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EFFECTS OF INSITU RAINWATER HARVESTING AND INTEGRATED NUTRIENT MANAGEMENT OPTIONS ON SORGHUM PRODUCTION

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Abstract

Reduced food productivity in smallholder farms is the principal cause of food insecurity in semi-arid and arid areas in Zimbabwe. Crop productivity is low due to inherent soil fertility and limited soil moisture to promote crop growth. The use of insitu rain water harvesting and integrated soil fertility management (ISFM) are the promising practices which can improve crop productivity but their use is not yet clear for sorghum productivity in Zimbabwe. The study aimed to assess the effects of tied ridges, planting pits and conventional tillage in combination with selected organic (cattle manure) / inorganic amendments on sorghum grain and stover yields. The water harvesting techniques evaluated were planting pits, tied ridges and conventional tillage (control). Cattle manure was applied at 0 and 2500 kgha⁻¹, 30 kg N ha^{-1} was applied in combination with cattle manure and 60 kg N ha^{-1} was applied as a sole amendment. The experiment was run as a complete randomised design. Experimental data was subjective to analysis of variance (ANOVA) and mean separation using least significance difference (LSD) at p < 0.05. the results showed that planting pits with cattle manure (PC) had the highest grain yield of 4.40 t/ha compared to tied ridges and conventional tillage although the results for tied ridges and planting pits were not significantly (p>0.05) different and significantly (p<0.05) different to conventional tillage grain yields. Grain yields from tied ridges and planting pits with cattle manure + 30 kg N ha⁻¹ and with 60 kg N ha⁻¹ only were not significantly (p>0.05) different to grain yield from conventional tillage with cattle manure. Stover yields were highest from planting pits with 60 kg N ha⁻¹ (9.20 t/ha) followed by tied ridges with 60 kg N ha⁻¹ (9.10 t/ha). Treatments with no amendment had the least stover yields which were not significantly (p>0.05) different. The use of rainwater harvesting like planting pits integrated with cattle manure can increase sorghum production. It is recommended not to use insitu rainwater harvesting alone as this does not increase productivity.

Keywords: Insitu, rainwater harvesting, integrated, nutrient, management, sorghum

Introduction

Agriculture is the backbone of Zimbabwe and most African countries and is expected to be the driver of Zimbabwe's economy. Zimbabwe has been cited as the southern Africa's food supplier for both maize and impotent cereals such as sorghum. Sorghum production in arid and semi-arid regions had shown a great decline in recent years due to poor rainfall distribution and patterns. In World context, Arid and semi-Arid Lands are characterized by its insufficient water, low productivity especially in agriculture and serious land degradation. This led to poor food security and also causes conflicts between farmers for declining resources such as land for agriculture (Ngigi, 2003). The recent emerging climate change has caused a rapid decline in sorghum production in most arid and semi-arid regions of Zimbabwe as farmers in these regions solely depends on sorghum since maize production was challenged by long dry spell. The use of proper soil fertility and water management options needs to be adopted to increase food productivity in these areas. The major constraints in food productivity in arid and semi-arid areas are inadequate, unreliable, poorly distributed rainfall and declining soil fertility (Nikus *et al.*, 2004; Munamati, Nyagumbo and Gumbo, 2009).

To improve agriculture production in these arid and semi-arid regions there is need to promote *in-situ* rainwater harvesting as an option to conserve soil moisture and extend the availability of water to crops (Twomlow and Bruneau, 2000). To mitigate effects of drought researchers and farmers have introduces a number of *in-situ* rainwater harvesting technologies. According to Mupangwa (2006) in-situ rainwater harvesting techniques are methods used to collect and conserve rainwater, increasing the time in which water will be available to crops. In-situ rainwater harvesting has little or no use in semi-arid areas characterised with course textured soils with high hydraulic conductivity (Rockström, 2000) hence the need to add cattle manure as an option to improve soil structure, texture and decrease hydraulic conductivity. Farmers in arid and semi-arid areas have arable lands characterised with poor texture soils which have low water retention and need addition of organic manure such as cattle manure to improve their texture and structure. The addition of cattle manure to these soils has a greater value addition such as an ability to form water soluble aggregates and this has a positive effect on soil structure and soil physical characteristics (Mwadalu, 2014). Addition of manure decreases compaction and erosion thereby increasing root penetration and water holding capacity (Mwadalu, 2014). Cattle manure application supplies macro-nutrients such as nitrogen which is the most limiting nutrient in arid and semi-arid areas soils. Cattle manure is one of the cheapest sources of fertiliser to most farmers in smallholder farming areas in arid and semi-arid (Mutambanengwe, 2006). The integration of *in-situ* rainwater harvesting and cattle manure increases food production in arid and semi-arid areas together with conserving the soil.

Sorghum (*Sorghum bicolor* L. Moench) is one of the drought tolerant crops grown in arid and semi-arid areas and is the fifth important cereal crop in the world surpassed by maize, wheat, rice and barley (Akram *et al.*, 2007). Sorghum is one of the main staple foods for the world's poorest and food insecure countries (Timu *et al.*, 2012) such as Zimbabwe, Kenya, Ethiopia and Somalia. Early maturing sorghum varieties such as Macia, Vumba and Shirikure were introduced to improve food security in marginal areas of Zimbabwe and also to improve income after selling surpluses. These varieties are high yielding and thrive well in harsh conditions. Sorghum is high in starch and low in protein which offers it suitable to be used as staple food (Esipisu, 2011) and alternative source of starch by replacing maize.

Methodology

Description of study area

The research was carried out in Chivi district in Masvingo Province (Fig 1). The district is home to 155 442 people (Mutekwa and Kusangaya, 2006) density of 43.9 people/ km². Chivi district receives an average 500 mm of rainfall per annum. However, this rainfall is erratic and unreliable hence often fails to support rain-fed agriculture resulting in persistent crop failures and subsequent food shortages in the district. Despite this, rain-fed farming continues to be the principal livelihood activity for most farmers with subsistence agriculture forming the mainstay of household economy. Chivi district was selected for this study because the area, besides being prone to droughts, was also one of the first districts in which RWH technologies were introduced on a large scale (Motsi et al., 2004) and later abandoned by farmers citing high labour costs. Soil and water conservation activities were promoted by a number of organisations including, Intermediate Technology Development Group (ITDG) food security project, German Technical Development Agency (GTZ) conservation tillage project and Agritex (Mutekwa and Kusangaya, 2006) and Zvishavane Water Projects. The NGOs named above operated in smaller administrative units (wards) within the district. Each ward is a clearly defined region with a total population ranging approximately, from 6 000 to 10 000 people. Vuravhi Communal Land in ward 8 is approximately 175km from Masvingo and has a total population of 450 people.



Fig 1: Map showing Chivi district and ward 8 (Adapted from Kugedera, 2016)

The main source of livelihood for the people in Vuravhi Communal Land revolves around marginal farming and livestock rearing which are greatly affected by long spells of drought, which at times lead to total crop failure and massive loss of livestock. The major crops grown are common bean (*Phaseolus vulgaris*), maize (*Zea mays*), sorghum (*Sorghum bicolor*), mango (*Mangifera indica*), common millet (*Panicum spp*), sorghum (*Sorghum spp*.) and finger millet, (*Eleusine coracana*). Although farmers grow maize in this subzone, it is not a suitable crop. Due to dependence on unreliable and unpredictable means of livelihood, poverty is widespread causing a lot of youth to move from the areas. This has led to emigration of the youth in search of food and employment in South Africa leaving behind mostly children, the old, weak and women. Consequently, the overall development of the distribution of relief food and school-feeding programme, are some of the indicators of the extent of poverty.

Experimental Design and Treatments

The Complete Randomized Design was used in the experiment with three treatments: conventional tillage (C) used as control, tied ridges (T), planting pits (P). The ridges were made to be of 0.25m in height and the ties were at a height of 0.20m. A total of 15 (4m by 2m) plots were prepared and planted according to the described treatments. There were four rows of sorghum in each plot planted at a 0.90 m row spacing and 15cm plant spacing. The sorghum seed was planted at a 50 mm soil depth. The cattle manure was evenly applied for all treatments indicated addition of manure.

Treatment No.	Technique	Organics or Inorganics	Treatment
			combination
1	Planting pits	cattle manure	PC
2	Planting pits	Mineral fertilizer 60 kg N ha ⁻¹	PF60
3	Planting pits	Cattle manure + 30 kg N ha ⁻¹	PC30
4	Planting pits	No inputs	PNO
5	Tied ridge	cattle manure	тс
6	Tied ridges	Mineral fertilizer 60 kg N ha ⁻¹	TF60
7	Tied ridges	Cattle manure $+$ 30 kg N ha ⁻¹	ТС30
8	Tied ridges	No inputs	TNO
9	Conventional	cattle manure	ССМ
10	Conventional	Mineral fertilizer 60 kg N ha ⁻¹	CF60
11	Conventional	Cattle manure + 30 kg N ha ⁻¹	CC30
12	Conventional	No inputs	CNO

Table 1: Main treatments and their sub-treatments

Cattle manure and mineral fertiliser acquisition

Cattle manure was obtained from a local farmer. Manure consisted of faecal matter, urine and orts was collected from the kraal after accumulating from July to June. The kraal had no roof consequently; manure was exposed to the weather and lost nutrients through leaching, denitrification and volatilization leading to reduced quality. Triple super phosphate, Calcium ammonium nitrate and ammonium nitrate fertiliser were bought form GMB Chivi.

Land preparation and experimental set-up

The trials were established at one site during the short rain season (December 2017 to May 2018). Land was prepared using ox-plough to approximately a depth of 20 cm. The size of each plot was 4.5 x 4.5 m with spacing of 75cm between the rows and 20 cm within the rows. Macia sorghum seeds obtained from SEDCO Seed Unit were used. Five seeds were planted per hole and thinned to two 10 days after emergence. Triple Super Phosphate (TSP) was applied at planting and was placed in the planting holes while Calcium Ammonium Nitrate (CAN) was top-dressed four weeks after emergence. Cattle manure was applied at planting and was placed holes where it was mixed thoroughly with soil. Cattle manure was broadcasted before ploughing for conventional tillage and construction of tied ridges. Fertilizers were pre-weighed for each plot before going to the field and applied using dollop cups to ensure uniform distribution within the plot. Weeding was done two times during the growth period and insect pest control was carried out to eradicate stem borers using Bulldock. The main plot factor were planting pits, tied ridges and conventional tillage with sub plot factors being cattle manure and mineral fertiliser.

Data Collection

Grain and stover yield

Plants in the area reserved (net plot) for final harvest were harvested after 150 days from a delineated area of 3 m x 3 m (9 m²) in the middle of each treatment plot leaving the border rows. Ears were sun - dried for one week. After threshing of ears of each treatment, grain was weighed at 12 % moisture content and converted into grain yield (kg ha⁻¹).

Grain yield
$$(\text{kgha}^{-1}) = \frac{Yield \text{ in the treatment } \times 10000}{Harvest area}$$

Where harvest area = 9 m^2 and 10000 is equivalent to area of one hectare.

Stover yield was also measured from the net plot by cutting stover into small pieces and weigh using a digital scale and convert the mass to kg ha⁻¹.

Stover yield $(kgha^{-1}) = \frac{Yield in the treatment \times 10000}{Harvest area}$

Where harvest area = 9 m^2 and 10000 is equivalent to area of one hectare.

Statistical Analysis

Data was analyzed using the IBM SPSS statistics version 25 analysis software (IBM, 2017). Variation among treatments was determined using the descriptive statistics and the means were separated using the least significant difference (LSD).

Results

The results indicated that planting pits and tied ridges as water harvesting techniques and fertility amendments had significant (p<0.05) effect on sorghum grain yields (Table 1). Grain yields were mainly higher in planting pits with amendments as a soil water conservation technique. Manure was applied at a constant rate of 5000 kgha⁻¹. Planting pits treatments showed higher yields compared to other treatments, although some results were not significantly different for some treatments with tied ridges treatments. Planting pits amended with cattle manure (PC) yielded 4.40 t/ha followed by tied ridges with cattle manure (TC) which yields 4.30 t/ha. These results were not significantly different as indicated by same superscript (Table 1). Planting pits with cattle manure and 30 kg N ha⁻¹ yields 3.98 t/ha compared to 3.94 t/ha for tied ridges with cattle manure and 30 kg N ha⁻¹ although the results were not significantly different as indicated in Table 1. Planting pits treatments with 60 kg N ha⁻¹ produced 3.66 t/ha as compared to tied ridges treatment with 60 kg N ha⁻¹ which yields 3.51 t/ha. There was no significant different (p>0.05) in yields from water harvesting techniques of planting pits and tied ridges without amendments. Results from conventional tillage amended with cattle manure were as follows; 3.81 t/ha for conventional tillage with cattle manure (CCM), 3.83 t/ha for conventional tillage with cattle manure and 30 kg N ha⁻¹ and 3.38 t/ha for conventional tillage with 60 kg N ha⁻¹.

Higher results were obtained from where water harvesting techniques of planting pits and tied ridges were used even if amendments were not included. Conventional tillage treatments yielded low grain yields compared to planting pits and tied ridges treatments although there were no significant different for some treatments such as those without amendments as indicated in Table 1.

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Treatment	Grain yield (t/ha)	Stover yield (t/ha)
TC	4.30 ^a	8.23 ^{bc}
TC30	3.94 ^{ab}	8.01 ^{bc}
TF60	3.51 ^{ab}	9.10 ^a
TN0	1.82 ^c	4.84 ^d
PC	4.40 ^a	8.35 ^b
PC30	3.98 ^b	8.10 ^{bc}
PF60	3.66 ^{ab}	9.20 ^a
PN0	1.94 ^c	4.86 ^d
ССМ	3.81 ^{ab}	7.81 ^c
CC30	3.83 ^{ab}	7.93 ^{bc}
CF60	3.38 ^{ab}	8.15 ^{bc}
CN0	1.80 ^c	4.58 ^d

Table 1: Grain and stover yield of sorghum for the season

TC= tied ridge + cattle manure; TC30 = tied ridge with cattle manure + 30 kg N ha⁻¹; TF60= tied ridge with 60 kg N ha⁻¹; TN0= tied ridge with no amendments; PC = planting pits with cattle manure; PC30 = planting pits with cattle manure + 30 kg N ha⁻¹; PF60 = planting pits with 60 kg N ha⁻¹; PN0= planting pits with no amendments; CCM = conventional tillage with cattle manure; CC30 = conventional tillage with cattle manure + 30 kg N ha⁻¹; PF60 = conventional tillage with 60 kg N ha⁻¹; PN0= planting pits with no amendments; CCM = with no amendments.

Same superscripts in same column denotes no significant different between treatments at p =0.05.

Planting pits with cattle manure (PC) yielded 13 % higher grain yields compared to conventional tillage treatment with cattle manure (CCM). Tied ridges with cattle manure (TC) treatment had 11% grain yield higher than conventional tillage with cattle manure (CCM) treatment (Table 1). Planting pits with no amendments (PNO) treatments had 7% higher grain yields than conventional tillage with no amendments (CNO) treatments. On average results from planting pits and tied ridges treatments were 11% higher than those from

conventional tillage treatments (Table 4.1). Planting pits with cattle manure (PC) were 13% significantly higher (p=0.0001) than conventional tillage treatment with cattle manure (CCM).

Planting pits with full rate fertiliser (PF60) had the highest stover yields of 9.20 t/ha followed by tied ridges with full rate of fertiliser which had 9.10 t/ha. These results were significantly higher (p<0.05) than stover yields from conventional tillage with full rate fertiliser (CF60) treatments which yields 8.15t/ha (Table 1). The results also indicate that stover yield from TC (8.23 t/ha) and PC (8.35 t/ha) were even higher than those form CF60 treatments (Table 1). The results also indicated that there were no significant different (p>0.05) between stover yields from all treatments with no amendments although yields from TN0 and PN0 were higher than those form CN0 (Table 1).



Fig 1: Sorghum grain and stover yields

Discussion

Sorghum grown under tied ridges and planting pits had highest grain and stover yields compared to sorghum grown under conventional tillage technique. This may be attributed to an increase in soil water content in these rain water harvesting techniques which lead to better root development leading to increased sorghum growth. These results coincide with results by Kouyaté et al. (2012) who found that sorghum grown under zai pits (planting pits) increased sorghum growth. Higher grain and stover yields may also be as a result of amendments which improved soil fertility status of the soil. Planting pits increased water availability in the root zone (Fatondji et al., 2006) and amendments had positive significant effect on soil fertility (Patel et al., 2013). The use of planting pits was found to increase sorghum yields (Fatondji et al., 2000), increase cowpeas yields in South Africa (Ncube et al., 2008) and increase maize yields in Rwanda (Mudatenguha et al., 2014). Wedum et al. (1996) in Mali found that planting pits with cattle manure increased sorghum yields and these results concurred with results obtained from this experiment. Tied ridges increased sorghum grain yields with amendments and these results concurred with results by Kouyaté et al. (2012) who found that tied ridges increased sorghum grain yields. Miriti et al. (2007) in Kenya also reported that tied ridges integrated with nutrient management increased crop production compared to conventional tillage with amendments. In another study by Magombeyi and Taigbenu (2008) planting pits (chololo pits) results in higher yields compared to the use of conventional tillage as a technique. According to Kathuli and Itabari (2015) planting pits with no amendments increased sorghum grain yields than conventional tillage with no amendments and this coincides with the results of this experiment.

An increase in grain and stover yield was recorded where sorghum was grown in treatments with cattle manure and mineral fertiliser combination showed an increase in sorghum yields. These results coincides with report done by Patel *et al.* (2013) who highlighted that this combination showed high stover and grain yields compared to treatments without amendments. This finding was consistent with the report of Fatondji (2002) that total grain and stover yield increased with the use of planting pits and tied ridges compared to the use of conventional tillage. Increased grain and stover yield increased in treatments were cattle manure and mineral fertiliser were added due to reduced surface runoff, increased infiltration and soil nutrient availability (Nyamadzawo *et al.*, 2013), improved soil structure and soil moisture storage (Mudatenguha *et al.*, 2014). This increased crop growth leading to increased grain and stover yields.

Conclusion

Planting pits with cattle manure had the highest grain yield followed by tied ridges with cattle manure. Stover yield was highest in planting pits treated with 60mkg N ha⁻¹ and was least from conventional tillage with no amendment. Rainwater harvesting of planting pits integrated with soil fertility management of cattle manure was the best techniques and it can be easily adopted by poor resources farmers so that they increase their yields. If managed well planting pits treatments are the best soil and water conservation option to increase grain yield as compared to tied ridges and conventional tillage. Planting pits can be done even if the soil is dry so as to allow limited labour costs to smallholder farmers. Conventional tillage treatments had the least grain yield compared to planting pits and tied ridges.

Recommendations

Cattle manure and mineral fertiliser are reliable to enhance soil fertility and increase sorghum grain and stover yields. Planting pits are the best way of conserving soil moisture in semi-arid and arid environments where water is a priority compared to conventional tillage and tied ridges. To enhance sorghum grain yields both planting pits and tied ridges can be used as well as conventional tillage when the farmer have limited labour to dig planting pits and construct tied ridges.

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