Evaluating benefits of rainwater harvesting using infiltration pits in rainfed cropping systems: Preliminary results from Rushinga district, Zimbabwe

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ABSTRACT

Occurrence of dry spells during the rainfall season is the major cause of crop failure in semi-arid areas. Rainwater harvesting (RWH) is regarded as a viable option for mitigating these dry spells. However, benefits of most RWH systems have not been adequately quantified. The objective of this study was to assess maize crop yield and soil moisture content benefits of RWH using infiltration pits. Field experiments were set up using a split-plot design in Northern Zimbabwe. Major plots were distinguished by presence/absence of infiltration pits in the contour ridge (CR) channel and minor plots by the tillage method which was at two levels namely conventional tillage (CT) and planting pits (PP). Soil moisture content was measured during 2010/11 rainy season using the TDR and gravimetric methods at 0.20-m depth intervals to 2.0 m. Soil moisture content trends analyses, ANOVA and LSD test for maize yield were done using SPSS for Windows. Results showed no significant maize yield differences ($p>0.05$) in major treatments, but CT outperformed PP ($p<0.05$) at one site. Although the difference in maize yields between the major factor levels was insignificant, increased soil moisture content in the reinforced sections was observed only up to 2m downslope of the infiltration pits. Therefore, cropping systems which utilize soil moisture close to the CR are recommended. Such cropping systems also make use of heavy rains early in the season. More access tubes should be installed further down in the vicinity of 2 m in order to monitor moisture dynamics.

Key Words: Rainwater harvesting, food security, soil moisture, maize, dry spell mitigation, infiltration pit

INTRODUCTION

The present food insecurity and projected population growth in Sub-Saharan Africa (SSA) demand change from low yielding farming systems towards greater production and sustainability (Wallace, 2000; Rockström et al., 2002; Cai and Rosegrant, 2003; Kauffman et al., 2003), particularly in semi-arid tropics where food security is threatened by frequent droughts, dry spells (Steiner et al., 2003) and infertile soils (Sanchez, 2002). Maize (*Zea mays* L.), the most important cereal in Eastern and Southern Africa (Magorokosho et al., 2003; Barron, 2004) is among the priority crops. Semi-arid zones of SSA cover about 41% of the region (Sanchez, 2002). In Zimbabwe, >65% of land area is semi-arid and 60% of the communal area population live in these areas. Even though rainfall is marginal, low productivity in rain-fed smallholder agriculture in semi-arid tropics is more due to management-related sub-optimal performance than to low physical potential (Rockström and Falkenmark, 2000; SIWI, 2001). Stable yield increases from 0.5 to 2 t/ha (Rockström et al., 2003) are achievable. The green water fraction is only 15-30% of the total rainfall in SSA (Rockström et al., 2003; Falkenmark and Rockstrom), yet it may exceed 50% in comparable climates in the USA (Stroosnijder and Slegers, 2008).

Water productivity can be improved through maximizing plants' water uptake capacity, and dry spell mitigation using supplementary irrigation (Rockström et al., 2003). However, limited areal extent, competing claims for water (Cai and Rosegrant, 2003; Vohland and Barry, 2009) and prohibitive development costs limit the role of irrigation. In rain-fed agriculture rainwater harvesting (RWH) can contribute to improved crop productivity (Kauffman et al., 2003; Rockström et al., 2003; Vohland and Barry, 2009). In-situ RWH bridges the gap between rainfall events by increasing the amount of water stored in the soil for plant use through collecting runoff water and allowing it to infiltrate into the soil profile. This study focused on infiltration pits, a locally developed RWH technique adopted by most farmers in Southern Zimbabwe (Hagmann et al., 1999; Hughes and Venema, 2005; Mutekwa and Kusangaya, 2006). Infiltration pits are rectangular trenches of varying dimensions excavated at intervals in the channels of CRs for collecting runoff water, storing it and allowing it to infiltrate and presumably flow through the soil layers (Fig. 1). Contour ridges are hydraulic structures constructed in a cross slope direction in order to safely discharge runoff. Despite benefits claimed by farmers, the effectiveness of infiltration pits in retaining soil moisture and improving crop productivity have not been adequately quantified (Motsi et al., 2004; Mugabe, 2004).

Infiltration pits were combined with planting pits because the techniques complement each other by virtue of their different dimensions and locations (Nyagumbo, 1999). The planting pits, 20-25cm diameter and 15cm deep (FACHIG, 2009) are located inside the cropping area whilst infiltration pits, usually $\geq 1.5 m^3$ at 5-20-m intervals are constructed along field edges.

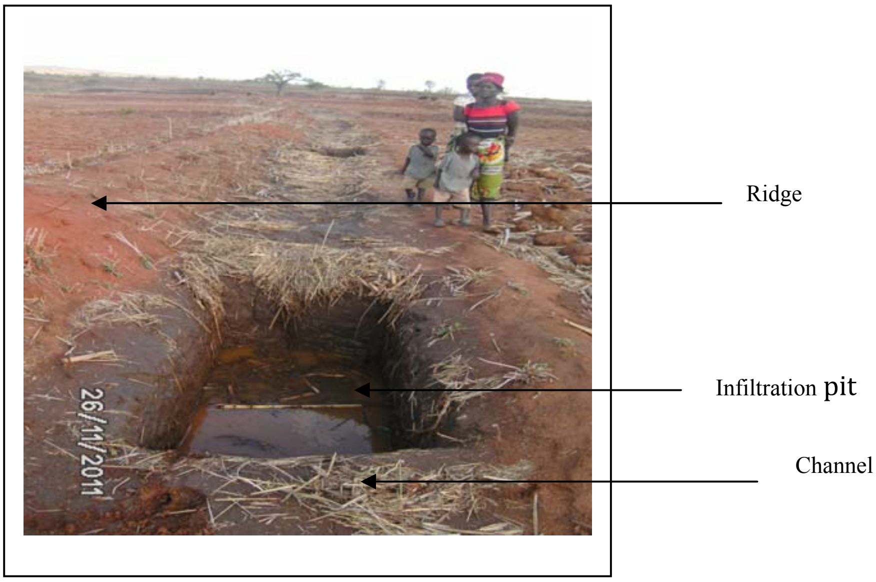

Figure 1. Infiltration pits in a contour ridge.

The objective of the study was to assess the benefits in terms of maize yield and soil moisture improvement of combining infiltration and planting pits.

METHODOLOGY

Description of the Study Area

The study was conducted in Rushinga District, located 16° 40' 00'' S and 32° 15' 0''E, altitude 730 m above sea level in Mazowe valley, Zimbabwe with 650 mm mean annual rainfall and mean minimum and maximum temperatures of 14.1 and 28.6 ^{0}C respectively. The rainy season is unimodal and stretches from November and March. The most cultivated crops are maize, cotton, groundnuts, roundnuts and sorghum.

Research Design and Description of Treatments

A split-plot design with major plots distinguished by the presence/absence of infiltration pits and minor plots by the tillage method at two levels namely conventional tillage (CT) and planting pits (PP) was used. Thus, four treatments were tested: (1) infiltration pits plus conventional tillage (I+CT); (2) infiltration pits plus planting pits (I+PP); (3) planting pits only (PP) and (4) conventional tillage only (CT). Infiltration pits of 2 m length x 1 m width x 0.75 m depth, 10 m spacing (Hughes and Venema, 2005) were used. Conventional tillage entailed ploughing to a depth to ±0.23 m and opening planting furrows at 0.90 m x 0.45-0.50 m spacing using the mouldboard plough. This represents the farmers' practice. The planting pits were 0.15 m deep and about 0.20 m wide (FACHIG, 2009) and spaced at 0.9 m × 0.5 m. Planting was done at two seeds per station. The experiments were conducted at two sites namely Chongoma Village (Ward 11) and Magaranhehwe Village (Ward 12) and replicated thrice.

Fields are hydrologically connected (Bouman, 2007), therefore only one major treatment was applied downslope to minimize treatments interaction. The experiment was laid out in three 60 m long and 20-25 m wide blocks separated by buffer zones of 5 m. In order to create experimental conditions for measurement, treatments were replicated in an adjoining upper field at both sites.

Crop management

An early maturing white maize cultivar, SC513, recommended for the agro-ecological region was planted at both sites. Basal dressing was done at 250 kg/ha Compound D (7%N: 14% P_2O_5:7%K_2O). Split application of NH_4NO_3 fertilizer was done at a rate of 77kg N/ha in two equal applications. Application rates were based on recommendations by the government extension department and correspond to a yield potential of 3 to 5 t/ha (SEED-CO, 2004).

Installation of Access Tubes

Access tubes were installed in a single block at the Ward 12 site in two treatments namely I + CT and CT. Installation was done to a depth of 2 m where soil depth allowed.

Access tubes were numbered from A1 to A6, with tubes equidistant and in the same direction from the centre of the CR channel or infiltration pit having the same number. A1 = 1 m upstream from the centre of the pit or CR channel; A2 = centre of the infiltration pit or CR channel; A3, A4, A5 and A6 were 1 m, 2 m, 11 m and 15.7 m downstream from centre of infiltration pit or CR channel respectively.

Data Collection

Field slopes were determined using levelling equipment. Soil samples for determining texture and bulk density were collected at representative sites in each block at 0.20-m depth intervals up to 1.0 m (Panigrahi and Panda, 2003). Soil colour and depth were concurrently determined. Soil chemical analysis was performed for pH (0.01M $CaCl_2$) and exchangeable bases.

Potential evapotranspiration was determined using the ET_0 calculator using data from a compact all-in-one meteo station. Rainfall was measured using rain gauges installed at each experimental site. At the Ward 12 site soil moisture content was measured weekly during the rainy-season using the TRIME-PICO IPH intelligent soil moisture probe. In Ward 11 six samples were taken up to 0.8 m using a soil auger at similar positions to those in Ward 12 for gravimetric soil moisture content determination.

Maize yield was measured from net harvest plots of 10 m × 10 m. Weight of grain was adjusted to 12.5%, the maximum storage moisture content. Harvest index was calculated as the ratio of the grain yield to the total above-ground biomass (Hallauer et al., 1988).

Data analysis

Graphic trends analysis for soil moisture content, ANOVA and the LSD test for maize grain and stover yields, and rainfall time series plots were done using SPSS for Windows.

RESULTS

Field and Soil Characteristics

The two sites had a uniform slope of 6 %. At Ward 12 site soils ranged from mSaL to mSaCL. Ward 11 site has more uniform soils generally mSaCL. At both sites the first 0.2 m had mSaL soils. The bulk densities follow a similar trend where the first top 0.2 m and the 0.8 – 1.0 m depths have higher densities than the intermediate depths. Beyond 0.80 m the soil became too compacted to dig or was gravelly. The mean soil pH values were 6.2 and 5.6 for Wards 12 and 11 respectively. The Ca:Mg ratios for the first two blocks at Ward 12 site were ≥ 4, higher than for block 3 which is ± 1, whilst Ward 11 site had a uniform ratio of 2.

Rainfall Data 2010/2011 Season

During the 2010/11 rainfall season Ward 12 site received more rainfall (861 mm) than Ward 11 site (545 mm), although the trend in rainfall amounts was similar during the season (Fig. 2). The ET_0 during this period was 515 mm. Both sites received normal rainfall basing on the 1980/81 to 2008/09 mean (SD) of 631 (175) mm and 10 % probability of exceedance rainfall of 887 mm (Nyakudya and Stroosnijder, 2011)

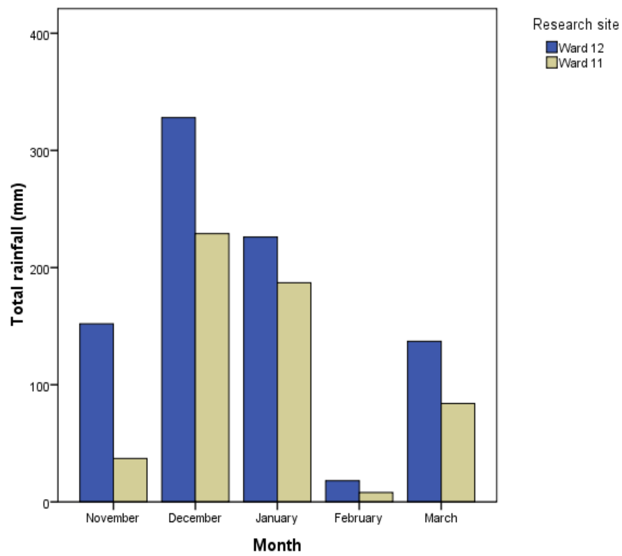

Figure 2. Monthly rainfall for the 2010/11 rainy season at the research sites

At both experimental sites, the first rains fell in the second dekad of November 2010 and the last rains fell in the third dekad of March 2011.

Soil Moisture Content Measurements

In general for access tube positions A1 and A3 to A6 depth 0 – 0.4 m soil moisture content levels were similar for sections of the CR channel reinforced with infiltration pits and the unreinforced section. For A2, depth 0.8 – 1.2 m the sections reinforced with infiltration pits had higher moisture content levels than the unreinforced sections. This is attributed to concentration of water by the infiltration pits. For A3 at the Ward 12 site, roots of a herbaceous plant that grew on the CR partially distorted soil moisture content, therefore, for this position, only Ward 11 site results were considered. For depth 0 – 0.8 m at this position the section reinforced with infiltration pits had higher moisture content levels than the unreinforced section. Similar results were obtained for A4 in Ward 12, depths 0.4 – 0.6, 0.6 – 0.8, 0.8 – 1.0 m. Lateral movement of water from infiltration pits contributed to the higher moisture content levels. For Access tube positions 1 and 6, moisture content appeared to be influenced by the micro-relief in the lower third of the field where water usually collects.

Crop Yield Results

For Ward 12, results were not significantly ($p > 0.05$) different for both maize grain and stover yields. High variability in both grain and stover yields was observed. For Ward 11 site, significant differences ($p < 0.05$) were observed in grain and stover yields. For both grain and stover yield: I + CT = CT > I+PP = PP. Harvest indices at both sites were not significantly ($p > 0.05$) different. Harvest indices oscillated around 0.30 and 0.24 for Wards 12 and 11 respectively.

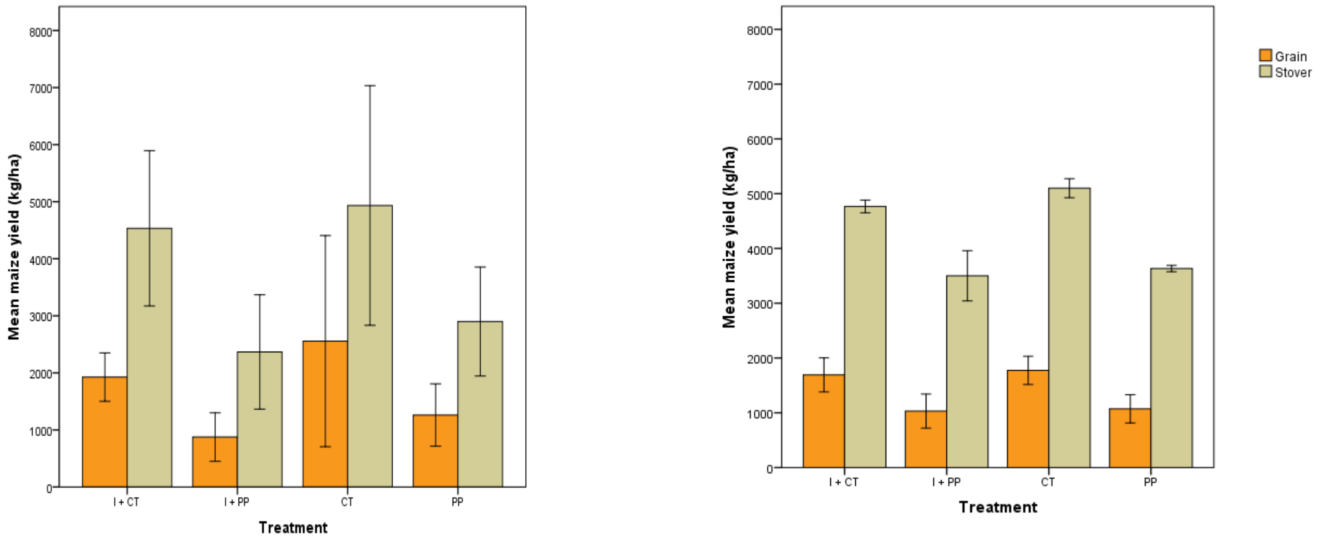

Figure 3. Maize grain and stover yields for Ward 12 site and Ward 11 sites respectively. (Error bars represent standard deviations).

DISCUSSION

Relatively high variation in yield within treatments at Ward 12 site was attributed to site characteristics. The mean soil pH, 6.2 is higher than the optimum 5.0-5.5. High Ca to Mg ratio in two of the three blocks implies that Mg deficiencies occur (Hussein, 1997). Nutritional problems for P, Zn and Fe are also encountered at high pH levels (Olson and Sander, 1988). Maize yields at the site (Fig. 3) were below the yield potential of 3 to 5 t/ha at the fertilizer application levels. At the Ward 11 site, for both grain and stover yield: I + CT = CT > I+PP = PP. It is the minor treatments: CT and PP that affected the crop yields.

Harvest indices, ≤0.31 are below the normal value of 0.50 for a good maize crop (Hallauer et al., 1988). Low values can be attributed to moisture stress in February (Fig. 2). During the ear-filling stage, significant yield reduction can occur from moisture stress (Shaw, 1988). The maize yields attained also fell below the yield potential. Soil moisture trends in the top 0.6 m of soil followed the rainfall trends. Mugabe (2004) and Wang et al. (2008) obtained similar results. Measuring soil moisture content at depths ≥ 1.0 m was compounded by the presence of rocks in the soil profile and the results were discarded except for two measuring points in the channel or pit and on the ridge.

Effects of infiltration pits are minimal only being experienced at up to 2 m from the center of the infiltration pits. Use of infiltration pits concentrated water and forced its lateral movement in the downslope field direction. Fine sediments deposited at the bottom of infiltration pits slow downward infiltration of water and promote lateral flow out of the pit. Makurira et al. (2009) also noted sediment deposition around *fanya juu* structures. However, the maize crop is unlikely to benefit much from the water that will have moved laterally due to the small distance covered. Insignificant differences in maize yields for plots in sections reinforced with infiltration pits and the unreinforced sections is in tandem with soil moisture content results. However, the wetter zones can better support crop growth (Makurira et al., 2009) The construction of infiltration pits was expensive (USD2.50 per pit for approximately 40 pits per ha). In order to offset the high cost, it is essential to grow high value crops that utilize the water inside and close to the infiltration pits. Li et al. (2006) recommended apples, grape and Jujube in China. In Tanzania farmers grow bananas, cassava and paw paws around the *fanya juus* (Makurira et al., 2009). In Rushinga possible fruit trees include bananas, paw paws and avocado pears. Close to Ward 12 site there is a farmer who already plants bananas from runoff water harvested from a nearby tarred road. Mutekwa and Kusangaya (2006) report that farmers in Chivi district in Southern Zimbabwe grow bananas and fruit trees as a result of adopting RWH technologies. Nyakudya and Stroosnijder (2011) propose a cropping system that includes more drought-tolerant cereals like sorghum and pearl millet and perennial crops like cassava. Cassava hedges grown close to the infiltration pits along the contour ridges will be able to utilize soil moisture throughout the rainy season including the heavy showers that fall at the beginning of the season when maize is still at the initial crop growth stage. In the second year soil moisture content levels will be determined further downslope in the vicinity of 2 m from the center of infiltration pits in order to establish the distance to which the effects of the pits is felt.

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