so the tractor ripper furrower was the deepest during land preparation.

TRF achieved 27% lower PR values than the CV methods (TDH and APM). This agrees with the findings of Borghei *et al.* (2008), who also found that sub-soiling improved penetration resistance. It also agrees with Fabrizzi et al. (2005) and Bayhan *et al.* (2006) who found that PR values increased under CT. Fuentes *et al.* (2009) also stressed that the use of crop residues resulted in lower penetration resistance regardless of tillage system.

According to Atwell (1993) and Aase *et al.* (2001) penetration values greater than 2 MPa are generally reported to produce a significant reduction in root growth. In this study, at time of harvesting and at deeper than 20 cm, PR values were above 2 MPa. Only TRF achieved PR values that were less than 2 MPa. Hermawan and Cameron (1993), however reported that rooting depth is only restricted where PR exceeds 3.0 MPa. Lampurlanes and Cantero-Martinez (2003) however, reported between 2 MPa and 5 MPa as the critical range above which root growth is severely impeded. Also, with PR values increasing with increase in depth, this suggests that for pearl millet it might not be that important to check how far the roots of particular crop can go so that implement depth can also be adjusted to cater for the root length of the crop. According to Al-Suhaibani and Ghaly (2013) the recommended ploughing depth should be based on the type of crop to take account of the depth of the particular root system. There is also evidence (Merrill, Tanaka, & Hanson, 2002; Cairns, Audebert, Townend, Price, & Mullins, 2004) that different plant species, or cultivars of the same species, differ in their ability to penetrate compacted soils.

5.2.10 On-Farm Penetration Resistance from Omuntele Constituency Farmers' Fields

Table 5.3 shows the results of PR measurements taken on fields of Omuntele and Ogongo farmers. There are significant differences (p=0.030) between NSCT and CV for Omuntele farmers' fields. Only 3 of the 9 farmers (33%) had fields with PR values less than 2 MPa. The maximum penetration in the NSCT fields of two out of the nine (22%) farmers was between 15 and 16 cm, and in the CV fields of seven of the nine (78%) farmers, the maximum penetration was between 8 and 18 cm. Six of the nine (67%) farmers had fields with PR above 2 MPa under NSCT only. The PR values of the NSCT fields of eight of the nine (89%) farmers were lower than the PR values under CV. The PR values of the CV plots of all nine farmers were above 2 MPa.

In Ogongo all of the four sampled farmers' fields had maximum penetration at 15 cm and less than 15 cm. Only one farmer out of the four had PR values less than 2 MPa; the other three had PR values greater than 3 MPa. This suggests that most of the farmers could have problems of root penetration in their fields, as predicted by Atwell (1993), Hermawan and Cameron (1993) and Aase *et al.* (2001). All four sampled fields had lower PR levels under NSCT than under CV.

Table 5.3: PR from Omuntele and Ogongo Constituencies Farmers' Fields

Farmer	Tillage method	PR (MPa)	Max penetrometer depth (cm)
Farmer 1	NSCT	2.06	25.00
	CV	3.43	15.00
Farmer 2	NSCT	2.94	20.00
	CV	3.20	8.00
Farmer 3	NSCT	1.92	50.00
	CV	2.34	50.00
Farmer 4	NSCT	1.98	50.00
	CV	3.31	15.00
Farmer 5	NSCT	2.02	50.00
	CV	3.59	14.00
Farmer 6	NSCT	1.65	50.00
	CV	2.82	18.00
Farmer 7	NSCT	2.16	50.00
	CV	2.79	19.00
Farmer 8	NSCT	2.92	16.00
	CV	3.38	10.00
Farmer 9	NSCT	3.52	15.00
	CV	3.13	8.00
Farmer 10	NSCT	3.39	10.00
	CV	3.57	10.00
Farmer 11	NSCT	1.34	15.00
	CV	1.36	15.00
Farmer 12	NSCT	2.35	10.00
	CV	3.00	10.00
Farmer 13	NSCT	3.40	15.00
	CV	3.66	10.00

The results were further analysed by grouping the farmers into 2 groups, one, with fields with highest maximum penetration and the other group with lower penetration depth as shown in Tables 5.4 and 5.5 Table 5.4 shows that CV has significantly high mean penetration resistance ($p=0.002$) whilst the opposite is true for mean maximum penetration, NSCT has a higher mean. NSCT has lower PR than CV and also shows that CV contributed to increased PR. This shows that NSCT actually reduced compaction in the fields. All the farmers in this group are from Omuntele constituency.

Table 5.4 Mean Penetration resistance for five farmers' fields with unlimited penetrometer depth

Variable Tillage method	n	Mean Penetration Resistance (MPa)	Mean Maximum Penetration (cm)	s.e ($\bar{x}$)
CV	5	2.97	23.2	6.763

NSCT	5	1.95	50.0	0.000* (all values are the same)
Overall	10	P=0.002	P=0.04	5.488

Table 5.5 shows that within this group there are no significant difference in mean penetration resistance between CV and NSCT (p=0.365) however NSCT has a significantly higher mean maximum (p=0.026). Four out of the five farmers in this category were all from Ogongo constituency and all the fields had limited penetrometer depths. It is possible that the fields of the sample of farmers from Ogongo had hard pans. It could also be because the farmers used the animal-drawn ripper furrower that does not penetrate as deep as the tractor ripper furrower. It could also be because the soil conditions in Ogongo were different from Omuntele.

Table 5.5.Mean penetration resistance for eight farmers' fields only with lower max penetrometer depth

Variable Tillage method	N	Mean Penetration Resistance	Mean Maximum Penetration	s.e ($\bar{x}$)
CV	8	3.09	10.75	0.977
NSCT	8	2.74	15.75	1.750
Overall	16	p=0.365	p=0.026	1.163

5.3 Soil Moisture Content

5.3.1 Soil Moisture and Mulch

Table 5.6 shows a comparison of moisture content from planting to harvesting among tillage methods for 2011 and 2012. There was no significant interaction between tillage and mulch in both 2011 and 2012.

Table 5.6: Mean Soil Moisture Content for 2011 and 2012

Tillage Treatment	Mean Moisture Content 2011 (%)		Mean Moisture Content 2012 (%)	
	Mulch	**No Mulch**	**Mulch**	**No Mulch**
AMP	3.375	3.659	3.163	3.064
ARF	3.387	3.697	3.100	3.200
FALLOW	3.073	3.098	2.753	2.761
TDH	3.537	3.474	3.194	3.322
TRF	3.174	3.324	3.731	4.058

(No significant difference between mulch treatments)

Comparing mean soil moisture content for mulch and no mulch among the tillage methods reveals that there is no interaction (p=0.421) between tillage and mulch for both years. It could be that the amount of mulch was not sufficiently significant to change the levels of moisture conservation. This is in line with a study conducted in Zimbabwe (Mupangwa et al., 2011) on the effect of mulching and minimum tillage on maize yield and the water content of clayey and sandy soils. That study showed that maize yield was not significantly influenced by mulching or minimum tillage, individually or in combination. According to Mupangwa *et al.* (2011) soil water benefits increase linearly with increase in mulch cover but beyond $4tha^{-1}$ benefits derived from mulching begin to decline on both clayey and sandy soils.

Despite there being no significant difference in the results for soil moisture in the mulch and no mulch treatments, from 2011 to 2012, TRF had the highest percentage increase in moisture content with 8.1%, whilst TDH increased by 3.85% and ARF increased by 3.13%. AMP actually decreased by 3.13%, whereas the FALLOW (control) increased by 2.90%. Scopel *et al.* (2004) showed that mulches played an important role in the conservation of soil water through reduced soil evaporation in semi-arid conditions. Nyagumbo (2002) also reported increased soil moisture content by 5% in mulch ripping methods compared to conventional mouldboard ploughing. In the same study by Nyagumbo, No Till Tied Ridging also increased soil water storage by about 7% over conventional mouldboard ploughing. Fuentes *et al.* (2009) emphasized that the retention of crop residues resulted in higher moisture content regardless of tillage system. Erenstein (2002) also pointed out that mulching significantly reduced surface runoff.

There was significant ($p=0.001$) interaction between year and tillage, TRF had higher moisture levels in 2012 than in 2011. This could be because TRF harvested water and retained it longer, and then continued to harvest more water in 2012. In 2011, the moisture was higher for all the other tillage methods than it was in 2012. This could also be because there was less rainfall in 2012 than in 2011 as reported earlier in section 5.2.6.

5.3.2 Moisture 2011

Fig 5.7 shows the average soil moisture levels for 2011 between January 2011 and April 2011. There were significant ($p<0.003$) differences in moisture among tillage methods. Significant ($p<0.001$) interaction between time and tillage was observed, with soil moisture peaks in February, a decline in March and went up again in April. Among the treatments, the FALLOW (control) treatment had the lowest soil moisture most of the time. This suggests that tillage in general helps to improve soil moisture content.

No differences in moisture among TDH, AMP and ARF were observed. The three methods are significantly different from TRF and FALLOW (l.s.d = 0.2545). TRF produced lower soil moisture values than the other three. ARF produced the highest value at 3.54%, while AMP produced 3.52 %, TDH 3.51 %, TRF 3.25 % and FALLOW 3.09 %.

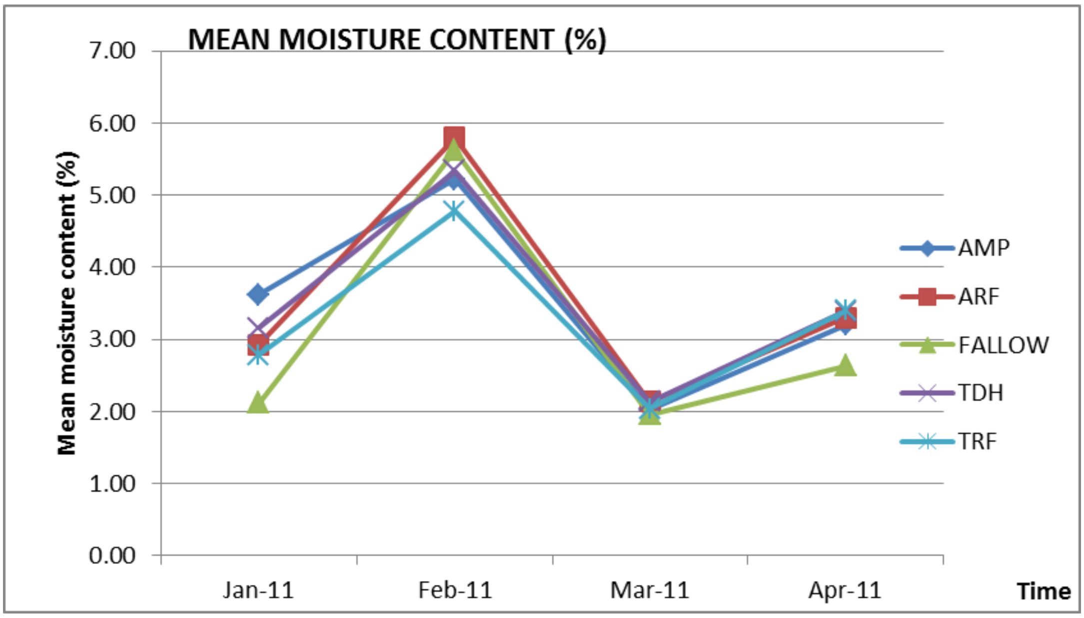

Fig 5.7: Changes in Soil Moisture over Time during 2011

In the course of the 2011 growing season, ARF resulted in a 13.84% increase whilst AMP resulted in a 13.35% increase in soil moisture compared to FALLOW. TDH increased by 13.11% whilst TRF increased by 6.44%. Overall, in 2011 ARF (NSCT) resulted only in 1% more soil moisture than AMP (CV) whilst TDH (CV) resulted in 7% more moisture than TRF (NSCT). The tractor group therefore improved soil moisture better than the animal group independent of tillage technology.

5.3.3 Moisture 2012

Fig 5.8 shows the changes in soil moisture levels between January 2012 and April 2012. There were significant ($p<0.003$) differences in moisture among tillage methods. Significant (p<0.001) interaction between time and tillage was observed, with soil moisture peaks in February and a decline in March and April. Soils under TRF showed the highest moisture levels. This suggests that TRF could have harvested more water, as intended. Mean soil moisture contents under the different treatments were: TRF 3.89%, TDH 3.26%, ARF 3.15%, AMP 3.11% and FALLOW 2.76%.

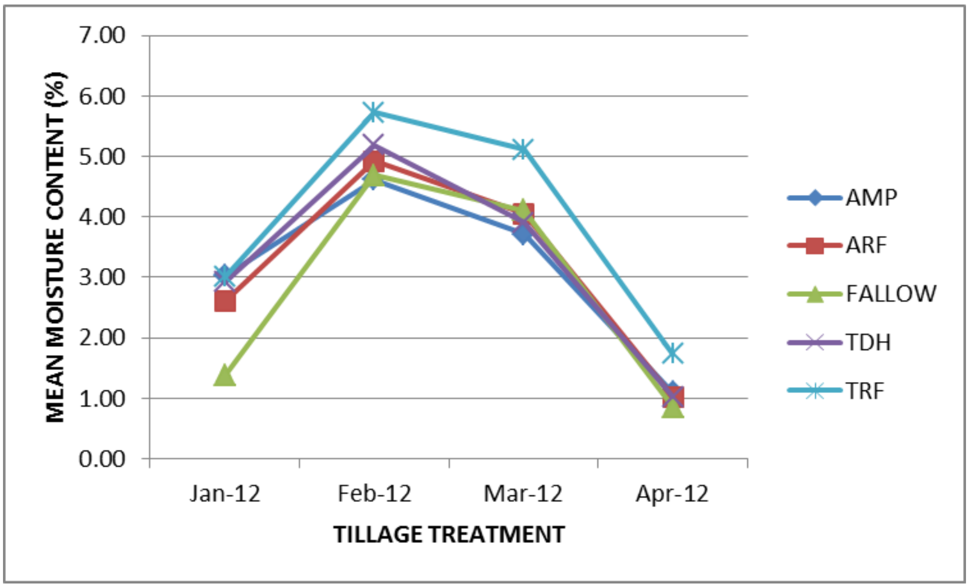

Fig 5.8: Changes in Soil Moisture over Time during 2012

From 2011 to 2012, soils under TRF showed the highest increase in moisture, by 29.1%, whilst TDH showed a 15.3% increase compared to FALLOW. AMP resulted in an 11.3% increase whilst ARF increased by 12.4% compared to FALLOW. Only one NSCT method (TRF) resulted in higher levels of soil moisture than both CV methods. However, within the tractor group, TRF (NSCT) resulted in 16% better soil moisture levels than TDH (CV), and in the animal group ARF (NSCT) resulted in 1% higher soil moisture levels than under AMP (CV). Overall, the tractor group showed a higher increase in soil moisture content than the animal group. This would suggest that, in order to achieve high moisture content in the field, farmers should choose tractor-drawn NSCT implements over animal-drawn NSCT implements. This reinforces the view that it might be advisable to use the tractor-drawn ripper-furrower in the first year and then the animal-drawn ripper-furrower as suggested in Chapter 4.

5.3.4 Overall Mean Moisture Content for 2011 and 2012.

The overall soil moisture levels for the two years is laid out in Table 5.7, TRF (NSCT) had 5.4% higher moisture content than TDH (CV). And ARF (NSCT) had 4.5% higher moisture content than AMP (CV).

Table 5.7: Overall Soil Moisture Contents for 2011 and 2012

	2011		2012	
	Overall Moisture Content (mulch %)	Overall Moisture Content (No mulch %)	Overall Moisture Content (mulch %)	Overall Moisture Content (No mulch %)
AMP	13.50	14.64	12.65	12.26
ARF	13.55	14.75	12.40	12.80
FALLOW	12.29	12.28	11.01	11.05
TDH	14.15	13.90	12.78	13.29
TRF	12.70	13.30	14.92	16.23

A comparison of total moisture across tillage methods from 2011 to 2012 showed the use of the tractor-drawn ripper-furrower resulted in the highest total moisture with the least being found in the FALLOW (control) plot. The tractor-drawn ripper-furrower must have harvested more water as intended than the other methods. This suggests that the tractor-drawn ripper-furrower would be the most favourable tillage method when it comes to harvesting water.

There were significant ($p<0.001$) differences in soil moisture among the tillage methods. . The soil moisture in the FALLOW (control) plot remained lower than for all the tillage methods. This confirms that tillage, in general, helps to improve soil moisture content. February showed high soil moisture levels in both 2011 and 2012. Rainfall values for Ogongo Campus also showed higher precipitation levels in February than in the other months. Since February registered high soil moisture content in both seasons, it would be important for farmers to plant crops before February so that the crops can benefit from the increased moisture in that month.

Overall, NSCT methods resulted in higher soil moisture levels than did the CV methods, i.e. TRF vs TDH and ARF vs AMP. Soils under TRF showed the highest percentage increase in moisture content from 2011 to 2012, with 8.1%, whilst TDH increased by 3.85 %, ARF increased by 3.13%, and AMP actually decreased by 3.13% over the two-year period. This is in agreement with the findings of Cavalaris and Gemtos (2002); Altuntas and Dede (2009); Małecka, Blecharczyk, Sawinska and Dobrzeniecki (2012) who also found that conservation tillage systems resulted in higher soil water content than conventional tillage systems.

Soils under TRF had the highest moisture. This could be because more water was harvested and retained in the TRF technology in 2011which still continued in 2012. The soil moisture was higher in 2011 than in 2012 under all the other tillage methods. As for total moisture for 2011 and 2012, TRF had greater moisture content and it is reasoned that could have harvested water as intended, managing to keep the moisture in the furrow whereas the other methods did not. The TRF implement during field performance tests, as reported in Chapter 4 section 4.1, achieved greater depths and achieved good furrows that could harvest water. This study therefore suggests that using the right tool, like the tractor-drawn ripper–furrower, can contribute to increased soil moisture content.

5.4 Pearl Millet Root Length

Table 5.8 shows mean pearl millet root length in centimetres. There were no significant (p=0.120) differences in mean root length among the tillage methods in the 2011 season, but they were significantly (p<0.005) different in 2012. Overall, the NSCT methods resulted in longer roots for pearl millet that the CV methods i.e. roots under TRF were longer than under TDH, and were longer under ARF than under AMP. There were no significant differences in mean root length under the different mulch levels

Table 5.8: Pearl Millet Mean Root Lengths

Tillage treatment	2011 Mean Root Length (cm)		2012 Mean Root Length (cm)	
	Mulch	No Mulch	Mulch	No Mulch
AMP	22.5	22.9	23.8	23.5
ARF	24.7	22.9	26.0	22.5
TDH	23.5	24.5	25.3	24.3
TRF	30.1	29.1	33.5	31.0

No significant (p=0,120) difference between treatments in 2011 but significantly different (p<0.05) in 2012.

There were significant differences in mean root length among the tillage methods in 2012. This could be because there was more moisture and also as highlighted by Nyamangara, Bergstrorn, Piha & Giller (2003) fertilizer could have become more available in the second year, making it possible for the crop to utilize it. Longer roots under TRF are also in line with Borghei et al. (2008) who concluded that sub-soiling not only increased the yield of cotton but also improved penetration resistance to ensure root aeration and propagation. TRF achieved greater depths, so the roots also had more room to grow.

Several studies concluded that a high penetration resistance in CV systems resulted in a lower root growth (Atwell, 1993; Petersen, Ayers & Westfall, 2004; Wells, Stombaugh & Sheraer, 2005; Raper, 2006). Despite this assertion by other researchers, in this study, whilst NSCT methods (TRF and ARF) achieved less PR compared to CV methods (AMP and TDH), this study showed no significant differences among the tillage methods. In other words, the PR values that were found in this study did not necessarily hinder root penetration. This could also be attributed to soil type and the use of manure in all the plots. Manure or organic matter has been shown by other researchers to help ameliorate soil compaction. For instance, Mosaddeghi *et al.* (2009) showed that incorporating 50 and 100 t ha^{-1} of cattle manure significantly counteracted the effects of load. This study used manure in all the plots, and this could have significantly reduced soil compaction in all the treatments.

In 2012, NSCT methods – TRF and ARF with mulch achieved longer roots than the CV methods TDH and AMP by (24.48%) and (8.46%) respectively. The assertions by a number of researchers (Atwell, 1993; Aase, Bjorneberg & Sojka, 2001; Reichert *et al.,* 2004; Kees, 2005; So *et al*., 2009), that penetration values greater than 2 MPa produce a significant reduction in root growth, do hold true for this study. The results of this study are more in line with the findings of Hermawan and Cameron (1993) and those of Lampurlanes and Cantero-Martinez (2003), who reported flexible PR values between 2 MPa, and 5 MPa as the critical upper limits above which root growth is severely impeded. All PR values for NSCT methods in the on-station trials were less than 2 MPa, and in some of the farmers' fields less than 4 MPa. For the sandy soils of Ogongo and in the two constituencies, the critical values of PR should be as specified by Lampurlanes and Cantero-Martinez (2003) who chose flexible PR values between 2 MPa and 5 MPa.

There were also no significant differences in mean root lengths between mulched and un-mulched plots. This is most likely attributable to there being no differences in water harvesting found among the methods where mulch was concerned. In both 2011 and 2012

TRF achieved the highest mean root lengths. TRF also achieved the highest mean depth on implement performance, as established in Chapter 4. This suggests that the tractor-drawn ripper-furrower can be used to break the plough pan better than the other three methods. In other words, one method of NSCT was found to be more capable of effectively breaking the plough pan compared to the other three methods which included two CV methods.

5.5 Pearl Millet Yields

Table 5.9 shows pearl millet yields in kg ha^{-1}. There were no significant differences (p = 0.410 in 2011 and 0.078 in 2012) in mean yield among the tillage methods. In addition, no significant differences (p = 0.758 and 0.348 in 2012) in mean yield for the mulch treatments were observed.

Table 5.9: Pearl Millet Yield in kg ha^{-1}

Tillage Treatment	2011 Mean Pearl Millet Yield (kg ha^{-1})		2012 Mean Pearl Millet Yield (kg ha^{-1})	
	Mulch	No Mulch	Mulch	No Mulch
AMP	1415	1505	4434	4241
ARF	1547	1516	4981	4759
TDH	1544	1608	4587	4823
TRF	1702	1652	5362	5344

(No significant difference between treatments)

Despite the results for pearl millet yields showing no significant differences between the treatments, these yields were high under all methods irrespective of mulch. In 2012, both NSCT methods – TRF (10.05%) and ARF (10.97%) – achieved higher yields than the CV methods TDH and AMP.

The findings of this study are consistent with those of other researchers who have shown that tillage method had no effect on yield (Dam *et al.*, 2005; Kaumbutho & Kienzle, 2007; Rusinamhodzi et al., 2011; Małecka *et al.*, 2012). All reported that there are no significant differences in yields between CT and CV technologies. The findings of this study are also in line with those of Rusinamhodzi *et al.* (2013) who conducted a meta-analysis using worldwide rain-fed maize grain yield data from long-term studies on tillage and residue management from semi-arid to sub-humid environments. They found no change over time in the weighted mean differences in maize grain yield and concluded that No Till technology had no positive effect on maize yield compared with conventional tillage. Rusinamhodzi *et al*. (2013) also showed that, in the first 10 years, crop yields under No Till were lower than under conventional tillage practices.

Mazvimavi (2011) however, showed contradictory results and demonstrated that conservation agriculture in southern Africa had resulted in significant yield gains in maize, where 42% to 105% increases were reported for conservation tillage systems compared to conventional tillage in Zambia and Zimbabwe. This could be attributable to there being no standardization in CT research worldwide, as earlier stated by Derpsch *et al.* (2014) who maintained there was a need to standardize No-Till research as many researchers and practitioners all over the world were using different terminologies and methodologies, and this made it very difficult to compare results worldwide.

In this study, whilst there were no significant differences in mean yield among the tillage technologies in both years, results from the study show a vast improvement in the yields under all four tillage methods, particularly in the second year. This suggests that other factors contributed to the increase in yield, such as early planting, mulch, manure and fertiliser, as well as maintaining a clean field with no weeds. Rusinamhodzi (2013) concluded from his studies that crop productivity under conservation agriculture depends on the ability of farmers to achieve correct fertilizer application, timely weeding, the availability of crop residues for mulching, and systematic crop rotations – almost all of which are currently lacking in southern Africa. Dam *et al.* (2005) also reported that, in 11 years, maize yields were not affected by tillage and residue practices, but that climate-related difference seemed to have a greater influence on the variation in yields.

Other researchers have shown that CT gives better yields than CV. For instance, De Vita *et al.* (2007) showed that No Till achieved greater yields than conventional tillage. Dillalessa (2006) showed that minimum tillage with residue retention significantly increased grain yield by 6.6% and 12.2%, compared to minimum tillage with residue removal and conventional tillage, respectively. The high increase in yields in the second year in this study is also in line with results from Zimbabwe where it was shown that nitrogen from manure become more available to crops in the second season after application (Nyamangara *et al.*, 2003).

One other reason for the high yields recorded in this study could be the plant population of 80 000 plants/ha that the NSCT used, compared to 40 000 plants/ha that the extension services normally recommend to farmers. This means that, when farmers thin out their pearl millet seedlings, they now leave two plants per station instead of one. But this will only work if there is enough manure and fertilizer, timely weeding, the availability of crop residues for mulching, and systematic crop rotations – all of which are currently lacking in Namibia. An increase in yield could also be attributed to controlled/constant traffic and placing manure and fertiliser at more or less the same place in the furrows, and also harvesting water in the same furrow as provided by NSCT methods.

Table 5.10 compares the on-station yields with those of CONTILL and farmer Keshongo from the Omuntele Constituency. Apart from pearl millet yields, the Lima Nawa project also reported high yields for maize, which is normally not much produced in the Omusati Region (Table 5.10). The Lima Nawa (CONTILL) project used the NSCT technology. Farmer Keshongo also used the same technology.

Table 5.10: Comparison of TRF On-station Pearl Millet Yields with those of CONTILL and Farmer Keshongo

	Yield in kg ha^{-1}
Highest On-station Yields (2012)	5 362
Lowest On-station Yields (2012)	1 652
Lima Nawa Omusati yields – highest (2010-11)	3 063
Lima Nawa Omusati yields – lowest (2010-11)	1 213
Farmer Keshongo Oshikoto region (2013)	4 660

It is every farmer's dream to have high yields, and Mr Keshongo achieved his dream by achieving yields of 4 660 kg ha^{-1}. Mr Keshongo, however, grew traditional varieties of pearl millet making it difficult to compare his yields objectively with those of the on-station trials. Nonetheless, the yields from his fields still show that conservation tillage methods could have contributed to what he achieved in his fields. Uno (2005) reported that in good seasons, the yield of the indigenous farmers' local varieties are just as good as or even better than the 3 improved varieties although they take longer to mature, up to 120 days compared to the shorter-maturing new varieties.

The yields of pearl millet (*Pennisetum glaucum*) of Namibian smallholder farmers have been reported to be extremely low, at around 400 kg ha^{-1} (Mallet & Rigoud, 2004; Vigne and Associates, 2004; Davis & Lenhardt, 2009; MSTT, 2009; von Hase, 2013). The increase in yields as observed in this study has great implications for the improvement of pearl millet yields of 230 000 farmers in the NCAs through the use of NSCT technologies. Technologies such as the use of the ripper-furrower to harvest water, the application of manure and fertilizer, timely weeding, the availability of crop residues for mulching, and systematic crop rotations could greatly increase yields.

5.6 Conclusion

This study showed significant ($p<0.001$) differences in PR among the tillage methods in the two years and a significant positive linear relationship between penetration resistance (PR) and depth in 2012 at planting and at harvesting for various depths for the four tillage methods ($p<0.001$). Overall all NSCT methods (TRF and ARF) resulted in lower PR than the CV methods (TDH and AMP) showing that the NSCT methods contributed to better reduction in soil compaction. In the farmers' fields, NSCT methods also had lower PR than CV methods and 31% (n=13) had PR values that are less than 2 MPa showing that the fields for the rest of the farmers (69%) could have problems of soil compaction. For moisture results, there were significant ($p<0.003$) differences in moisture among tillage methods and also interaction between time and tillage ($p<0.001$). TRF had the highest percentage increase in moisture content followed by TDH, then ARF and lastly AMP over the two year period.

The study also showed that, whilst yield and root length could not be significantly influenced by tillage method or mulch, high yields and long roots could still be achieved under all four tillage methods. Root length was however significantly different among the tillage methods in the second year. In addition, yields and root lengths increased greatly in the second year.

In agreement with the present findings, it has been shown by various researchers that there are some conservation tillage methods that can reduce soil compaction, increase soil moisture, increase root lengths and overall increase in yields.

6. COMPARISON OF THE FIELD PERFORMANCE OF THE NSCT RIPPING TECHNIQUES OF THE ANIMAL-DRAWN RIPPER-FURROWER

6.1 Introduction

This chapter presents the results of the experiments carried out to study the field performance of the ripping techniques of the animal –drawn ripper furrower. The following parameters were measured: depth of cut, width of cut, draught force, specific draught, efficiency, effective field capacity, penetration resistance and moisture content. The following treatments tested were: DRIP2 – Double ripping with 2 donkeys, DRIP3 – Double ripping with 3 donkeys, SRIP2 – Single ripping with 2 donkeys, SRIP3 -Single ripping with 3 donkeys and FALLOW as a control.

6.2 Results and Discussion: ARF Performance Characteristics

The study found out that there are no significant differences among draught force, draught power, and time per run, efficiency, EFC and Specific draught. There is however significant differences in mean depth, width, speed and turn time among the techniques. Table 6.1 summarises the performance characteristics for the four treatments for variables that showed some significant differences between treatments. Table 6.2 summarises the performance characteristics for the four treatments for variables that showed no significant differences among treatments. Further analysis showed that some of the variables showed significant differences among some ripping techniques whilst some of the measured variables failed to reach levels of significance.

Table 6.1: ARF Performance Variables showing significant differences among treatments

Implement	Depth (cm)	Width (m)	Speed (km hr^{-1}.	Turn time (s)
DRIP3	19.30 a	0.14 a	1.95 ab	11.93 a
DRIP2	18.98 ab	0.13 ab	2.00 ab	06.90 b
SRIP2	15.43 bc	0.12 b	2.40 a	11.00 a
SRIP3	14.84 c	0.12 b	1.75 b	10.62 a
P.level	0.093	0.084	0.193	0.075
SED	1.709	0.00729	0.2764	1.739
LSD	3.865	0.01648	0.6252	3.934

*Values with different letters are significantly different at $p < 0.05$.

Table 6.2: ARF Performance Variables showing no significant differences among treatments

Implement	Draught force (kN)	Draught Power (kW)	Time per run (s)	Efficiency (%)	Effective Field Capacity (ha hr^{-1}.)	Specific draught kN m^{-2}
DRIP3	0.21	0.12	18.73	61.50	0.0021	08.8
DRIP2	0.32	0.19	18.47	72.25	0.0029	13.2
SRIP2	0.17	0.13	15.67	58.25	0.0034	09.9
SRIP3	0.11	0.06	21.05	66.50	0.0023	06.6
P.level	0.534	0.381	0.265	0.108	0.175	0.534
SED	0.1098	0.0703	2.49	5.25	0.000587	4.37
LSD	0.2484	0.1589	5.632	11.88	0.001329	9.88

Whilst some of the variables showed significant differences among some ripping techniques (Table 6.1) and some variables as reflected in Table 6.2 failed to reach levels of significance, the following sections highlight what was observed.

6.2.1 Depth of Cut

There were no significant differences between double ripping for both two and three donkeys. There were also no significant differences between double ripping with two donkeys and single ripping with two donkeys. There were however significant differences between double ripping with three donkeys and single ripping with three donkeys. This shows that double ripping with three donkeys can achieve increased depth. Double ripping with two donkeys achieved greater depths than single ripping with two donkeys. Double ripping with three donkeys gave the maximum mean depth, while the least depth was observed for single ripping with three donkeys. Goe (1983) suggested that the more animals that work in a team, the less work is achieved per unit animal. Other researchers (ILCA, 1986; Panin and Ellis-Jones, 1992) have also shown that the inclusion of more animals in a team (span) is associated with a loss of efficiency due to co-ordination problems. ILCA (1986) likewise reported that team efficiency is a function of team size, and declines by 7.5% for each extra animal used in a team. This suggest that double ripping with two donkeys would be the better choice than double ripping with three donkeys.

6.2.2 Width of cut

There were no statistically significant (p=0.084) differences between mean width among the ripping techniques. There was however significant differences between double ripping with three donkeys and single ripping with both two and three donkeys. This shows that ripping for the second time can actually achieve increased width of cut. Double ripping achieved wider furrows than single ripping. As can be observed in Table 6.1, above, the widest furrow was achieved by double ripping with three donkeys. The difference in width between double ripping with two and three donkeys can be explained by the difficulty in keeping three donkeys abreast moving in a straight line, as they were hitched abreast for pulling the implement. When there were two, it was easier to keep them towing the ripper in a straight line. Pulling the ripper with three donkeys thus resulted in slightly wider furrows.

6.2.3 Time per run and Turning time

There were no significant differences in time per run ($p= 0.265$) between the tillage treatments. Time per run is important in establishing the speed of the animals, whilst turning time is important in order to establish how much time the animals take in doing unproductive work. Together they can be used to calculate effective cultivation time.The turning time for double ripping with two donkeys was however significantly different from the other three treatments showing that increasing another rip line can contribute to reduce turning time thereby improving on the time the animals take doing actual work. On a large area the difference can be of economic value to the farmer. Time saved could be converted into other meaningful activities on the farm and rest for draught animals.

6.2.4 Speed

There were significant differences in mean speed between single ripping with two donkeys and single ripping with three donkeys. Higher speeds were found on single ripping with two donkeys. Pulling the ripper-furrower with two donkeys achieved a higher speed than with three donkeys. This could be as a result of donkeys pulling in different directions when hitched abreast, the more so when there were three. DRIP2 achieved a speed of 2 km hr^{-1} compared to DRIP3 with a speed of 1.95 km hr^{-1}, whilst SRIP2 achieved a speed of 2.4 km hr^{-1} and SRIP3 achieved a speed of 1.75 km hr^{-1}. Again this is in line with Goe (1983), ILCA, 1986; Panin and Ellis-Jones, 1992 who suggested that the more the number of animals that work in a team; the less the work that is achieved per unit animal.

6.2.5. Draught Force

Although there were no significant (p=0.338) differences in draught force between the various ripping techniques, the highest draught forces were experienced with double ripping with two donkeys (Table 6.2). Table 6.2 also shows that double ripping used more draught than single ripping irrespective of the number of donkeys. This suggests that adding an extra donkey can reduce draught.

6.2.6 Specific Draught

There were no significant (p=0.534) differences in mean specific draught between the tillage treatments. Highest mean specific draught was experienced on double ripping with two donkeys while the least depth was observed on single ripping with three donkeys. This suggests that, as the ripper goes deeper, more force is required to pull the implement. This is in line with the results reported in Chapters 4 and 5. In other words, more resistance to pull is offered by the wings of the ripper furrower as they work deeper in the soils.

6.2.7 Draught Power

Although there were no significant (p=0.381) differences between mean draught power among the tillage treatments, the highest mean draught power was achieved with double ripping with two donkeys. Use of two donkeys generally resulted in more draught power than the use of three donkeys.

6.2.8 Efficiency

There were no significant differences ($p=0.108$) in mean efficiency between the ripping techniques. The best efficiency was observed on double ripping with two donkeys and the least was experienced on single ripping with two donkeys, with a marked difference of approximately 14% between the best and the least efficiencies. Over a large area, such a difference can be of economic value to the farmer, as time saved could be converted into other meaningful activities on the farm, rest for the animals and the farmer.

6.2.9 Effective Field Capacity

There were no significant differences ($p=0.175$) in effective field capacities among the different ripping techniques. The highest work rates were found on single ripping with two donkeys. Generally, the use of two donkeys achieved greater effective field capacity than using three donkeys. This suggests that there is no justification for farmers to continue to use three donkeys, as they are doing currently if the objective is to reduce the amount of time that the animals effectively work in the field.

6.3 Penetration

Fig 6.1 shows a comparison of mean penetration resistance among the different ripping techniques. There were significant differences ($p<0.001$) in mean penetration resistance (PR) between the ripping techniques.

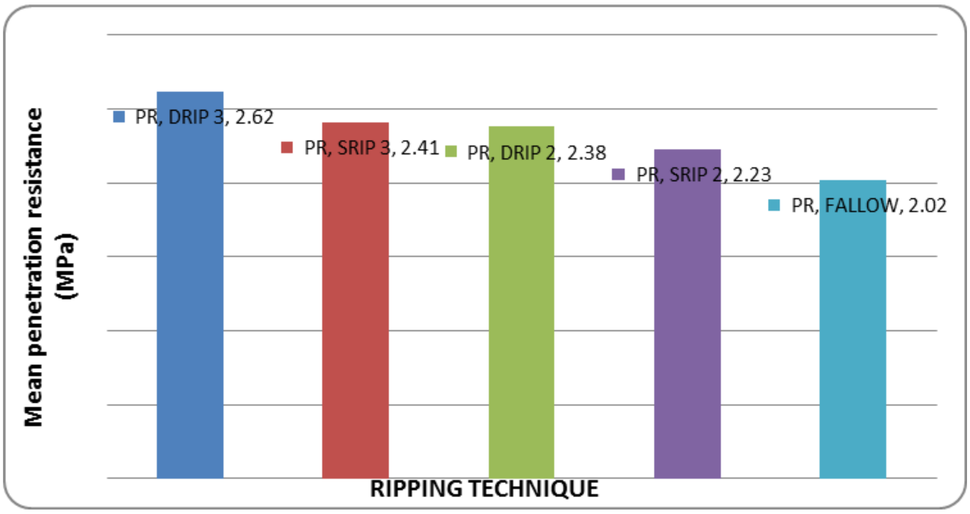

Fig 6.1: Comparison of mean penetration resistance among the different ripping techniques

As can be seen from Fig. 6.1, the highest compaction or penetration resistance of 2.615 MPa was found where there was double ripping with three donkeys. Compared to the untilled FALLOW plot, double ripping with two donkeys increased compaction by 15.13%, double ripping with three donkeys increased it by 22.9%, and single ripping with two donkeys increased it by 9.42%, whilst single ripping with three donkeys increased compaction by 16.18%. The increase in depth could be because a hard part was formed where the rippers ended whereas on the FALLOW plot the penetrometer could still penetrate better than on the tilled plots. Double ripping in general showed the highest increased compaction but also achieved the greatest depth. This will only be an advantage if the plough pan is ripped off, otherwise this can lead to more compaction with negative effects on crop growth. Penetration values greater than 2 MPa are generally reported to produce a significant root growth reduction (Atwell, 1993), as at pressures in excess of 2 MPa, root growth has been shown to be restricted to varying degrees (Aase *et al.*, 2001). Results in chapter 5 however showed that for the sandy soils of Ogongo, the critical values of PR should be as specified by Lampurlanes and Cantero-Martinez (2003) who chose flexible PR values between 2 MPa and 5 MPa. Results in chapter five also showed that PR increased with depth. If the crop that is grown is pearl millet, then there is no justification in going to greater depths as the roots do not go that deep. It therefore means that unless the objective is to break the plough pan, farmers can safely use single ripping.

6.4 Moisture content

There were no significant (p=0.516) differences in moisture content among the ripping techniques. This shows that double ripping did not improve the moisture content. The mean moisture content for all treatments was 5.0%.

6.5 Conclusions and Recommendations

Results showed that there were significant differences between double ripping with three donkeys and single ripping with three donkeys. This shows that double ripping with three donkeys can achieve increased depth of cut. There were also significant differences in mean width of cut between double ripping with three donkeys and single ripping with both two and three donkeys. This shows that ripping for the second time can actually achieve increased width of cut. Double ripping with two donkeys was however significantly different from the other three treatments showing that increasing another rip line can contribute to reduced turning time thereby improving on the time the animals take doing actual work. There were however no significant differences in mean draught force (p =0.338), mean draught power (p =0.381), mean time per run (p= 0.265), mean efficiency (p =0.108) and mean effective field capacity (p =0.175). There were also significant (p <0.001) differences in penetration resistance (PR) between the tillage methods.

Whilst greater depths were achieved with double ripping with three donkeys, this is not comparable with the tractor-ripping performance in which, according to Mudamburi, Ogunmokun, Kachigunda and Kaurivi (2012) depths of 29.4 cm were achieved. Chapter 4 also reported tractor ripping depths of 31.5cm for 2012. This could therefore mean that, where possible and needed, farmers should use tractors to achieve maximum depths and widths, and thereafter use an animal-drawn ripper-furrower in subsequent years. The study also showed that two or three donkeys can be used for heavy work i.e. double ripping.

Single ripping with two donkeys had the least PR at 2.4 MPa. The FALLOW however had 2.02 MPa. Again it may well be best to use a tractor-drawn ripper furrower to break the plough pan and thereafter use an animal-drawn ripper. Further research needs to be done on this problem.

Chapter 4 also reported that a tractor-drawn ripper-furrower could achieve greater depth than one drawn by donkeys. More work needs to be done in trying various options that can combine tractors ripping and furrowing with animals ripping and furrowing in order to achieve maximum depths and widths with ARF. The use of cattle in the place of donkeys could be as an option to complement tractors, and this is also an option to be explored.

7. ADOPTION OF NSCT TECHNOLOGIES BY FARMERS: OMUNTELE AND OGONGO CONSTITUENCIES OF NAMIBIA

7.1 **Introduction**

This chapter describes the findings on the adoption of NSCT technology as obtained from interviews with a sample of thirteen farmers in the Ogongo and Omuntele Constituencies, supplemented by information obtained by other means. This part of the study was conducted in 2012 and 2013. It explored the farmers' general information and perspectives on agricultural practices and land preparation. The goal was to complement the on-station study with a study to assess the relative importance of CT to farmers after their conversion to the NSCT technology.

Farmers from the two constituencies were introduced to the concept of CT by MAWF, CONTILL, CES and NCAP, so questions for this study were structured to tie in with the NSCT which had been introduced. Of particular importance are the current practices that farmers employ in using the ripper-furrower technology, their knowledge, attitudes, priorities and constraints. The concept of KAP (knowledge, attitudes and practice) has a bearing on whether farmers adopt a technology or not. The farmers' fields were also observed to see any differences between CV and NSCT prepared fields, and penetration resistance of the soils on the farmers' fields were measured. The results of the PR from the farmers' fields and their analysis are given in chapter 5.

Various CT technologies are used by various farmers in all the crop-growing regions of Namibia. The 'basin method' was promoted by CLUSA in the Zambezi Region, while ripping and the NSCT system are promoted in the North Central Regions and Kavango East and West Regions by the CONTILL project, MAWF, CES and CLUSA. Use of tine implements, minimum disturbance of soil, crop rotation, mulching, fertilizing, manuring and early planting are being practised at different levels by various farmers in the NCA (Kaurivi *et al.,* 2010).

The University of Namibia (UNAM), together with Ministry of Agriculture Water and Forestry (MAWF) and the Polytechnic of Namibia, promoted CA through the Food and Agriculture Organization (FAO) of the United Nations, which funded the project. The main objectives were to document all CA activities in Namibia, to train farmers and staff in CA, establish demonstration plots in the crop-growing regions of Namibia, and to establish and strengthen a working team to manage CA at the national level (Kaurivi *et al*., 2010). The projects highlighted in the study all tended to concentrate particularly on agronomic issues, especially yield increase. It must be emphasized that all the activities described as CA in the study did not exclude CV.

7.2 CONTILL Farmers from Ogongo and Omuntele Constituencies of Omusati amd Oshikoto Regions of Namibia

7.2.1 Ogongo Constituency of Omusati Region

The Ogongo Constituency is an electoral constituency of the Omusati Region in the NCA which is one of the fourteen regions of Namibia. In 2011, it had 18,498 inhabitants, and its district capital is the settlement of Ogongo (NSA, 2011). The constituency also contains six other settlements. Omusati is predominantly an agricultural region in which pearl millet (*mahangu*) is cultivated successfully. With intensive fertilisation and tilling of the soil, selfsufficiency should in theory be attainable. The University of Namibia thus has one of its agricultural campuses in the Ogongo constituency.

The Omusati Region has an average rainfall that decreases from 600 mm year^{-1} in the north east to 300 mm year^{-1} in the west. A canal carries water from the Ruacana River to Oshakati and passes through the Ogongo Constituency. A water purification plant also exists at Ogongo to purify for human consumption the water supplied by the canal.

There is a very good road network in the Omusati Region. The C46 (Ruacana – Oshakati) road provides links to other regions and the rest of Namibia. This road also passes through the Ogongo Constituency and makes it easy for farmers to market their agricultural products if they so wish.

7.2.2 Omuntele Constituency of Oshikoto Region

Omuntele Constituency is an electoral constituency in the Oshikoto Region of the NCA. The population of Omuntele was 16 865 in 2011 according to NSA (2011). The 2011 Population and Housing Census show that in Oshikoto Region, agriculture, forestry and fishing are the dominant economic sectors.

The constituency is situated in the northwest part of Oshikoto, about 60 km southeast of Ondangwa. Oshiwambo-speaking people are predominant, but there are a small number of San people. People in the area survive by cultivating crops and, as in the Omusati region, pearl millet (*mahangu*) is the main crop grown.

Average rainfall in the Oshikoto Region increases from 350 mm year^{-1} in the southwest to 550 mm year^{-1} in the northeast. Most of the rain usually falls between November and April, with a peak in February (IECN, 2011).

Prominent in both constituencies is the vegetation, which is mainly mopane (*Colophospermum mopane*) and *Acacia* spp, and most of the land is barely covered, making the land vulnerable to flood run-off during the rainy season. Both constituencies have schools, open markets, churches and clinics.

7.2.3 Farmer Characteristics and Socio-Economic Issues

A total of thirteen farmers were interviewed from both the Ogongo and Omuntele constituencies (Appendix 3 & 3.1). From Omuntele, a total of nine farmers who used the NSCT method were interviewed. Eight of them were female and one was male. In Ogongo all four interviewees were female, housewives and owned land. Thus, from the two constituencies, twelve of the thirteen farmers (92%) that were interviewed were female.

The land ownership among the four interviewed women from Ogongo ranged from 6 to 30 ha. In Omuntele, land holdings for the interviewees ranged from 3.5 to 6 ha, whilst land under NSCT ranged from 1 ha to 5 ha. (Appendix 3.1 & 3.2)

Fig 7.1 shows NSCT and CV land sizes in hectares for the sample of Omuntele and Ogongo Constituency farmers. The main reason why most of the farmers had less land under NSCT was because they could not access the ripping services for all their fields.

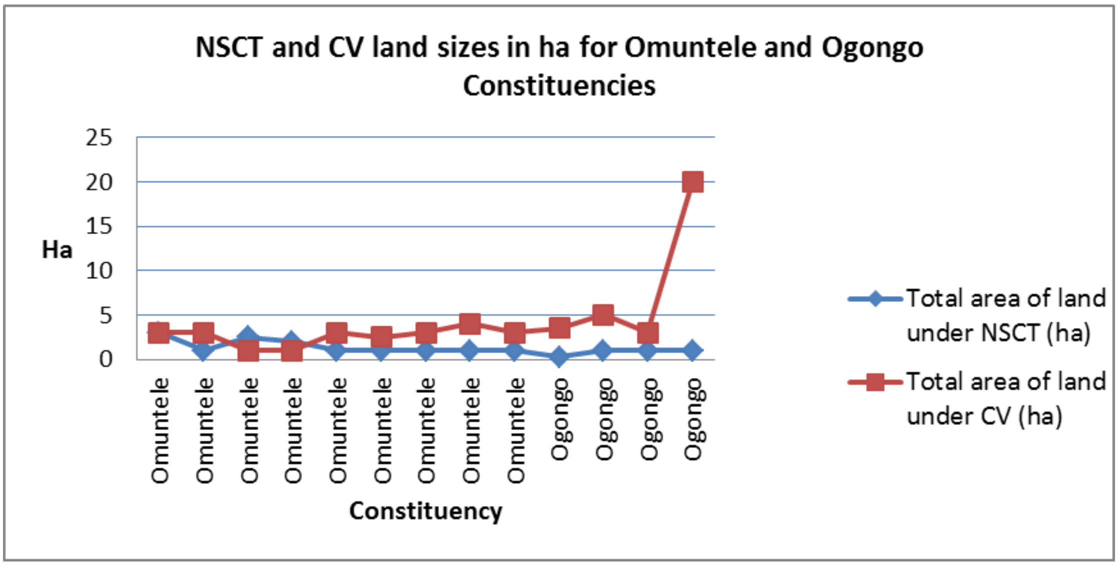

Fig 7.1: NSCT and CV land sizes in ha for interviewees in Omuntele and Ogongo Constituencies

Twelve out of the sample of thirteen farmers (92%) had either 1 ha or less under NSCT and remained with CV on the rest of their fields. This suggests that they were not quick to go all out with NSCT. However, they mentioned that this was mainly because of the unavailability of land preparations services, particularly those favoured by farmers and provided by MAWF, as farmers benefit from the 50% subsidy.

7.2.4 Crops Grown

Farmers in Omuntele and Ogongo grew bambara nuts, groundnuts, beans, pearl millet, sorghum, maize, peanuts, pumpkins, sunflower and water melon. Ogongo farmers also grew cowpeas. The major crops that all thirteen farmers grew were pearl millet, beans and sorghum. The specific crops that each of the farmers were growing in both constituencies are listed in Appendix 3.3. One of the farmers said that the Wambos (the local ethnic group) only grow maize, beans, sorghum and pearl millet for consumption, not for sale. He went on to say that this was because it was their culture: their elders did it and therefore they just follow what their elders used to do.

7.2.5 Livelihood Strategies

The main livelihood strategies for the four women in Ogongo were selling products obtained from the field and other goods such as clothes. All the Ogongo farmers interviewed said that they produce only for their own consumption and market only if there were surpluses. One of the Ogongo farmers sold some surplus in the year before the interview (2011) because she got high yields. Another farmer, however, said that she normally sells fresh bambara nuts and cowpeas whereas another said she sells sorghum and pearl millet. Their selling mainly depended on whether they had high yields and surpluses. The other one was not so sure. Those who sold would normally sell soon after harvest.

Although all the four farmers from Ogongo said that they produced enough food for their household consumption, they also mentioned that they always supplemented their food by buying maize meal from the shops. Three of them mentioned that they also received food through the drought relief programmes. This indicated that they did not in fact obtain enough from what they harvested.

In Omuntele, the main livelihood was farming. Crop products are used as a source of food, but there is some income from livestock production. Four (44.4%) farmers from Omuntele said they did not sell their products at all, while four (44.4%) said they sell any surplus after meeting home consumption needs. The crops that most of the farmers normally sell are bambara groundnuts, peanuts and sometimes maize. One said that she only sold bambara nuts. Others said they normally sold 50% of the produce after harvest. When asked whether they produced enough food for household consumption, only one out of the nine farmers felt food insecure, while the other eight maintained they produced enough food. The farmer who did not produce enough said the family depended on their mother's pension for the remainder of the year and also bought maize after selling domestic animals. Eight of the nine farmers said they had enough for household consumption because of the NSCT. The main livelihood in both constituencies is farming i.e. crops and livestock.

7.3 Farmers' Knowledge about NSCT

7.3.1 Training by MAWF and other projects working with farmers in Ogongo and Omuntele Constituencies

Three out of the four interviewed farmers (75%) from Ogongo said that they had received training on NSCT – because the project staff demonstrated to them how it works. All four mentioned that they had heard of CA and NSCT from the people who trained them in Outapi. However, they could not remember the names of the trainers. They also mentioned that they had been taken to Oshiku-shonkete in Omusati region to see how NSCT works when it was demonstrated in one farmer's field. After the researcher followed this up with a key informant from MAWF, it was revealed that these farmers had in fact received training from MAWF.

The four farmers from Ogongo thought that the use of the ripper-furrower under NSCT was a good method because it retained soil moisture and it was easy for the water to penetrate the soil. One farmer said it was the best method to use because it gave good yield, the stalks and roots were big. "CA has high yield" said one of these farmers.

Eight of the nine interviewed farmers from Omuntele, said they had received training in NSCT whilst one said she had not received any. Those who had been trained mentioned that they had received training from CES, and one of them had received training from Mr Keshongo who was also one of the interviewees. More information about Mr Keshongo is given in Appendix 14. All nine farmers from Omuntele said they had heard about the concepts of NSCT and CA. Three of them (33%) said they had heard about CA from Mr Keshongo. Three others said they had heard from MAWF whilst two said they had heard from the staff of CES and Lima Nawa. One said she had heard from other farmers.

Eight of the nine farmers from Omuntele mentioned water-harvesting as the reason why they chose the ripper-furrower and the remaining one mentioned only reduction in soil compaction. Three of the eight also mentioned increased root penetration and reduction of soil compaction. All of them mentioned that they had learnt about this during their training. This suggests that farmers now have some knowledge about CT after having been exposed to it.

When the sample of Omuntele farmers was asked whether they understood the concept of soil compaction or water harvesting, seven of the nine mentioned that soil compaction hindered root penetration. Two of them mentioned that the ripper-furrower conserved moisture and that compaction resulted in waterlogging. Farmers who mentioned reduction in soil compaction and water harvesting said that they understood these two concepts. They recognized that there was a need to loosen the soil in order to reduce soil compaction. Only one farmer did not fully understand the two concepts.

All the interviewed farmers from Omuntele were aware of the NSCT concept. They were also aware of the principles behind the use of crop rotation, manure and compost. According to them, manure is more affordable than buying fertilisers that are anyway sometimes not available. The manure they said that they can produce or obtain it, however, it is not enough for all their fields.

Only two Ogongo farmers could explain clearly NSCT method. The other two farmers were, however, partially able to explain the process, suggesting that they did have some knowledge of the NSCT method.

The areas with regard to NSCT that farmers from the two constituencies perceive as needing improvement are as follows: Seven farmers understood that more NSCT tractors and implements were needed whilst three mentioned that early land preparation was needed in order to get good yields. Two farmers perceived that the subsidised land under NSCT needed to be increased to more than a hectare for them to get more yields. One farmer said that the need to apply fertilizers and manure every year in order to have high yield should be reduced. One farmer mentioned that NSCT should not be implemented in an area where floods occur. Another said that since the NCAs are too dry, no NSCT is needed, to loosen soil. Only one farmer said that she needs further training since she is a Lead Farmer. This also shows that farmers had some knowledge about NSCT and how it could be improved.

Farmers also gave some of the information that was not covered by the interview schedule. This helped to reinforce findings on the knowledge about NSCT possessed by the sample of farmers, and also their attitudes towards NSCT as follows: Two lead farmers for CLUSA from Omuntele are trying to involve other youths in the NSCT project if they are willing.

Two farmers mentioned that transport is needed to collect manure from elsewhere. One of the farmers wanted to know where to send farmers coming for help on NSCT. Three of the farmers want the Government to supply farmers with more seed and fertilisers as one hectare is too small. One farmer mentioned that the Government does not pay for the land preparation services in time and that there is need to train other farmers to use NSCT. The rest of the farmers mentioned that some of them had received training on the use of the ripper-furrower from Mr Johannes Keshongo, and some had seen it in other farmers' fields. The Ogongo farmers were trained in NSCT and practised from 2009 to 2011; in 2012 they also used it even though the Agricultural Extension did not come to assess what they had done as their contract with the project was over. We can therefore conclude that twelve out of the sample of thirteen farmers from both constituencies received training in NSCT technology. This showed that farmers had some knowledge about the NSCT technology. This is supported by Khoram, Shariat, Azar, Moharamnejad and Mahjub (2006), who found that rural farmers had a very good knowledge of and a good attitude regarding the fundamentals of sustainable agriculture, due to the expansion of communications provided by the agricultural extension services. In this case the extension services of MAWF and NGOs like CES and NCAP, CLUSA played the role by providing training to the farmers. Godtland, Sadoulet, de Janvry, Murgai and Ortiz (2004) also found that farmers who participated in a programme had significantly more knowledge about IPM practices than those in the non-participant comparison group. In this case the farmers who participated in "CA" projects had knowledge about the NSCT technology. However more work needs to be done to compare farmers who had been exposed to NSCT technology with farmers who had not been exposed to the technology.

Some of the interviewed farmers in Omuntele who belong to a women's group assumed that the Government was offering them free land preparation service for only one hectare and that they only had to pay for more. In fact, the researcher learnt from a key informant in CES that farmers pay by means of group membership fees to which they contribute, and this is used indirectly for land preparation and other inputs like seed. This also shows that the farmers did not have full knowledge about what was happening around them when working with various institutions promoting the technology. The MAWF prepares one hectare and the rest is supposed to be paid for by the farmer. The MAWF key informant, however, said that MAWF in fact subsidizes 3 ha. However, because they always have a long list of farmers they often opt to give a larger number of farmers at least one hectare instead of ripping 3 ha for only a few. It is therefore a question of balancing numbers against timing.

7.3. 2 Knowledge from the Manufacture of the Ripper Furrower Technologies

Ripper furrowers are supplied with small pamphlets and the manufacturer is available on request to train farmers. There is only one company in Windhoek, Namibia, that manufactures tractor and animal-drawn ripper furrowers and also planter attachments. The implements are not that much in demand, as farmers are still expecting free services from the Government and NGOs. The company has, however, sold some ripper furrowers to the DAPAP programme and exported some to other African countries like Senegal (Baufelt, 2014). The manufacturer has no doubt that using NSCT is the way for farmers to go, and one way of moving towards CA is through the use of the ripper-furrower that the interviewed farmers from Ogongo and Omuntele are already using. Farmers therefore can get training from the manufacturer if they so wish.

7.4 Attitudes of farmers, Successes and Achievements with NSCT

All the thirteen interviewed farmers in Ogongo and Omuntele were positive about the NSCT and, according to some of them; it is the best method ever. The typical successes and achievements from NSCT that the farmers mentioned were:

- It increased yields (9 farmers)
- It was a job opportunity for some (1 farmer).
- The inflorescence was longer than where they used the animal-drawn plough (1 farmer)
- It was easier to weed (1 farmer)
- Early planting is possible (1 farmer),

They also mentioned healthy improved seed which enable one to harvest twice and the stems keep standing strong. All the interviewed farmers also mentioned that their ripped fields had better yields than the conventionally-tilled fields. They mentioned that, on tractor-ripped fields, crops grew faster even when planted a bit later than on the ones where they used the animal-drawn plough. Farmers had seen that the NSCT method conserved moisture, as some of their crops were still green in the ripped fields.

Two of the four interviewed farmers from Ogongo mentioned early planting and the application of fertilizer as the factors that led to successes of NSCT. Another said that there were fewer pests and diseases, and no labour was hired on NSCT plots. Three of them mentioned that high yields were obtained due to early planting. One farmer from Ogongo still continues to use the animal-drawn ripper-furrower as she gets enough yields for home consumption and income for paying school fees for the children. This shows that the attitude of this farmer has changed. One farmer from Ogongo did not use the ripper furrower in 2012.

The changes that have occurred in Farmers' lives as a result of NSCT (Appendix 7) and personal attitude towards NSCT when each farmer started, and how it may have changed are as follows: in Omuntele one mentioned that she was able to provide for the family another said life in general had improved. One could take care of siblings from proceeds that come from NSCT project. One said that life had improved a lot and manages to sell and save money to use in next season. Seven farmers mentioned that they got more good yields and were able to provide for their families. Another said that she would continue using NSCT. Only one farmer mentioned that the food was not enough for household consumption. Another mentioned that NSCT was easier to handle than CV and the time spent in the field is less. One of the farmers from Ogongo mentioned that if NSCT was the only method used in Namibia at large then no one would suffer from hunger because the NSCT methods would bring high yield. One farmer was confident that this method was good. During heavy rains, they did not get anything as it got flooded but when there was not enough rain they planted in furrows and they got high yield. One farmer mentioned that she had no skills or knowledge about how to implement NSCT. One farmer has decided to use NSCT in all fields and another mentioned that NSCT could help in getting more stalks for reed-fencing her homestead. One of the farmers was regretting not starting a long time ago as it was easy to handle as less time was required to do NSCT.

According to the interviewed farmers from Omuntele, some neighbours went to join due to high yields. Perception of neighbours towards the respondent’s practice of NSCT is listed in Appendix 9. Neighbours also want to start using NSCT after seeing how successful it was on

Mr Keshongo’s farm. The interviewees mentioned that at first the neighbours were critical, but now they could see the benefits from yield increases. The other neighbouring farmers were already going to register at MAWF to get ripper furrowers and others were coming to ask about the NSCT technology. The interviewed farmers also said that many farmers were asking for advice and also many farmers wanted to join CLUSA, whilst others were willing to adopt NSCT and use it. They said that they accepted NSCT practice after seeing good results. According to the interviewed farmers from Ogongo, their neighbours were happy with the practice as some requested for the practical demonstration in their field. They thought it was the best way to use NSCT and many of them are interested and they were impressed by the yield obtained and the practice itself. Farmer from Ogongo mentioned that whilst the neighbours liked NSCT, they could not afford to pay for tillage services.

From the two constituencies, the numbers of farmers now implementing NSCT as a result of the interviewee’s influence were as follows (Appendix 10): Three farmers mentioned that other farmers were willing to adopt but do not know where to get the tractors. One farmer mentioned that she and other farmers learnt from Mr Keshongo showing that they had learnt from their neighbours. Two farmers mentioned that more than 20 farmers were now implementing whilst two farmers were not sure. One farmer mentioned that she had a high influence but implements were a major problem for successful adoption. Three farmers mentioned that no one was practising NSCT as it was expensive. One farmer had a list of names of farmers who registered to get tillage services. However, they were faced by some challenges such as lack of money to pay for NSCT services. One farmer from Ogongo said that almost the entire village was now using NSCT, but on small portions.

It was observed that the farmers' attitudes towards NSCT were positive. Seven farmers from both constituencies mentioned that neighbours wanted to implement NSCT because they had seen high yields in others' fields. The personal attitudes of farmers had changed and they also mentioned positive changes in their lives. Farmers in Omuntele were more positive about the adoption of NSCT compared to those in Ogongo who, throughout the interviews, emphasized that the NSCT was expensive.

Six out of the nine farmers (33%) from Omuntele had only used the ripper- furrower for one year, but were already convinced that it was the way to go after observing the ripped fields of other farmers. Since 69% of these farmers also mentioned that their neighbours wanted to implement the NSCT after seeing its performance in their fields, it was clear that neighbours played a very important role in influencing adoption of technologies. All the farmers from Omuntele mentioned that Mr Johannes Keshongo, who was one of the interviewees and a Lead Farmer, played a very big role in encouraging others to use the NSCT technology. This kind of influence is supported by Oster and Thorton (2009), who mentioned that peer effects played an important role in any process of technology adoption. Rogers (2003) also mentioned that observability is the degree to which the innovation's use and effects are visible to others and reflects how the results of an innovation are seen, as when neighbours can see the application of technology in their neighbour's field.

When the sample of farmers was asked to express their thoughts about the NSCT method that they were using, (Appendix 11) all farmers were positive about the NSCT concept and mentioned that it increased yields. For some the pearl millet inflorescence was longer than when they used CV, the field was easier to weed and they could do early planting. Healthy improved seed made a difference: two harvests were possible and the stems kept standing strong. Almost all (92.3 %) of the farmers mentioned something positive, suggesting that most of the interviewed farmers had a positive attitude towards NSCT technology. This positive attitude influences the adoption of the technology. According to Rogers (2003) relative advantage of one technology over another is a key determinant in the adoption of a new technology; in this case NSCT technology was seen by famers from both constituencies as better in many aspects than CV technology.

7.5 Farmers' practice with NSCT

7.5.1 Time for land preparation and planting and methods used by farmers

One of the Omuntele farmers mentioned that they usually started land preparation and planting in September, whilst three started in October and five started in November. All of them continued planting through to January, depending on the rain situation. One of the Ogongo farmers usually started land preparation and planting early in October going through to November. Another starts in late December whilst the remaining two farmers mentioned that it depended on the rain, but in most cases they start in November and December.

All the nine farmers from Omuntele mentioned that they used the hand hoe for planting. Six of these nine mentioned that their reasons for using the hand method was tradition, whereas the other three mentioned that it was the only method known to them. Three of the farmers from Ogongo said that they used both the animal-drawn planter and the hand hoe; whilst one said she used only the hand hoe for planting. The three farmers mentioned that using the hand for planting was due to lack of planting implements.

All the farmers interviewed in Omuntele had part of their land prepared by tractor-drawn rippers subsidized by MAWF, or by private service providers. Six of the nine farmers from Omuntele mentioned that they were being assisted by MAWF with tillage services while three said that they were being assisted by CES and CLUSA. They also mentioned that they were getting “free” tillage services from MAWF for only one hectare although the MAWF said that they subsidized three hectares. All the farmers interviewed in Omuntele were able to access tractor ploughing and ripping services from MAWF which subsidizes the land preparation service by 50%. At the time of the interviews, the MAWF service costs N$300 per ha, whilst that of private service providers cost N$ 470 per ha.

The MAWF has played a major role in making subsidised land preparation services available, even if they cannot meet all the farmers’ needs. It would be important for MAWF to explore options for increasing land preparation services to farmers in the NCAs. Appendix 2 shows tractor numbers and also the numbers given for 2014 by MAWF. MAWF or private institutions need to increase these numbers in order for more farmers in the NCAs to access land preparation services on more than 1 hectare. MAWF should improve their services specifically by offering more land preparations services in NSCT. This is also suggested by von Hase (2013) who found that lack of land preparation services was the most significant factor influencing the adoption of CT in the NCR.

Four of the nine farmers from Omuntele mentioned that they would continue with NSCT even if there was no organisation assisting them while the rest said that they may continue although they would face difficulty in paying for the tillage services. All four farmers interviewed in Ogongo mentioned that they did their own tillage and used their own methods and implements. Farmers in Ogongo said that they sometimes access tractor-drawn ripper-furrowers from MAWF. The farmers also said that they would continue using NSCT if the implements were readily available to them. For both constituencies, nine out of the thirteen farmers (69.2%) use tractors if available. All the thirteen interviewed farmers used DAP. In Omuntele all the farmers interviewed had access to DAP and tractors, whereas in Ogongo one farmer had access to tractors but all had access to DAP. Nine (69.2%) farmers out of sample of thirteen from both constituencies mentioned that DAP was affordable to them. In Omuntele, all nine farmers owned animal-drawn ploughs and also hoes. In addition, they had access to tractor-drawn disc harrows and ripper-furrowers through the NSCT project or MAWF. In Ogongo, they had access to the animal-drawn plough, tractor-drawn disc harrow and hoe. Table 7.1 shows the method of land preparation that the sampled farmers used and their reason for using it. This indicates that all the sampled farmers do make use of DAP and it's cheaper for them than other methods.

Table 7.1: Method used for land preparation and reason for using the method

Farmer Constituency	**How does the farmer do land preparation?**	**Reasons for using method for land preparation? Are the methods affordable?**
Omuntele	Tractor ripper, disc harrow, AMP	DAP used because its affordable and tractors sometimes take time to come and it will be too late
Omuntele	Tractor, AMP and hand hoe	Tractor and DAP complement each other
Omuntele	TDH, TRF, AMP	DAP cheaper but also getting help from GRN on tractors
Omuntele	Tractor, animal power, hand hoe	DAP cheaper affordable and tractors are faster
Omuntele	Tractor, TRF, AMP, hand hoe	DAP affordable and tractors only when they have money
Omuntele	Tractor, AMP	Tractor is faster
Omuntele	Tractor, AMP	DAP affordable, lack of money to hire tractor
Omuntele	Tractor , AMP	Fields too big to finish with animals alone
Omuntele	AMP, TRF, TDH	All affordable
Ogongo	AMP	Easier to use
Ogongo	AMP	Tractors are expensive
Ogongo	AMP	I can afford it and that is what I have
Ogongo	AMP and tractor if available	Own DAP and hand hoes

* AMP = animal-drawn plough; TDH = tractor-drawn harrow; TRF = tractor-drawn ripper-furrower; DAP = Draught Animal Power

Appendices 5 to 6 show the tillage methods and practices that the farmers from Ogongo and Omuntele used on their fields during the previous season. It also gives the farmers' reasons for use of the implements. This was a follow-up question to see if farmers had practised NSCT in the previous year.

7.5.2 Use of Donkeys as Draught Animals and animal-drawn equipment

In Omuntele all nine farmers in the sample owned animal draught power, especially donkeys. Whilst they all had access to draught animal power and could use the animal-drawn plough, they did not have access to the animal-drawn ripper. All had also used the tractor-drawn ripper-furrower in some of their fields. Six of the nine farmers had also used tractor-drawn disc harrows. In the previous season all the interviewed Omuntele farmers had used the animal-drawn plough and the tractor-drawn ripper in some of their fields. Thus, in Omuntele these farmers use the animal-drawn ploughs, tractor-drawn disc harrows, tractor-drawn ripper-furrowers and hoes for land preparation. On land that they used for the NSCT project, all interviewed farmers had had their land preparation done by tractor-drawn ripper-furrowers subsidized by MAWF or from a private service provider. This indicated that farmers were indeed practising NSCT.

All four farmers from Ogongo also owned animal draught power and also had donkeys, but had access to both the animal-drawn plough and the animal-drawn ripper. The reason they gave for using animal-drawn ploughs was that they provided easy and fast cultivation, and one respondent even said it was to improve the structure of the soil. Another thought that it was the best method and another maintained that, as they only had donkeys and the animal-drawn plough was the only type of implement available to them. These farmers in Ogongo sometimes use tractors if they could access them and said that they sometimes accessed tractor-drawn ripper-furrowers from MAWF. This also indicates that farmers were using

NSCT methods if they were made available to them. All these farmers agreed that tractors were expensive and animal power and hand hoes were the only methods available and affordable. Out of the sample of thirteen farmers, 69% use tractors and this suggests that a large number of farmers do indeed use this power source, even if for limited purposes. However, all (100%) of the interviewed farmers also used donkeys for draught power.

7.5.3 Weeding - Practice

All thirteen interviewed farmers from Omuntele and Ogongo used the hand hoe for weeding, as this was the only method traditionally known to them and they had been taught by their parents. They also mentioned that it was affordable. Apart from using hand hoes, they also considered that it was easy to pull the weeds in the rows by hand. They also mentioned that they did not have access to current methods of weed control, such as the use of herbicides. However, one farmer from Ogongo mentioned that there was no way they could get other methods as they did not even have knowledge about them.

7.5.4 Labour - Practice

Eight out of the nine farmers from Omuntele said they mostly used family labour. One mentioned that they only hired labour for planting and weeding. One mentioned that it cost them N$ 350 per hectare to hire labour. Four of the farmers said NSCT increased the labour needed for planting and weeding. Some even had to invite other farmers to help with the weeding, and then they gave the helpers food. This reflects the fact that planting and weeding are peak times when farmers would require extra labour. The remaining five farmers said that

NSCT reduced labour, as they now planted in rows instead of using the broadcasting method employed before.

All four farmers from Ogongo also mentioned that NSCT reduced labour because they now planted in rows and not in a harp hazard manner. They said that they sometimes hired people to help them, but they did most of the work on their own with family members. They also said that the method was easy to practise, as there was no need to weed once the method was established. One said that labour was reduced because the planting was done only on the furrows, which is easy and fast compared to the broadcasting that they normally practise.

It can be concluded that all the thirteen farmers interviewed in both Ogongo and Omuntele mostly used own family labour in both ripped and conventionally-tilled fields. Of the sampled farmers from both constituencies, 69.23% said that NSCT reduced labour, as they now plant in rows as compared to the broadcasting that they used to do when using the animal-drawn plough and disc harrow (CV methods). This suggests that farmers were taught how to plant in rows only for NSCT and not for the conventional systems.

Since all of the interviewed farmers did hand-weeding and most of them were women, this suggests that they simply accepted the laborious work of weeding, but noticed when it became easier when row-planting was introduced. Men and women have different roles to play in agriculture in Africa, where issues of land ownership and decision-making regarding its utilization are still being debated. Here, though, most of the women owned land and were the decision–makers, and as targeting the decision-maker can be seen as vital in the adoption process, it is with women where the final choice about adoption rests (Solano, León, Pérez & Herrero (2001). Labour-intensive technology is not likely to be preferred by women if it takes up too much of their time, which must also be allocated to reproductive and other productive roles. The NSCT technology was seen as suitable for women, as farmers mentioned that it reduced labour of weeding due to only planting in rows.

All (12) interviewed women in both constituencies were using the NSCT technology. This is evidence that women are quick to see good technologies, as there was a high level of participation of women in the NSCT programme. This could also be because women are at home and are in a position to take up new technologies while the men are working in other areas to earn an income. Women here have the right attitude and are in a position to contribute more significantly to poverty reduction, so Government strategies and NGO efforts should focus on the promotion of CT amongst smallholder farmers, particularly women, as a method of livelihood improvement and food security. Using the NSCT technology can also enable the interviewed women to have spare time for other activities and also to rest.

7.5.5 Farmers' Yields - practice and attitude

Farmers from both constituencies did not seem to know how much yield per hectare they got for the 2011/2012 season but remembered the total yields for all the fields. All the nine farmers in Omuntele mentioned that NSCT increased their yields as compared to CV practices. One farmer mentioned that the conventional practices failed due to drought. Another mentioned that they got more from NSCT plots because it was easy to apply manure, and weeding was easy. She also mentioned that she got a strong crop stand by using the NSCT method. Out of the nine farmers from Omuntele, only one could specify his yields because they had been measured for him by the MAWF. It was difficult to establish the exact yield for the other eight farmers, even for earlier years.

All the thirteen interviewed farmers from Ogongo and Omuntele claimed that they obtained high yields from NSCT compared to the CV practices. They had even realized that the land that they had put under NSCT may have been too small, as the yield was very good compared to conventional practices.

All the thirteen interviewed farmers were aware that NSCT had contributed to increased yields. It was difficult to compare the yields obtained by farmers with those of the research at the on-station field trials at Ogongo Campus, as most of the farmers used traditional cultivars and seed varieties. The researcher observed that the panicles of the traditional varieties of pearl millet are much bigger and longer than the Okashana and Kangara varieties, making comparison difficult when it came to land preparation methods (Fig 7.2). Mr Keshongo, who had yields of up to 4 660 kg per hectare, also grew a mixture of traditional and improved varieties.

Fig 7.2: Panicle of traditional pearl millet variety compared to the Okashana at Mr Keshongo's field

Observations also showed that farmers in both Ogongo and Omuntele did not use the recommended plant populations in their conventionally-tilled fields. Some of them also said that they did not apply fertilisers and manure. This also makes it difficult to compare the yields, although it was clear from observation that there were differences between the crops in the two types of field cultivated by all the sampled farmers. The fields prepared by the NSCT method were always much healthier and in some cases were still green compared to the conventionally-tilled field. The millet stems were longer and thicker. This would help farmers in choosing which method to use, and is supported by Quisumbing (2003), who reported that chances of adoption could be higher if there were clear prospects for higher profitability and greater yields. Rogers (2003) also mentioned relative advantage of one technology over another as a key determinant in the adoption of a new technology; in this case NSCT technology is viewed by farmers as better than CV methods.

The fact that all the interviewed farmers owned land suggested that they were in a position to make their own decisions with regard to what services to use in their fields and also if they could afford them. They are in a position to choose a technology that can increase yields and also reduce land degradation. Since all the farmers saw the NSCT as a method that could increase their yields, they could, if they chose, increase the number or sizes of NSCT plots. They had the means to increase their production even on the one hectare that MAWF could rip and furrow for them. They could also hire the services from a private service provider if they can afford it.

7.5.6 Challenges Faced by NSCT Farmers

The main problem that the thirteen farmers had was that it was difficult to access implements, as MAWF did not have enough tractors and rippers. Some of the Lead Farmers already had long lists of farmers in need of ripping services, and the long lists clearly indicated a positive attitude towards the NSCT technology.

The major agriculture-related challenges that the sampled households from Ogongo constituency faced were pests including birds, flood, drought, labour, inadequate equipment, and diseases. These farmers mentioned that they did not know how to control the insects that were attacking their crops. All four farmers from Ogongo mentioned pests including birds as their main challenge. They mentioned that they scared away birds by beating drums. In Omuntele, the major agricultural-related challenges that the sampled households faced were drought and floods.

Seven out of the thirteen farmers from both constituencies mentioned drought as their major agricultural challenge and one mentioned army worm. One mentioned shortage of labour and the need to train donkeys to use ripper–furrowers; another mentioned animals breaking fences to eat crops and couch grass and one other mentioned lack of fertilizers. In Omuntele the interviewed farmers also mentioned some of their major challenges as being couch grass in their crop fields, transport to collect manure, and birds. They also mentioned that they were not able to access the land preparation services in time. They added that, even if they managed to access the land preparation services in time, MAWF only ripped one hectare as MAWF did not have enough implements and tractors. In fact most of the farmers own draught animals and they were in a position to access manure. Nonetheless, they maintained that the manure was not enough for their fields.

Another challenge, deduced from the discussions with the sample of farmers and observations of their fields, was lack of mulch. Farmers are not able to keep crop residues, as they give them to their animals and do not have enough for their fields. It is important that farmers using the NSCT technology in Namibia should use mulch. This was emphasized by Giller *et al*. (2009) and Rusinamhodzi (2013), who reported that, in low rainfall environments, reduced tillage without mulch cover leads to lower yields than conventional agriculture. However the on-station part of this study showed that there were no significant differences in yields between mulched and un-mulched plots.

All the thirteen interviewed farmers from both constituencies were partially aware of the concept of mulching. One problem is that stover is needed for the livestock and fencing homesteads, making it difficult for farmers to keep it as mulch for the field. This is confirmed by Rusinamhodzi (2013), who concluded that crop productivity under conservation agriculture depended on the ability of farmers to achieve correct fertilizer application, timely weeding, the availability of crop residues for mulching and systematic crop rotations – most of which are currently lacking in southern Africa and Namibia in particular.

7.6 Observation of Farmers' Fields

In most of the Ogongo and Omuntele fields there were distinct differences between the fields that were prepared by ripper-furrowers and those prepared by the animal-drawn plough or the disc plough or harrow. Fig 7.3 shows a field that that was conventionally tilled by an animal-drawn plough in comparison to Fig 7.4 which shows a field where a ripper furrower was used.

Fig 7.3: One of the CV fields in Omuntele constituency tilled by an animal-drawn plough

Fig 7.4: One of the NSCT fields in Omuntele constituency

The crops of pearl millet that were in the NSCT fields looked healthier, had bigger stems and bigger panicles. Farmers were growing the traditional local variety and the panicles were very long. The panicles of the traditional variety were far bigger and three to five times longer than the Okashana variety. The roots in Mr Keshongo's ripped field were on average 38 cm long compared to an average of 23 cm in the conventionally-tilled fields. This amounts to a

60.3 % increase in root length in the NSCT field over the CV fields. The on-station trials in 2012 also showed that NSCT methods – TRF and ARF with mulch achieved longer roots than the CV methods TDH and AMP by (24.48%) and (8.46%) respectively.

In all the four farms in the Ogongo constituency, there were distinct differences between the fields that were prepared by ripper-furrowers and those prepared by an animal-drawn plough. The crops that were in the NSCT fields looked healthier and the cobs looked bigger. This helped a lot to change farmers' attitude with regards to NSCT

7.7 Comparison of costs between NSCT and CV technologies impacting on knowledge, attitude and practice

This study showed that, for the NSCT technology to be fully integrated, the technology must be economically viable. Farmers have to be able to afford the tillage services, fertiliser and manure. This also means that farmers have to afford either CT tractor-drawn or animal-drawn implements. Twelve out of the thirteen interviewed farmers in both constituencies have land sizes ranging from three to eight hectares; such sizes would make it uneconomic to invest in tractors and large pieces of tractor-drawn equipment.

Considering the initial capital needed for buying tractors and tractor-drawn implements (see Table 7.2, which does not include tractor prices. An 80kW tractor at John Deer in Otjiwarongo was costing N$307 000 in 2015 and the cost of their maintenance, smallholder farmers would be better off using animals and/or hiring the tractor services. This is supported by the FAO (2008b), which found that, compared to draught animals, tractors achieve the greatest savings in time and labour, but at a great initial expense with regard to capital investment. According to Bishop-Sambrook (2005), tractors tend for this reason to be more appropriate for large-scale commercial farming. The FAO (2008b) also reported that, because of the high initial capital investment needed in order to purchase the tractors, individual tractor ownership is in most cases difficult for farmers with small areas of land for cultivation.

Table 7.2: Purchase prices for tillage implements (September 2015)

Implement Type	**Cost (N$)**
Standard animal-drawn single furrow plough	N$ 1 200 Onawa Market, Ombalantu
Animal-drawn ripper-furrower attachment	N$ 1 500 (Baufis Agricultural Services)
Tractor-drawn disc harrow	N$ 31 900 Hoffmanns, Otjiwarongo
Tractor-drawn 2-tine ripper-furrower	N$ 45 000 (Baufis Agricultural Services)

Ownership of a tractor and associated items of equipment can involve a substantial investment. Improper choice of size of tractor can be even more costly, because a very small tractor can result in long hours of field work, excessive delays and premature replacement, whereas a tractor which is too large can result in excessive operating and overhead costs (Summer & Williams, 2007). The ideal tractor with matching equipment should get the work completed on time at the lowest possible cost.

Use of tractors also involves use of fuel, which is another high cost. Adewoyin (2013) reported that fuel consumption significantly increased with ploughing depth, and concluded that the depth of crop roots should determine the appropriate ploughing depth in order to minimize expenditure on fuel. Use of the tractor ripper furrower involves operating at great depths in order to break the plough pan. This also means that farmers have to be able to choose the right depth of land preparation for the various crops so that they can reduce fuel costs. Farmers have to be trained on how to do that as part of gaining essential knowledge about the use of CT implements.

According to Vozka (2007), the main factors affecting machinery costs are: annual cropped area; local soil conditions (heavy or light); local climate (number of days available between harvest and planting); tractor availability (average size and age of the tractors, tractor use) and labour availability. It is essential to look at all of these factors in both Omuntele and Ogongo Constituencies. The farmers' landholdings are small; tractors and related implements are not readily available and are expensive; labour is expensive and farmers mostly just use family labour as that is what they can afford. Whilst farmers have knowledge and good attitude about the NSCT technology, part of the training package should also include issues of farm machinery management.

All the nine interviewed farmers in Omuntele were able partly to access the tractor ploughing and ripping service from MAWF, which subsidizes the land preparation service at 50%. In 2013 the cost of land preparation by MAWF was N$ 300 per hectare whilst that of private service providers was N$ 470.00 per hectare. At least the farmers could make use of the 1 hectare that MAWF could offer at that time.

Chigariro *et al.* (2008) estimated that using donkeys would cost N$ 177.58 ha^{-1}, while using tractors would cost N$ 483.26 ha^{-1}. By this comparison, using donkeys is still far cheaper than using tractors, especially given the fact that MAWF can only offer one hectare of land preparation. Even if farmers chose to use the subsidized tractor it was still cheaper by N$ 13.00 than hiring from a private service provider. Tractor and implement hire would be better than purchase, if the capital cost of buying a tractor together with related implements, and maintaining them is also considered. This is also supported by Chigariro, *et al*. (2008), who listed four lessons that could be learnt from the comparison of the different draught power sources. Two of the lessons are:

-For a large field (e.g. 10 ha and above), it is convenient and economical to use a tractor because of the amount of effort and time required if other power sources are used.

- For an average-sized field (e.g. around 2 ha) it is economic and convenient to use draught animals, since they are affordable and fast enough to carry out the operations in good time.

7.8 Conclusions and Recomendations

7.8.1 Farmers' Practices

All the interviewed farmers now use the NSCT whenever it is available to them, even if on small pieces of land. The fact that farmers are not using good practices like fertilizer and/or mulch in their conventionally tilled fields suggests that farmers associate these good practices specifically with the NSCT technology. This means that farmers also need knowledge that these good practices can still be used with CV. Another example which would likewise apply is planting in rows, which could easily be done even in the CV fields. Fig 7.3 shows a mahangu crop that was broadcast.

Farmers are capable of gaining yields of up to 4 660 kg ha^{-1} with a combination of improved and traditional varieties of pearl millet, as shown in Mr Keshongo's field. This means that, if farmers can follow all the principles of CT and eventually CA, they can greatly improve their yields for both the improved and traditional varieties. In this study, therefore, NSCT is seen as a stepping stone to CA. Hobbs, Sayre and Gupta (2008) compared traditional tillage, CT and CA as in. Table 7.3, which show that CA is superior to CT on a number of issues. However there are no differences in yield between the three tillage practices and shows that timeliness in planting plays a very important role.

However, more work needs to be done in the area of traditional crop varieties in order to ascertain whether high yields are due to particular varieties, crop management practices or to NSCT, and also to establish sustainability. If farmers can improve the yields of traditional varieties, the Government will not have to import grain ; in 2012 alone, when the main crop in the northern regions was pearl millet, 42 800 tonnes of this grain had to be imported (NEWFIU, 2012).

Table 7.3: A comparison of tillage, conservation tillage (CT) and conservation agriculture (CA) for various issues.

Issues	**Traditional tillage (TT)**	**Conservation tillage (CT)**	**Conservation agriculture (CA)**
Practice	Disturbs the soil and leaves a bare surface	Reduces the soil disturbance in TT and keeps the soil covered	Minimal soil disturbance and soil surface permanently covered
Erosion	Wind and soil erosion: maximum	Wind and soil erosion: reduced significantly	Wind and soil erosion: the least of the three
Soil physical health	The lowest of the three	Significantly improved	The best of the three
Compaction	Used to reduce compaction and can also induce it by destroying biological pores	Reduced tillage is used to reduce compaction	Compaction can be a problem but use of mulch and promotion of biological tillage helps reduce this problem
Soil biological health	The lowest of the three owing to frequent disturbance	Moderately better soil biological health	More diverse and healthy biological properties and populations
Water infiltration	Lowest after soil pores clogged	Good water infiltration	Best water infiltration
Soil organic matter	Oxidizes soil organic matter and causes its loss	Soil organic build-up possible in the surface layers	Soil organic build-up in the surface layers even better than CT
Weeds	Controls weeds and also causes more weed seeds to germinate	Reduced tillage controls weeds and also exposes other weed seeds for germination	Weeds are a problem especially in the early stages of adoption, but problems are reduced with time and residues can help suppress weed growth
Soil temperature	Surface soil temperature: more variable	Surface soil temperature: intermediate in variability	Surface soil temperature: moderated the most
Diesel use and costs	Diesel use high	Diesel use intermediate	Diesel use much reduced
Production costs	Highest costs	Intermediate costs	Lowest costs
Timeliness	Operations can be delayed	Intermediate timeliness of operations	Timeliness of operations more optimal
Yield	Can be lower where planting delayed	Yields same as TT	Yields same as TT but can be higher if planting done more timely

Since the farmers in the NCAs are using NSCT, they need at this point to realize the advantages that are derived from that method so that they may progress to where they are able to graduate to CA. NSCT can therefore contribute to rural households being able to engage effectively in diverse livelihood strategies in two very important areas, i.e. improved productivity through use of the NSCT methodology resulting in increased yields, and being able to have spare time for other activities because most of the farmers from Ogongo and Omuntele said that the NSCT required less labour than conventional practices. This means that famers can benefit from NSCT through improved food security (Fowler & Rockstrom (2001).

The interviewed farmers in Ogongo and Omuntele are used to their traditional methods of broadcasting manure, fertiliser and seed. Since they now plant in rows, also applying manure and fertiliser in rows, this will eventually help farmers to realize that they can now save on those inputs by applying and concentrating them where they are really needed.

It was also observed that some of the farmers spent a lot of time weeding in broadcast fields with very low plant population densities. This practice requires a lot of labour when in fact just weeding in the rows and using an animal-drawn cultivator to weed between rows would be easier and faster. With CT and cover crops, farmers might not even have to weed between rows, as this will be covered by crops and mulch. Farmers obviously still need more knowledge in this area.

7.8.2 Adoption of the NSCT technology by farmers

As reported in section 7.5, draught animals still make an important contribution in the crop production system as practised by smallholder farmers in the NCAs. Animal-drawn equipment especially the animal-drawn plough was dominant throughout both constituencies, indicating that many farmers are still using DAP and engaging in conventional tillage (CV). It also goes to show that efforts should be made to explore CT implements that are both tractor- and animal–drawn, especially as animal-drawn equipment is on the whole much cheaper (Table 7.2). The use of the animal-drawn ripper-furrower should be explored further.

For farmers to make use of available resources (i.e. family labour and or DAP) might be important as a major determinant of system sustainability and whether farmers adopt the technology or not. Therefore, tractor power and animal power should complement each other even as the use of the hand hoe continues. The three can complement each other with the introduction of NSCT. Donkeys should also continue to be used by farmers. Both on-station trials showed that it was possible for donkeys to pull both the plough and the animal-drawn ripper. The animal-drawn ripper-furrower outperformed the animal-drawn mouldboard plough by 45.20% on depth of cut. Overall, NSCT methods showed that they were superior to CV methods in terms of depth, regardless of power source. Table 2.1 also shows many advantages to using donkeys, indicating that donkeys use should be explored further. Fuel prices will definitely impact negatively on the operating costs of tractors. Since tractor-drawn equipment is expensive, and most smallholder farmers use draught animals, in this context too it might be important to explore options that address the utilization of animal-drawn CT equipment.

The challenge for Namibia is to develop a package of technologies which are affordable, environmentally sustainable, and significantly more productive than present practices. The replacement of tractor disking with tractor- and animal-drawn ripper-furrowers should, on present evidence, contribute to sustainable pearl millet production in the Ogongo and Omuntele Constituencies of Namibia.

With the concept of early land preparation, using the ripper-furrower has also shown that it allows for the land to be prepared well in advance – so that, as soon as it rains, farmers can go straight to planting. They can thus take advantage of the first rains, thereby making it possible to increase their yields. Farmers here show that they want to practice.

Compared to hand labour, animal power can lead to yield increases due to improved timeliness in cultivation, planting and weeding. This is very important in semi-arid areas, where the time of planting after the first rains is critical. In theory, better timing can be provided by tractors, but in practice this is only true for the first in the tractor queue, as seen in Ogongo and Omuntele where MAWF was not able to give all land preparation services required by farmers. When many smallholder farmers own animals, they can all plough their fields at the same optimum time (Starkey, 2010).

Use of animal-drawn implements could also limit the damage caused by tractor wheels as seen in Fig 7.5 during land preparation or weeding. Apart from that, soil compaction associated with overuse of heavy machinery has been highlighted as a worldwide problem in modern agriculture (Hamza & Anderson, 2005; Ziyaee & Roshani, 2012; Ramzan *et al*., 2012) aggravated by the intensification of cropping systems. Although tillage is traditionally used to alleviate the effects of compaction, increasing concerns about the environmental impacts of tillage have led to interest in conservation tillage systems. In Namibia, where soils are fragile but most farmers want to use tractors rather than animals, using tractors and heavy machinery may cause increased soil compaction.

Fig 7.5: Compacted soil, waterlogging in wheel tracks after heavy shower (Photo by Rod Davis)

Competition for crop residue use, low fertiliser use, non-use of herbicides, labour shortage, erratic rainfall, lack of crop rotations and poor soils combine to offer many challenges for the practice of conservation agriculture among smallholder farmers in Southern Africa (Siziba, 2007; Giller *et al*., 2009 as cited by Rusinamhodzi, 2013).

Farmers in Ogongo and Omuntele have been exposed to the NSCT technology and, together with organisations like MAWF, LIMA NAWA, CES and CLUSA, are now practising some of the concepts of CT. These organisations have worked together with farmers as Lead Farmers and also used other farmers' fields as demonstration plots.

Whilst the research trials were conducted on station at Ogongo, it remains important and crucial that CT be a field-based concept that can be tested further on a farmer's field. Any interventions and practices should ultimately be tested with a farmer in that farmer's field. This can ultimately increase the adoption of the NSCT technology as farmers can see the outcomes for themselves.

The increase in yield in the farmer's field, as seen at Mr Keshongo's farm in Omuntele, can work positively for crop and livestock interaction, as a high yield also means there is a parallel increase in biomass, thereby making it possible for farmers to use more of the biomass for mulch and still have some for feeding the livestock. Appendix 14 gives further details on the case of Mr Keshongo in the Omuntele Constituency.

According to Straub (2009) "technology adoption is a complex, inherently social, developmental process; individuals construct unique perceptions of technology that influence the adoption process; and successfully facilitating a technology adoption needs to address cognitive, emotional, and contextual concerns".

Farmers in both constituencies showed that they had some knowledge of both CV and NSCT. The study revealed that farmers have positive attitudes as well as willingness to practise the NSCT technology whenever the land preparation services were made available to them. Fig 7.6 shows TAM model and illustrates the linkages between technology knowledge, attitude and practice thereby leading to adoption and the various factors that influence the adoption.

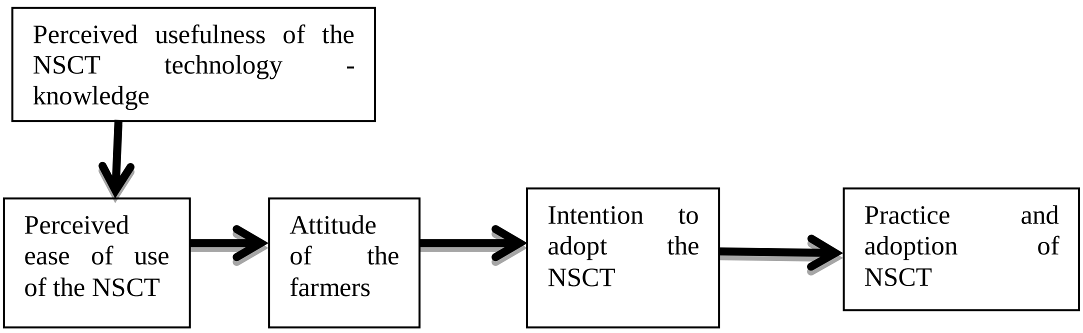

Fig 7.6: Adapted from Technology Acceptance Model (Davis, 1993)

The five stages Rogers (2003) states are that, in general, successful adoption of a particular innovation should result from high scores in terms of (1) its relative advantage over existing practices, (2) compatibility to users' needs, (3) trialability (4) observability, and (5) simplicity of use. Such characteristics of innovations can explain their rate of adoption.

Relative advantage of one technology over another is a key determinant in the adoption of a new technology, in this case NSCT technology. The notion of relative advantage is a reflection of how the innovation is subjectively perceived as being superior to the previous practice. In this case farmers from both constituencies mentioned that NSCT was better than CV. Compatibility of the innovation reflects how the innovation is perceived based on the existing values, past experiences, and needs of potential adopters. Trialability is the characteristic which enables users, i.e. farmers, to be given a chance to try out the technology themselves. In this case farmers got a chance to experience first-hand and try the NSCT themselves. Observability is degree to which the innovation's use and effects are visible to others. Observability reflects how the results of an innovation are seen, as when neighbours can see the application of technology in their neighbour's field. In this case the interviewees mentioned that the neighboughs around them wanted to try out NSCT as well and were pleased about the yields that the interviewees were getting. Simplicity reflects the perceived lack of difficulty in understanding and using the innovation leading to adoption.

This study indicates that farmers in both the Ogongo and Omuntele Constituencies perceived the NSCT to be useful and important in enabling them to increase their yields, reduce labour and have excess produce to sell in order to improve their livelihood strategies. They have some knowledge of the ripper furrower-technology, their attitudes are positive towards adoption of the technology, and they use the technology even if it is on a small part of their land.

Given the timing of the study, the results that were obtained are only suggestive. To confirm these results, it would be necessary collect evidence to compare changes over time in actual productivity between farmers who used and those that did not use the new technology.

7.9 Summary

Only thirteen farmers from Omuntele and Ogongo Constituencies participated in this study. Farmers from both constituencies showed that they had some knowledge, positive attitudes towards NSCT but only practiced it when the implement was available to them. Farmers mentioned more positive attributes throughout the interviews for the NSCT technologies. Therefore NSCT production system holds promise and has the potential to significantly transform Namibian small-holder agriculture into a sustainable and productive crop production option.

8. CONCLUSIONS AND FUTURE RESEARCH NEEDS

8.1 Introduction

This chapter brings out and summarizes the conclusions to be drawn from the study, and also highlights the perceived recommendations and future research needs. The study aimed to describe a holistic picture, dealing with implement, soil and crop together. No farmer would be satisfied to learn only about draught and soil requirements without being able to understand whether, at the end of the day, he or she could expect increased crop yields. High yields are the ultimate goal of every farmer. Conclusions drawn from the study are separated into the various categories used in the research, but this does not mean that they are not integrally connected.

8.2 Conclusions

8.2.1 Field perfomances of tillage technologies on fields without crop

Four tillage technologies as used by farmers in Ogongo, Omusati Region were tested, two for Conventional Tillage (CV) being an animal-drawn mouldboard plough (AMP); a tractor-drawn disc harrow (TDH), and two for the Namibia Specific Conservation Tillage (NSCT) programme, being an animal-drawn ripper-furrower (ARF) and a tractor-drawn ripper–furrower (TRF). The results showed that there were significant ($p<0.001$) differences in depth of cut, mean width of cut, draught, specific draught, efficiency and effective field capacity to be found among the four tillage methods during the three years (2010, 2011 and 2012) in which the research was conducted.

The NSCT implements gave better field performances than the CV implements in terms of depth, regardless of power source. The tractor-drawn ripper-furrower achieved the greatest mean depth of cut in all three years. The animal-drawn mouldboard plough achieved the least mean depth of cut. The tractor-drawn ripper-furrower achieved the greatest depth, and therefore it is probably the best implement to be used for breaking the plough pans to enable root penetration and water infiltration. It can also be concluded that animal-drawn equipment could not achieve deeper depths and could also not achieve furrows as wide as for tractor drawn equipment.

Satisfactorily wide furrows were achieved by TRF (NSCT) and not achieved by ARF (NSCT) in the harvesting of the water expected from ripper furrowers, meaning that ARF might not be very effective in doing this. The best implement for achieving wide furrows to harvest water is therefore the TRF.

When the two tractor-drawn implements were compared, TDH (CV) required 34.81% less draught force than TRF (NSCT). Comparing the animal-drawn implements, AMP (CV) required 15.56% less draught force than ARF (NSCT). Overall NSCT implements achieved higher draught forces than did CV ones. NSCT methods, however, outperformed the CV methods on specific draught. TRF and ARF showed lower specific draught than TDH and AMP across the three years, suggesting that NSCT methods were more energy-efficient than CV methods.

This therefore suggests that there is need to strike a balance between depth and required force when undertaking land preparation. Increasing depth will definitely increase draught, draught power and specific draught, thereby impacting on the power source. For animal-drawn implements, the results show that, because of the design of the implements, there is a limit to how much depth and width of cut can be increased.

Neither of the tractor-drawn implements in the study met the ASAE Standards of Efficiency, i.e. 70-90%. The on-station field efficiencies fell short by 16% (TDH) and 8% (TRF). This suggests that it is necessary to be very careful in land preparation so as not to waste time at headlands and also on changing operators. The TDH was the least efficient, reinforcing the point that the TDH should be discarded as it has particular disadvantages in terms of poor depth of cut and lowest efficiency.

Across the three years the effective field capacities for tractor-drawn tillage methods were: TDH = 0.68 ha hr^{-1} and TRF = 0.74 ha hr^{-1}, 8.1% better than TDH. For animal-drawn tillage methods: AMP = 0.03 ha hr^{-1} and ARF = 0.15 ha hr^{-1}, 80% better than AMP. Working for six hours per day to allow animals to rest and graze, this would translate into 0.89 ha per day for ARF and 0.18 ha for AMP. The best methods to achieve greater EFC are therefore TRF and ARF, both NSCT implements. Use of the NSCT implements can also be translated into low production costs, as the implement, power source and operators will spend less time in the field. For draught animals it also translates into improved welfare for the animals for the same reason. For the operator it translates to time saved to rest or do other meaningful economic activities on the farm.

The animal-drawn ripper-furrower has shown that it can achieve comparable results in terms of effective field capacity. It can also cause less soil disturbance than the tractor-drawn ripper-furrower. Nonetheless, results in this study showed that animal-drawn ripper-furrower alone will not be able to break the plough pans and to make wide furrows, so it is recommended that it be complemented with the tractor-drawn ripper-furrower. This can be used in the first year to break the plough pan, and thereafter an animal-drawn ripper-furrower can be used. In this way tractors and animals can actually complement one another. In cases of excessive compaction, farmers can hire a tractor-drawn ripper-furrower in the first year, and then use a ripper–furrower powered by their own animals in subsequent years. It was found that the tractor-drawn ripper-furrower was able to make good furrows capable of harvesting water, whereas this was difficult for the ARF, which ripped only. Thus minimal soil disturbance will also be achieved if a tractor-drawn ripper-furrower is used in the first year to make furrows, and an ARF in subsequent years.

For this study, the hypothesis is accepted at probability levels of 0.05 that animal-and tractor-drawn NSCT technologies can exhibit significantly different field performance characteristics in terms of depth, draught force, specific draught, efficiency and effective field capacity when compared to CV technologies used at Ogongo in Omusati region of Namibia.

With the idea of early land preparation, it has also been shown that using the ripper furrow enables the land to be prepared well in advance and quicker. This means that farmers can start planting as soon as the rains come, thereby taking advantage of the first rains.

Many farmers own draught animals and, compared to hand labour, animal power can lead to yield increases due to improved timeliness in cultivation, planting and weeding. This is very important in semi-arid areas, where the time of planting after the first rains is critical. In theory, greater timeliness can come from tractors, but in practice, this is only true for the farmer who is first in the tractor queue, as smallholder farmers cannot be expected to afford their own tractors.

8.2.2 Field Performance of Ripping Techniques of the Animal-Drawn Ripper-Furrower in Ogongo, Namibia

This study showed that there is no justification for practising double ripping with three donkeys. Bigger furrows were not achieved. Greater depths were achieved with double ripping with two donkeys, but it was not comparable to the tractor-ripping performance. Since high PR resulted from double ripping with 3 donkeys, there is no justification for double ripping as it did not manage to go past the compaction level. As recommended in section 8.2.1, it would be best to use a tractor-drawn ripper-furrower to break the plough pan in the first year, and thereafter to use an animal-drawn ripper.

For this study, the hypothesis that using single ripping of the NSCT technologies are significantly different to the field performance characteristics of the two or three combinations of donkey numbers in a span, using double ripping of the NSCT technologies at the 95% CI, was accepted for depth, width, speed and turning time.

8.2.3 Field performances of tillage technologies under cropped conditions

8.2.3.1 Compaction and Penetration Resistance

There were significant ($p<0.001$) differences in mean penetration resistance among the tillage methods. PR increased with depth across all four tillage methods at planting and at harvesting for 2011 and 2012. The general trend is an increase in PR with depth for all tillage methods, with TRF having lower values than the other methods. The study also showed that, as the depth increases, so does the draught and specific draught thereby making greater depth energy inefficient. In other words, as the ripper goes deeper, more force is required to pull the implement in order to overcome the compaction. Therefore there is no justification in tilling at greater depths unless the roots of the crop have to go to those greater depths. One NSCT method (TRF) achieved a 27% lower PR values than the CV methods (TDH and APM). However, in the animal group, AMP achieved 6% lower PR values than ARF.

When the results from the on-station trials were compared with the results from the farmers' fields, most PR values from farmers' fields were above 3 MPa. The results from on-station trials showed that roots continued to grow and good yields were achieved above the critical value of 2 MPa reported by other researchers, so it is difficult to say whether the low yields in the farmers' fields were due to compaction. From this study it was thus apparent that the more flexible approach of 2–5 MPa could be used as the critical limits above which root growth is severely impeded, as roots continued to grow and high yields were achieved in this study for all the tillage methods. This suggests that it is important to check how far the roots of a particular crop can go, so the implement depth may be adjusted to cater for the root length of the crop. For this study, the hypothesis was accepted that use of animal and tractor drawn NSCT technologies can results in significantly reduced soil compaction compared to CV technologies, especially for TRF.

8.2.3.2 Soil Moisture Content

There were significant ($p<0.003$) differences in mean moisture among tillage methods. Significant ($p<0.001$) interaction between time and tillage was observed with soil moisture peaks in February. Moisture content could not be significantly influenced by mulch.

Overall, the NSCT methods (TRF and ARF) resulted in higher soil moisture levels than the CV methods, (TDH and AMP). TRF had the highest percentage increase in moisture content with 8.1%, whilst TDH increased by 3.85 %, ARF increased by 3.13%, AMP actually decreased by 3.13%; over the same two-year period soil moisture in the FALLOW (control) plot increased by 2.90 %. Compared with the other methods, TRF could have harvested water as intended and kept moisture in the furrow. During performance tests TRF also achieved greater depths and achieved good furrows so as to harvest water.

Comparing mulch and no-mulch treatments, TRF had the highest percentage increase in moisture content. For this study, the hypothesis was accepted that the use of NSCT implements, TRF especially, results in significantly higher soil moisture content compared to CV implements.

8.2.3.3 Yields and Roots

In both years there were no significant differences in mean pearl millet yield among the four tillage methods. However, in 2012, both NSCT methods (TRF and ARF) achieved higher yields than CV methods. Although there were no significant differences in mean yield among the tillage methods in both years, yields from the study show a vast improvement in yields under all the tillage methods, particularly in the second year. This suggests that other factors – like mulch, manure and fertilizer, and also having a field with no weeds – contributed to the increase in yield.

The increase in pearl millet yields realized in this study has shown that it is possible greatly to improve the yields of 230 000 farmers through the use of Conservation Tillage practices. It is also important to note that all the principles of CT contribute to the achievement of high yields. Practises like early planting, use of the ripper-furrower to harvest water, fertilizer application, timely weeding, and the availability of crop residues for mulching, and systematic crop rotations and associations could greatly increase the yields. Yields increases are an encouraging factor for the adoption of the NSCT method.

There were no significant differences in mean root length among the tillage methods in the 2011 season, but they were significantly different in 2012. There were also no significant differences in mean root lengths between mulched and un-mulched plots. Both CT methods (TRFmulch and ARFmulch) achieved longer root lengths than the CV methods (TDH and AMP). The greatest mean root lengths were achieved by TRF in both years. Not coincidentally, the tractor-drawn ripper-furrower also achieved highest values for depth of cut, width of furrow, and increase in moisture, as well as mean root length and yield in 2012.

In the farmers' fields, the longest roots were measured in Farmer Keshongo's field. These root lengths were achieved despite the year 2012 to 2013 being a drought year, again suggesting that the TRF method contributed to increased root penetration and harvested some water in the furrows. This reinforces the suggestion that the tractor-drawn ripper-furrower is better used to break the plough pan and to harvest water than the other three methods. This is another reason to suggest that TRF (NSCT) should be used in the first year to break the plough pan and to make furrows, and the animal-drawn drawn ripper can be used in subsequent years.

In this study, TRF produced higher yields overall. From field performance tests TRF achieved greater depths and wider furrows that could harvest water and also reduced PR, resulting on high soil moisture content, longer roots and higher yields. Under TRF, the pearl millet yields from the trials ranged from 1 702 kg ha^{-1} in 2011 to 5 362 kg ha^{-1} in 2012. All tillage methods resulted in increased yields, but TRF produced the highest.

For this study, the hypothesis is not accepted that NSCT significantly improves pearl millet yield compared with CV. All methods resulted in improvement and only one NSCT method (TRF) more than the others.

The use of traditional pearl millet varieties suggested another method whereby it is possible to increase yields per unit area, as was demonstrated by Mr Keshongo who achieved yields of 4 660 kg ha^{-1}. This does not exclude the suggestion that it is possible to achieve high yields through the use of conservation tillage methods, which in this case could also have contributed to high yields in Famer Keshongo's field.

Increasing crop yields is every farmer's dream, although various factors affect the realization of this dream. Having the right implement and power source are important, as implements should be matched to the sizes of the animals and tractors, and also the skill of operation. The implements concerned are important for land preparation, harvesting of water and the achievement of the right depth for roots to penetrate. It is important to find a balance between the right depths that are efficient with regard to draught and also sufficient for roots to penetrate and water to infiltrate the soil, thereby achieving high yields.

8.2.4 Adoption of NSCT technologies by farmers: Omuntele and Ogongo constituencies of Namibia

A key component of this study was the involvement of farmers. This was explored by discussion to find out whether they had knowledge of NSCT, what their attitudes were and if they practised NSCT. The sample of farmers showed that they had some knowledge as well as positive attitudes towards NSCT, but only practised it when the right implement was available to them. The lack of ripping services provided by Government or the private sector for land preparation was one of the major hindrances to increasing the sizes of farmers' fields with NSCT. However, farmers could still maximize yields per unit area by using NSCT if the ripping services were readily available to them or to those with access to the one-hectare support given by MAWF.

For this study NSCT is seen as a stepping stone towards CA. In the present study of farmers' fields in both Ogongo and Omuntele Constituencies, crops on the ripped plots were observed to be healthy compared to the ones in conventionally-tilled fields. Yields were also high from Farmer Keshongo's field which included traditional pearl millet varieties. This suggests that it may be necessary to explore options that include the breeding of traditional varieties for increased yields and biomass. If biomass could be increased, it would then be available for both livestock feed and mulch. From observations made in the farmers' fields, the stalks of the traditional varieties of pearl millet are huge, enough for it to be possible to have enough for animals and mulch.

It might be important for farmers to make use of available resources (i.e. family labour and DAP) is a major determinant of system sustainability. Tractor power and animal power should therefore complement each other whilst the use of the hand hoe, particularly for weeding, can also continue. The three can complement one another even with introduction of NSCT.

This study confirms that farmers in the Ogongo and Omuntele Constituencies need to change to another way of farming, i.e. NSCT, as their crop yields have been unacceptably low under the conventional methods used hitherto. It nonetheless remains crucial that NSCT should be a field-based concept that can be further tested on the farmer's fields, as has been done by MAWF, CES, CLUSA and CONTILL. Any interventions and new practices should ultimately be tested with the farmer in the farmer's field.

This study has also shown that donkeys can be used with the ripper-furrower as the three donkeys together can pull 11.29% of their combined body weight for the plough and 13.37% for the animal-drawn ripper-furrower (respectively 760 and 900 N). It is therefore important that the welfare of donkeys be given priority among the packages that are being offered to smallholder farmers, who have shown in the past that they give little attention to donkeys.

The NSCT implements in this study showed some positive attributes throughout, and this conservation tillage production system therefore holds promise and has the potential to transform Namibian smallholder agriculture into a sustainable and productive crop production strategy. However, pro-active efforts towards the adoption of conservation tillage in Namibia need to be put in place throughout the NCA. At the same time, Conservation Tillage should be seen as a stepping stone towards CA.

8.3 Recommendations and Future Research Needs

It is recommended that the described research be conducted over a longer period of time, at least a minimum of ten years. Since two of the seasons during which this research ran were characterised by low rainfall, it would also be important to test the ripper-furrower under irrigation and try various moisture regimes to determine differences in implement field performance, soil moisture and yield. Small-scale experimentation using rainfall simulators and tillage should be designed specifically to observe the relationships between tillage, soil water movement and yield.

Testing and modelling of the ripper-furrower could be done with all instrumentation available to control certain parameters, for example by using a depth position transducer and accurately measuring the draught forces. This could also be done in the soil bin, where it would be easier to control certain parameters. The soil bin, i.e. laboratory conditions, can ensure the uniformity of the various tests.

It is also recommended that MAWF and NGOs should continue to explore animal-drawn CT implement options, since most farmers have draught animals. These can offer sustainable solutions and can complement tractors. It is recommended that Government and the NGOs strongly support farmers in terms of land preparation services. The MAWF has already been offering subsidized services, but they need to offer more at a reasonable cost for the strategy to be sustainable.

The interminable rise in fuel prices will definitely impact negatively on the operating costs of tractors. Since tractor-drawn equipment is expensive and most smallholder farmers in the NCA use draught animals, it might be important to explore options that address the utilization of animal-drawn CT equipment. Animals still make an important contribution in the crop production system used by smallholder farmers in Ogongo, Omusati and Omuntele, Oshikoto. The use of animal-drawn implements could also limit the damage and compaction caused by tractor wheels during land preparation or weeding.

Further research is required to test the combination in which a tractor-drawn ripper-furrower is used to make furrows and break the plough pan, and thereafter an animal-drawn ripper is used in subsequent years. However, more work needs to be done in order to establish how effective and how often the farmers would need to return to tractor-drawn ripper–furrower use.

Animal-drawn ripper-furrowers still need more work compared to tractor-drawn ripper-furrowers. More work needs to be done to explore the various options that are available for achieving maximum depths and widths with ARF. The use of cattle instead of donkeys could be one option; the use of larger donkey teams could be another.

The amount of compaction caused by tractor wheels during land preparation and other activities in the fields should also be explored in Namibia. This could also be compared with the compaction caused by the plough pan.

Further research is required to show a clear distinction between increases in yield due to NSCT for traditional crop variety and that of improved varieties. This study focused on only one soil type, i.e. sandy soils. Similar studies need to be extended into different soil types in Namibia.

A survey should be undertaken to establish if farmers would access the land preparation service if they were asked to pay for it. It is important to assess the sustainability of the present land preparation service, and to know whether farmers would still use NSCT if they had to pay more to a private provider.

Given the timing of the study for the adoption of NSCT technologies by farmers, the results that were obtained are only suggestive. To confirm these results, it would be necessary to collect evidence to compare changes over time in actual productivity between farmers who used and those that did not use the NSCT technology.

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APPENDICES

Appendix 1: Soil results from Analytical laboratory in Windhoek

ANALYTICAL LABORATORY SERVICES cc

P.O. Box 86782 Eros, Windhoek, Namibia

Tel (061) 210132 Fax (061) 210058 e.mail analab@mweb.com.na

TEST REPORT

To: **University of Namibia**
Crop Science Department
Private Bag 5520
Oshakati
Attn: Ms. B. Mudamburi

Type of Test:		**pH (H_2O)**	**Conductivity**	**Calcium carbonate equivalent**	**Organic carbon**	**Organic matter**	**Phosphorus**	**Sodium**	6	**Magnesium**	**Calcium**
		2:5	**2:5**			calculated	extractable	extractable/exchangeable			
Method details:		electrometric	electrometric	acid neutralisation	Walkey Black	factor = 1.724	Ohlsen	1M ammonium acetate (pH 7.0) followed by ICP.OES			
Units:			mS/m	% $CaCO_3$ equivalent	% m/m C	% m/m OM	mg P /kg	mg Na/kg	mg K/kg	mg Mg/kg	mg Ca/kg
Lab No.											
1	**Soil**	**6.0**	**3.0**	**<0.1**	**0.1**	**0.2**	**13**	**4**	33	**26**	**120**
Type of Test:		**Particle Size Analysis**						**Textural class**			
		pipette method									
Method details:		Sand (>53 µm)		Silt (53.2 µm)		Clay (< 2 µm)					
Units:		%		%		%					
Lab No.											
1	**Soil**	**92.7**		**4.8**		**2.6**		**sand**			

Extractable/exchangeable calcium and magnesium

Since calcium and magnesium carbonates dissolve to a large extent in ammonium acetate at pH 7.0; the concentrations

of these cations are over.estimated in calcareous soils

Assessment of soil fertility

Following interpretation of soil test results is only a very general one.

The soil test values are indictors of the relative available nutrient levels in the depth soil sampled. The soil test values for phosphorus, potassium, calcium and magnesium are not equal to the total amounts of these nutrients available in the soil for plants uptake, but they are correlated with plant growth and yield responses, and with fertiliser needs.

As the soil test values increase, the need for supplemental fertiliser nutrients decreases.

pH (H_2O) pH between 5.2 and 6.0 is moderately acid

A pH value between 5.5 and 6.7 is best for production of most crops

Soil pH affects soil fertility in the following ways:

plant nutrients such as iron, manganese, zinc and others become less available if the pH is too high. Severe deficiencies of these nutrients result in poor plant growth. The elements aluminium and manganese can be toxic to some crops below pH 5.4.

Soil microorganisms are also affected by soil pH.

	Although soil pH is a critical factor in determining response of crops to fertilisers, pH per se is not the factor that adversely affects plant growth.
Organic matter	Organic matter influences physical and chemical properties of soils. It commonly accounts for least half of the cation exchange capacity of surface soils and is responsible for the stability of soil aggregates. Furthermore, it supplies energy and bodybuilding constituents for microorganisms The active rather than the total organic matter content is reported
Phosphorus	levels between 10.20ppm are medium Phosphorus is not very mobile in soil and should thus be incorporated into the soil at the expected rooting depth before planting
Cation	K <150ppm low Mg <60ppm low Ca <1000ppm low Of the three primary cations (potassium, calcium and magnesium), potassium requires the most management attention. If extremely high levels of a single cation exist, plant deficiencies of other cations may occur due to competition for plant uptake. Sodium is not a plant nutrient and therefore is not necessary for plant growth. High levels of sodium are detrimental to soil tilth and plant growth.
Micronutrients	Availability of most micronutrients is largely pH dependent; availability decreases as pH increases (except for molybdenum, which becomes more available as pH increases). Deficiencies rarely occur in soils with pH below 6.5. Lowering soil pH to increase zinc, manganese and iron availability on a field scale is not economical. However, adding acidifying materials such as elemental sulphur to fertiliser mixes can acidify microzones around the fertilizer material and increase micronutrient availability. If you suspect a micronutrient deficiency, plant tissue testing may be a better diagnostic tool than soil testing.
Soil texture	Three broad groups of soil textural classes are recognised: sands, loams and clays. Within each of these groups exist specific textural class names Lightly textured soils (such as sandy soils) have poor water holding capacity and mostly low cation exchange capacities (poor in nutrients)

Appendix 2: Number of tractors purchased by GRN for the 2010/2011 season

Region	**Number of tractors**	**Area of delivery**
Zambezi	7	Bukalo (2x), Sibinda (2x), Chinchimani (2x), Kongola (1x)
Kavango	8	Vungu Irrigation Project
Ohangwena	10	Eenhana ADC
Oshikoto	6	Onankali ADC
Oshana	6	Ongwediva ADC
Omusati	5	Oshikuku ADC (3x) and Outapi (2x)
Kunene North	2	Okangwati ADC and Otjisokotjongava ADCs
Total	**44**	

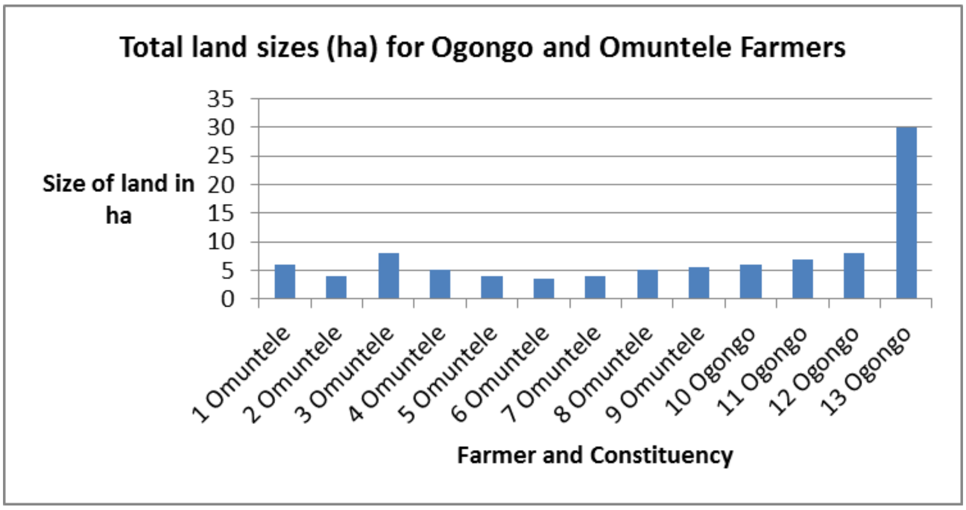
Source: Agricultural Inputs and Household Food Security Assessment Report (2010)

Appendix 3: Farmer data

Appendix 3.1: Farmers Interviewed in Ogongo and Omuntele Constituencies List of farmers that were interviewed and their land sizes for both CA and CV from Omuntele and Ogongo Constituencies

Name of farmer	Village	Constituency	Total Size of land (ha)	Total area of land under NSCT (ha)	Total land under Conventional tillage
Johannes Keshongo	Okakoto	Omuntele	6	3 ha	3 ha
Elizabeth T. Nangula	Okadombo	Omuntele	4	1ha	3ha
Soin Nangula	Okaluwa	Omuntele	8	2.5 ha	1 ha on DAP
Victoria Kalekela	Onamavo	Omuntele	5	2 ha	1 ha
Ester Negongo	Omuntele	Omuntele	4	1 ha	3 ha
Elizabeth Nangula	Omuntele	Omuntele	3.5	1 ha	2.5 ha
Selma Uugulu	Etuli	Omuntele	4	1 ha	3 ha
Cornelia Sheya	Omalangefo	Omuntele	5	1 ha	4 ha
Frieda Samuel	Omuntele	Omuntele	5.5	1 ha	3 ha
Lyetushila Haikukutu	Okeeke	Ogongo	6	30 farrows	3.5 ha
Aina Nekundi	Okapya Kambidhi	Ogongo	7	1 ha	5 ha
Hendrina Shilongo	Okathitu kakathimbi	Ogongo	8	1 ha	3 ha
Elisabeth Erastus	Ombathi	Ogongo	30	1 ha	20 ha

Appendix 3.2 Total land sizes in ha for Ogongo and Omuntele Farmers



Appendix 3.1: Crops Grown by Farmers from Ogongo and Omuntele Constituencies

Farmer	
1 Omuntele	Pearl Millet, .Sorghum, maize, sunflower
2 Omuntele	Pearl Millet, .Sorghum, beans, Bambara nuts
3Omuntele	Pearl Millet, .Sorghum, beans, Bambara nuts, water melon, maize
4Omuntele	Pearl Millet, .Sorghum, beans, Bambara nuts, water melon, maize
5Omuntele	Pearl Millet, .Sorghum, beans, Bambara nuts, maize
6Omuntele	Tomatoes, spinach, green paper, lettuce
7Omuntele	Pearl Millet, .Sorghum, beans, Bambara nuts, water melon, maize, pumpkin and groundnuts
8Omuntele	Pearl Millet, beans, Bambara nuts, pumpkin and groundnuts
9 Omuntele	Pearl Millet, .Sorghum, beans, Bambara nuts, , maize, groundnuts
10 Ogongo	Pearl millet, Sorghum, Maize, Water melons, Cow peas
11 Ogongo	peal millet, Bambara nuts, sorghum, maize, watermelons and cowpeas
12 Ogongo	Pearl millet, Bambara nuts, beans, Sorghum and Maize
13 Ogongo	Pearl millet, Bambara nuts, Cow peas, Sorghum and Maize

Appendix 3.4: Farmers' yields per hectare for 2012 season

Farmer and Constituency	**Yields/ha for previous season**
Omuntele	Pearl millet 200 kg
Omuntele	Poor yield last year but got good yields this year.
Omuntele	Need training on calculating yields
Omuntele	Better than last year and other methods
Omuntele	Need training on calculating yields
Omuntele	More than last year, not threshed
Omuntele	180 kg and need training
Omuntele	Does not know
Omuntele	4 660 kg/ha pearl millet.
Ogongo	Pearl millet (250 kg/ ha), Sorghum (300kg, the whole field), Maize (50kg, whole field) and Cowpeas (300kg, the whole field)
Ogongo	Pearl millet, about 800kg, Sorghum 200kg, and Cowpeas 50kg. Figs for whole field
Ogongo	Pearl millet 300kg, Sorghum 20kg and Maize 20kg
Ogongo	Pearl millet 400kg, Sorghum (not sure), Maize, Cowpeas 100kg

Appendix 4: Tools and equipment available to farmers from Ogongo and Omuntele

Farmer and Constituency	Tools / equipment that the farmer has access to/own, can borrow, can hire / rent
Omuntele	AMP, Tractor ripper borrowed, hoe
Omuntele	TDH, hoe, TRF, ox drawn planter
Omuntele	AMP, TDH, TRF, hand hoe
Omuntele	AMP, TDH, TRF, hand hoe
Omuntele	TRF, TDH, AMP, hoe
Omuntele	TDH, hoe
Omuntele	AMP, TDH, TRF, and hoe.
Omuntele	AMP, TRF, hoe
Omuntele	AMP, TDH and hoe
Ogongo	AMP, TDH and hoe
Ogongo	AMP, TDH and hoe
Ogongo	AMP, TDH and hoe
Ogongo	AMP, TDH and hoe

Appendix 5: Tillage methods that the farmers from Ogongo and Omuntele used and reasons for use of the implements

Farmer	Tillage equipment used in the previous season	Reason for use of the implements
Omuntele	AMP, TRF	Tractors take time to come and cultivates only 1 ha hence the use of DAP
Omuntele	TDH, AMP, TR and hand hoe	DAP is their own and TRF and TDH borrowed
Omuntele	AMP, TRF, TDH	Use TRF to try and see if it's better
Omuntele	AMP, TRF, hand hoe	Tried TRF to see if it would give high yields
Omuntele	AMP, TRF , TDH	TRF mixes soil whilst DAP does not conserve moisture
Omuntele	AMP, TRF, TDH	DAP cheaper and tractors expensive
Omuntele	AMP, TDH, TRF	High yields on TRF, DAP own equipment so don't have to pay for it
Omuntele	AMP, TRF	Tractors take time to come and cultivates only 1 ha so uses DAP
Omuntele	AMP, TDH, TRF	DAP is their own and TRF and TDH is borrowed
Ogongo	AMP	Easier to use
Ogongo	AMP	Tractors are expensive
Ogongo	AMP	Can afford it and that is what they have
Ogongo	AMP	DAP and hand hoes only sources available to them

Appendix 6: Reason for farmers' use of crop rotations and intercropping

Farmer and Constituency	reasons mentioned by farmers for use of crop rotations and intercropping
Omuntele	Beans maintain nutrients in the soil
Omuntele	To improve nutrients
Omuntele	That is what is traditionally used
Omuntele	Change to other crops when yields are not good
Omuntele	To give enough yield
Omuntele	To avoid exhausting the soil
Omuntele	Intercropping you plant everything at once whilst crop rotations improve soil fertility
Omuntele	To avoid poor yield if one repeats same crop
Omuntele	Beans maintain nutrients in the soil
Ogongo	crop rotations to improve nutrients
Ogongo	intercropping Pearl millet and cowpeas to improve soil fertility
Ogongo	intercropping Pearl millet and cowpeas to improve soil fertility
Ogongo	inter-cropping Pearl millet and cowpeas to improve soil fertility

Appendix 7: Changes that have occurred in Farmers' lives as a result of NSCT

Farmer	Changes that have occurred in their lives as a result of NSCT
Omuntele	Takes care of siblings from proceeds that come from NSCT project
Omuntele	Sustainable compared to old method
Omuntele	Gets more yields
Omuntele	Gets good harvest
Omuntele	Improved due to good yields
Omuntele	Able to provide for the family
Omuntele	Life in general has improved
Omuntele	Food not enough for household consumption
Omuntele	Improved a lot and is managing to sell and save money to use in next season
Ogongo	NSCT was easy to handle than CV and the time spent in the field is less
Ogongo	If NSCT was the only method to be use in Namibia at large then no one would suffer from hunger because the NSCT methods brings high yield
Ogongo	during heavy rain, they don't get anything as it will get flooded but when there is not enough rain they planted in furrows and they got high yield
Ogongo	Farmer said she did not have skills and knowledge of how to implement NSCT

Appendix 8: Personal attitude towards NSCT when farmer started and how it had changed now

Farmer	
Omuntele	Method produces high yields and one needs to work harder
Omuntele	More yield
Omuntele	Deciding to use NSCT in all fields
Omuntele	NSCT can help her to get more stalks to fence her house
Omuntele	Good and regretting why he did not start long time ago
Omuntele	Able to provide for family
Omuntele	Improved yield
Omuntele	NSCT good as land preparation is done early
Omuntele	Good for them as they got more yield
Ogongo	It was easy to handle as less time is required to do NSCT
Ogongo	She was having confidence that this method was good
Ogongo	They will continue using NSCT because it gives them high yield
Ogongo	They will be able to get enough yields when NSCT is practiced.

Appendix 9: Perception of neighbours towards NSCT that the farmer practices

Farmer	
Omuntele	Want to join due to high yields. At first was criticized by other farmers
Omuntele	They can see the benefits from yield increases
Omuntele	Others going to register at MAWF to get ripper furrower implements
Omuntele	Willing to take up NSCT and other farmers are coming to ask her about it
Omuntele	Many farmers asking for advice
Omuntele	Many farmers asking to join CLUSA
Omuntele	Others willing to adopt NSCT and use it
Omuntele	Accepted NSCT practice after seeing good results
Omuntele	They want to join due to high yields. At first was criticized by other farmers
Ogongo	Happy with the practice as some requested for the practical to be demonstrated in their field.
Ogongo	Neighbours think it is the best way to use NSCT and many of them are interested
Ogongo	They liked it but they cannot afford to pay the amount of money needed for tillage services
Ogongo	They were impressed by the yield obtained and the practice itself.

Appendix 10: Number of farmers now implementing NSCT as a result of the interviewee's influence

Farmer	
Omuntele	Others willing to adopt but do not know where to get the tractors
Omuntele	Many are willing but implements not readily available
Omuntele	She and other farmers learnt from Tate Keshongo
Omuntele	more than 20 farmers
Omuntele	More than 20 farmers joined
Omuntele	Not sure
Omuntele	Not sure
Omuntele	High influence but implements major problem for successful implementation
Omuntele	Others willing to adopt but do not know where to get the tractors
Ogongo	no one was practicing NSCT as it was expensive
Ogongo	no one was practicing NSCT as it was expensive
Ogongo	no one was practicing NSCT as it was expensive but I have a list of names for some farmers who registered to get tillage services but they are being faced by some challenges such as lack of money to pay for them to be introduced to NSCT
Ogongo	almost the entire village was now using NSCT but on small portions

Appendix 11: Farmers' thoughts about NSCT or conservation tillage

Farmer and Constituency	**What farmers thought about NSCT or conservation tillage**
Omuntele	Happy about using NSCT
Omuntele	Good practice for root development and moisture conservation
Omuntele	Best method for the farmer because of good yields
Omuntele	Good method that increases yields. Plans to use TRF on whole field
Omuntele	Conserves water in the soil
Omuntele	Gets more yields
Omuntele	Good practice for farmers to use
Omuntele	Happy about using CA because of good yields
Omuntele	Good practice for root development and moisture conservation
Ogongo	Used NSCT because of reduction in soil compaction
Ogongo	Good because of water harvesting
Ogongo	It harvests water
Ogongo	Not sure

Appendix 12: Areas of improvement with regards to NSCT

Farmer	Areas of improvement with regards to NSCT
Omuntele	Needs further training since she is a lead farmer
Omuntele	More implements needed, requires ripper and planter
Omuntele	Land preparation to be done early
Omuntele	More implements needed
Omuntele	Need for more implements
Omuntele	Early land preparation is needed
Omuntele	Early land prep, more tractors and implements needed, more vouchers needed for tractors services
Omuntele	On land prep GRN to increase subsidized area from 1 ha to 4 ha
Omuntele	Tractors and implements required
Ogongo	Since their areas were too dry no NSCT is needed as the practice of NSCT needs a loose soil.
Ogongo	Increasing land with NSCT, time and money to pay for services.
Ogongo	They needed to apply fertilizers and manure every year in order to have high yield.
Ogongo	NSCT should not be implemented at the area where floods occur.

Appendix 13: Some of the stories told by farmers that were not asked

Farmer	
Omuntele	Lead farmer for CLUSA and trying to involve other youths if willing
Omuntele	Transport needed to collect manure from elsewhere
Omuntele	Would like to know where to send farmers coming to her for help on NSCT?
Omuntele	Need for GRN to supply farmers with more seed and fertilisers
Omuntele	Ripper yield far better than DAP. Seed difficult to get. GRN to supply seed.
Omuntele	Subsidy on land prep to be increased from 1 ha to 4 ha as 1 ha is too small.
Omuntele	Limited fertilizer, GRN does not pay in time, training other farmers to use NSCT.
Omuntele	Lead farmer for CLUSA and trying to involve other youths if willing
Omuntele	Transport needed to collect manure from elsewhere
Ogongo	Farmers were trained in NSCT and practiced from 2009.2011 but 2012 they used it even though the Agricultural extension did not come and assess what they have done as their contract is over
Ogongo	Agricultural extension will not come and assess what they have done as their contract is over
Ogongo	They are still continuing to using (animal-drawn ripper furrow) as they are getting yield for consumption and income for paying school fees for the children
Ogongo	Did not use the ripper furrower in 2012.

Appendix 14: Case of Mr Keshongo of Omuntele constituency in Oshikoto region.

Mr Johannes Keshongo is a male smallholder farmer from Okakoto village in Omuntele constituency of the Oshikoto region. His total land holding is 6 ha with 1 ha on disc harrow and 5 ha ripped. He uses the ripper furrower, animal-drawn plough, hand hoe and a disc harrow in his fields.

Mr Keshongo is a designated "Lead Farmer" for a number of farmers with the Namibia Conservation Agriculture Project implemented by CLUSA International. Previously he had participated in the CONTILL (LIMA NAWA) project where he received training in 2010. Apart from that, he also participated in the UNDP GEF-SGP Community Based Adaptation to Climate Change pilot project implemented by Creative Entrepreneurs Solutions. He gives demonstrations and holds field days on ripper-furrower technology.

Mr Keshongo's land preparation consisted of ripping and furrowing by MAWF for N$ 150/ha (subsidized at 50%) and a private provider (N$ 470.00/ha). He normally starts planting by hand in September and continues through to November. The crops that he plants are pearl millet maize, bambara nuts, beans, and groundnuts.

He mentioned that for the 2012/2013 season he prepared the land in September and planted with first rains in November. He went on to thin and weed the crops. "I prepared my land early and planted first week of November 2012, having received a heavy rain. It rained on and off until the end of December, but since January I have only received scattered showers. However, the soil moisture in the ripped lines is still high."

He normally uses cover crops, as he intercrops pearl millet and beans (*omakunde*). He also used the hand hoe for weeding because traditionally that's what he has been using. He used manure and compost because it's affordable for him. He attributes the good yields to early land preparation, planting with the first rain, thinning seedlings and applying a mixture of manure and fertilizer

According to Mr Keshongo, ripping and furrowing land preparation can be done throughout the dry season beginning straight after harvest, thus creating optimal planting opportunities for farmers who can then plant with the onset of rain.

The major constraints noticed by Mr. Keshongo are drought, limitation of fertilizer and MAWF is not able to sell to him the amounts that he wants. The implements and tractors are also not as readily available as he would require them. Successful adoption has been greatly hindered by lack of tractors and rippers. He also mentioned that NSCT was not good on steep areas, especially when heavy rains fall because of erosion.

He mentioned that, at the beginning, some of the farmers used to laugh at him but now, after seeing the good yields, they want to implement ripping in their fields as well. Because of planting in rows, weeding has become easier. He has also sold 40% of his produce because of increased yields. In addition, Tate Keshongo used indigenous seed carefully selected from the best performing plants.

He is willing to continue with NSCT even if NCAP pulls out, as he has seen the benefits, especially that of increased yields. Mr. Keshongo got a yield of 4 660 kg per ha in 2013 which was measured for him by the MAWF. His total yields were therefore 23 300 kg. Mr. Keshongo is very happy with the NSCT technology and said "With ripping you can even harvest twice and the stems keep standing strong" "As I witnessed my yields increasing, I have expanded to five hectares under ripping and furrowing. Now I will put my entire farm of seven hectares under NSCT. My neighbours have registered their interest to take up Conservation Tillage."

Appendix 15: Questionnaire for CONTILL (LIMA NAWA) farmers

Date of visit:
Interviewer:

Introduction
Introduction of team members.
The purpose of this survey is to learn and document NSCT experiences from farmers of Ogongo/Omuntele Constituency. 2. To draw key lessons from these experiences for improved NSCT in future. 3. To identify farmer perceived information gaps on NSCT and draw key guidelines for further development of NSCT .4. To measure penetration resistance in farmers' field that was prepared by conservation tillage (ripper or ripper furrower) and one that was prepared by Conventional tillage (plough or disc harrow). Your responses will be used to prepare a report for study purposes; we appreciate your participation in this survey. Do you have time to participate? If yes go ahead and ask the questions. Afterwards ask farmer to show where the two fields are and on to measure penetration resistance and infiltration rate. Only one of each field needed. Collect ten random samples.

A. Respondent Details
Name:
Region:
Village:
Extension centre/ADC:
Mobile number (explain reason for asking for telephone):
What is your status in the household?
Sex of the respondent:
Land holding size for respondent/household:
Main livelihood sources. List at least three in order of importance:
Land ownership. What size of land do you own?
Do you own the land?

B. Agricultural Practices and Land preparation

1. Which crops is the farmer planting?
2. How does the farmer do land preparation? How do you prepare your fields? 1. By hand 2.animal power 3. tractor (tick all that apply and add if other)
3. Reasons for use of the above? Are they affordable?
4. Which of the following tools / equipment do you have access to/own, can borrow, Can hire / rent

a. Plough
b. Disc harrow
c. ripper
d. hoe
e. ox-drawn planter
f. jab planter
g. other

(Specify whether <u>animal-drawn</u> or tractor drawn where applicable)

5. Which of the following tillage methods did you use last season on any of your fields? tick all that apply

a. Conventional plough ox-drawn
b. tractor drawn plough/disc harrow
c. permanent planting basins (potholes)

d. Tractor ripper
e. other:

6. Reason for use of the above?

KNOWLEDGE

7. Which method do you use for protecting soil – practices
a. retention of crop residues
b. mulching
c. cover crop (specify):
d. animal exclusion
e. other:

8. Which method do you use for Planting
a. no till planter ox-drawn
b. no till planter tractor drawn
c. jab planter
d. hand hoe
e. other using hands

9. Reason for use of the above?

10. Which method do you use for weed control
    a. hand weeding (including hoe)
    b. mechanical weeding
    c. herbicides
    d. winter weeding
    e. other:
    f. Reason for use of the above?

11. Which method do you use for improving soil fertility – practices
a. crop rotations which crops________________
b. inter-cropping which crops________________
c. improved FALLOWs which species____________
d. other:
e. Reason for use of the above?

12. Which method do you use for improving soil fertility – additives
a. compost

b. manure
c. termitaria (ant hill clay)
d. basal dressing:
e. top dressing:
f. other:

13. Reason for use of the above?

14. Is the farmer using the tillage practice that they are using on their own or they are being assisted by an organisation? Explain further.

15. If it is an organisation will the farmer continue to use the method after the organisation has pulled out? Explain further.

16. Crop-livestock integration
a. fencing specify type (wire or live or both)_____
b. used manure for fertilizer
c. used livestock for draught power
d. used crop residue for livestock feed
e. planted forage crops
f. other:

17. Which method do you use for pest control
a. commercial pesticides
b. homemade bio pesticides
c. biological, control
18. When does the farmer do land preparation and when does the farmer do planting?

19. What are the reasons for the farmer to choose these methods?
- Water harvesting
- Increased root development
- Reduction in soil compaction
- Other..

20. If farmer chooses reduction in soil compaction or water harvesting ask if they understand the concept of soil compaction and water harvesting.

21. Have you heard of conservation agriculture/ conservation tillage? yes no
a. If yes, from where?
b. If yes, what do you think about NSCT or conservation tillage?

22. Have you received any training on conservation agriculture? yes no
23. If no, how and when did the farmer acquire the knowledge that they have?
24. Ask farmer to explain NSCT method that they are using
25. In which year did you start practicing NSCT?
26. Which farm equipment did you use?
27. What is the area of land under NSCT?
28. How much land is under Conventional farming?
29. Which crop is the farmer growing?
30. How much yield do you get per hectare for the mentioned crops grown?
31. Is there any incremental benefit in terms of yield from NSCT compared to Conventional practices?
32. Labour. What is the source of your farm labour? Do you hire labour for your NSCT fields?
33. Is NSCT reducing or increasing labour? If either how?
34. Market. Do you produce for the market?
35. What percentage of the yield do you take to the market (specify the crop)?
36. When do you sell the produce (e.g. soon after harvest or later when the season is dry)?

ATTITUDE

37. Food security. Do you produce enough food for your household consumption?
38. If you don't produce enough, how do you cope for the remainder of the year?
39. Success and challenges. What are the factors leading to successes of NSCT?
40. What are the typical successes / achievements from NSCT?
41. What challenges did you meet and how did you overcome them?
42. Livelihood impacts. What are the changes that have occurred in your life as a result of NSCT?
43. What was your personal attitude towards NSCT when you started? How has it changed now?
44. What is the perception of your neighbours towards the NSCT you practice?
45. How many farmers are now implementing NSCT as a result of your influence?
46. What do you think are the areas of improvement with regards to NSCT?
47. What are the major agricultural related challenges that the household faces
48. Below are some of the stories told by individual farmers that were not asked in the questionnaire

Appendix 16 : List of Published and Presented Articles from this study

1. B. Mudamburi, A Ogunmokun, B Kachigunda & J Kaurivi (2012). A Comparison of Conventional and Conservation Tillage Implements Used for Crop Production in Omusati Region of Northern Namibia." Published in the Journal of the International Conference on Environmental and Agriculture Engineering IPCBEE vol.37 pp 73-78.
2. Mudamburi B, Ogunmokun A & Kachigunda B (2014). Pearl millet's root lengths and yields under conventional and conservation tillage methods in Ogongo, Namibia. Book of condensed papers, African Congress on Conservation Agriculture. 1ACCA conference in Lusaka, Zambia. pp 119-122.
3. Mudamburi B, Ogunmokun A & Kachigunda B (2015). A Comparison of the Namibia Specific Conservation Ripping Techniques of Animal-drawn Ripper Furrower in Ogongo, Namibia. Presented at the 3rd Annual Science Research Conference "Innovation: the Heart of Development". UNAM, November 18-19, 2015.