RAINWATER HARVESTING AND NUTRIENT INTENSIFICATION IN MAIZE-LEGUME FARMING SYSTEMS IN SEMI-ARID ZIMBABWE

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ABSTRACT

Agricultural productivity in Zimbabwe is declining mainly due to climate change, high cost of fertilizers and inherently poor soil fertility. In response to these challenges, most smallholder farmers are implementing either rainwater harvesting (RWH) or integrated soil fertility management (ISFM). This study sought to investigate the role of integrating the tied-contour RWH (TC-RWH) technique and ISFM on soil moisture, soil fertility, crop growth, and subsequent crop yields in semi-arid areas of Zimbabwe. A split-split-split plot design was established where water harvesting technologies namely tied contour (TC) and standard contour (SC) were considered as the main plots, cropping system (sole maize, sole cowpea and maize-cowpea intercrop) as sub-plots, different N-levels as sub-sub plots and manure as sub-sub-sub plots. Manure application demonstrated a higher grain yield advantage by 297 kg ha^{-1} over treatments without manure. Similarly, top dressing yielded more grain yield by 1146 kg ha^{-1} than untopdressed plots. Intercropping had a total systems' biomass yield 4397 kg ha^{-1} while cowpea sole and maize sole yielded 3863 and 3247 kg ha^{-1} respectively. Standard contours without manure had the least total biomass output. With respect to soil moisture, sole cowpea under SC retained more moisture than intercropped plots and sole maize during first season. The Land Equivalent Ratio of 1.3 kg ha^{-1} obtained signifies a greater land productivity and efficiency realized through intercropping compared to sole cropping systems. The study shows that when rainfall is abundant, as in the first season, sole cowpea conserves more moisture under standard contours than intercrops and sole maize. However, when conditions are dry, as in the case of the second season, sole and intercrops performed similarly. On the other hand, under excessively dry environments, sole maize systems with lower plant populations conserve moisture than sole cowpeas and maize-cowpea intercrop while in wet conditions, intercrops conserve more moisture than sole crops. Overall, in the sandy soils, failure to apply top dressing and manure resulted in serious yield penalties.

INTRODUCTION

The majority of smallholder farmers in Zimbabwe are located in semi-arid areas where rainfall is low (Mupangwa, Makanza, et al. 2021), and soils are inherently poor. Of the little rain that is received in the semi-arid regions, most is lost as runoff, and very little water is harvested for plant growth or future use (Nyamadzawo et al. 2012). Expansion of cultivatable areas and the practice of crop rotations have been ways of increasing crop productivity (Mupangwa et al., 2021; Nyagumbo et al., 2016) in Sub-Saharan Africa (SSA), but is no longer sustainable with SSA's population expected to increase by 2050 (Trisos et al., 2022). Additionally, exorbitant prices of inorganic fertilizers resulted in many farmers applying no to low rates of inorganic fertilizers, thus leading to poor yields.

Some smallholder farmers are already practicing water harvesting (Madamombe et al. 2024), and maize legume intercropping/rotations (Thierfelder et al. 2024), whilst adding organic and or inorganic fertilizers (Mutsamba, Nyagumbo, and Mupangwa 2019). To increase agricultural productivity in these areas, there may be a need to combine various techniques such as in-field water harvesting techniques, nutrient intensification and integrated nutrient management in semi-arid conditions. Specifically, this study investigated the role of integrating tied-contour rainwater harvesting (TC-RWH) technique and ISFM on soil moisture, soil fertility, crop growth and subsequent crop yields in semi-arid areas of Zimbabwe.

MATERIALS AND METHODS

The study was carried out in Mutoko District located in the semi-arid region of Zimbabwe. Mutoko receives annual rainfall of 450-600 mm and mean temperatures of about 35°C. The soils (Table 1) are mainly predominated by low fertile inherent granitic sandy soil (Lixisols: (FAO 2014). The suitable farming systems in these regions are semi-intensive farming systems with a mixture of crops and livestock.

Table 8. Soil characteristics of the experimental site before trial establishment.

% Carbon	Colour	Texture	pH ($CaCl_2$)	N (ppm)	P (ppm)	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)
1.19	PB	Mgs	5.05	29.5	37.5	0.15	1.35	0.49

Where PB =Pale brown colour and Mgs = Medium grained sand

The experiment was laid out in a split-split-split plot design, replicated three times on one on-farm field from 2020/21 to 2021/22 agricultural seasons. Water harvesting structures (tied and standard contours) were the main plots, cropping systems (maize-cowpea intercrops and the respective sole crops) were the sub-plots, N-fertiliser rates (top dressed and untopdressed) were the sub-sub plots, and the manure application (with or without) were the sub-sub-sub plots (Fig 1b).

Tied contours (Fig 1a) measuring 0.3 m deep and 1 m wide were prepared at a slope of 1:250. The cross ties were placed after every 5 m with a breadth of 0.5 m and a small opening was made at the upper side of the tie to allow water to flow from one compartment to another when it was full. SCs were made at a gradient of 1:250 with the same measurements as of tied contours. SCs are existing water channels designed at 1:250 gradient to dispose of field water. Both TCs and SCs were spaced at 8 m. Top dressing of ammonium nitrate (34.5% N) was applied to maize only at the different specified rates 3-4 weeks after planting.

Crop height, chlorophyll, NDVI and soil moisture were measured using a meter rule, chlorophyll meter (Apogee Instruments, MC 10), handheld green seeker (SPL technologies and a Field Scout$_{TM}$ TDR 300 soil Moisture Meter (Spectrum Technologies, Inc.) respectively. Daily rainfall was recorded using a rain gauge mounted at the experimental site. Analysis of variance (ANOVA) across treatments was conducted using R-software to determine the effects of tied contours, fertiliser and manure use on chlorophyll, NDVI, plant height and grain yield. For significant treatment*season interactions, each season was the analysed separately.

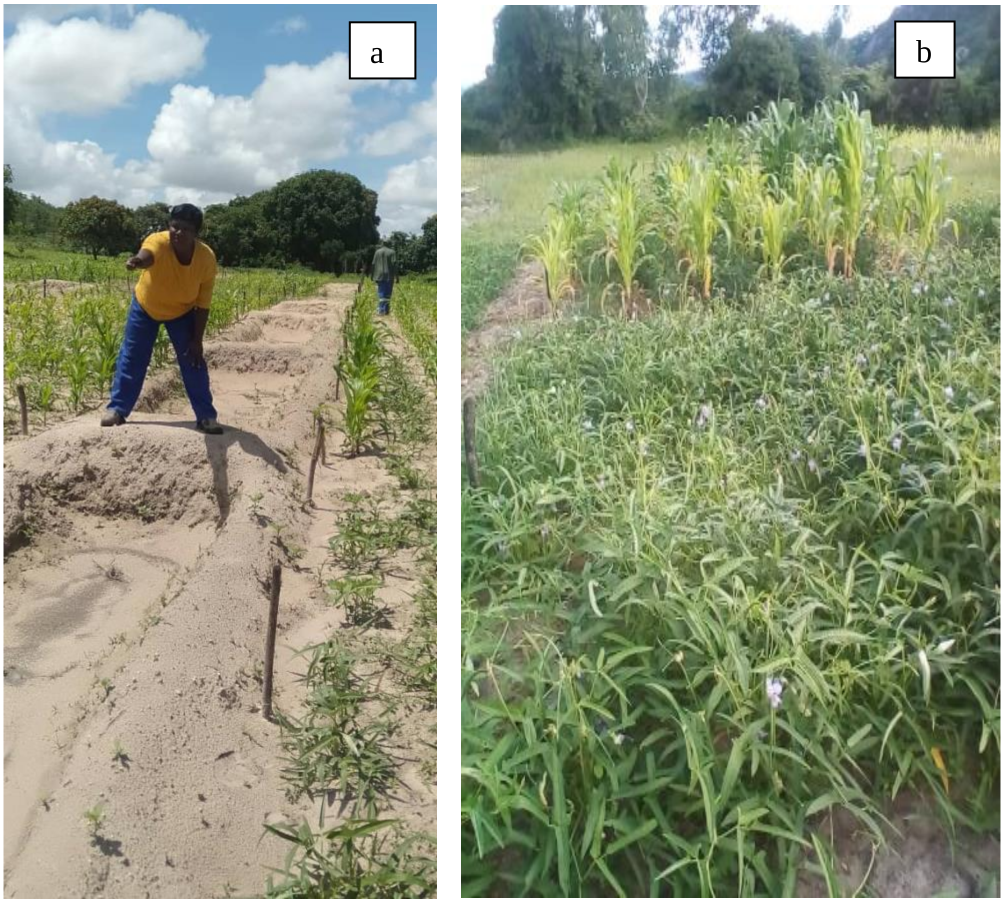

Figure 1. Picture of a) tied ridges b) cropping systems (maize-cowpea intercrop and sole cowpeas) and maize with and without top dressing.

RESULTS AND DISCUSION

The 2020-21 and 2021-22 seasons received a total annual rainfall of 684 mm and 461 mm respectively. There 4-way interaction between the cropping systems, water harvesting techniques, manure application and top-dressing application was insignificant. Across the two cropping seasons, it was observed that manure application demonstrated a higher grain yield advantage by 297 kg ha^{-1} over treatments without manure. Similarly, top dressing yielded more grain yield by 1146 kg ha^{-1} than untopdressed plots. In addition, the application of top dressing significantly increased total biomass yield compared to untopdressed plots. However, there was no significant difference in total above-ground biomass in plots applied manure and those without manure. The results clearly indicate that despite the importance of inorganic fertilisers, it is crucial to acquire nutrients from diverse sources, including organic materials like livestock manure and nitrogen-fixing legumes (Sanginga and Woomer 2009). The use of both organic and inorganic inputs is important because both resources fulfil different functions towards plant growth and neither of them is available or affordable in sufficient quantities (Vanlauwe et al. 2015).

Total biomass yield was significantly affected by cropping system, where maize-cowpea intercrop had significantly higher output than sole maize, concurring with (Mutsamba, Nyagumbo, and

Mupangwa 2019). Intercropping yielded 4397 kg ha^{-1} while cowpea sole and maize sole yielded 3863 and 3247 kg ha^{-1} respectively. Standard contours without manure had the least total biomass output. In other studies, tied ridging and rip & potholing yielded 25% more grain yield than conventional mouldboard ploughing (Nyagumbo and Bationo, 2011). The Land Equivalent Ratio (LER) of 1.3 kg ha^{-1} obtained signifies a greater land productivity and efficiency realized through intercropping compared to sole cropping systems, concurring with (Bitew and Abera 2019; Mutsamba, Nyagumbo, and Mupangwa 2019).

On soil moisture, sole cowpea under SC retained more moisture than intercropped plots and sole maize during first season. This can be attributed to the ability of cowpea reducing evaporation from the soil surface. As sole cowpeas' plant populations doubled that of sole crops, it translated to higher ground coverage and there was no competition for moisture due to adequate rains received. However, during the second season under SC, all cropping systems performed similarly due to very low rainfall amounts received. Conversely, under TC, intercrop systems had higher soil moisture content compared to the sole cowpea and maize during first season, while sole maize had higher soil moisture compared to intercrops during the second season. Given the dry conditions experienced during the second season, sole maize retained more moisture compared to sole cowpea and intercrop systems. This may be due to high plant densities in intercrops and sole cowpea competing for soil moisture in the root zone. This can be attributed to high plant densities in intercrops and sole cowpea competing for soil moisture in the root zone, as studies have reported that intercrops often have lower soil moisture than sole crops due to greater root moisture extraction (Eskandari and Kazemi 2011). This contradicts with (Ghanbari et al. 2010) who showed that maize monocrop tend to have a lower soil moisture content compared to sole cowpea due to high soil water losses through evapotranspiration..

Top dressed plants under TC displayed greater heights compared to plants under SC. This is attributed to the water harvesting under TCs compared to SCs which disposed water due to gradient. Manure application led to taller plants during second seasons. Intercropped plots had higher NDVI than sole maize indicating the benefits of biological nitrogen fixation (Franke et al. 2018). NDVI was measured during the second season only when the green seeker was made available. In conclusion, the benefits of water harvesting are determined by rainfall received.

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