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Comparative effects of partial conservation farming practices on plant development and yield

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A B S T R A C T

Sustainable farming systems are being introduced to ensure optimum agricultural productivity despite climate change and environmental degradation. One such sustainable agricultural technology is conservation farming (CF). The uptake of this technology has remained low at about 5% years after its introduction. CF has five interrelated practices but for a variety of reasons, farmers are unable or unwilling to adopt all recommended practices. This study studied the agronomic effects of incomplete or partial conservation practice whereby not all the five practices are used, mimicking actual practices adopted by farmers. A split- plot design experiment involving partial or incomplete CF mainly use of basins, ripping were compared to conventional farming of normal ploughing (as main plots) and three crops - cowpea, millet and sorghum (split plot) was conducted. The objective was to determine the agronomic effects and efficacy of partial adoption of CF compared to conventional farming system. Data were collected on vegetative and reproductive parameters including, plant height, germination percentage, canopy density, number of leaves, number of branches/tillers/stems, SPAD (Soil Plant Analysis Development) readings a proxy for leaf chlorophyll content. Plants grown in basins had higher plant development (plant height, total biomass) and higher yields compared to those on conventional methods. This effect could be explained by better soil physical and chemical conditions in the basins as indicated by higher SPAD readings.

Keywords: Climate change, Environment, Sustainability, Small-scale farmers

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Introduction

Agriculture is the main stay of the majority of the rural population in developing countries such as Zambia (Mataa, 2021). It is the source of income and livelihood for most people (Mulenga *et al.*, 2020). The world's climate is changing because of a number of reasons largely due to increase in greenhouse gas (GHG) emissions arising out of anthropogenic activities. The main effect is the emergence of extreme weather patterns exemplified by altered rainfall patterns hence regular occurrence of droughts, or floods. Rural populations are affected by the change of the climate because they are typically reliant on farming. Many farmers in Zambia are vulnerable because they practice rain-fed agriculture. Climate change has disrupted food systems endangering food security and reducing the access to food and adequate nutrition (Godfray *et al.*, 2010).

Agriculture is the second major contributor to climate change through greenhouse gas emissions, generating about 13,427.5 m metric ton of CO_2 equivalent (Munyinda *et al.*, 2015). Additionally agriculture contributes to pollution and land degradation through conventional land preparation. In order to redress the situation there has been initiatives to develop and introduce agricultural systems that are environmentally safe such as conservation farming. Conservation farming as practiced in Zambia is a 'bundle' of practices that includes dry season land preparation of a precise grid permanent planting basins, practicing crop rotation for nitrogen-fixing, seeds and fertilizer applied in the fixed planting stations, crop residue retention and preparing the land with minimum tillage practices (Haggblade and Tembo, 2003). Many African countries have adopted conservation farming as a modified traditional minimum tillage technology (Haggblade and Tembo, 2003; Ng'ombe *et al.*, 2014). Countries like Tanzania, Uganda, Nigeria, Cameroon, and in the Sahel have adopted a practice of hand hoe planting in basin systems. Tanzania, Mozambique, Kenya and Namibia have adopted ox-drawn rippers while others have adopted minimum tillage tractor- drawn implements supplied by conservation farming programs (Haggblade and Tembo, 2003).

The benefits of conservation farming are diverse. Under conservation farming system, planting on time, improved water retention and infiltration, good root growth, careful use of farming inputs, and the step by step build-up of organic matter, result in high yields. It has been reported that farmers using conservation farming systems have higher yields of up to 45-48% and less use of water, fertilizer and labor inputs, which has made farmers have more profit (Conservation Farming Unit, 2017).

A number of studies have been done in Zambia to evaluate the benefits of conservation farming with a view of optimizing practices. Most of the research has concentrated on comparing the national average yields instead of comparing with the outputs to match the farmer groups and farming standards (Conservation farming unit, 2017; Haggblade and Tembo, 2003).

Despite the known benefits of conservation farming, a number of features make the technology unattractive to farmers (Munyinda *et al.*, 2015). These include a) CF practices like soil ripping encourage weed development, b) Timely planting and soil fertility management is difficult especially for farmers without reliable access to drought power such as oxen, c) Crop residue retention is difficult, especially where the farming system combines crop and animal production, d) Crop rotation is difficult in light of the dominance of maize cultivation and the lack of markets for crop legumes and inadequate amounts of organic matter available e) It is difficult to mechanize without access to appropriate and machinery where the cropping system is diverse (Moonga and Moonga, 2018).

Therefore, the adoption rate among Zambian smallholder farmers is low, despite the effort to promote conservation farming (CF) (Munyinda *et al.*, 2015). Commonly, farmers adopt only one or two of the recommended practices, a practice termed partial or incomplete adoption. This study sought to determine the effects or benefits of such partial adoptions.

This study was done to determine the effects of incomplete conservation agriculture farming practices on the productivity of selected crops (cowpea, sorghum, and millet).

Materials and Methods

Experimental site

The experiment was conducted at Sakala farm, Shimabala in Chilanga, which is about 20 km south of Lusaka located on latitude-15.65° S, longitude-28.24 ° E and altitude -1088.9 m. The site has been under conservation farming for more than ten years. Using such, a site ensured that full effects of conservation practices had been established in the soil.

Soils and climatic factors

According to the Zambian agro ecological classification, the site is in Region IIa. The following are the key geographic factors.

i. An elevation/altitude of between 900-1300 m above sea level.
ii. Rainfall of between 800-1000 mm.
iii. Average rainfall period 100-140 days.
iv. Temperature range 23 to 25°C, maximum 32°C in October and minimum 10°C in July.

Land preparation

Land was prepared according to the three tillage practices (Ripping, Basins and Conventional tillage). Ripping was done by using a light ox-drawn ripper to rip the soil. Basins were made using the hand hoe following the standard of the length, depth, and width. Conventional tillage - ploughing was done to maximize disturbance of the soil through loosen and turn the soil to a depth of about 30-40 cm.

Plant materials

Planting materials: cowpeas *(Vigna unguiculata*), pearl millet (*Pennisetum glaucum)* and sorghum *(Sorghum bicolor)* were obtained from University of Zambia (UNZA) and Golden Valley Agricultural Research Trust.

Experimental design

The experiment was set up as a split- plot design with four replications (Sokal and Rolfe, 1981). Main plots- three test crops (cowpea, pearl millet and sorghum*)*. The Split- plot comprised the three types of tillage practices (Ripping, Basins and Conventional).

Data were collected on the following parameters:

i. Total biomass.
ii. Plant height.
iii. Number of leaves.
iv. Number of branches/tillers/stems.
v. SPAD - a proxy of chlorophyll content.
vi. Grain yield.

Data were collected at two phenological stages:

i. Vegetative components- data which included, Plant height, Canopy size, Number of leaves, Number of Branches/Tillers/Stems, SPAD Reading.
ii. Reproductive component included, Total biomass and grain yield.

Data collection and analysis

The data was arranged using excel spreadsheet and subjected to statistical analysis-ANOVA. Where significant treatment effects were detected, means separation was done using the least significant difference method using GenStat statistical package 18th edition (Sokal and Rolfe, 1981; VSN, 2001).

Results

Single factor effects

There were significant effects of tillage method, crop type and the two treatments interacted significantly for all measured parameters (Table 1).

Table 1. Summary of ANOVA table showing source of variation and factor significance.

Source of variation	Df	Yield	Canopy size	No. of leaves	SPAD reading	Plant height	Total biomass
Rep	3	56413	0.9280ns	30.22ns	30.9ns	711.4ns	18064ns
Tillage Method	2	3345571***	6.1246**	85.27**	910.8**	14594***	814946***
Crop	2	10287075***	1.2620*	163.54***	5476.0***	4799003***	4799003***
Tillage x Crop	4	1839780***	1.6975**	100.25***	536.5*	87791**	87791**

-Significant (p< 0.1), **-very significant (p < 0.01), *-very highly significant differences (p < 0.001) and ns- not Significant.*

Leaves per plant

Vegetative and reproductive performance is shown in Table 2. Ripping treatment had the highest number of leaves (12.6) followed those in basins (10.1) and basins (9.8). There were no significant differences in leaf number between those under basins and conventional tillage. As expected there were differences in leaf number among the different crops.

Table 2. Single factor effect of tillage method and crop type on vegetative and reproductive development.

Source of variation		Leaves Plant^{-1}	SPAD	Plant height (cm)	Biomass (tons ha^{-1})	Yield (kg ha^{-1})
Tillage (Main)	Basins	9.79	47.90	184.6	0.4270	665
	Ripping	12.58	32.60	144.5	0.2680	391
	Conventional tillage	10.07	30.50	162.5	0.2910	404
Lsd		1.86	4.27	19.03	0.0345	73.60
Crop (Split)	Cowpea	10.81	37.00	163.9	0.3290	487
	Millet	9.31	42.00	178.8	0.1810	355
	Sorghum	12.32	31.00	148.9	0.4760	618
Lsd		1.59	3.90	18.03	0.0420	115.9

SPAD readings

Plants under basins at 47.9 had significantly higher reading compared to ripping (32.6) and conventional tillage (30.5). Millets had higher SAPD reading (37) followed by cowpea (37) and sorghum (31).

Plant height

Plants under basins were significantly taller (184.6 cm), followed by those under conventional planting, with the lowest plant height recorded under ripping (144.5 cm)

Biomass

The highest biomass was recorded under basins (748 g plant^{-1}), which was almost twice that of ripping (470 g plant^{-1}). Ripping was intermediate (509 g plant^{-1}).

Grain yield

The highest grain yield was recorded in basins (665 kg ha^{-1}), followed by conventional (404 kg ha^{-1}) and ripping (391 kg ha^{-1}). The difference between conventional planting and ripping was not significant.

Two factor effects of the tillage system and crop types

The interactive effects of tillage system and crop type are shown in Table 3.

Table 3. Two- factor effect of tillage method and crop type on vegetative and reproductive development in crops grown under different tillage systems.

Source of variation		Leaves plant^{-1}	SPAD	Plant height (cm)	Biomass (tons ha^{-1})	Yield (tons ha $^{-1}$)
Crop x TM^{z}	B x C^{y}	9.79	47.9	184.6	0.427	665
	B x M	9.67	60.2	197.8	0.254	549
	B x S	9.92	35.6	171.5	0.611	781
	R x C	12.58	30.5	144.5	0.268	391
	R x M	8.73	32.4	161.1	0.161	314
	R x S	16.44	28.7	127.8	0.129	469
	CV x C	10.07	32.6	162.5	0.291	403
	CV x M	9.52	36.2	177.4	0.129	203
	CV x S	10.61	29.0	147.5	0.161	604
Lsd		2.67	6.40	29. 25	0.007	171.84

^{z} *Tillage method.*
^{y} *B -Basins, R- ripping; CV- conservation farming; C- cowpea; M- millet and S- sorghum*

Effect on the number of leaves

Generally, the highest number of leaves was in the ripping treatment, with ripping under sorghum being the highest (16.4) followed by ripping in cowpea. Millet under ripping was lowest at 8.7 leaves.

Effects of cultivation methods on SPAD reading among different crops

Basin treatment for all the crops had highest SPAD reading especially under millet (60.2), followed by cowpea under basins (47.9). The lowest readings were recorded were recorded in sorghum under conventional tillage (Table 3).

Effect of tillage practices on plant height in different crops

The tallest plants were millet under basins (197.8 cm) and cowpea under basins (basins. Sorghum under ripping (127.8 cm) and sorghum under conventional were lowest (147.5 cm).

Effect of tillage practices and crop type on with total biomass

Biomass was highly influenced by tillage method, and the differences were significant for the different crops (Table 3). Basins produced plants with highest biomass (0.43 ton ha^{-1}) compared to 0.27 ton ha^{-1} and 0.29 ton ha^{-1} for ripping and conventional land preparation, respectively.

Interaction between tillage practices and crop type on yield

Highest grain yield occurred in sorghum under basins (781 kg ha^{-1}) and cowpea under basins (665 kg ha^{-1}). The lowest was in millets in conventional (203 kg ha^{-1}) and cowpea under conventional (403 kg ha^{-1}).

Discussion

Ravages of climate change have affected Zambia like other countries. Climate change is manifested by phenomena such as increase in frequency and severity of droughts, occasional dry spells and high environmental temperatures (Mulenga *et al.*, 2020; Chompolola and Kaonga, 2016). To reduce food insecurity resulting from impacts of these phenomena on agriculture, many African governments are promoting sustainable agricultural practices such as conservation farming (CF) practices (Muoni *et al.*, 2019). A study conducted in Zambia, Zimbabwe and South Africa, indicated that the introduction of conservation farming to small-scale farmers improved crop productivity and raised the standard of living and ability of the vulnerable population gain food security.

Our study showed that tillage system has significant effects on plant development and crop yield. Basins appeared to exert significant benefits on crop development and ultimately increased yield. It is postulated that this was due to improved soil effects such as water and nutrient retention (Mataa *et al.*, 2018). This suggestion is supported by the significantly higher SPAD readings that indicated higher chlorophyll content. Higher leaf chlorophyll content could have been due to higher soil nitrogen, soil water and thus increased photosynthetic rate. However, we did not determine water retention. SPAD reading of 35 is generally recognized as lower minimum threshold or critical value in rice, maize, and sorghum. When the value falls below 35, the crops suffer from nitrogen deficiency and the yields will decline if N fertilizer is not added. In this experiment, SPAD reading has shown accuracy in predicting crop performance *vis a vis* chlorophyll and N levels and probably basin crops did not require addition of N fertilizers.

Overall, there were no significant differences in most parameters between conventional tillage and ripping. Possibly these two practices exert similar effects on the soil. Additionally, there is need to analyze the economic returns because ripping is less demanding in terms of labour and since only a small area of land is disturbed. It can therefore, be considered to exert less impact on soil structure. Sustainable Agriculture focuses on conserving productive capacity of land, minimizing energy and resources use and optimizing the rate of turnover and recycling of organic matter and nutrients.

Typically, Conservation farming has five component technologies that should be practiced simultaneously (Kassam and Friedrich, 2011). These are: Retention of biomass (no burning) of at least 30% of crop residue; Land tillage of only 10 to 15% of the surface area without soil inversion; Land preparation immediately after harvest to break the hard pan; Precise and permanent grid of planting stations, furrows, pits, trenches or ridges on the contour, Rotation with nitrogen fixing legume of at least 30 % of the cropped area; Minimum use of agro chemicals-fertilizers, pesticides. Conservation agriculture seeks to achieve economic and sustained production and yet preserve the resource base. It was worthwhile noting that in this study, despite not including all the five recommended conservation practices, the partial or incomplete conservation system performed better than ripping and conventional tillage.

The results of this study that compared partial conservation practice of ripping and basins demonstrated the superior performance of these partial conservation practices compared to conventional farming. As a continuation of these studies, we hope to compare full conservation practices and compare this to partial conservation practices and conventional practices for the results to be more meaningful. Additionally economic analysis should be included to determine relative profitability.

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