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Maize and Pearl Millet Production in Hot Semi-Arid North Eastern Namibia Under Conventional Tillage and Conservation Agriculture Practices

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Abstract

This article focuses on the results from experiments conducted to test and compare the effects of selected agricultural practices and principles on maize and pearl millet production of the major cropping systems in north-eastern regions of Namibia. Conventional Tillage (CT), Minimum Tillage (MT), Minimum Tillage with Mulch (MT-M), Minimum Tillage with Rotation (MT-R) and Minimum Tillage with Mulch and Rotation (MT-MR) were the primary treatments tested. Significant differences were observed on pearl millet grain in the first season (p=0.0496) and for maize grain in the second season (p=0.0206). For pearl millet, CT yielded the highest with 1783.0 kg $ha^{-1}$and MT (1520.8 kg ha^{-1}) had the lowest pearl millet grain yield at SE 240.35. For maize, CT-MR yielded the highest maize grain, 3852.3 kg ha^{-1}, Standard Error of Mean 240.35. Results suggest that CA has the potential to increase or maintain maize production while noting projected declines in crop production of at least 50% or more through the influence of climate change according to Namibia's Country Climate Smart Agriculture Programme (2015 – 2030).

Keywords: conservation agriculture, conventional tillage, grain yield

1. Introduction

According to Fourie et al. (2007) good maintenance and improvement of soil quality are critical for sustainable and booming agricultural crop productivity. The agricultural sector of Namibia is particularly affected by climate change, in the form of droughts, erratic rains and floods, all major threats leading to failed harvests, affecting food, water security and general livelihoods. Soil degradation and desertification are also increasing threats to the productivity of Namibia's agricultural sector. Besides impacts of erratic weather conditions as a result of climate change, the widespread use of outdated traditional farming practices has also been identified as a significant driver of low agricultural outputs (FAO, 2009). Purcell et al. (2007) highlighted that soil moisture stress resulting from drought, dry spells and high moisture loss through evaporation is one of the primary limiting factors in crop production as it affects many plant biochemical and physiological processes.

Pearl millet, locally better known as Mahangu is the staple food crop, grown largely for home consumption predominantly in the north-central and parts of the north-eastern regions of Namibia, while maize (*Zea mays*) is the staple food crop of the north eastern regions of the country, particularly in the Zambezi region. According to the 2009 report by the Food and Agriculture Organization of the United Nations (FAO), the average annual pearl millet (*Pennisetum glaucum*) and maize production in communal areas in 2008 in Namibia was about 250-400 kg ha^{-1} and 500-550 kg ha^{-1}, respectively. According to Namibia's Country Climate Smart Agriculture Programme, jointly implemented by Ministry of Agriculture Water and Forestry (MAWF) and Ministry of Environment and Tourism (MET) (2015 – 2030). It is projected that through the influence of climate change crop production is expected to decrease by at least 50% or more. Maize in particular is expected to experience a 0.5 t/ha yield decline based on the above mentioned projections. Due to climate change (Rowswell and Fairhurst 2011) and need for increased crop productivity, it is critical that mitigation, good maintenance and improvement of soil quality is undertaken (Fourie et al. 2007), especially as erratic weather patterns are projected to become increasingly worse.

Tillage is the preparation of the soil for the production of crops for human consumption, animal feed and/or for the improvement of the soil. It is known to influence soil physical properties such as soil hydraulic properties, change flow path, rate of water infiltration and percolation and the stability of the biotic factors (Dexter 1988). Tillage methods (Fuentes et al. 2003) and climatic factors, especially rainfall distribution and reliability (Fowler and Rockstrom 2001) influence available soil moisture, key for plant growth, development and soil physical properties. Conventional tillage (CT) is the most common practice used among small holder farmers and has been practiced for a long time (Chen, Liu et al. 2011). In Namibia, tillage is largely done using the hand hoe and animal drawn moldboard plough introduced in the early 20th century from Europe usually referred to as Conventional Tillage (CT). CT is reported to be unsustainable over the long term in more intensive production setup as it contributes to inefficient natural resource use, poor soil water retention, soil degradation and global warming (Ferna´ndez, Quiroga et al. 2009). Conservation agriculture (CA), on the other hand is a crop management system that involves a combination of soil management practices to reduce soil disruption, compaction whilst enhancing natural biodiversity and is based on three principles namely (1) minimal soil disturbance, (2) crop rotation and (3) permanent soil cover with crop residues or growing plants (Kassam, Friedrich, Shaxson, & Jules, 2009; FAO, 2009; & Friedrich, Derpsch, & Kassam, 2012).

CA is a less energy intensive system as compared to CT and has been known to improve crop yields whilst conserving water/moisture, reduce erosion and eliminate organic matter loss among others (Dumanski et al. 2006). The influence of tillage on crop growth and development is reported to however depend on a number of factors, including the type of tillage practice used to prepare the land (Martinez et al., 2008). Tillage methods (Fuentes,Flury, Huggins & Bezdicek, 2003), climatic factors especially rainfall distribution and reliability (Fowler & Rockstrom, 2001) influence available soil moisture, which is a key factor for plant growth and development and stability of soil physical properties. Tillage and mulch/residue retention have been reported to have beneficial effects on the retention of soil moisture (Gicheru, Gachene, Mbuvi & Mare, 2004; Benites, 2008; Landers, 2008). Reduced tillage practices such as ripping and sub-soiling have the potential to mitigate the effects of dry spells and moisture stress and contribute to improved soil moisture retention (Ahmed and Suliman, 2010). Soil moisture stress is one of the primary limiting factors in crop production as it affects a host of plant physiological and biochemical processes (Purcell et al., 2007). However, Jalota Khera & Chahal, (2001), acknowledged that the success of a crop depends upon the nature of the soil and the amount of moisture stored in it. Kl-Kaisi & Broner (2012) stated that, in most legumes, when moisture stress occurs at critical growth stages such as flowering, podding and pod/seed filling, high grain yield loss is all too often the final outcome.

Dry spells, water scarcity, unreliable rain pattern and agricultural systems play a large role in the amount of moisture available in the soil. Namibia is classified as the driest country in Southern Africa, where 10–25% of rainwater is lost to runoff, and another 30–50% is lost through evaporation from unprotected soil surfaces. Conventional tillage is widely practiced in Namibia and is associated with increased soil erosion, loss of soil organic matter and destruction of soil structure. In Namibia, conventional agriculture has for decades existed as the major agricultural system up to the year 2005, in which the government through MAWF introducing another agricultural system namely CA. Unfortunately due to variable findings little documented knowledge of the influence of Conventional and CA Tillage systems and principles on soil moisture content and water infiltration in Namibia exist. Therefore, this necessitated the research on suitable tillage methods for two agro-ecological north eastern regions of Namibia.

The main objective was to document and compare the effects of different tillage systems (Conventional and CA) and the influence of the individual CA principles on soil moisture and infiltration. Specific objectives included determination of the effects of different reduced tillage options on soil moisture dynamics and water infiltration under maize, millet on a sandy soil and to determine the effects of minimum tillage and mulch/rotation on soil moisture and grain yields of maize and pearl millet. The hypothesis of the study was that there were no significant differences in soil water infiltration between CA and Conventional plots and that no significant differences existed between the effect of no mulch, mulch only, rotation only and mulch plus rotation on the soil moisture content and crop grain yields for both CA and Conventional plots.

Taking into account Namibia's dry climatic condition, findings would significantly contribute towards water conservation endeavors and good crop production practices for small holder and commercial farmers and influencing further adoption of CA systems in Liselo, Mashare, Kavango East region, Zambezi region and Namibia at large.

2. Methods

2.1 Site Characteristics

Mashare Irrigation Training Center (17.889300 °S; 20.170258 °E), 50km east of Rundu town in Kavango East region, and the Liselo Research Station (17.524745 °S; 24.238707 °E) located 7 km west of Katima Mulilo town in the Zambezi Region of Namibia were the sites chosen for the experiments. Both are situated in the hot, sub-humid north eastern parts of the country (Table 1). The sites were predominantly having slightly acidic soils with pH of 5.3-6.1 (Table 2).

Table 1. Site Characteristics for Liselo Research Station and Mashare Irrigation, Training Center

Site	Elevation (m asl)	Climate	Annual Mean Temperature	Annual Mean Rainfall	Soil Texture Class
Liselo Research Station	964	Hot, semi-arid	21.3 °C	600-700 mm	Loamy sand to sand
Mashare Irrigation Training Center	1050	Hot, semi-arid	22.3 °C	450-650 mm	Sandy Loam to loamy sand

2.2 Experimental Design

The experiment consisted of eight (8) treatments in a Randomized Complete Block Design (RCBD) set-up with four (4) replications on a 2,419.2 m^2 trial plot (50.4 m x 48 m). Treatments tested were; Conventional Tillage (CP), Convectional Tillage with Mulch (CP-M), Conventional Tillage with Rotation (CP-R), Conventional Tillage with Mulch and Rotation (CP-MR), Minimum Tillage (MT), Minimum Tillage with Mulch (MT-M), Minimum Tillage with Rotation (MT-R) and Minimum Tillage with Mulch and Rotation (MT-MR). Each plot was composed of 7 rows (90 cm row spacing & 35 cm within row) by 12 m and plots with rotation were split into subplots each with 7 rows by 6 m. CT plots were tilled with an animal drawn moldboard plough, while CA/minimum-tillage plots were tilled with an animal drawn Magoye ripper, opening narrow furrows about 5-10 cm deep.

2.3 Seeding and Weed Management

Maize (*Zea mays*, commercial hybrid maize variety Zamseed 606) and commercial pearl millet variety Okashana 2 were the principal crops and cowpea (*Vigna unguiculata* L. Walp.) an important secondary crop used in rotation with maize or pearl millet. Maize, pearl millet and cowpea crop varieties were manually seeded, Maize (90cm x 35cm) with 31 746 plants/ha target population while, pearl millet (75cm x 25cm) with a target population of 53 333 plants/ha. Rotational crop, commercial cowpea variety BIRA was manually seeded in rows spaced 45 cm apart and inter row spaced 25 cm. Basal fertilizer, NPK (2:3:2) was applied at a rate of 150 kg/ha to cereal only plots and a split application of Urea at a rate of (150 kg ha^{-1}) was applied as top dressing to the same plots.

Treatments with cowpea rotation were mulched with 2.5-3 t/ha of grass at the onset and all crop residues retained on the soil surface in the subsequent seasons after harvesting. Weed control was achieved by disturbing only the top soil using a hoe at 30-day intervals and when necessary. At harvest, cobs were removed from the plots and crop residues (stover) were retained on the respective CA and CT treatments.

2.4 Data Collection

2.4.1 Soil Fertility Test

Prior to plot establishment, the Liselo Research station had natural vegetation of mixed subtropical woodland containing copalwood (*Guibourtia coleosperma*), *Terminalia serecea*, Zambezi teak (*baikiaea plurijuga)*, and *Acacia eriolaba* trees, shrubs and grasses. Mashare Irrigation Training Center on the other hand was used as part of the Irrigation Training Center for pearl millet production. Soil samples were taken from the sites at the onset of the study and levels of nitrogen and phosphorous, Organic C, estimated SOM and pH were tested, for comparison against suggested nutrient ranges suitable for grains.

2.4.2 Harvest Data Collection

Maize, pearl millet and cowpea grain were harvested at physiological maturity and total above-ground biomass and grain yield of each plot were determined. Sub-samples of 20 cobs/heads were taken from each plot as samples and used to determine maize grain moisture.

2.5 Statistical Data Analysis

Linear model, Analysis of variance (ANOVA) using Statistical analysis software 'Statistix 9' for personal computers was used to test for normality and test for any significant difference in moisture content and grain yield. Probability levels of 0.05 were used to determine the level of significance among the means. LSD All-Pair wise Comparisons Test was used to compare soil moisture and grain yield for treatment effect.

3. Results

3.1 Soil Nutrient Levels

Soil from research sites were evaluated for soil fertility levels (Nitrogen, Phosphorus and Potassium), organic C, soil organic matter (SOM) and pH. At both study sites, the levels of nitrogen and phosphorous, Organic C, and SOM were far below the suggested range for grains. Only potassium and Soil pH fell within the suggested range for grains at both sites (Table 2).

Table 2. Site Characteristics of Liselo Research Station and Mashare Irrigation, Training Center

Characteristics	Suggested range for grains	LRS	MITC
N (g kg^{-1})	1.0– 2.0	0.48	0.28
P (g kg^{-1})	0.2 – 0.6	<0.1	<0.1
K (g kg^{-1})	1.5 – 3.0	2.2	2.8
Organic C (g kg^{-1})	17 – 50	6.9	2.9
SOM (%)*	2.9 – 8.6	1.2	<1
pH	4.9 – 6.4	5.3	6.1

Soil Cares (2007,www.soilcares.com) provided the suggested range for grains which is based on soil analysis. N = NItrogen; P = Phosphorus; K = Potassium; C= Carbon; SOM = Soil Organic Matter. N= 24 at Liselo Research Station.

*Soil Organic matter is estimated based on a conversion factor of 1.72 [Soil organic matter=58%C]

3.2 Rainfall

Rainfall at both LRS and MITC for the 2016/17cropping season was erratic with a short rainy season especially at LRS (Figure 1). At LRS, total seasonal rainfall recorded was 499.9 mm for the first cropping season 2016/17, while at MITC it was 715.2 mm. Rainfall at both LRS and MITC for the second season, 2017/18 was again erratic with especially low rain incidences at the early stages of the season (Figure 1). AT LRS and MITC, 521 mm and 530.4 mm of rainfall was recorded for the 2017/18 cropping season, respectively. In January 2018, LRS received 44 mm, while 233 mm of total rain fell in February 2018. Rainfall amount of 1.3 mm at MITC, from 31 December 2017 to 21 January 2018, was insufficient for crop growth and development. Rainfall eventually increased as the season advanced, particularly in March, during which the site received 214 mm of the total 521mm (see Figure 1).

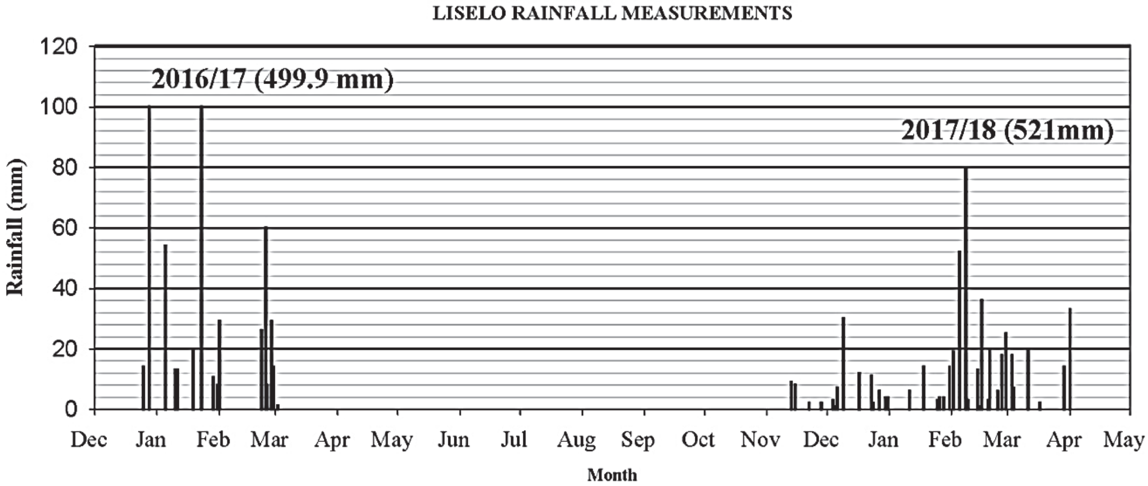

Figure 1. Rainfall Measurements at LRS for the first and second season

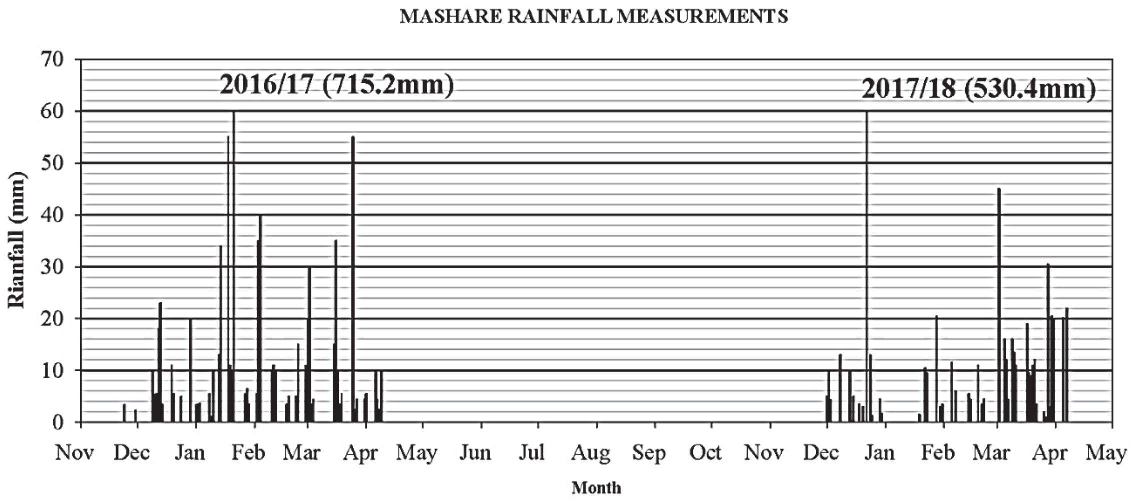

Figure 2. Rainfall Measurements at MITC for the first and second season

3.3 Maize Grain Yields

Maize grain yield at LRS for the first season was not significantly affected by tillage and principles. However, during the second season maize grain yield was significantly affected (p=0.0206) (Table 3), during which CT-MR yielded the highest with 3852.3 kg ha^{-1}of maize, followed by MT-MR (3550.8 kg ha^{-1}) and CT-M (3371.8 kg ha^{-1}).

Table 3. Average maize grain yield at Liselo Research Station

Treatment	2016/2017 cropping season yield (Kg ha^{-1})	2017/2018 cropping season (Kg ha^{-1})
CT	2023.5	**2899.5^{BC}**
CT-M	2160.3	**3371.8^{AB}**
CT-R	1570.0	**2948.3^{BC}**
CT-MR	1846.5	**3852.3^{A}**
MT	1937.3	**2524.0^{C}**
MT-M	1206.8	**2920.0^{BC}**
MT-R	1404.0	**3225.0^{ABC}**
MT-MR	1142.3	**3550.8^{AB}**
P	*0.0884*	*0.0206*

Minimum tillage with selective incorporation of CA principles yielded increased maize grain yields [MTM (2920.0 kg ha^{-1}), MT-R (3225.0 kg ha^{-1}) and MT-MR with 3550.8 kg ha^{-1}]. MT however produced the lowest maize grain yield of 2524.0kg ha^{-1}, but was found to have yielded higher than all the treatments in the first season. Conventional Tillage in both seasons yielded higher maize yield than Minimum Tillage (Table 3).

Maize grain yields were found to follow no particular order over the two seasons. Most Minimum tillage treatments averaged less than 1500 kg ha^{-1} maize grain yield in the first season and more than 2500 kg ha^{-1} in the second season (Table 3). Although no significant difference (p=0.0884) was observed in the first season, conventional tillage treatments were found to have yielded more maize grain than minimum tillage treatments, indicating the benefit of CT in the first season. Maize grain yield followed the order CT-MR > MT-MR >CT-M > MT-R >CT-R > MT-M >CT>MT in the second season (Table 3).

3.4 Pearl Millet Grain Yield

Pearl millet grain yield at MITC was significantly affected by the various treatments in the first cropping season (p =0.0496) and not significantly affected in the second season. In the first season, CT produced the highest average pearl millet grain yield of 1783.0 kg ha^{-1}, followed by MT-M and MT which produced pearl millet grain yield of 1562.0 kg ha^{-1} and 1520.8 kg ha^{-1}, respectively. Minimum tillage treatments produced varied average pearl millet grain yields [MT-M produced 1562 kg ha^{-1}, MT-MR produced1439.8 kg ha^{-1} and MT-R plots had the least yield, at 1044.8 kg ha^{-1}] (Table 4).

Table 4. Average pearl millet grain yield (kg ha-1) at Mashare Irrigation Training Centre

Treatment	2016/2017 cropping season yield (Kg ha^{-1})	2017/2018 cropping season (Kg ha^{-1})
CT	**1783.0^{A}**	980.7
CT-M	**1369.5^{BC}**	1051.0
CT-R	**1247.0^{BC}**	935.0
CT-MR	**1371.3^{ABC}**	1137.5
MT	**1520.8^{AB}**	854.9
MT-M	**1562.0^{AB}**	1009.4
MT-R	**1044.8^{C}**	889.0
MT-MR	**1439.8^{ABC}**	1071.8
P	***0.0496***	*0.0752*

4. Discussion

In the first season (2016/17), CT (Conventional tillage) treatments yielded an average of 477.5Kg ha^{-1} and 50.85 Kg ha^{-1} more maize and pearl millet than CA (Minimum Tillage) treatments, respectively. Maize grain yield followed the order CT-M>CT>MT>CT-MR>CT-R>MT-R>MT-M>MT-MR, highlighting the lack of influence of Conservation tillage in the first season whilst, pearl millet grain yield for the same season followed the order, CT>MT-M>MT>MT-MR>CT-MR>CT-M>CT-R>MT-R, contrary to finding on maize. In the subsequent season 2017/18, with a 4.2% (21.1mm) increase in rainfall at LRS and a 25.8% (184.8mm) decrease at MITC respectively, maize grain yields experienced an average increase of 1500.1 Kg ha^{-1}, whilst pearl millet decreased by 426.1 Kg ha^{-1}. The decline in pearl millet yield was primarily the result of drastic decline of 25.8% in rainfall over the two year period. On the basis of average group yields, CT (Conventional tillage) treatments again out performed MT treatments with averages of 213.0 Kg ha^{-1} and 69.78 Kg ha^{-1}, more maize and pearl millet than CA (Minimum Tillage) treatments, respectively. Maize yields followed the order CT-MR > MT-MR >CT-M > MT-R >CT-R > MT-M >CT>MT and Pearl millet CT-MR > MT-MR >CT-M > MT-M >CT>CT-R >MT-R >MT with CT-MR yielding the highest and MT least productive.

Mulch coupled with crop rotation appeared to have positive influence, by providing a physical barrier that reduced soil movement, allowed organic matter accumulation as similarly observed by Mutema, et al., (2013), and ultimately led to increased crop yield particularly in maize as found by McHugh et al., (2007), Pansak, (2008) and Govaerts et al., (2009).

5. Conclusion

The results indicated that minimum/CA tillage methods can improve maize grain yield. Application of mulch and crop rotation appeared to positively influence maize grain yield over the study period compared to no mulching and, not practicing rotation. Yield outcomes clearly showed mulch's influence on crop yield and solidified its status as a great contributor towards increased crop production. Implementation of CA in Namibia is at different stages, driven significantly by Non-Governmental Organizations (NGO's) in collaboration with government and with recent policy adoption and implementation in some parts of the country and indifferent in other parts. In Namibia, the government adopted the Climate Smart Agriculture Programme, jointly implemented by the Ministry of Agriculture Water And Forestry (MAWF) and the Ministry of Environment And Tourism (MET) (2015 – 2030). The adoption of such sustainable technologies is believed to increase productivity and production. Namibia also developed a Namibia specific conservation tillage (NSCT) technique, as a method that advocates for use of rippers, mulch, improved seeds, constant monitoring, new planting and fertilizing methods and techniques. CA is not exclusively practiced at local level and with the finding of this study, in part showing that reduced soil disturbance and mulching together with crop rotation enhance maize performance and production and can influence fast tracking and encourage its widespread practice in in the hot sub-humid north-eastern regions of Namibia and similar areas.

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