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A Comparison of the Effects of Conventional and Namibia Specific Conservation Tillage Methods Used in Ogongo, Namibia on Root Development and Yield of Pearl Millet. Volume 1

Bertha Mudamburi[a*], Adedayo Akinade Ogunmokun[b], Barbara Kachigunda[c]

[a,c]University of Namibia (UNAM), Ogongo Campus, P Bag 5520, Oshakati. Namibia

[b]UNAM, Faculty of Engineering and Information Technology, P. O. Box 3624, Ongwediva. Namibia

[a]Email: bmudamburi@gmail.com, [b]Email: aogunmokun@unam.na, [c]Email: bkachigunda@gmail.com

Abstract

Studies were conducted at the Ogongo Campus of University of Namibia between 2011 and 2012 to compare the differences between two conventional tillage (CV) treatments (i.e. tractor - drawn disc harrow (TDH) and animal - drawn mouldboard plough (AMP) and two NSCT treatments (tractor - drawn ripper furrower (TRF) and animal - drawn ripper furrowers (ARF) used by farmers in the Northern Communal Areas (NCA) of Namibia. This paper is the first volume of a series of papers to report on the comparisons of the two technologies on field performances of tillage methods and their effects on moisture, compaction, roots and yield. For this paper, the parameters evaluated were root length and yield. The research design was a split plot design with tillage as main plot treatment whilst mulch was the sub plot treatment. Yields were not significantly influenced by tillage ($p = 0.410$ in 2011 and 0.078 in 2012) but root length were significantly influenced by tillage in the second year ($p<0.005$). There were no significant differences in mulched plots vs unmulched plots among the tillage methods. Both NSCT methods (TRF with mulch and ARF with mulch) achieved longer root lengths than CV methods (TDH and AMP) by 24.5% and 8.5% respectively. Tractor ripper furrower (TRF) achieved the longest mean roots and yields in 2012. The NSCT methods (TRF and ARF) achieved higher yields than CV methods (TDH and AMP) by 10.1% and 11% respectively. The results also suggests that farmers' yields can be increased from an average of 400 kg ha^{-1} through better management that includes use of CT implements, manure, fertilizer and mulch.

Keywords: conservation tillage; conventional tillage; root development; yields.

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* Corresponding author.

1. Introduction

More than 70% of the population of Namibia's two million people depend on agriculture for their livelihood [1 - 3]. Pearl millet (*Pennisetum glaucum*) is the most widely grown crop by small holder farmers in Northern Communal Areas (NCA) of Namibia and it is also their staple food. The yields of pearl millet (also known as mahangu locally) from these small holder farms are extremely low at about 400 kg ha^{-1} [4-7]. This low yield has been blamed on removal of all crop residues (stover), either for livestock or other domestic use, mono-cropping of pearl millet crops leading to deterioration of the farm's ecology [7, 8] and by the frequent disturbance of top soil by ploughing [4, 7, 9].

The NCA is characterised by sandy soils that are highly susceptible to many forms of degradation which manifests in the form of soil erosion, decline in soil fertility, deforestation, flash flooding, declining water tables and river flows [6, 10]. Farmers in these areas prepare their fields using Conventional Tillage (CV) practices i.e. mouldboard ploughing, disc ploughing and/or harrowing [4, 5]. 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 [4, 5, 7, 9 -12]. References [10 -12] 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 CV systems has resulted in reduced root growth [13 -15] thereby affecting water and nutrient uptake by crops and thus resulting in lower yields.

In trying to address some of the problems in the NCA, a Conservation Tillage (CONTILL) project was implemented in Northern Namibia between 2005 and 2011 [8, 9]. The project involved setting up demonstration plots in farmers' fields across the NCA, based on what is termed the Namibia Specific Conservation Tillage (NSCT) method [8, 9]. The method makes use of the animal-drawn or tractor-drawn ripper-furrowers to rip and make furrows in one operation. The technology also emphasizes the use of mulch, manure and crop rotations. The NSCT was reported to have improved some farmers' pearl millet yields to 1500 kg ha^{-1} to 3 063 kg ha^{-1} which is 5 to 8 times higher than the national average of 225 to 400 kg ha^{-1} [4, 7, 16]

Conservation Tillage (CT) is operationally defined as any tillage or tillage and planting combination which leaves 30% or more mulch or crop cover on the surface [11, 12, 17-19]. Other researchers [20, 21] defined CT as any tillage system that conserves water and soil while saving labour and traction needs.

Various researchers have reported different results on field performances of 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 [11] and maybe other reasons.

Yield is a major factor in farm-level profitability, and the most documented in literature. Generally, crop yields in Sub Saharan Africa (SSA) are very low when compared with other regions in the world. For example, the 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, as cited by [22]. A number of researchers have reported increased yields from CT [23-31]. References [32,33], in contrast, reported yields reductions of various crops under minimum tillage methods as compared to CV methods. Others [33 -36] also reported that no-till had no positive effect on yields of various crops. This suggests that there are no significant differences between CT and CV when it comes to yield. However, Reference [37] showed that tillage methods significantly ($p \leq 0.05$) influenced the yield of tomatoes. Several studies reported that a high penetration resistance in CV systems resulted in a lower root growth thereby affecting yield [13, 38 - 40].

Despite its touted excellent increases in pearl millet yield, fewer farmers than anticipated have adopted the NSCT technology in the NCA since its inception, making one wonder what the reasons could be. Few researches have been carried out in the NCA to compare the field performances of animal- and tractor- drawn tillage technologies and how they affect the root lengths and yields of pearl millet.

2. Objective and Hypothesis of the Study

The objective of this study was to compare the effects of two NSCT technologies to those of two CV technologies on root development and yield of pearl millet under NCA conditions in Namibia. The two conventional tillage (CV) technologies/treatments are tractor - drawn disc harrow (TDH) and animal - drawn mouldboard plough (AMP) whilst the two NSCT treatments are tractor - drawn ripper furrower (TRF) and animal - drawn ripper furrowers (ARF). It was hypothesized that the use of NSCT technologies can result in significantly increased root lengths and yields of pearl millet when compared to the use of CV Technologies at the 95% CI.

3. Materials and Methods

On-station trials to compare CV and NSCT technologies under NCA conditions in Namibia were carried out at the Ogongo Campus of the University of Namibia (UNAM) between 2010 and 2012. The Ogongo Campus is located in Omusati Region which is one of the 8 regions that constitute the Northern Communal Areas (NCA) of Namibia. The rainfall of Ogongo is seasonal, falling mostly between the months of November and April [41]. The mean annual rainfall is between 300 and 500 mm [42]. However, an above average total rainfall of 621.6 mm was recorded at Ogongo from December 2010 to May 2011 while an average rainfall of 377.4 mm was recorded in the following year, from December 2011 to May 2012. Samples of soils taken at five randomly selected places at the research site in Ogongo was analysed at the Analytical Laboratory Services in Windhoek. The soil was found to be sandy with particle size analysis indicating 92.7 % sand, with 4.8 % silt and 2.6 % clay.

Limitations: The trials in this study were designed to run for three seasons. However, 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 as the crops were established very late. As a consequence, there was no harvest 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.

The research 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, totaling 32 plots. 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. Research trials comprised four treatments namely: (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 random application of treatments to plots was carried out using Genstat, 4th Edition. The specifications of the power sources (tractors and donkeys) and the CV and NSCT implements used in the study are outlined in Table 1.

Table 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	Standard animal-drawn single furrow plough (AMP)	Conventional tillage	Standard V8 mouldboard plough	0.2 m
3 Donkeys Total mass - 673.2 kg	Animal-drawn ripper furrower (ARF)	Namibia Specific Conservation Tillage	Baufis ripper-furrower	0.1m
Tractors John Deer 5415 (65kW) and 2351 (55kW)	Tractor-drawn offset disc harrow (TDH)	Conventional tillage	Offset .20 discs	2.2 m
Tractors John Deer 5415 (65kW) and 2351 (55kW)	Tractor-drawn ripper furrower (TRF)	Namibia Specific Conservation tillage	Baufis 2-tine	1.85m

The CV plots were conventionally tilled using an animal-drawn mouldboard plough or a tractor-drawn disc harrow, whilst the NSCT plots were prepared using an animal-drawn ripper furrower or a tractor-drawn ripper furrower. As is common among NCA small holder farmers, donkeys were used as draught animals. Seeds were planted along straight lines for the CV plots and along the ripped furrows in the NSCT plots. The same planting lines were used within each plot for both seasons following the 'Principle of Constant Traffic'. One meter inter-row spacing and in-row spacing of 25 cm was used. The plant population used is as recommended for pearl millet in the NSCT method which is 80 000 plants per hectare or 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 is double the pearl millet seed rate normally used by small scale farmers in the NCA. However, it was decided to use the higher seed rate so as have results that can be comparable to yields from other NSCT studies. For all treatments and 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 knee height, ammonium nitrate was also applied at 150 kg per ha. The plots were hand-weeded two to three times during the growing season, depending on weed intensities. 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.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 washed in water [43, 44] and then separated carefully from the whole plant and measured from the base of the stem to the tip of the root. 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. The yields for whole plots were also measured and recorded. The data were first subjected to normality tests before analysis of variance (ANOVA) tests using Genstat were used to test for any significant differences in yields and root length among all treatments (AMP, ARF, TDH, and TRF). ANOVA was also used to test for interaction between tillage and mulching, and the main effects of tillage and mulching on root length and yield. Alpha levels of 0.05 were used to determine the level of significance among the means.

4. Results and Discussions

4.1 Pearl Millet Root Length

Table 2 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, each NSCT method resulted in longer roots for pearl millet that the corresponding CV method i.e. roots under TRF were longer than under TDH, and roots were longer under ARF than under AMP. However, mulching at 3 tons/ha seems to have no effect on mean root lengths compared to no mulching condition.

Table 2: Pearl Millet Mean Root Lengths

Tillage treatment	2011 Mean Root Length (cm)			2012 Mean Root Length (cm)		
	Mulch	**No Mulch**	**Overall**	**Mulch**	**No Mulch**	**Overall**
AMP	22.5	22.9	22.7	23.8	23.5	23.65
ARF	24.7	22.9	23.8	26.0	22.5	24.25
TDH	23.5	24.5	24.0	25.3	24.3	24.8
TRF	30.1	29.1	29.6	33.5	31.0	32.25

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 due to moisture and fertilizer becoming more available in the second year of the NSCT plots, making it possible for the crops to utilize it better as highlighted by [45]. The NSCT methods (TRF and ARF) with mulch resulted in longer roots than the CV methods (TDH and AMP) with mulch (Table 2) by 24.5% and 8.5% for tractor and animal drawn systems respectively. However, similar to the 2011 results, there were also no significant differences between the mean root lengths of mulched and un-mulched plots. This could be because the rate of mulching was too low (at 3 ton/ha) for there to be a noticeable effect.

For both years (2011 and 2012), the longest roots overall were found under the TRF method. The presence of longer roots under TRF is also in line with [46] who concluded that sub-soiling not only increased the yield of cotton but also improved penetration resistance to ensure root propagation.

4.2 Pearl Millet Yields

Table 3 shows pearl millet yields for the different tillage technologies (NSCT and CV) for mulched and unmulched plots. There were no significant differences (p = 0.410 in 2011 and 0.078 in 2012) in mean yields among the tillage methods. In addition, no significant differences (p = 0.758 in 2011 and 0.348 in 2012) in mean yield for the mulch treatments were observed.

Table 3: Pearl Millet Yields for the different tillage Technologies

Tillage Treatment	**2011 Mean Pearl Millet Yield (kg ha^{-1})**			**2012 Mean Pearl Millet Yield (kg ha^{-1})**		
	Mulch	**No Mulch**	**Average**	**Mulch**	**No Mulch**	**Overall**
AMP	1415	1505	1460	4434	4241	4337.5
ARF	1547	1516	1531.5	4981	4759	4870
TDH	1544	1608	1576	4587	4823	4705
TRF	1702	1652	1677	5362	5344	5353

(No significant difference among treatments)

The findings of this study are consistent with those of other researchers [33 - 36] who have shown that there are no significant differences between CT and CV when it comes to yield; meaning that differences in the tillage methods had no effect on crop yield. Moreover, Reference [47], 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 and found no change over time in the weighted mean differences in maize grain yield, and therefore No Till had no positive effect on maize yield compared with conventional tillage.

Reference [47] also showed that, in the first 10 years, crop yields under No Till were lower than under conventional tillage practices. However, Reference [31] reported 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 CV in Zambia and Zimbabwe. These contradictions could be attributable to there being no standardization in tillage research worldwide, as stated by [11] who maintained that there was a need to standardize tillage 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 2012 both NSCT methods – TRF (10.1%) and ARF (11%) – achieved higher yields than their corresponding CV methods -TDH and AMP. Whilst there were no significant differences in mean yield among the tillage methods in both years, there were vast improvements in the yields under all four tillage methods, between the years. The yields in the second year were generally three times greater than the yields in the first year. This suggests that other factors than tillage types contributed to the increase in yield, such as early planting, mulch, manure and fertiliser, and also having a clean field with no weeds.

Reference [47] reported that crop productivity under conservation agriculture depends more 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 and his colleagues [34] 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 variations in yields.

Other researchers have shown that CT gives better yields than CV. For instance, Reference [28] showed that No Till achieved greater yields than CV. Reference [27] 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 CV, respectively. The high increase in yields in the second year in the current study is also in line with results from Zimbabwe that have also shown that nutrients like nitrogen from manure become more available to crops in the second season of application [45].

Another observation is that yield results achieved in this study even under conventional tillage systems were 5-10 times higher than yields achieved by the NCA farmers under similar conventional systems. One of the reasons for the high yields recorded in this study could be the plant population of 80 000 plants per ha (as recommended for NSCT) that was used compared to 40 000 plants per ha that the extension services normally recommend to farmers.

This means that, NCA farmers should be advised to leave two plants per station instead of one when they are thinning out their pearl millet seedlings. 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 among most of the NCA farmers.

An increase in yield could also be attributed to the use of 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 the NSCT methods.

Table 4 compares the yields achieved under the TRF systems in this study with those achieved under the NSCT system by the CONTILL project and those under farmer Keshongo from the Omuntele Constituency who also used the NSCT system.

Table 4: Comparison of TRF On-station Pearl Millet Yields with those of CONTILLand Farmer Keshongo

Station	**Yield in kg ha^{-1}**
Highest TRF On-station Yields (2012)	5 362
Lowest TRF On-station Yields (2012)	1652
CONTILL Omusati yields – highest (2010-11)	3 063
CONTILL 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 [48] reported that in good seasons, the yield of the indigenous farmers' local varieties are just as good as, or even better than, the improved varieties of pearl millet available to small scale farmers in NCA, although they take longer to mature, (up to 120 days) compared to the shorter-maturing new varieties.

5. Conclusion

This study showed that, in both years there were no significant differences in mean pearl millet yield among the four tillage methods. There were also no significant differences in mean yield between mulched and un-mulched plots. The hypothesis that the NSCT methods used in this study will significantly improve pearl millet yields compared with CV methods was therefore rejected. In 2012 both NSCT methods – TRF (10.1%) and ARF (11%) – achieved higher yields than the CV methods of TDH and AMP. Although there were no significant differences in mean yield among the tillage methods in both years, yields from the study was better than yields under smallholder farmers in the NCA, particularly in the second year. This suggests that other factors than tillage methods– like mulch, manure and fertilizer, and also having a field with no weeds – contributed to the increase in yield. The Tractor Ripper Furrower method produced the highest pearl millet yields overall ranging from 1 702 kg ha^{-1} in 2011 to 5 362 kg ha^{-1} in 2012.

The present study also shows that it is important to have high plant populations where possible, so that when farmers thin out the pearl millet they leave two plants per station instead of one. However, this will only work if there is enough manure and fertilizer, timely weeding, crop residues available for mulching, and systematic crop rotations – all of which are currently lacking in the NCAs of Namibia. The control of traffic has also shown that it could help to increase yields, as one result is that manure and fertilizer are applied at more or less the same place in the furrows. Water is also harvested in the same furrows.

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 NSCT methods (TRF with mulch and ARF with mulch) achieved longer pearl millet roots than CV methods (TDH and AMP) by 24.5% and 8.5% respectively. The greatest mean root lengths were achieved by TRF in both years.

The pearl millet (*Pennisetum glaucum*) yields of Namibian smallholder farmers have been reported to be extremely low, at around 400 kg ha^{-1} [4, 5, 49]. The increase in yields as observed in the present study can greatly improve the pearl millet yields of 230 000 farmers in the NCAs through the use of NSCT and CT practices in general. Technologies such as early planting, 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. Yields increases are an encouraging factor for the adoption of the NSCT method by farmers.

6. Recommendations

It is recommended that this 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 yield and root lengths. Small-scale experimentation using rainfall simulators and tillage should be designed specifically to observe the relationships between tillage, soil water movement and yield.

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. Given the timing of the study, 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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References

[1]. AGRI Views, Newsletter Edition 1. Ministry of Agriculture, Water and Forestry.

http://www.mawf.gov.na/Documents/AgriViews_Newsletter_new.pdf, 2010. [1st May 2013]

[2]. P. Shifeta, "No such thing as a free lunch – Invest in healthy soils" Statement by Minister of Environment and Tourism, Hon. Pohamba Shifeta On behalf of His Excellency, President of the Republic of Namibia, Dr. Hage Geingob. On the occasion of the world day to combat desertification. Global observance event. Wednesday 17th June 2015 Conference Center, Expo Milano, Italy, 2015.

[3]. NSA, "Namibia Census of Agriculture 2013/2014" Communal Sector Report, November, 2015.

[4]. R. Davis and P. Lenhardt, "Namibia-specific Conservation Tillage On-farm Trials: 2005.2009". Paper presented at Agrison Conference 2009 at Oshakati Country Club, Namibia, 2009.

[5]. Mahangu and Sorghum Task Team (MSTT), "Position paper on Land Preparation prepared for Ministry of Agriculture, Water and Forestry". Windhoek. Namibian Agronomic Board, 2009.

[6]. FAO, "Namibia Country Program. Conservation Agriculture Capacity Building and Expansion Project in the SADC Region" (CAESAR), 2009.

[7]. F. von Hase, "Facilitating Conservation Agriculture in Namibia through Understanding Farmers Understanding Farmers' Planned Behaviour and Decision Making". Master's Thesis in Agricultural Science 30 HEC Advanced level, A2E Agro ecology – Master's programme. Självständigt arbete vid LTJ.fakulteten, SLU Alnarp, 2013.

[8]. Contill (Conservation Tillage Project), "Reports. Windhoek, Namibia: Conservation Tillage Project and Namibia Agronomic Board", 2009.

[9]. NAB, "Conservation Tillage Project (CONTILL (LIMA NAWA) reports" Windhoek, Namibia: Namibian Agronomic Board, 2009.

[10]. FAO, "Conservation Agriculture". http://www.fao.org/ag/ca, 2014. [30 March 2014].

[11]. R. Derpsch, A.J Franzluebbers, S.W. Duiker, D.C. Reicosky and K. Koeller. "Why do we need to standardize no-tillage research?" Letter to the Editor. Soil & Tillage Research 137, 16–22, 2014.

[12]. D. Reicosky, "Conservation tillage is not conservation agriculture". Journal of Soil and Water Conservation. Vol 70.NO 5. doi:10.2489/jswc.70.5.103A, 2015. Openly accessible at http://www.jswconline.org/. [1st October 2015].

[13]. B.J. Atwell, "Response of roots mechanical impedance". Environ. Exp. Bot. 33, 27–40, 1993.

[14]. J.M. Reichert, V.R. da Silva and D.J. Reinert, "Soil moisture, penetration resistance, and least limiting water range for three soil management systems and black beans yield". ISCO 2004. 13th International Soil Conservation Organisation Conference – Brisbane, July 2004. Conserving Soil and Water for Society: Sharing Solutions, Paper No. 721 page 1, 2004.

[15]. H.B. So, A. Grabski and P. Desborough, "The Impact of 14 Years of Conventional and No-Till Cultivation on the Physical Properties and Crop Yields of a Loam Soil at Grafton NSW", Australia. Soil and Tillage Research 104, 180–184, 2009.

[16]. NCBA, "Conservation Agriculture Program for Northern Namibia to Help Mitigate Drought Disasters". Program Description. Washington, National Cooperative Business Association's CLUSA International Program, 2012.

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

[18]. ACT, Newsletter, 21 November, 2003. Harare: University of Zimbabwe and the African Conservation

Tillage Network, 2005.

[19]. ASABE, “EP291.3 FEB2005 Standards: Terminology and Definitions for Soil Tillage and Soil-Tool Relationships”, 51st ed. ASABE, St. Joseph, MI. 2005.

[20]. J. Rockstrom, P. Kaumbutho, P. Mwalley and M. Temesgen, “Conservation Farming among small-holder farmers in E. Africa: Adapting and adopting innovative land management options. Conservation agriculture, a worldwide challenge”. In: Proceedings of the First World Congress on Conservation Agriculture, vol. 1: Keynote Contributions, Madrid, Spain, October 1–5, 363–374, 2001.

[21]. D. Hunt, Farm Power and Machinery Management. Tenth edition. 2001. Iowa State University Press, 2001.

[22]. FAO & UNIDO, “Agricultural mechanisation in Africa … Time for action: planning investment for enhanced agricultural productivity”. Report of an expert group meeting jointly held by FAO and UNIDO in Vienna on 29–30 November 2007. Rome, FAO. 26 pp, 2008.

[23]. E. Scopel, F.Tardieu, G.O. Ema, and M. Sebillotte, “Effects of conservation tillage on water supply and rain fed maize production in semi-arid zones of West-Central Mexico”. NRG paper 01.01. Mexico, D.F.: CIMMYT, 32-47, 2001.

[24]. M. Diaz-Zorita, G. A. Duarte and J. H. Grove, “A Review of No-till Systems and Soil Management for Sustainable Crop Production in the Sub humid and Semi-arid Pampas of Argentina”. Soil Till. Res. 65, 1-25, 2002.

[25]. J. Rockstrom, “Potential of rainwater harvesting to reduce pressure on freshwater resources”. Paper Prepared for the Dialogue on Water for Food and Environment, International Water Conference, Hanoi, Vietnam, 2002.

[26]. S. Haggblade and G. Tembo, “Early Evidence on Conservation Farming in Zambia”. Paper presented at the Conference: Reconciling Rural Poverty and Resource Conservation: Identifying Relationships and Remedies held at Cornell University, May 2.3, 2003. Ithaca, N.Y.: Cornell University, 2003.

[27]. T. D. Dilallessa, “Effect of tillage system, residue management and nitrogen fertilization on maize production in Western Ethiopia”. Unpublished PhD. University of the Free State, Bloemfontein, South Africa, 2006.

[28]. P. De Vita, E. Di Paolo, G. Fecondo, N. Di. Fonzo and M. Pisante, “No-tillage and Conventional tillage effects on durum wheat yield, grain quality and soil moisture content in southern Italy”. Soil and Tillage Research, 92, 69-78, 2007.

[29]. W. Mupangwa, S. Twomlow and S. Walker, “Conservation Tillage for Soil Water Management in the Semi-Arid Southern Zimbabwe”. Journal of Physics and Chemistry of the Earth.33 in press, 2008.

[30]. M. Rashidi and S. Abbassi, “Effect of Different Tillage Methods on Root Yield, Yield Components and Quality of Sugar Beet (Beta vulgaris)”. Libyan Agriculture Research Center Journal International 2 (2), 51-56, 2011.

[31]. K. Mazvimavi, “Socio-Economic Analysis of Conservation Agriculture in Southern Africa”. Food and Agricultural Organization of the United Nations (FAO). © FAO 2011 Regional Emergency Office for Southern Africa (REOSA). Network Paper 02 January 2011. ISBN 978.92.5.106761.1. ISSN 2220.5144, 2011.

[32]. C.K. Cavalaris and T.A. Gemtos, “Evaluation of four conservation tillage methods in the Sugar Beet

Crop". Agricultural Engineering International: the CIGR Journal of Scientific Research and Development IV. Manuscript LW 01 008 6, 1- 24, 2002.

[33]. L. Rusinamhodzi, M. Corbeels, M.T. Van Wijk, M.C. Rufino, J. Nyamangara and K.E. Giller, "A meta-analysis of long term effects of conservation agriculture on maize grain yield under rain-fed conditions". Agronomy for Sustainable Development 31, 657- 673, 2011.

[34]. R.F Dam, B.B Mehdi, M.S.E. Burgess, C.A. Madramootoo, G.R. Mehuys and I.R. Callum, "Soil bulk density and crop yield under eleven consecutive years of corn with different tillage and residue practices in a sandy loam soil in central Canada". Soil and Tillage Research 84, 41-53, 2005.

[35]. P. Kaumbutho and J. Kienzle, (Eds.) "Conservation agriculture as practised in Kenya: two case studies". African Conservation Tillage Network (ACT), Centre de Coopération Internationale de Recherche Agronomique pour le Développement (CIRAD), Food and Agriculture Organization of the United Nations (FAO), Nairobi, Paris, Rome, 2007.

[36]. I. Małecka, A. Blecharczyk, Z. Sawinska and T. Dobrzeniecki, "The effect of various long-term tillage systems on soil properties and spring barley yield". Turk J Argic 36, 217-226. doi:10.3906/tar.1104.20, 2012.

[37]. M. Rashidi, M. Gholami and S. Abbassi, "Effect of different tillage methods on yield and yield components of tomato (lycopersicon esculentum)". ARPN Journal of Agricultural and Biological Science ©2006.2010 Asian Research Publishing Network (ARPN). Vol. 5, No. 2, 26-30, 2010.

[38]. M. Petersen, P. Ayers and D. Westfall, "Managing Soil Compaction" CSU Cooperative Extension Agriculture No: 0519, 2004.

[39]. L. G Wells, T. S. Stombaugh and S. A. Sheraer, "Crop yield response to precision deep tillage". Trans. ASAE 48 (3), 895-901, 2005.

[40]. R. L. Raper, "In-row sub-soiling south eastern soils to reduce compaction and improve crop yield". Southern Conservation Systems Conference, Amarillo TX, June 26.28, 2006.

[41]. J. Mendelsohn, S. El Obeid and C. Roberts, A profile of North Central Namibia. Gamsberg Macmillan. Windhoek, 2000. pp 1-79.

[42]. U. Kuvare, T. Maharero and G. Kamupingene, "Research on Farming Systems Change to Enable Adaptation to Climate Change". Undertaken for the Ministry of Environment and Tourism and the United Nations Development Program Namibia, in preparation of Namibia's Second National Communication to the United Nations Framework Convention on Climate Change, 2008.

[43]. W. Bohm, "Methods of Studying Root Systems". Springer-Verlag, Berlin, 1979.

[44]. J.B., Fehrenbacher and J.D. Alexander. "A method for studying corn root distribution using soil-core sampling machine and a shaker-type washer. Agron. J. 47, 468-472, 1955.

[45]. J. Nyamangara, L.F. Bergstrorn, M.I. Piha and K.E. Giller, "Fertilizer use efficiency and nitrate leaching in a tropical sandy soil. Journal of Environmental Quality 32, 599-606, 2003.

[46]. A.M. Borghei, J. Taghenejad, S. Minaei, M. Karimi and M. Ghasemi Varnamkhasti, "Effect of sub soiling on soil bulk density, penetration resistance and cotton yield in northwest of Iran". International Journal of Agriculture & Biology.10, 120-123, 2008.

[47]. L. Rusinamhodzi, "NUANCES and NUISANCES: Crop production intensification options for smallholder farming systems of southern Africa". PhD Thesis, Wageningen University, Wageningen,

NL. ISBN: 978.94.6173.573.7, 2013.

[48]. D. Uno, “Famer's Selection of Local and Improved Pear Millet Varieties in Ovamboland, Northern Namibia. African Study Monographs”, 30,107.117. Supplementary issue (2005), 30: pp 107-117. Kyoto University. Available at http://hdl.handle.net/2433/68457. African Study Monographs, Suppl.30, 107-117, March, 2005.

[49]. P. Vigne and Associates, “An investigation of Possible Future MAWRD Interventions to Support Agronomic Mechanisation (Tractors) in the Communal Areas”. Phase 2 Regional Situation Review. Presented to the Namibian Agronomic Board 14 May, 2004.