International Journal of Recent Engineering Research and Development (IJRERD)
ISSN: 2455-8761
www.ijrerd.com || Volume 04 – Issue 02 || February 2019 || PP. 48-55

Effects of conventional and Namibia specific conservation tillage on soil moisture content in Ogongo, Namibia

Bertha Mudamburi[1], Adedayo Akinade Ogunmokun[2], Barbara Kachigunda[3]

[1]*University of Namibia, Ogongo Campus,*
[2]*University of Namibia,* Faculty of Engineering and Information Technology,
[3]*Murdoch University*

Abstract: Farmers in Northern Communal Areas (NCA) of Namibia practise conventional tillage using mouldboard or disc implements that pulverise fragile soil structures thereby destroying vital organic matter. This subsequently creates hard pans and plough lines that lead to soil degradation and consequently reduced moisture content and low yields leading to food insecurity. Studies were conducted at the Ogongo Campus of the University of Namibia between 2011 and 2013 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 Namibia Specific Conservation tillage (NSCT) treatments (tractor - drawn ripper furrower (TRF) and animal - drawn ripper furrowers (ARF) used by farmers in Namibia. A Fallow treatment of No tillage No crop (NTNC) was used as a control. The experimental research design used was 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. This study showed 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 both years. 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. There was however no mulch effect on the moisture levels over the two years. Overall, the moisture contents under the NSCT treatments were higher than the corresponding moisture contents under the CV technologies and fallow treatments, Farmers in the NCA of Namibia are therefore advised to adopt the NSCT methods.

Keywords: Namibia specific conservation tillage, ripper furrower, soil moisture, yield

1. Introduction

The Northern Communal Area (NCA) of Namibia 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 (FAO, 2009; 2014). Farmers in these areas practise Conventional Tillage (CV) i.e. mouldboard ploughing, disc ploughing and harrowing (Davis & Lenhardt, 2009; NAB, 2009; von Hase, 2013, Mudamburi et al. (2018a); Mudamburi (2016). These practices, especially when high-speed disc harrows are used, pulverise the soil thereby destroying the soil structure. Several authors have predicted that these soil-pulverising and hardpan effects of disc harrows will lead to soil degradation and restrict moisture and consequently depress crop yields (Rigourd & Sappe, 1999; Strohbach, 1999; NRC, 2009; Vigne & Associates, 2004; Davis & Lenhardt, 2009; NAB, 2009; von Hase, 2013). The farmers also generally remove all crop residues (stover), either for livestock or for domestic use, in addition there is a lot of mono-cropping of pearl millet leading to deterioration of the farm's ecology and declining yields (NAB, 2009, von Hase, 2013; Mudamburi, et al. (2018a); Mudamburi (2016).

In trying to address some of the problems in the NCA, a Conservation Tillage (CONTILL) project, termed 'Lima Nawa', was implemented in Northern Namibia between 2005 and 2011. 'Lima Nawa' in the Oshiwambo language means "cultivate well". 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/technology. The method makes use of the animal-drawn and/or tractor-drawn ripper-furrowers to rip and make furrows in the land in one operation. Apart from that, the technology emphasizes the use of mulch, manure and crop rotations. The technology is also explained in detail in Mudamburi, et al. (2018a) and in Mudamburi (2016). The moisture increases were hypothesised to have resulted in the better improvement of soil moisture harvest under NSCT compared to under CV methods (NRC, 2009). The NSCT was reported to have improved some farmers' pearl millet yield of 225 to 400 kg ha^{-1} to a range of 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} (Davis & Lenhardt, 2009; NCBA, 2012; von Hase, 2013).

Several researchers (Bescansa et al. 2006; Dumanski et al. 2006; Mupangwa et al. (2008) have reported that conservation tillage brings about positive changes in the physical properties of the soil such as improved water infiltration and retention. Conservation tillage (CT) methods were also reported to have resulted in higher soil moisture content as compared to conventional tillage methods (Cavalaris & Gemtos, 2002; Altuntas & Dede, 2009; Małecka et al. 2012; Dangolani & Narob, 2013). On the contrary, results by Kováč et al. (2005), however, showed that conventional tillage resulted in improved soil moisture than all the CT methods they studied.

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). Farmers in Namibia are known to remove or burn all crop residues (stover) without adequate soil nutrient replenishment (NAB, 2009). The NSCT method however emphasizes the use of mulch, manure and crop rotations. 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 (Erenstein 2003; Dumanski et al. 2006; Simmons & Nafziger, 2009).

In a study conducted in Zimbabwe, the measured topsoil moisture contents under 'mulch ripping' (CT) 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 another study conducted in Zimbabwe on a sandy soil, direct seeded CT plots resulted in 49% and 45% greater infiltration rates than the conventionally tilled plots after a simulated rainfall in two seasons. In Zambia, on a finer textured soil, the direct seeded CT plots resulted in 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 et al. 2005). 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 et al. (2011) studied the effect of mulching and minimum tillage and showed that maize yield was not significantly influenced by mulching or minimum tillage, individually or in combination. They found that maize yields for conventionally ploughed plots 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.

Despite the significantly improved yields reported under the NSCT technology compared to the conventional tillage technology (CV) practised traditionally by the farmers in the NCA (Davis & Lenhardt, 2009; NCBA, 2012; von Hase, 2013), there were no reports of measured improvement in the soil moisture content of NSCT plots compared to the CV plots. The moisture increases were only hypothesised by them to have resulted in the higher soil moisture under NSCT compared to under CV methods without any concrete evidence. So this study set out to cover that gap.

2. Materials and Methods

In order to be able to compare the change in moisture under CV and NSCT technologies in Namibia, on-station trials were carried out at the Ogongo Campus of the University of Namibia; in the Omusati Region between 2011 and 2012. Ogongo rainfall is seasonal, and it falls mostly between the months of November and April. A total of 621.6 mm of rainfall was recorded at Ogongo from December 2010 to May 2011 while 377.4 mm was recorded from December 2011 to May 2012. Rainfall therefore decreased from 2011 to 2012.

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 moisture data collected in the third year due to late and patchy rains and there was subsequently no harvest collected. 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} - the recommended rate for the NSCT method) as the subplot factor in 4 blocks, totalling 40 plots. Research trials comprised five treatments comprising of four tillage methods 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) and a fifth treatment which was Fallow i.e. No tillage No crop (NTNC). The treatments were randomly assigned to the plots using GenStat (DE3, 2004). 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. The 'Principle of Constant Traffic', where the same planting lines were used for both seasons, was also used for all treatments.

In the course of land preparation and during the growing period, soil samples for determining the gravimetric moisture contents were collected from ten randomly selected places in the four middle rows from each plot in all the treatments. 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 1:

$$\% SM = (Mw (g) – Md (g) / (Md (g) * 100 \quad (1)$$

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

Concurrently, a DSM moisture meter was used to collect moisture data at the same points, making it also ten sampled places. 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.

The analysis of variance (ANOVA) function in GenStat was used to test for any significant differences in moisture content among all treatments being AMP, ARF, TDH, TRF and Fallow (NTNC). Analysis of variance was also used to test for interaction effects between tillage and mulching, and the main effects of tillage and mulching on soil moisture. The data were subjected to normality and variance tests during the ANOVA and an alpha level of 0.05 was used to determine the level of significance among the means. Repeated Measures Analysis was used to determine the changes in moisture content between the seasons (2011 and 2012) among the five methods and the two mulch application levels.

3. Results and Discussions

3.1 Soil Moisture and Mulch

Table 1 shows a comparison of the average moisture content from planting to harvesting among tillage methods and mulch levels for 2011 and 2012. There was no interaction between tillage and mulch in the moisture contents recorded for both 2011 and 2012. 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. There was, however, significant (p=0.001) interaction between year and tillage,

Table 1: 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	3.38	3.66	3.16	3.06
ARF	3.39	3. 70	3.10	3.20
FALLOW	3.07	3.10	2.75	2.76
TDH	3.54	3.47	3.19	3.32
TRF	3.17	3.32	3.73	4.06

(No significant difference between mulch treatments)

Moisture content was not significantly influenced by the presence of the 3 t ha^{-1} mulch (the recommended rate for the NSCT method). The choice of 3 t ha^{-1} mulch level was a compromise between the need for moisture conservation and what the farmers need for other uses like thatching, fencing and feed for animals. It seems that the amount of mulch could not change the levels of moisture conservation in the plots. This is in line with the Zimbabwean study of Mupangwa et al. (2011) where soil water benefits derived from mulching begin to decline on both clayey and sandy soils beyond 4 t ha^{-1} mulch level. On the contrary, Fuentes et al. (2009) emphasized that the retention of crop residues resulted in higher moisture content regardless of tillage system and Erenstein (2002) also pointed out that mulching significantly reduced surface runoff (thereby potentially increasing soil moisture content.

3.2 Moisture 2011

Fig 1 shows the average soil moisture levels at different times 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.

A post hoc test indicates that there were no differences in moisture content among TDH, AMP and ARF but the moisture under the three methods were significantly different from the moisture under TRF and FALLOW (l.s.d = 0.2545). The mean moisture content under Fallow for 2011 was the lowest at 3.09% followed by TRF at 3.25%; while it was highest under ARF at 3.54% followed by AMP at 3.52 % and TDH at 3.51 %.

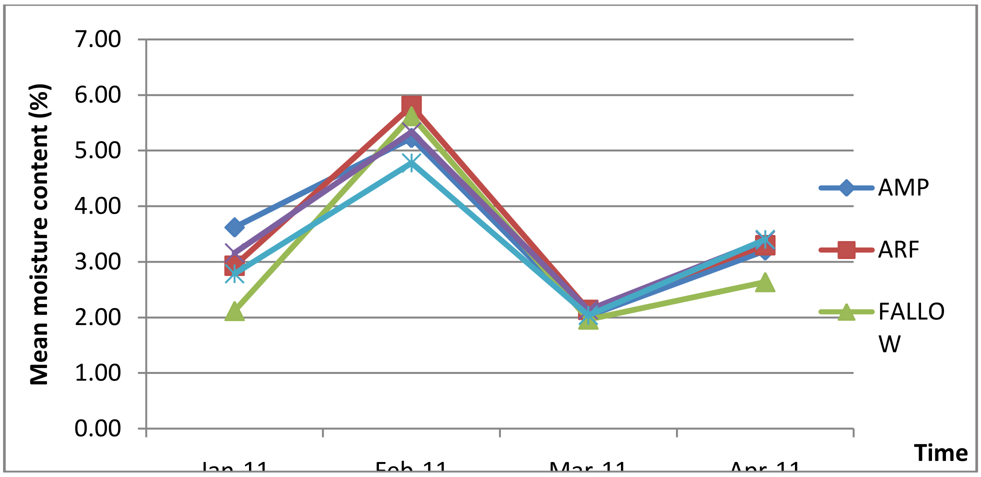


Fig 1: Changes in Soil Moisture over Time during 2011

The fact that the Fallow (control) treatment had the lowest soil moisture most of the time suggests that tillage in general helps to improve soil moisture content. The ARF resulted in a 13.8% increase in soil moisture compared to FALLOW whilst AMP resulted in 13.4% increase. TDH by 13.1% and TRF by 6.4%. 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).

3.3 Moisture 2012

Fig 2 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. Similar to 2011 results, plots under TRF showed the highest moisture levels. This suggests that TRF harvested more water, as intended. Mean soil moisture contents under the different treatments were: TRF 3.9%, TDH 3.3%, ARF 3.2%, AMP 3.1% and FALLOW 2.8%.

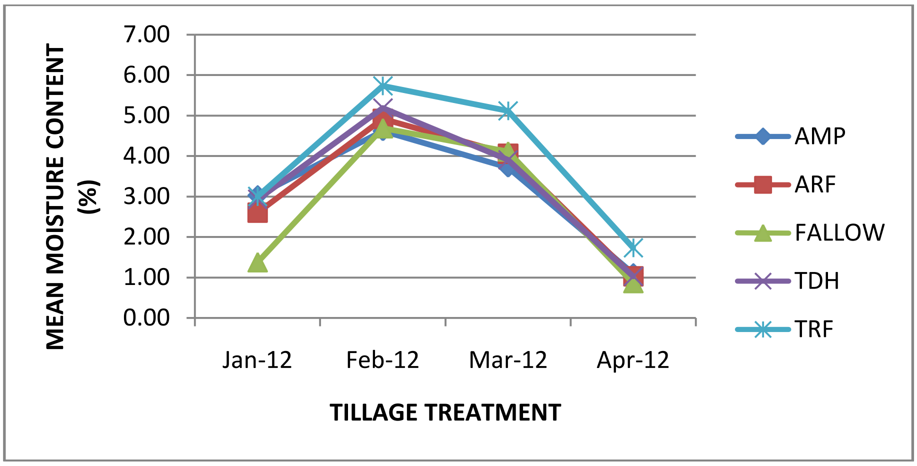


Fig 2: Changes in Soil Moisture over Time during 2012

From 2011 to 2012, plots under TRF showed the highest increase in moisture by 29.1% compared to FALLOW, whilst moisture under TDH increased by 15.3%. AMP increased by 11.3% and ARF increased by 12.4% compared to FALLOW. Only one NSCT method (TRF) resulted in higher levels of soil moisture than both CV methods. Within the tractor group, TRF (NSCT) resulted in 16% better soil moisture than TDH (CV), but in the animal group ARF (NSCT) only resulted in 1% higher soil moisture compared to AMP (CV). 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.

3.4 Overall Mean Moisture Content for 2011 and 2012.

The overall soil moisture levels for the two years is laid out in table 2. TRF (NSCT) resulted in 5.4% higher moisture content than TDH (CV) and ARF (NSCT) resulted in 4.5% higher moisture content than AMP (CV). There were significant ($p<0.001$) differences in soil moisture among the tillage methods.

Table 2: Overall Mean Soil Moisture Contents for 2011 and 2012

	Overall Moisture Content (%) 2011		**Overall Moisture Content (%) 2012**	
	Mulch	**No mulch**	**Mulch**	**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. This confirms that tillage, in general, helps to improve soil moisture content. February showed high soil moisture levels in both 2011 and 2012. The tractor-drawn ripper-furrower must have harvested more water as intended managing to keep the moisture in the furrow 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.

In 2011, the moisture contents was higher for TRF method than in 2012 despite there being less rainfall in 2012 than in 2011 as reported earlier in section 2. This could be because more of the harvested water in the TRF plots in 2011 was still retained in 2012 (residual moisture). However, soil moisture contents were higher in 2011 than in 2012 under all the other tillage methods and the Fallow.

The TRF implement during field performance tests, as reported in Mudamburi et al. (2018b) 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.

Overall, the NSCT methods (TRF and ARF) resulted in higher soil moisture levels than their corresponding CV methods, (TDH and AMP). NSCT methods resulted in higher soil moisture levels than did the CV methods, i.e. TRF vs TDH and ARF vs AMP. Over the two year period, TRF had the highest percentage increase in moisture content with 8.1%, whilst TDH increased by 3.9 %, ARF increased by 3.1%, and AMP actually decreased by 3.1%. Over the same two-year period, soil moisture in the FALLOW (control) plot increased by 2.9 %. This is in agreement with the findings of Cavalaris and Gemtos (2002); Altuntas and Dede (2009); Małecka et al. (2012) who found that conservation tillage systems resulted in higher soil water content than conventional tillage systems.

4. Conclusions

The ability of the TRF method to store moisture residually from one year (2011) to the other (2012) as intended resulted in the highest moisture content being recorded under this technology. Since TRF had the highest percentage increase in moisture content followed by TDH, then ARF and lastly AMP over the two year period, it can be hypothesised that the use of NSCT implements, TRF especially, results in significantly higher soil moisture content compared to CV implements.

During field performance tests, it was reported that the TRF method resulted in the greatest depths and best furrows that could harvest and store more water effectively (Mudamburi et al (2018b) compared to other methods. It can therefore be concluded that using the right tillage implements, like the tractor-drawn ripper–furrower, can contribute to increased soil moisture content.

When coupled with the results of Mudamburi et al. (2018a) which reported significantly higher yields and the results of Mudamburi et al. (2018b) reporting best implement field performances, the NSCT technology with improved moisture content compared to CV technology and Fallow showed some positive attributes throughout. This conservation tillage production system therefore holds promise and has the potential to transform the Namibian smallholder agriculture into a sustainable and productive crop production strategy. However, pro-active efforts need to be put in place throughout the NCA towards the adoption of conservation tillage in Namibia. At the same time, Conservation Tillage should be seen as a stepping stone towards Conservation Agriculture.

It is recommended that a research similar to this be conducted over a longer period of time, at least a minimum of ten years. Since one of the seasons during which this research ran was 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 soil moisture retention.

5. Acknowledgements

We gratefully acknowledge the financial support given by the Namibia Agronomic Board and Conservation Tillage project for the tractor ripper furrower and tractor. We further extend our gratitude to the University of Namibia for allowing us to use the facilities and equipment at the Faculty of Engineering and Information Technology and Ogongo Campus.

6. References

[1]. ACT, (2005). Newsletter, 21 November, 2003. Harare: University of Zimbabwe and the *African Conservation Tillage Network*.

[2]. Altuntas, E., & Dede, S. 2009. Emergence of Silage Maize as Affected by Conservation Tillage and Ridge Planting System. Agricultural Engineering International: the *CIGR E-journal. Manuscript 1363. Vol. XI*. October, 2009.

[3]. Bescansa, P., Imaz, M. J., Virto, I., Enrique, A., & Hoogmoed, W. B., 2006. Soil water retention as affected by tillage and residue management in semi-arid Spain. *Soil and Tillage Research, 87, 19.27.*

[4]. Cavalaris, C.K., & Gemtos. T.A. 2002. Evaluation of four conservation tillage methods in the Sugar Beet Crop. Agricultural Engineering International: the *CIGR Journal of Scientific Research and Development IV (June): pp24.).*

[5]. Dam, R.F., Mehdi, B.B., Burgess, M.S.E., Madramootoo, C.A., Mehuys, G.R., & Callum, I.R. 2005. 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.*

[6]. Dangolani, S. K., & Narob, M. C. 2013. The effect of four types of tillage operations on soil moisture and morphology and performance of three varieties of cotton European *Journal of Experimental Biology, 2013, 3(1):694.698*. Pelagia Research Library. ISSN: 2248 –9215 CODEN (USA): EJEBAU 694.

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

[8]. Davis, R., & Vigne, P. 2004. *Investigation of the Feasibility of Commercial Pearl millet Production in Northern Communal Areas of Namibia*, December 2004.

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

[10]. Dumanski, J., Peiretti, R., Benetis, J., McGarry, D., & Pieri. C. 2006. The paradigm of conservation tillage. Proc. *World Assoc. Soil and Water Conserv*. P1: 58.64.

[11]. Erenstein, O. (2002). Crop Residue Mulching in Tropical and Semi-Tropical Countries: An Evaluation of Residue Availability and Other Technological Implications. *Soil Tillage Research, 67, 115.133.*

[12]. Erenstein, O. 2003. Smallholder conservation farming in the tropics and sub-tropics: a guide to the development and dissemination of mulching with crop residues and cover crops. *Agriculture, Ecosystems and Environment 100:17–37*

[13]. Fabrizzi, K. P., Gorcia, F. O., Costa J. L., & Picone, L. I. 2005. Soil water dynamics, physical properties and corn and wheat responses to minimum and no-tillage systems in south eastern Pampas of Argentina. *Soil & Tillage Research, 81: 57.69. 221.231*.

[14]. FAO, 2009. *Up-scaling Conservation Agriculture for improved food security using the CADAP framework (UP.CA) in Lesotho, Mozambique, Swaziland and Zimbabwe*. (OSRO/RAF/812/NOR. Project Document). Rome, Italy: Food and Agriculture Organization of the United Nations.

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

[16]. FAO, 2014. Conservation Agriculture. Retrieved on 30March 2014 from: http://www.fao.org/ag/ca.

[17]. Fuentes, M., Govaerts B., De Leon, F., Hidalgo, C., Dendooven, L., Sayre, K.D. & Etchevers, J. 2009. Fourteen years of applying zero and conventional tillage, crop rotation and residue management systems and its effect on physical and chemical soil quality. *European Journal of Agronomy, 30 (228.237).*

[18]. Genstat Discovery Edition 3 and 4th Edition, VSN International Ltd, Hemel Hempstead, UK.

[19]. GenStat, 2003. GenStat for Windows. Release 4.23DE Discovery Edition. VSN International Ltd., Hemel Hempstead, UK.

[20]. Govaerts, B., Mezzalama, M., Sayre, K.D., Crossa, J., Lichter, K., Troch ,V., Vanherck K., De Corte, P., & Deckers, J. 2008. Long-term consequences of tillage, residue management, and crop rotation on selected soil micro-flora groups in the subtropical highlands. *Applied Soil Ecology, 38 (197.210).*

[21]. Kováč, K., Macák, M., & Švančárková, M. (2005). The effect of soil conservation tillage on soil moisture dynamics under single cropping and crop rotation. *Plant, Soil and Environment. 3, p. 124.130*

[22]. Małecka, I., Blecharczyk. A., Sawinska, Z., & Dobrzeniecki, T. 2012. The effect of various long-term tillage systems on soil properties and spring barley yield. *Turk J Agric For 36 (2012)* 217.226 © TÜBİTAK doi:10.3906/tar.1104.20

[23]. Mudamburi, B; Ogunmokun A and Kachigunda B. 2018a. 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. American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS). (2018) Volume 40, No 1, pp 27-39.

[24]. Mudamburi, B.,Ogunmokun A and Lutaaya, E. 2018b.A Comparison of Performances of Conventional Tillage Implements versus Namibia Specific Conservation Tillage Implements under Ogongo, Namibia Conditions. American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS) (2018) Volume 41, No 1, pp 181-199.

[25]. Mudamburi, B. 2016. A comparison of the performance of Namibia-Specific Conservation and Conventional tillage technologies as used for pearl millet production in Northern Namibia. PhD dissertation submitted to the University of Namibia, 2016.

[26]. Mupangwa, W., Twomlow S., & Walker, S. 2008. Conservation Tillage for Soil Water Management in the Semi-Arid Southern Zimbabwe. *Journal of Physics and Chemistry of the Earth.*

[27]. Mupangwa, W., Dimes, J., Walker, S., & Twomlow, S. 2011. Measuring and simulating maize (Zea mays L.) yield responses to reduced tillage and mulching under semi-arid conditions. *Agricultural Sciences*, 2, 167.174. doi: 10.4236/as.2011.23023. Openly accessible at http://www.scirp.org/journal/AS/Retrieved on 26th August 2013.

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

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

[30]. NRC, 2009. Conservation Agriculture in Namibia. An Introductory Guide.CA Training Materials. Windhoek, Namibia Resource Consultants, Namibian National Farmers Union and Namibian Agronomic Board.

[31]. Nyagumbo, I. 2002. The effects of three tillage systems on seasonal water budgets and drainage of two Zimbabwean soils under maize. A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy. Department of Soil Science and Agricultural Engineering. Faculty of Agriculture University of Zimbabwe. April 2002.

[32]. Rigourd, C., & Sappe, T. 1999. Investigating into soil fertility in the North Central regions. Published in: *Kaumbutho P G and Simalenga T E (eds), 1999. Conservation tillage with animal traction.* A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Harare. Zimbabwe. 173p. A publication supported by French Cooperation, Namibia.

[33]. Simmons, F. W., & Nafziger, E. D. 2009. *Soil Management and Tillage*. Illinois Agronomy Handbook.

[34]. Strohbach, B. J. 1999. Impact Assessment on the bio-physical environment: Oshivelo. Omutsegwonime – Okankolo Piped water supply project. Environmental Associates of Namibia, Windhoek.

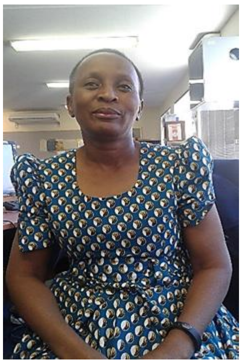
[35]. Thierfelder, C., & Wall, P.C. 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. *Soil Tillage Res 105:217–227.*

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

[37]. Vogel, H. 1993. Tillage effects on maize yields, rooting depth and soil water and water content on sandy soils in Zimbabwe. *Field Crops Research 33, 367.384.*

[38]. von Hase, F. 2013. 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.

Author Profile



Dr Bertha Mudamburi obtained a Diploma in Agriculture in 1985 at Chibero College in Zimbabwe, the Zimbabwe National Further Education Teachers Certificate at Kwe Kwe Tech College, Zimbabwe in 1987, and a BSc (Honours) in Agricultural Technology and Management, from Silsoe in UK in 1993. In 2001 she obtained an MSc at Wageningen University in The Netherlands, subsequently a Certificate in Farm Machinery Management at JKUAT in 2002 and finally a PhD in Agricultural Engineering from University of Namibia (UNAM) in 2016. From 1985 – 1987, she was an Instructor at Mlezu Agricultural Institute and 1987- 2003 a Training Officer at the Agricultural Engineering Training Centre in Zimbabwe. From 2003 to 2007, she was Lecturer at Neudamm in Namibia. She also assisted in the DAP programme in the Ministry of Agriculture Water and Forestry. From 2007 to 2009 she was a Project Manager of the DAP Acceleration Programme 2 at Namibian Agronomic Board. She was Lecturer in Agricultural Engineering at the University of Namibia, Ogongo, from 2009 to 2012. From October 2012 to March 2018 she worked as an Agriculture Advisor at Promotion of Vocational Education and Training in Namibia (ProVET), a joint initiative between GIZ and the NTA, funded by the German Government. Since March 2018 to date she is a lecturer in agricultural engineering at UNAM Ogongo Campus.