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Evaluation Of Conservation Agriculture On Sorghum Grain Yield In Pandamatenga Vertisols Of Northern Botswana

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***Abstract*—Conservation agriculture (CA) is an important alternative farming system in the control and improvement of the soil regimes in vertisols for increased crop production. A field experiment was conducted at the Department of Agricultural Research station at Pandamatenga, Northern Botswana during the 2015-2017 planting seasons. The objective of the experiment was to evaluate the effects of CA technologies on sorghum grain yield in the vertisols of Pandamatenga region. A randomized complete block design was used for the on-station field experimentation. The design had trial plots with four treatments, namely No tillage (NT), No tillage + mulch (NT+M), Minimum tillage (MT), and broad bed and furrow (BBF), with four replicates rotated between sorghum and cowpea. Sorghum grain yield results were analysed using the Statistical Analysis Software (SAS version 9.2). Analysis of variance and means were separated using Duncan's multiple range test at 5% confidence level. On average no tillage (594 kg/ha) and no tillage plus mulch (560 kg/ha) technologies were found to have the highest sorghum grain yield in different growing seasons in both continuous and cowpea- rotated- with- sorghum trials. No tillage plus mulch (NT+M) would be a suitable farming system for smallholder rainfed farmers for enhancement of physical properties of vertisols to facilitate sustained growth and yield of sorghum.**

Keywords— conservation agriculture technologies, adoption, smallholder arable farmers, vertisols

I. INTRODUCTION

Rainfed agriculture plays an important role in rural development by providing food, employment and income for most rural dwellers in Botswana [1]. The Government of Botswana placed high priority on the development of agriculture in

Pandamatenga because of the area's inherent potential to contribute to food security, poverty alleviation and socio – economic growth. Vertisols such as those found in the Pandamatenga region have a high crop production potential. Farmers are however unable to manage these types of soils because of their unique properties that require a careful special management to translate their high potential fertility into successful crop production.

The physical properties of these soils make them difficult to cultivate and present inherent problems of low infiltration rates, waterlogging and high erodibility.

Furthermore, most farmers in Pandamatenga practice conventional tillage where the whole field is ploughed using a mouldboard and followed by harrowing. These repeated machinery operations are known to destroy soil structure. This leads to problems of soil degradation and compaction and result in an increased exposure of soils to high intensity storms [2]. The long-term effect of which is the decline in crop yields.

To maximize production under these vertisols' unique properties, a systematic understanding of the properties and processes of these soils is crucial for the development and implementation of farming practices. This will keep them productive for the current and future generation. Better management of vertisols, apart from enhancing crop production is also necessary in the protection of the environment [3]. To mitigate the physical constraints of vertisols properties, some organizations such as the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) and International Livestock Centre for Africa (ILCA) have been promoting alternative methods of crop production especially in vertisols. These farming systems such as conservation agriculture enhance productivity while conserving soil and water. According to Food and Agriculture Organization [4] conservation farming or Conservation Agriculture (CA) is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resources base and the environment. Conservation Agriculture is characterized by three linked principles namely, continuous minimum mechanical soil disturbance, permanent organic soil cover and diversification of crop species grown in sequence and or associations. Under favourable climatic conditions and appropriate management, vertisols have proved to be productive and capable of producing a much greater contribution to food production [5]. A study conducted in Ethiopian vertisols showed that soil losses and run off were significantly higher in conventional tillage systems [6]. It was also found out that the gross margin was significantly higher in CA systems as compared to conventional tillage. Oicha *et al*. [7] similarly stated that in Ethiopia conventional tillage includes a primary tillage followed by repeated secondary shallow tillage and these repeated operations cause moist soil to move to the surface favouring water loss by evaporation, exposing the soil to both wind and water erosion and causing structural damage. Soil erosion due to high tillage frequency and other soil management problems has seriously affected over 25% of the Ethiopian highlands [7]. Nevertheless, there is evidence that substantial increases in crop yield could be obtained on vertisols if excess surface soil water is drained off and if appropriate cropping practices are used [3]. This is supported by Araya *et al*. [6], who stated that CA has been practiced around the world to reduce cropland degradation and improve soil quality, thereby increasing crop productivity. Conservation Agriculture is an important alternative farming system in the control and improvement of the soil regimes in vertisols for increased crop production thus improving livelihoods [6]. Derpsch *et al.* [8] and Hati *et al.* [9] further reported that for clay soils no tillage is a suitable management option which minimises sub-soil compaction and also induces natural structure formation through shrink-swell cycles. The maintenance of a permanent soil cover with mulch or cover crops also increased the stability of vertisols [7].

Residues provide a constant food source for the soil and a habitation of many organisms. The fauna and flora produce soil pores and their increased biological activity with crop residue retention enables the slow breakdown of the residues and incorporate these residues in the soil as organic matter [10]. Soil organic matter promotes aggregation through the linkage of clay-organic matter [11]. The effects of these practices on sorghum grain yields has not been fully appraised under Botswana conditions especially in the Pandamatenga vertisols despite their influence on offering sustainability of crop production through more effective management of soil and water. Therefore, the objective of the study was to assess the potential of CA technologies namely, no tillage (NT), minimum tillage (MT), no tillage + mulch (NT + M) and broad bed and furrow (BBF) on improving sorghum yields.

II. MATERIALS AND METHODS

A. *Description of the study area*

The study was based at Pandamatenga village (Figure 1). Pandamatenga region lies in the northern part of Botswana between latitude 18º 32' South, and longitude 25º 38' East and it covers an area of 280, 380ha. The village is about 100km South of Kasane in the Chobe District. The Pandamatenga farms (Figure 2) cover only 25,074 ha of this total land area [2]. The climate for the Chobe district and Pandamatenga is semi–arid characterized by hot and moist summers and dry mild winters. Rainfall is derived from convective processes and is highly variable even over small distances and averages 600 mm annually, thus making Pandamatenga one of Botswana's least arid areas. Almost all rain falls between October and April, with December, January and February being the peak months. A substantial proportion of this rain falls in short duration of high intensity storms, thus, leading to high run–on into some farms, which become flooded instantly. Maximum temperatures of 26˚C to 34˚C occur in October to March. Minimum temperatures of 11˚C to 20˚C are experienced between November and July. The vegetation is extensive grassland savannah in association with Mophane (*Colophospermum mopane*) and acacia species [12]. The Pandamatenga plains are underlain by basalt which occurs at the base of the black cotton soils. This basalt occurs subordinately with the sandstones. This basalt is mostly exposed around Pandamatenga village and extends eastwards across the border into Zimbabwe [12]. The area is dominated by vertisolic clay soils, which are potentially good farming soils. The soils are characterized by very high clay contents dominated by expanding lattice clay minerals which give them their physical and chemical properties. The area is generally flat with a gentle slope and rain water flows following natural drainage routes [2].

Figure 1. Location of study area in Africa

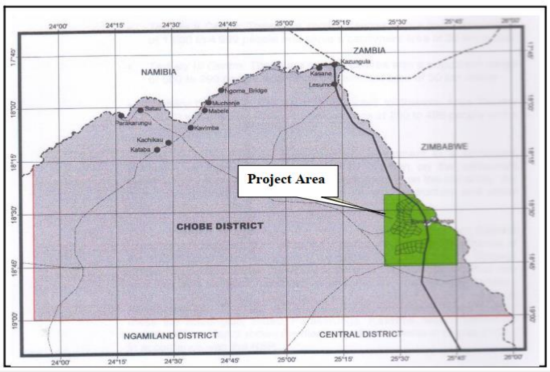

Figure 2. Detailed inset of Pandamatenga Farms.

B. Experimental design

The field experiment was conducted at the Pandamatenga Agricultural Research station under

rainfed conditions during 2015/17 growing seasons. A randomized complete block design was used for the field experimentation with plot dimensions of 20m by 7.5m. The design was subjected to the on-station trial plots with four treatments, namely No Tillage (NT), No Tillage + Mulch (NT+M), Minimum Tillage (MT) and Broad Bed and Furrow (BBF), of four replicates rotated between sorghum and cowpea. Sorghum variety Segaolane and cowpea variety Tswana were used for the experiment. A field book was used to record all relevant variables (sorghum grain yield, anthesis date and days to maturity) for three consecutive cropping seasons between the years 2015 and 2017.

C. Data analysis

Data on sorghum grain yield (kg/ha) were analysed using the Statistical Analysis Software computer package version 9.2 [13]. Analysis of variance and means were separated using Duncan's multiple range test at 5% confidence level.

III. RESULTS AND DISCUSSIONS

A. Weather data for Pandamatenga Department of Agricultural Research Station

The weather data for the study area is shown in Figure 3. The month of February had the highest amount of rainfall in all the growing seasons. The highest temperatures were experienced in January and October.

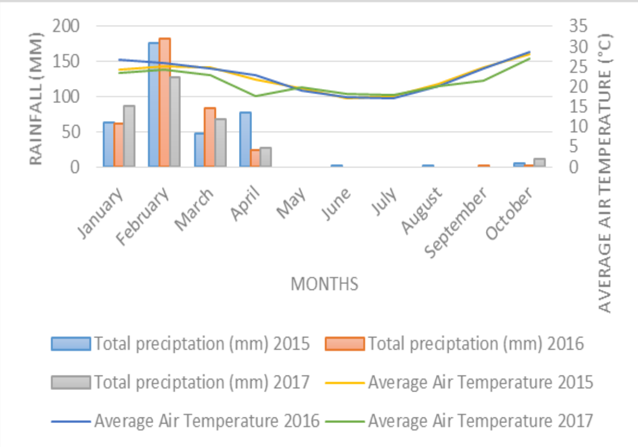

Figure 3. Average air temperature (˚C) and total rainfall amount (mm) for the period 2015 – 2017.

B. Soil sampling and analysis

Bulk density showed a decrease in its values across the growing seasons for NT, MT and BBF (Table 1). The decrease is attributed to the increase of volumetric moisture content due to the continuous expansion of vertisols on wetting [5]. There was an increase in volumetric water content from all the treatments from 2016 to 2017. This is attributed to the fact that collection of soil samples was done during wet periods.

Table 1. Selected soil physical parameters during 2016 - 2017 growing

seasons at 0-5cm depth

Conservation Agriculture practice	Growing seasons			
	2016		2017	
	Bulk density (g/cm^3)	Volumetric water content (cm^3/cm^3)	Bulk density (g/cm^3)	Volumetric water content (cm^3/cm^3)
No Tillage	1.320	0.127	1.261	0.270
Minimum Tillage	1.267	0.140	1.242	0.278
No Tillage + Mulch	1.240	0.113	1.267	0.249
Broad bed and Furrows	1.362	0.141	1.259	0.278

C. Effect of CA practices on continuous sorghum grain yield

Table 2 shows that sorghum grain yield was highest in 2016 cropping season as compared to 2015 and 2017 growing seasons. The highest sorghum grain yield was within the potential yield range of the Segaolane variety (1000-3000 kg/ha) at optimum conditions in Botswana. This highest amount of grain yield was attributed to the highest amount of rainfall which was received in 2016 growing season (Figure 3). The continuous sorghum grain yields for 2015 growing season were not significantly different among CA practices. Although not significant, NT+M had the highest amount of sorghum grain yield in 2015. The lowest sorghum grain yield in 2015 and 2017 growing seasons was attributed to the lowest amount of rainfall which was experienced.

In 2016 growing season the sorghum grain yield was highest in NT (1313 kg/ha) but not significantly different from NT+M and BBF. The yield was, however, significantly lower in MT (893 kg/ha). Sorghum grain yields were not significantly different among the treatments in 2017. No tillage had the highest sorghum grain yield (340kg/ha) in 2017 growing season (Table 2).

In this study, NT and NT+M treatments had the highest sorghum grain yield in all the growing seasons (Table 2). The highest yield from these treatments is attributed to the fact that NT or minimum disturbance of the soil allowed the retention of soil organic matter, which provided more nutrients for the growing crop and also stabilized the structure of the soil and made it less vulnerable to crusting and erosion thus benefiting crop growth under dry condition [14]. No tillage is an optimal management practice which minimises subsoil compaction and induces natural structure formation through shrink and swelling cycles [9]. The maintenance of a permanent soil cover with mulch also increased the stability of vertisols. Furthermore, soil surface was protected from raindrops resulting in high infiltration rates and reduced runoff leading to moisture availability to crops [10]. Mulch also reduces cracking in vertisols as residues form a physical barrier that reduces speed of wind over the surface and this leads to the reduction of soil moisture evaporation thus enhancing soil availability for plants uptake [15, 16]. Similarly, Zheng et al. [17] stated that no tillage had the highest grain yield as compared to other CA practices. Similar results were reported by Araya et al. [18], in which yield of crops were significantly affected by CA practice treatments.

Table 2. Sorghum grain yield (kg/ha) for the different treatments under

continuous sorghum

Treatments	Years		
	2015	2016	2017
	Grain yield (kg/ha)		
No tillage	222a	1313a	340a
Minimum Tillage	231a	893b	260a
No Tillage + Mulch	260a	1153a	112a
Broad bed and furrows	169a	1113a	258a

Difference letters within a column indicate significant difference between values at P ≤ 0.05

D. *Effect of CA practices on cowpea rotated sorghum grain yield*

In 2015 growing season, NT+M had the highest grain yield followed by MT, and NT had the lowest amount of yield. The NT+M had the highest yield again in 2016 while BBF had the lowest amount of grain yield (Table 3). The higher yield from this practice is attributed to the fact that no tillage with mulch improved soil fertility as there was less soil disturbance and this allowed soil organic matter retention as living organisms in this environment broke down the mulch and incorporated it into the soil. Mulch also improved soil moisture conditions by improving soil structure and reduced soil water evaporation, thus benefiting crop growth under dry conditions. Similarly, Zheng et al. [17] stated that no tillage with straw retention had the highest grain yield as compared to other CA practices.

In all the cropping seasons there was no significant difference among the treatments (Table 3). On the other hand, BBF had the lowest amount of cowpea rotated sorghum grain yield (Table 3). Wubie [3] however, reported an increase of 59% as compared to the control and it was attributed to the fact that in BBF the surface drainage was enhanced which resulted in early establishment of the crop so that it relatively tolerated the rainstorm and escaped the terminal moisture stress. The yield benefit of including cowpea in the rotation was not apparent as sorghum grain yield between continous sorghum and cowpea rotated sorghum was not significant in all the treatments except in 2016 growing season for MT (Tables 4, 5 and 6). This could be due to the short period of field experimentation.

Table 3. Sorghum grain yield (kg/ha) for the different treatments under

cowpea rotated sorghum

Treatments	Years		
	2015	2016	2017
	Grain yield (kg/ha)		
No Tillage	128a	1313a	247a
Minimum Tillage	133a	1260a	223a
No Tillage + Mulch	240a	1403a	165a
Broad Bed and Furrow	131a	1117a	327a

Different letters within a column indicate significant difference between values at P≤0.05

Table 4. Comparison of yield for continuous sorghum and cowpea

rotated sorghum (2015)

Treatment (2015)	Cowpea rotated sorghum	Continuous sorghum	F-value
No Tillage	128	222	1.734ns
Minimum Tillage	133	231	2.160ns
No Tillage + Mulch	260	240	0.036ns
Broad Bed and Furrow	131	169	0.924ns

Table 5. Comparison of yield for continuous sorghum and cowpea

rotated sorghum (2016)

Treatment (2016)	Cowpea rotated sorghum	Continuous sorghum	F- value
No Tillage	1313	1313	3.85ns
Minimum Tillage	1260	893	9.035*
No Tillage + Mulch	1403	1153	3.200ns
Broad Bed and Furrow	1117	1113	0.713ns

*: P≤ 0.05; ns = Not significant

Table 6. Comparison of yield for continuous sorghum and cowpea

rotated sorghum (2017)

Treatment (2016)	Cowpea rotated sorghum	Continuous sorghum	F- value
No Tillage	247	340	0.380ns
Minimum Tillage	223	260	0.171ns
No Tillage + Mulch	165	112	0.287ns
Broad Bed and Furrow	327	258	0.281ns

*: P≤ 0.05; ns = Not significant

IV. CONCLUSION

This study has shown that no tillage (NT) and no tillage plus mulch (NT+M) consistently had the highest sorghum grain yield in different growing seasons in both continuous and cowpea- rotated -sorghum trials. It is thus concluded that no tillage plus mulch (NT+M) and practising crop rotation are a suitable cropping system for adoption by smallholder rainfed farmers in the Pandamatenga vertisols of Northern Botswana. The main reason for adoption of the Conservation Agriculture (CA) technology is for the enhancement of the physical properties of vertisols to facilitate sustained growth and yield of sorghum.

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