RESEARCH ARTICLE

Available online at https://nje.org.na

NJE Namibian Journal of Environment

Received: 14 January 2025
Accepted: 5 May 2025
Published: 17 September 2025
Edited by: Thinah Moyo

Comparing conventional and conservation agriculture for multi-seasonal maize production in the Zambezi Region, Namibia

Teofilus Shiimi

Department of Agricultural Sciences and Agribusiness, Namibia University of Science and Technology, Windhoek, Namibia

Correspondence: T. Shiimi (tshiimi@nust.na)

ABSTRACT Half of Namibia's population resides in rural areas, and many rely on small-scale farming. Crop production declines in the region over recent decades have been associated with the degradation of soils as a result of conventional farming methods. Conservation agriculture has been identified as a smart agricultural technique that can remedy challenges around agricultural land degradation and climatic uncertainty. This study undertook an experimental trial in farmers' crop fields in the Zambezi Region to compare the maize yield performance of conventional and conservation agriculture methods. I collected data from experimental research plots on four participating farming clusters. Data collection commenced during the 2016/2017 cropping season and continued through the 2019/2020 cropping season. I found no statistically significant difference in the average yield of maize biomass across seasons and within the growing season between the two primary tillage systems examined (conventional mould board plough and conservation agriculture using rippers). However, there was a significant difference in the average maize grain yield across treatments (plough, ripper, and ripper intercropped) in the 2018 cropping season. My findings indicate that conservation agriculture can offer a viable alternative to conventional methods, despite implemental inconsistencies. Based on my findings, I also encourage the pursuit of longer-term studies that might better capture soil recovery processes and other long-term effects. This will help compile a more comprehensive evidence base and prepare for a potential transition to conservation agriculture in Namibia.

KEYWORDS conservation agriculture; crop production; maize; Namibia; ripper; rotation

INTRODUCTION

Across Africa, there is a perpetual deficit in staple food, and most African states, including Namibia, are net importers of staple foods (Mushendami et al. 2008, Kiesel et al. 2022, Kristof 2022, NAB 2022a). Approximately half of Namibia's population lives in rural areas (NSA 2024) and a large proportion of this population relies on smallholder, subsistence farming - primarily maize production - for both food and income generation (Mendelson 2002, Lai et al. 2012, MAWF 2015, Shifiona et al. 2016). Despite efforts toward achieving self-sufficient food production, food security remains unachievable for many rural communities. This situation can be attributed to factors ranging from environmental to structural (Shifiona et al. 2016, Fortunato & Enciso 2023). In Namibia's northern communal areas, the soil is typically nutrient-poor and exhibits inadequate water-holding capacity, except for the Zambezi Region in the northeast (Krebs 2014). Compounding these issues are the irregular and insufficient rainfall predominantly occurring between October and March, often leading to inadequate crop production. Small-scale farming based on traditional cultivation methods prevails among these rural communities. These cultivation conventions include the use of animal-drawn mouldboards for ploughing, and can lead to poor soil moisture and nutrient retention, and ultimately to reduced long-term agricultural productivity (Grabowski & Kerr 2014, Krebs 2014, Wang et al. 2020).

An alternative to conventional farming methods is conservation agriculture, which represents a shift towards more sustainable agricultural practices and technologies. Defined by its commitment to improving soil sustainability, conservation agriculture encompasses a variety of practices centred around three core principles: (a) minimising soil disturbance through methods like ripping instead of ploughing, (b) maintaining permanent soil cover by adding organic matter, and (c) implementing crop rotation, specifically alternating cereal crops with leguminous ones (Wagstaff & Harty 2010). This agricultural method safeguards soil fertility, bolsters land resilience against drought and other adverse climatic conditions (Akpalu & Ekbom 2010, Palm et al. 2014), and is applicable across different farming systems (Kassam et al. 2014). Importantly, the shift from traditional to conservation agriculture practices, can also result in enhanced yields (Gebru 2010, Hall et al. 2010). Deep ripping and decompaction are key factors that help restore soil pore space and permeability for water infiltration (Thierfelder & Wall 2009). Krebs (2014) notes that transitioning from conventional to conservation tillage can significantly improve soil carbon levels. Moreover, incorporating organic matter, like manure, into the soil enhances water retention, reduces erosion, and promotes crop growth (He et al. 2009, Krebs 2014). A study in Zambia found that maize yields per hectare were consistently higher on conservation agriculture fields than those using conventional methods, particularly in seasons of low rainfall (Nyanga et al. 2011). Rising environmental concerns have underscored the need for alternative approaches that reconcile development activities, including agriculture, with the imperatives of future investment and environmental sustainability (Kassam et al. 2016, Xavier et al. 2020). Transitioning to conservation agriculture could help facilitate such a reconciliation (Pittelkow et al. 2014).

This study evaluates the impact of conservation agriculture on maize grain and biomass yields during the first three years of its implementation in Namibia's Zambezi Region – a key maize-producing area where most subsistence farmers rely on rainfed agriculture amid increasingly unpredictable climatic conditions (NAB 2022b; Muradzikwa et al. 2023). With its agricultural potential, subsistence culture and widespread use of conventional agricultural practices (Kiesel et al. 2022), the region presents an ideal experimental setting for a comparative evaluation and builds on other conservation agriculture research in Namibia (Taapopi et al. 2018).

MATERIALS AND METHODS

Study area

The Zambezi Region in Namibia is located in the northeastern part of the country, as shown in Figure 1. It benefits from having Namibia's highest precipitation, with an average annual rainfall of 650 mm, and the lowest water shortage rates (Angombe & Shikangalah 2021, Kiesel 2019). It covers an area of 14 785 km², and has a population of over 142 000 (NSA 2024).

Crops commonly grown are maize, pearl millet and sorghum, and cowpea. Maize is the staple crop in the region, and most farmers who grow maize at a large scale, especially in the floodplain area, are farming for commercial purposes. The soils are heavy with high clay content in areas regularly flooded, such as hydromorphic and organic clay soils (Teweldemedhin et al. 2015).

Research design and layout

A total of 24 farmers volunteered to participate in this study. These farmers were divided into four clusters, with each cluster consisting of farmers from the same village. Each cluster consisted of six farmers. A 0.3-ha experimental research plot was established in the fields of each participating farmer. The study employed a Randomised Complete Block Design (or RCBD), which relies on different treatments being applied to one contiguous block (Figure 2). Participating farmers

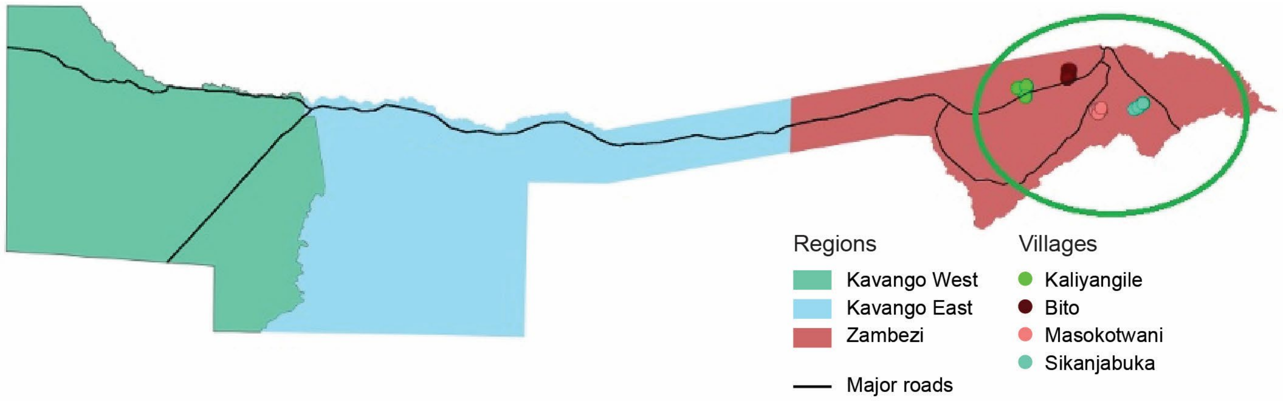

Figure 1: Location of the experimental plots in the study area. Plots are grouped according to farmer clusters. Each cluster consists of farmers residing in the same village.

underwent a week-long training programme tailored to the research objectives.

All farmers planted Maize Zamseed 606. This variety has semi-flint white grain, with good storability and yield potential of 8–9 Mt/ha, and it takes 125–130 days to maturity. For consistency, participants were provided with inputs sufficient for 0.3 ha only. However, farmers had the freedom to replicate the research protocols anywhere in their crop fields. Experimental plots were divided into six equally sized (10 × 50 m) and adjacent subplots separated by only 60 cm. Two different implements were used to prepare the research plots. In the conventional tillage section, an ox-drawn mouldboard plough was used to prepare the land, whereas in the conservation agriculture tillage section, an ox-drawn ripper was used to make ripper lines. The ploughed and ripped sections were retained over the study period and prepared every crop season with a rotation of the crops. Maize seeding was done in rows and in 35-cm intervals, with rows separated by 90 cm. On the intercropped sub-plot, cowpeas were planted between the rows of maize with 25 cm between planting point. A marked string was used to establish a straight line, and holes for seeding (planting points) were made along the marked string with a dibble stick at a depth of 4–5 cm.

Research plots were prepared depending on the onset of rainfall. Soil preparation and seeding were completed once we deemed soil moisture to be sufficient, which was usually achieved with a minimum of 20 mm rainfall. As a result, seeding occurred in December/January. Basal fertilisers were applied at seeding at a rate of 150 kg/ha, hence every farmer was given 1 x 50 kg bag of NPK (2:3:2). Top dressing of urea was applied at a rate of 75 kg/ha for four weeks after planting and another 75 kg/ha seven weeks after planting, farmers were expected to apply urea the same day. Urea was only applied to maize, both on the sole cropping sub-plots and on the intercropped sub-plots. Thus, every farmer received one 50 kg bag of urea to apply twice per cropping season. Each farmer managed their research plot individually, and weeding was not expected to be done in one day.

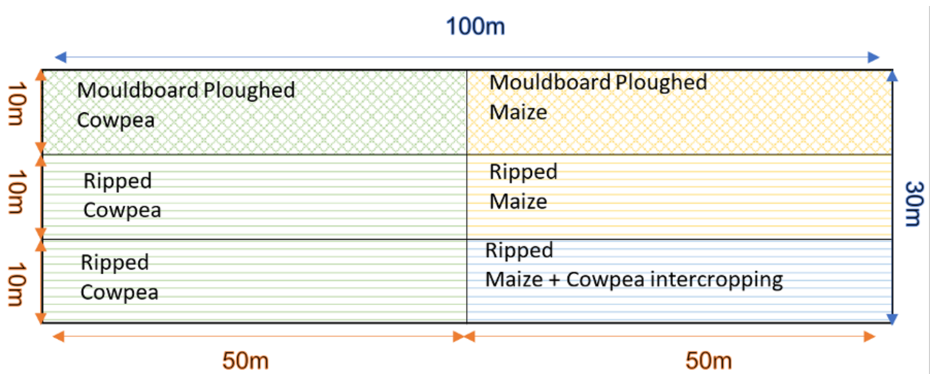

Figure 2 On-farm layout of an experimental plot, with each treatment divided into 10 × 50 m subplots.

Farmers were provided with all inputs and assisted by one research assistant per cluster in managing the research plots in order to ensure that research protocols were properly followed and implemented accordingly. All the crops were grown under rain-fed conditions. This ensured that the experimental variables were treated in a homogeneous way as much as possible, allowing for a clearer comparison between conservation agriculture and conventional tillage systems. Upon completion of the growing season, both grain and biomass yields for the crops were meticulously recorded following established harvesting protocols.

Data collection

To facilitate and ensure a smooth data collection process, I recruited research assistants, with one research assistant being assigned to one cluster. Research assistants were provided with a data collection sheet to record the rainfall figures, dates for each management or measurement activity in the plot, i.e., weeding time and date, or yield taken. All farmers were provided with a rain gauge and trained on how to record the rainfall figures on a data sheet. My research assistants, mobilised with bicycles, ensured that farmers recorded data correctly, which included land preparation, planting, weeding, fertiliser application, pest and disease control. Harvesting protocol training was given to all research assistants, and a harvesting data sheet was designed. Soil samples were taken at 0–20 cm depth before the experiment commenced, with at least ten samples taken at each experimental site. Harvesting was done when the maize plants were dry and the cobs ripe. Five blocks of four rows, each 5 m in length, were demarcated in each treatment, with the following data collected from each block: the distance of the sixth row (one row on each side of the harvesting block), number of planting points within a harvesting block, the number and weight of cobs within each harvesting block, the weight of stalks within the block cut down at the ground level, weighed and recorded as biomass. The maize cob sub-samples and stalk sub-samples were air dried for two weeks before they were re-weighed, the cobs were shelled, and the grain was weighed separately per treatment. An electronic grain moisture tester device was used to determine the grain moisture content after shelling. All the data were entered into a pre-programmed spreadsheet to extrapolate grain and biomass yield per hectare.

Rainfall records

Rainfall patterns showed sporadic variations throughout the experimental period from 2016/2017 to 2019/2020 and between clusters (Figure 3). It is also important to note that rainfall data were collected relatively inconsistently, depending on farmer participation and the occasional theft of rain gauges. In the 2016/2017 season, rainfall was generally fair across all clusters, with a maximum cumulative rainfall exceeding 600 mm. In the 2017/2018 season, the Zambezi Region experienced good rainfall, with the Bito cluster receiving more than 1 000 mm.

2018/2019 marked the shortest rainy season, with only 169 days. In contrast, the 2019/2020 season was the longest and most favourable, with an average annual rainfall of 800 mm being recorded over 199 days.

Data analysis

A two-way Analysis of Variance (ANOVA) was used to assess the effect of conservation agriculture on crop yield. This analysis involved comparing the grain and biomass yields of maize. Consequently, conventional (mouldboard plough) sub-plots were compared with conservation agriculture (ripped) sub-plots and conservation agriculture (ripped) sub-plots that were intercropped. To compare the mean yields of biomass and grains of maize, the Welch's t-test was employed. The significance of differences between various treatments across four cropping seasons was determined using the p value from Welch's t-test as the initial analytical step. Subsequently, a second test was conducted to assess whether there were differences in average yields between tillage methods within each cropping season. All analyses were conducted in R version 4.1.3 (R Core Team 2022).

RESULTS AND DISCUSSION

The analysis revealed no statistically significant difference in the maize biomass yield between the conventional and conservation tillage ($p > 0.05$) over four seasons (Figure 4). On average, plough treatment produced 8.07 kg/ha of biomass, followed by ripper intercropped (maize and cowpeas) treatment with 7.64 kg/ha and ripper with an average of 7.63 kg/ha of biomass. Biomass measurements and analyses are critical

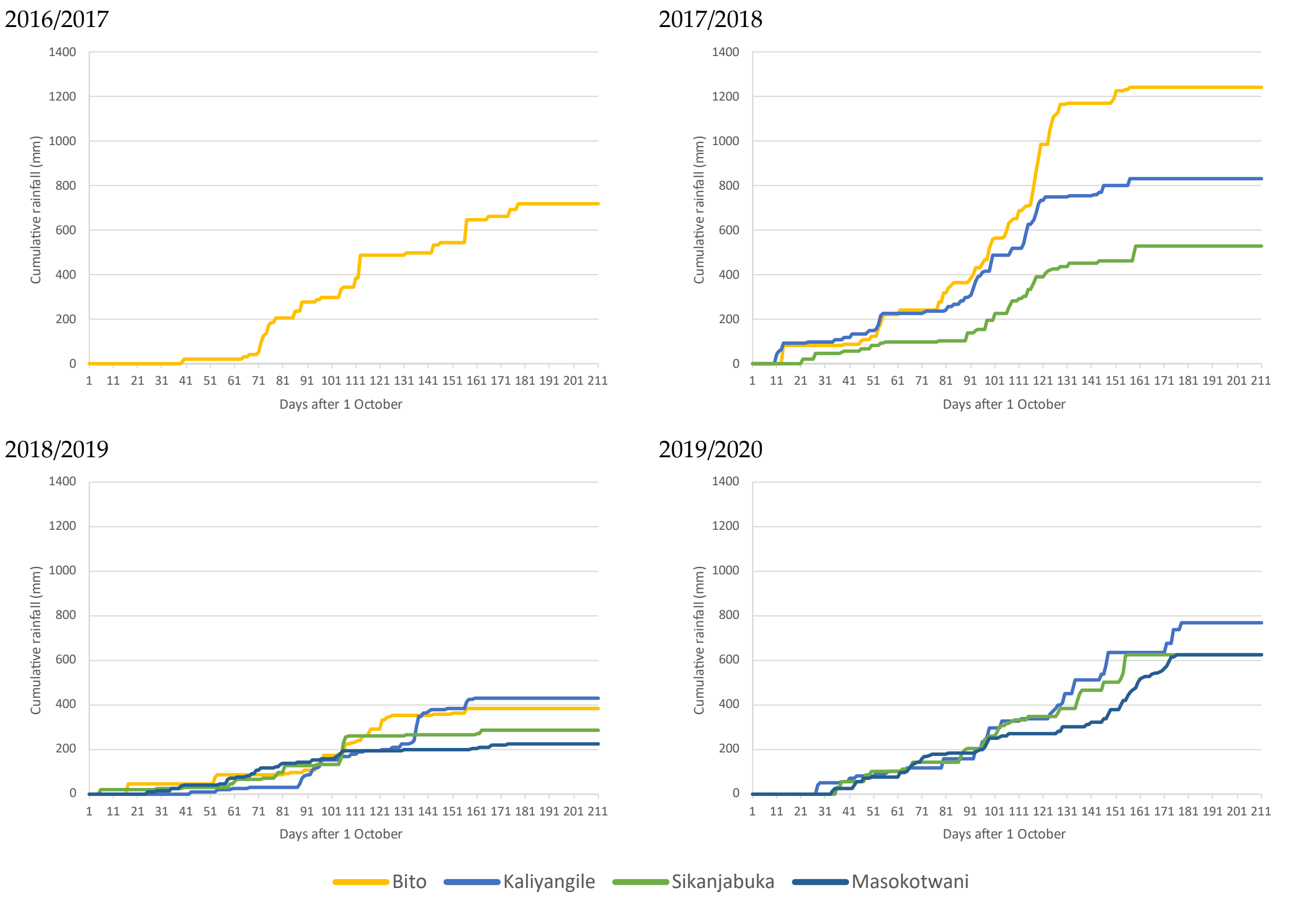

Figure 3 Cumulative rainfall at research clusters during the study period, starting on 1 October 2016.

components in quantifying carbon stocks and sequestration rates (Temesgen et al. 2015). The measure of biomass is important to determine the productivity of a given area, as it may be used as a proxy for yield if the crop did not bear a grain yield due to an unexpected cessation of rainfall.

A similar test was done to determine if there was a significant difference in maize grain yields over the study period across the three treatments (Figure 5). There was no significant difference in maize average grain yield between conventional and conservation tillage over the four cropping seasons. In terms of yields, conservation agriculture can only begin to outperform conventional methods after more than a decade, because of the amount of time it takes to restore or improve soil fertility (Giller et al. 2009). This has drawn mixed reactions from farmers and technocrats on whether conservation agriculture is a sustainable intervention in the era of climate change (Eze et al. 2020, Nyirenda & Balaka 2021, Li et al. 2024). However, an investigation into the effects of conservation agriculture on 17 soil properties, revealed soil health improving with long-term rises in temperatures (Teng et al. 2024). Considering temporal scale as a confounding influence, it is plausible that conservation agriculture's impact was not yet visible in this study and elsewhere (Nyamangara et al. 2013). Additionally, under semi-arid conditions, the performance of conservation agriculture has been found to be enhanced by the addition of small amounts of mineral nitrogen fertiliser and cattle manure, but depressed by surface mulching with high carbon-to-nitrogen crop residues (Nyamangara et al. 2013). When early years of transition might yield discouraging results though, some farmers might opt to abandon conservation agriculture techniques (Hobbs 2007), which presents a substantial challenge for any systemic transitions (Baudron et al. 2015, Ngoma et al. 2024).

There were no statistically significant differences in maize biomass yields across the study's seasons (Figure 5b). In the 2017 cropping season, ploughed plots had on average biomass yield of 10.33 kg/ha, followed by ripper with 8.32 kg/ha, and ripper intercropped with cowpeas with 8.23 kg/ha. In the cropping season of 2018, on average, the plough

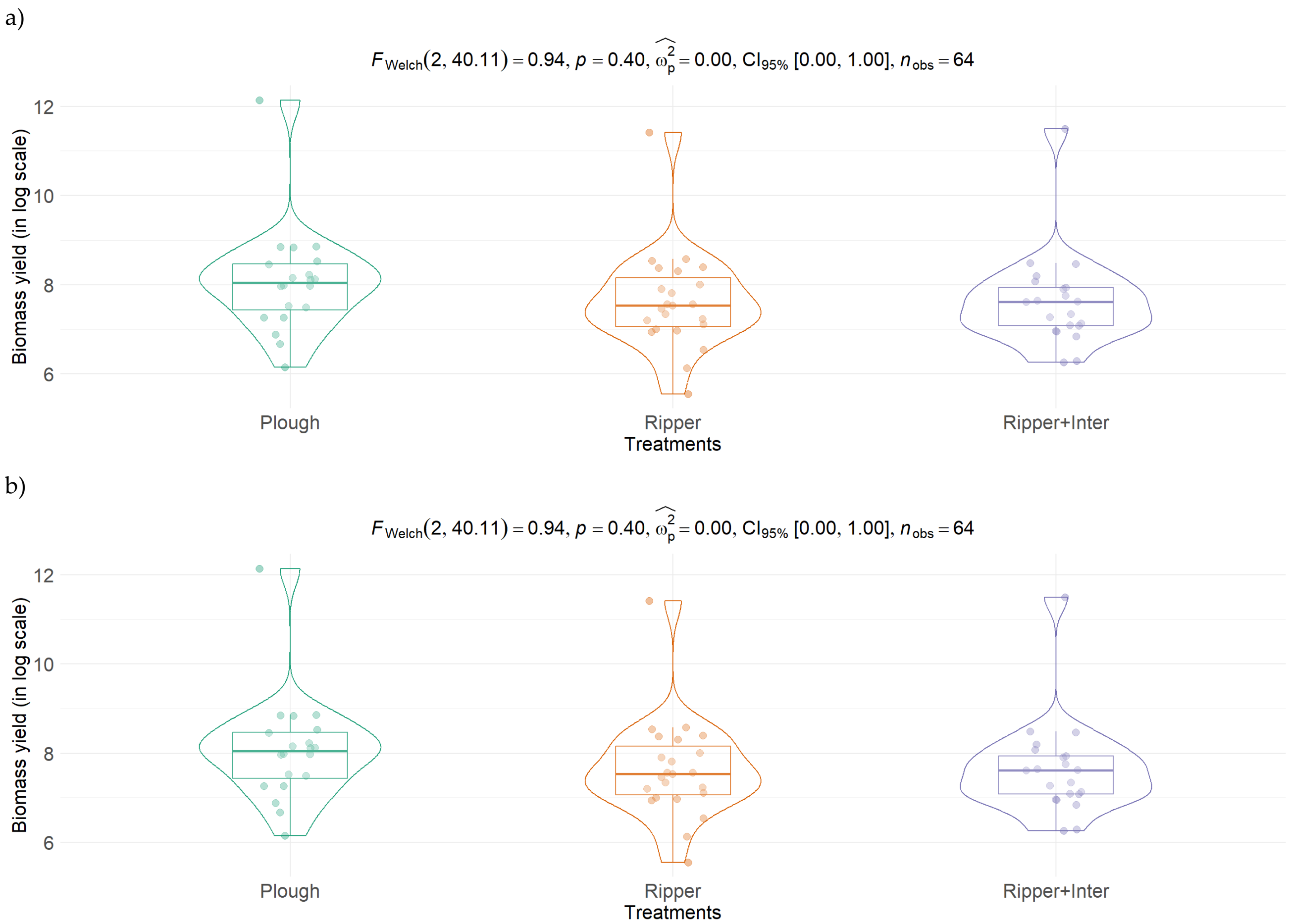

Figure 4 Violin plots illustrating (a) average maize biomass yield and (b) average maize grain yield for different treatments. Mean yield values have been log-transformed to improve visualisation. These plots depict both the central tendency and the distributional shape of the data across treatment groups. Any between-treatment differences are considered significant if the p-value (top) is equal to or below 0.05.

had a biomass yield of 8.09 kg/ha, the ripper yielded 7.54 kg/ha, and the ripper intercropped yielded 7.44 kg/ha. In the 2019 cropping season, on average, ploughed plots yielded 7.48 kg/ha in biomass, followed by ripper intercropping (7.47 kg/ha) and ripper maize (7.31 kg/ha). Notably, data for the 2019/2020 cropping season were not included due to the absence of harvest data - a consequence of movement restrictions imposed nationwide in response to COVID-19.

In the second season, the results demonstrated a statistically significant difference ($p < 0.05$) in the average grain yield of maize between tillage systems, leading to the rejection of the null hypothesis (Figure 5a). Rainfall was comparatively high in the first season. Traditional ploughing yielded more grain than both the ripping and intercropped ripping for that season. This variation in yield could be attributed to the favourable rainfall the Zambezi Region experienced during the first two seasons, with certain areas in the region receiving more than 1 000 mm. These results are in line with the findings by Donovan and McAndrew (2000) that indicate that zero tillage can be particularly effective in enhancing crop yield during years of relatively low precipitation. Both corn and soybean yields have been found to be greater in mouldboard ploughing than in no tillage because of lower weed density (Mulugeta & Stolenberg 1997). Another study reported that no-tillage treatment yielded less than ploughed treatment (Wilhelm & Wortmann 2004). A study carried out in the northeastern regions of Namibia found a significant difference in maize grain yield in the second year of experimenting, with conventional tillage recording the highest grain yield and minimum tillage being the least productive (Kudumo et al. 2023). However, minimum tillage with selective incorporation of conservation agriculture principles increased maize grain yields in the third year (Kudumo et al.

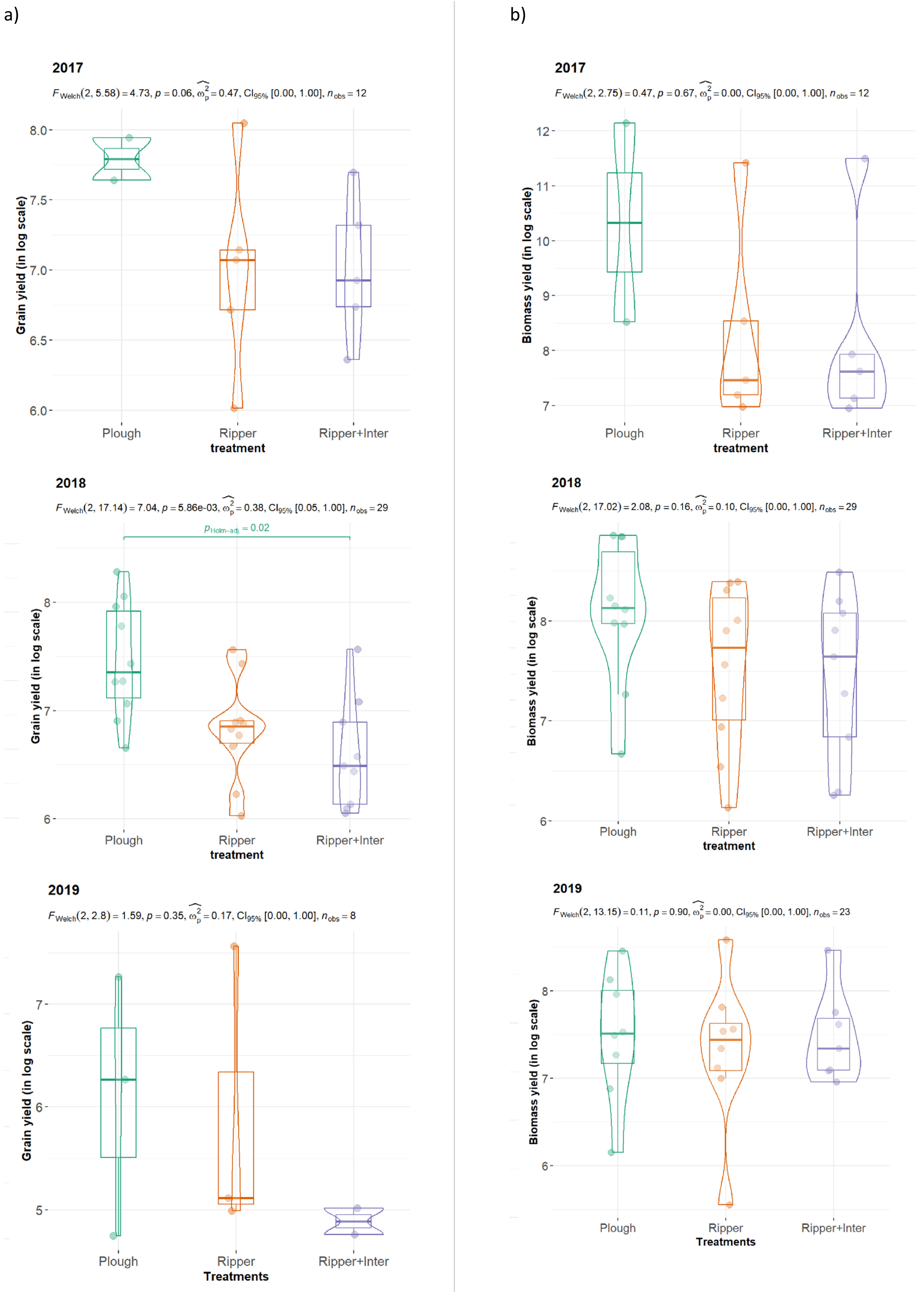

Figure 5 a) Average maize grain yield and b) average maize biomass across treatments within seasons. These plots depict both the central tendency and the distributional shape of the data across treatment groups. Any between-treatment differences are considered significant if the p-value (top) is equal to or below 0.05.

2023). In another study, animal traction conservation agriculture systems had slightly smaller yield benefits on a rip line seeded system compared to a ploughed control treatment (Thierfelder 2015). One of the contributing factors to low yield on the ripper sub-plots in this study is that ripper lines suffered from rat attacks, which were feeding on the germinating seed following ripper lines, necessitating re-seeding on many occasions. This led to delayed establishment and poorer growth of crops in ripper lines compared to those in ploughed sections, where conditions were more conducive to germination and early growth due to a softer, weed-free seedbed. Ripped plots were also disadvantaged because some farmers delayed the weeding process, exposing the crops in the ripper sub-plots to higher weed densities. Additionally, the intercropped areas reported lower average grain yields compared to mono-cropping with the ripper. This can be attributed to the competition between maize and cowpeas for moisture and nutrients, and aligns with other findings. Huang et al. (2019), for instance, found that maize grain yield from intercropped plots was 34% less than that from double-cropped plots. Intercropping treatments have also been found to produce relatively low number of grains per cob (Suhi et al. 2022). In contrast, other researchers have found that intercropping maize and cowpea enhances maize grain yield (Iderawumi et al. 2017), and has a profound effect on soil organic carbon (Ayele 2020).

CONCLUSION

This study found no observable difference in the average maize biomass yield between two primary tillage systems (conventional and conservation agriculture) and within the growing seasons. These results point towards conservation agriculture as a viable alternative to more conventional methods. During one season, however, a significantly higher average maize grain yield was recorded in conventional plots, which might be attributable to localised and context-specific factors. The research might also not have been conducted long enough for more potential effects to become observable, as other studies have demonstrated. Long-term implementation and monitoring are essential to studying the various principles of conservation agriculture and its influence on biomass and grain yield. Future research should aim to comprehensively evaluate the impacts of these practices on crop yield, microbial communities, and soil properties. This will not only provide empirical evidence to test the efficacy of conservation agriculture but also guide future policy and practice to enhance sustainable agriculture at large. In Namibia, long-term practical demonstrations could be organised on agricultural demonstration plots in each of the constituencies across the 14 regions, allowing farmers to witness the principles of conservation agriculture in action.

CONFLICT OF INTEREST

The author declares no conflicts of interest.

ACKNOWLEDGEMENTS

The author thanks the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Namibia for their financial support in conducting the experiments; the Ministry of Agriculture, Fisheries, Water, and Land Reform for technical support, and the Namibia University of Science and Technology for relinquishing the author from academic responsibility to collect data in the field. The author acknowledges the contribution of Mr Mwala Lubinda for assisting with data analysis.

REFERENCES

Akpalu W, Ekbom A (2010) Bio-economics of conservation agriculture and soil carbon sequestration in developing countries. *Working Papers in Economics* 431.

Angombe ST, Shikangalah RN (2021) *Pterocarpus angolensis* growth rings and precipitation: A comparison between Zambezi and Otjozondjupa region, Namibia. *International Science and Technology Journal of Namibia* 14: 34–45.

Ayele HM (2020) Evaluation of the effect of maize-legume intercropping on soil moisture improvement in arid area of Bena-Tsemay district, South omo zone, Southern Ethiopia. *International Journal of Agricultural Research, Innovation and Technology* 10(1): 80–86. https://doi.org/10.3329/ijarit.v10i1.48097

Baudron F, Thierfelder C, Nyagumbo I, Gerard B (2015) Where to target conservation agriculture for African smallholders? How to overcome challenges associated with its implementation? Experience from Eastern and Southern Africa. *Environments* 2: 338–357.

Eze S, Dougill AJ, Banwart SA, Hermans TDG, Ligowe IS, Thierfelder C (2020) Impacts of conservation agriculture on soil structure and hydraulic properties of Malawian agricultural systems. *Soil and Tillage Research* 201: 104639. https://doi.org/10.1016/j.still.2020.104639

Fortunato A, Enciso S (2023) Food for growth: A diagnostics of Namibia's Agriculture Sector. *Center for International Development at Harvard University Research Fellow and Graduate Student*, *Working Paper No. 154*.

Gebru A (2012) Can conservation agriculture improve the land productivity of smallholder farmers in Eastern Tigray, Ethiopia? In: Govaerts B, Vaghi F (eds) Compendium of deliverables of the conservation agriculture course 2010, pp 21–30. International Maize and Wheat Improvement Center, El Batán, Mexico.

Giller KE, Witter E, Corbeels M, Tittonell P (2009) Conservation agriculture and smallholder farming in Africa: The heretic's view. *Field Crops Research* 114: 23–34.

Grabowski PP, Kerr JM (2014) Resource constraints and partial adoption of conservation agriculture by hand-hoe farmers in Mozambique. *International Journal of Agricultural Sustainability* 12(1): 37–53. https://doi.org/10.1080/14735903.2013.782703

Hall DJM, Jones HR, Crabtree WL, Daniel TL (2010) Claying and deep ripping can increase crop yields and profits on water repellent sands with marginal fertility in southern Western Australia. *Australian Journal of Soil Research* 48: 178–187. https://doi.org/10.1071/SR09078

He J, Wang Q, Li H, Tullberg JN, McHugh AD, Bai Y, et al. (2009) Soil physical properties and infiltration after long-term no-tillage and ploughing on the Chinese Loess Plateau *New Zealand Journal of Crop and Horticultural Science* 37: 157–166.

Hobbs PR (2007) Conservation agriculture: What is it and why is it important for future sustainable food production? *The Journal of Agricultural Science* 145: 127–137. https://dx.doi.org/10.1017/S0021859607006892

Huang C-d, Liu Q-q, Li X-l, Zhang C-c (2019) Effect of intercropping on maize grain yield and yield components. *Journal of Integrative Agriculture* 18(8): 1690–1700.

Iderawumi AM, Mubo OA, Friday CE (2017) Growth characteristics and yield effect of plant spacing and intercropping maize and cowpea. *ABC Journal of Advanced Research* 7(1): 17–24.

Kassam A, Friedrich T, Shaxson F, Bartz H, Mello I, Kienzle J, et al. (2014) The spread of conservation agriculture: Policy and institutional support for adoption and uptake. *Field Actions Science Reports* 7: 1–13.

Kassam AH, Mkomwa S, Freindrich T (2016) Conservation agriculture for Africa: Building resilient farming systems in a changing climate. Centre for Agriculture and Bioscience International, Wallingford, UK.

Kiesel C (2019) The Namibian maize sector and the role of the state: Impacts on local value chain development. Master's thesis, University of Cologne, Cologne, Germany.

Kiesel C, Dannenberg P, Hulke C, Kairu J, Diez JR, Sandhage-Hofmann AS (2022) An argument for place-based policies: The importance of local agro-economic, political and environmental conditions for agricultural policies exemplified by the Zambezi region, Namibia. *Environmental Science and Policy* 129: 137–149. https://doi.org/org/10.1016/j.envsci.2021.12.012.

Krebs J (2014) A preliminary survey on soil management practices and land units on soil organic carbon of small-scale communal farmers in North Central Namibia. Master's thesis, University of Greifswald, Greifswald, Germany.

Kristof ST (2022) Analysis of factors influencing the technical efficiency of maize small-scale farmers of Kavango East region. Master's thesis, Namibia University of Science and Technology, Windhoek, Namibia.

Kudumo LP, Itanna F, Thierfelder C, Kambatuku J (2023) Soil moisture content and maize grain yield under conventional and conservation agriculture practices - results of short term field tests in Iiselo, Namibia. *African Journal of Agricultural Research* 19(9). https://doi.org/10.5897/AJAR2023.16327.

Lai C, Chan C, Halbrendt J, Shariq L, Roul P, Idol T, et al. (2012) Comparative economic and gender, labour analysis of conservation agriculture practices in tribal villages in India. *International Food and Agribusiness Management Review* 15(1) 73–86.

Li H, Tang J, Wang J, Qiao J, Zhu N (2024) Long-term conservation agriculture improves soil quality in sloped farmland planting systems. *Plants* 13(23): 3420. https://www.mdpi.com/2223-7747/13/23/3420.

MAWF (Ministry of Agriculture, Water and Forestry) (2015) Comprehensive conservation agriculture programme for Namibia 2015–2019. Ministry of Agriculture, Water and Forestry, Windhoek, Namibia.

Mendelsohn J, Jarvis A, Roberts C, Robertson T (2002) *Atlas of Namibia: A portrait of the land and its people*. Sunbird Publishers, Cape Town, South Africa.

Mulugeta D, Stolenberg DE (1997) Increased weed emergence and seed bank depletion by soil disturbance in a no-till system. *Weed Science Journal* 45(5): 706–715.

Muradzikwa EM, Nkenbeza D, Muradzikwa E (2023) An assessment of maize production status, challenges and opportunities in the Zambezi Region of Namibia during the period 2011 to 2020. *International Research Journal of Economics and Management Studies* 2(1): 172–182. https://doi.org/10.56472/25835238/IRJEMS-V2I1P123

Mushendami P, Biwa B, Gaomab II M (2008) Unleashing the potential of the agricultural sector in Namibia. Bank of Namibia Occasional Paper. Bank of Namibia Research Department, Windhoek, Namibia.

NAB (Namibian Agronomic Board) (2022a) Market intelligence report for maize grain. (Issue 1 of 2022). Namibian Agronomic Board, Windhoek, Namibia.

NAB (Namibian Agronomic Board) (2022b) White maize production forecast report: Harvesting/marketing season 2022/2023. Agronomy market development subdivision. Namibian Agronomic Board, Windhoek, Namibia.

Ngoma H, Marenya P, Tufa A, Alene A, Matin MA, Thierfelder C, Chikoye D (2024). Too fast or too slow: The speed and persistence of adoption of conservation agriculture in southern Africa. Technological Forecasting and Social Change, 208. https://doi.org/10.1016/j.techfore.2024.123689

NSA (Namibia Statistics Agency) (2021) Namibia Multidimensional Poverty Index (MPI) Report 2021. Namibia Statistics Agency, Windhoek, Namibia.

NSA (Namibia Statistics Agency) (2024) Namibia 2023 Population and Housing Census Report. Namibia Statistics Agency, Windhoek, Namibia.

Nyamangara J, Nyengerai K, Tirivavi R (2013) Effect of conservation agriculture on maize yield in the semi-arid areas of Zimbabwe. *Experimental Agriculture* 50(2): 159–177. https://doi.org/10.1017/S0014479713000562

Nyanga PH, Johnsen FH, Aune JB (2011) Smallholder farmers' perceptions of climate change and conservation agriculture: Evidence from Zambia. *Journal of Sustainable Development* 4: 73–85.

Nyirenda H, Balaka V (2021) Conservation agriculture-related practices contribute to maize (*Zea mays* L.) yield and soil improvement in Central Malawi. *Heliyon* 7(3): e06636. https://doi.org/10.1016/j.heliyon.2021.e06636

Palm C, Blanco-Canqui H, DeClerck F, Gatere L, Grace P (2014) Conservation agriculture and ecosystem services: An overview. *Agriculture, Ecosystem and Environment* 187: 87–105.

Pittelkow CM, Liang X, Linquist BA, Groenigen KJ, Lee J, Lundy ME, et al. (2014) Productivity limits and potentials of the principles of conservation agriculture. *Nature* 517: 365–368.

R Core Team (2022) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org.

Shifiona TK, Dongyang W, Zhiguan H (2016) Analysis of Namibia main crops annual production, consumption and trade: Maize and Pearl millet. *Journal of Agricultural Science* 8(3): 70–77. https://doi.org/10.5539/jas.v8n3P7

Suhi AA, Mia S, Khanam S, Mithu MH, Uddin MK, Muktadir MA, et al. (2022) How does maize-cowpea intercropping maximize land use and economic return? A field trial in Bangladesh. *Land* 11(4): 581. https://doi.org/10.3390/land11040581

Taapopi M, Kamwi JM, Siyambango N (2018) Perception of farmers on conservation agriculture for climate change adaptation in Namibia. *Environment and Natural Resources Research* 8(3): 33–43. https://dx.doi: 10.5539/enrr.v8n3p33

Temesgen H, Affleck D, Gray A, Sessions J (2015) Measurements and estimation of above ground biomass of the Western U.S. forests. *Scandinavian Journal of Forest Research* 30(4): 326–335. https://doi.org/10.1080/02827581.2015.1012114

Teng J, Hou R, Dungait JA, Zhou G, Kuzyakov Y, Zhang J, Tian J, Cui Z, Zhang F (2024) Conservation agriculture improves soil health and sustains crop yields after long-term warming. *Nature Communications* 15(1): 1–12. https://doi.org/10.1038/s41467-024-53169-6

Teweldemedhin MY, Durand W, Crespo O, Beletse YG, Nhemachena C (2015) Economic impact of climate change and benefit of adaptations for maize production: Case from Namibia, Zambezi region. *Journal of Development and Agricultural Economics* 7(2): 61–71. https://doi.org/10.5897/JDAE2014.0605

Thierfelder C, Wall PC (2009) Effects of conservation agriculture techniques on infiltration and social water content in Zambia and Zimbabwe. *Soil and Tillage Research* 105: 217–227.

Thierfelder C, Matemba-Mutasa R, Rusinamhodzi L (2015) Yield response of maize (*Zea mays* L.) to conservation agriculture cropping system in Southern Africa. *Soil and Tillage Research* 146: 230–242. https://doi.org/10.1016/j.still.2014.10.015

Wagstaff P, Harty M (2010) The impact of conservation agriculture on food security in three low veldt districts of Zimbabwe. *Trócaire Development Review*, 67–84.

Wang H, Li X, Wang J, Li X, Guo Q, Yu Z, et al. (2020) Long-term no-tillage and different residue amounts alter soil microbial community composition and increase the risk of maize root rot in northeast China. *Soil and Tillage Research* 196. https://doi.org/10.1016/j.still.2019.104452

Wilhelm WW, Wortmann CS (2004). Tillage and rotation interactions for corn and soybean grain yield as affected by precipitation and air temperature. *Agronomy Journal* 96(2): 425–432.

Xavier JHV, Gomes MC, Anjos SF, Scopel E, da Silva FAM, Corbeels M (2020) Participatory multicriteria assessment of maize cropping systems in the context of family farmers in the Brazilian Cerrado. *International Journal of Agricultural Sustainability* 18(5): 410–426. https://doi.org/10.1080/14735903.2020.1788253.