Potential of In-Field Rainwater Harvesting to Improve Resilience of Dryland Cropping in Smallholder Farms of Zimbabwe: A Review

Misi Amos Manyanga, Gabriel Soropa, and Munjonji Lawrence

Abstract Sustainable agriculture for food security and improved livelihoods in Zimbabwe has been greatly impacted by frequent droughts and prolonged mid-season dry spells due to climate change and variability. These impacts are further exacerbated by the farmers' limited capacity to adapt to these climatic shifts. Over the past years, different in-field rainwater harvesting technologies have been promoted to help farmers especially in arid and semi-arid regions to capture, store and utilize rainfall for improved crop yields. This article reviews different in-situ rainwater harvesting technologies implemented and promoted in some parts of Sub Saharan Africa, for suitability to the Zimbabwe context. The most common in field rainwater harvesting technologies promoted in parts of Zimbabwe and parts of Sub Saharan Africa include planting pits, contour ridges with infiltration pits, tied ridges, ridges, fanyajuu and zai pits. Farmers tend to adopt permanent and semi-permanent in-field rainwater harvesting structures with labour requirements being the main hindrance to adoption. In most cases, insitu rainwater harvesting strategies were found to significantly improve crop yields. In-field rainwater harvesting structures can thus be used for climate change adaptation in Zimbabwe. Rainwater harvesting structures are effective when integrated with soil fertility management. Structures such as modified planting pits (tumbuzika) need to be evaluated locally for their impact as rainwater harvesting strategies under different soil types and topographic conditions in the smallholder farming sector of Zimbabwe. There is need for policy formulation with regards to climate change adaptation strategies such as in-field rainwater harvesting if they are to be a success.

Keywords Dry spells in-field water harvesting · Small holder farms

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Introduction

Climate change has negative effects to various sectors of economic development including natural resources, agriculture and food security, forestry, tourism, manufacturing and health (IPCC 2007). Changes in rainfall distribution, increasing number of seasons with below normal rainfall and increased temperatures lead to extensive droughts and heat stress and lowers crop productivity (Komba and Muchapondwa 2012). In Zimbabwe, rainfall is becoming erratic and highly variable both spatially and temporally (Nyagumbo et al. 2009). In the semi-arid regions of the country, delayed on-set and premature end of the rainy season are experienced. The rainfall often occurs as high intensity short duration convective storms (Nonner 1997) giving rise to severe soil erosion especially in the early cropping season when the ground is bare. During the cropping season, longer intra-seasonal dry spells are common and their impact on crop production is often severe, especially if they coincide with critical stages of crop development (Rockstrom et al. 2002). Africa is already suffering from food insecurity and malnutrition, (IPCC 2007). About 23 million people in 11 African countries being affected by acute food insecurities and facing malnutrition. This shows climate change in this continent exposes smallholder farmers to worse hunger scenarios (Apata 2011). In an effort to adapt and mitigate the effects of climate change, farmers have adopted different strategies that include use of drought tolerant crop varieties, crop diversification, changing planting dates (Darwin 2004; Ubisi et al. 2017) and practicing in-field rainwater harvesting.

Broadly, rainwater harvesting (RWH) is defined as the collection and concentration of runoff water for productive purposes such as crop, fodder, pasture or tree production, livestock and domestic water supply (Ngigi 2003). RWH covers techniques and strategies to intercept and use rainfall near to where it first gets into contact with the earth surface (Hatibu and Mahoo 2000). If RWH is well utilized and applied in the right environment, it is a cheap and sustainable source of water to most of the smallholder farmers in drylands (Singh et al. 2019). In principle, rainwater harvesting is a simple low-cost technique which requires little expertise or knowledge and indeed it offers many potential benefits (Otti and Ezenwaji 2013). According to Mwenge et al. (2005), the advantages of RWH include increased income, improved food security and reduction in malnutrition besides moisture retention. In contextof the erratic nature of rainfall patterns being received, it is important to capture as much water as possible within the crop fields using in-field RWH structures. In-field RWH helps to increase water infiltration leading to improved groundwater recharge and preserves the soil moisture for crop use. Rainwater harvesting is applicable over a wide range of conditions especially in areas where seasonal average rainfall is insufficient to meet the crop water requirements (Oweis et al. 2001). In many localities, direct rainfall is insufficient to meet crop water requirement (Oweis and Hachum 2006). Therefore, increasing the amount of water available through RWH seems to be the most appropriate way of ensuring sustainable dryland crop production, increasing agricultural productivity, improving food security and alleviating poverty.

A number of in-field RWH technologies have been developed, tested and adopted by smallholder farmers across Sub Saharan Africa (SSA). The technologies being promoted are infiltration pits (Maseko 1995); cross-tied graded contours, deepened contours and fanyajuus (Hagmann 1994), no-till tied ridging, mulch ripping, clean ripping and hand hoeing (Nyagumbo 1999).The water harvesting projects have been set up in sub-Sahara Africa since the 1970s and 1980s in response to widespread droughts that left a trail of crop failures (Hatibu and Mahoo 1999; Ngigi 2003). Tolossa et al. (2020) also expressed that there are several in-field water conservation practices that have been used in several regions of Africa, including earth bunds, planting pits or planting basins, mulching, dead level contours and their modifications. Unfortunately, a few of these practices have succeeded in combining technical efficiency with low cost and acceptability to the local farmers. For example, experimental research on infiltration pits in Zimbabwe produced mixed results, and available information is inadequate to explain the causes of the differences in results (Nyakudya et al. 2014). This paper reviews some of the studies that have been done on in-field RWH in Zimbabwe and other parts of SSA in order to get a perspective of future research needs. The review mainly used secondary data from research done in parts of SSA such as Zimbabwe, Kenya, Tanzania and Malawi.

Materials and Methods

This chapter is a review of information collected from journal papers as well as conference, workshop proceedings and technical reports on in-field rainwater harvesting.

Results and Discussion

Rainwater Harvesting Strategies Promoted in Sub Saharan Africa (SSA)

Across SSA, various in-field rainwater harvesting structures have been promoted and extensive research efforts have been done on in-situ RWH strategies such as infiltration pits (Maseko 1995); cross-tied graded contours, deepened contours and fanya juus (Hagmann 1994). In Zimbabwe success stories have been documented (Nyagumbo 1999; Twomlow and Bruneau 2000; Rusike and Heinrich 2002; Motsi et al. 2004; Mugabe 2004). However, it is worth to note that planting pits resemble zai pits and in West Africa it is common and mostly adopted by many smallholder farmers across different agro-ecological farming zones (Twomlow et al. 2008). Planting pits are planting holes dug using hand hoe as part of the conservation farming system (Mupangwa et al. 2012). Water collected in the pit is retained by the effect of a

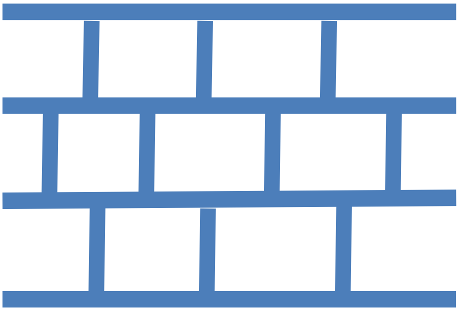

Fig. 1 An Illustration of how tied ridges are constructed for infield rainwater harvesting

structure created by the soil from the pit that is placed at the downstream side. The planting pits use a spacing of 0.9 × 0.6 m and the size of each planting pit is 0.15 × 0.15 × 0.15 m (Twomlow et al. 2008). In Rushinga, a semi-arid area of Zimbabwe, smallholder farmers modified contour ridges traditionally used for rainwater management by digging infiltration pits inside contour ridge channels for improving the amount of water retained in the crop fields (Nyakudya et al. 2014).

Tied Ridges

Tied ridges are rows of soil hipped to form lines and then tied in between in order to trap water thereby increasing infiltration and reducing runoff. To prevent possible erosion, the lower ridge is tied starting from the point between the above tied ridge such that tying is not perpendicular giving a pattern similar to a brick stretcher bond used in house construction (Kathuli and Itabari 2014) as illustrated below (Fig. 1).

Tumbuzika

Tumbuzika are very common in Kenya. They are enlarged planting pits which are 0.6 m wide and 0.6 cm deep. While using Tambuzika strategy, the top 0.2 m soil is mixed with manure or compost prior to planting. For example, 5–7 maize seeds are sown per pit with the pits spaced at 1 m row to row and 0.75 m pit to pit (Kathuli and Itabari 2014) (Fig. 2). Most of the smallholder farmers in sloppy areas of Kenya rely on fanya juus for cropping. Fanya juu, implying' throw it up' in Swahili, and it is the process of digging ditches and throwing soil upslope to form an embankment. The bank prevents the runoff water while the furrow, which is dug along the contour, retains water. Over time, well-formed and flat terraces develop naturally (Ngigi 2003). In some localities, fanya chinis which are the opposite of Fanya juus (here the soil is thrown down slope instead of up slope) are used but still works the same way.

Fig. 2 Maize in planting pits at an experimental station in Zimbabwe

Zai Pits

Another technique which has been promoted for RWH in Kenya and Tanzania are the zai pits. Zai pits which are similar to planting pits (basins) in Zimbabwe are a simple and effective form of RWH. They are small holes dug in the ground to capture and retain rainfall. The pits allow little water to escape and therefore enhance rainfall productivity (Black et al. 2012).The zai pits are shallow and wide pits that are about 0.3 m wide and 0.15–0.2 m deep, in which four to eight seeds of a cereal crop are planted (Fig. 3) (Mati 2005). Soil fertility can be improved through addition of organic manure and compost or even inorganic fertilizers into the pit. This technique works through water harvesting as well as conserving moisture and fertility in the pit. In southern Tanzania's Njombe district, the pits are made bigger and deeper (at least 0.6 m deep), and 20 L volume of manure is added. Since the area receives an annual rainfall of around 1000 mm, the farmers plant 15–20 seeds of maize per pit and the yield is more than double the conventionally tilled land (Mati 2005).

In Tanzania, many RWH techniques exist such as conservation tillage, pitting, contour barriers, strip catchment tillage and basin system (Hatibu and Mahoo 2000). The basin systems commonly known as the "negarim" micro-catchment technique is perhaps the best known RWH system. It is also known as the "meskat" system. In this system, each micro-catchment feeds runoff to a discrete cropped basin. The basin size is typically in the range 10 m^2 to 100 m^2 and is surrounded by an earth bund approximately 0.3–0.4 m high. They are particularly well suited to tree crops, but other crops can be grown successfully under non-mechanized farming systems. There is a long tradition of using this system in arid regions (Oweis and Taimeh 1996). Many farmers recognize the natural redistribution of runoff that occurs in the farming landscape and adjust their management to reflect differences in soil-moisture availability. Planting pits are also a common RWH technique in Tanzania. A notable example is the 'ngoro' technique which is common in the Mbinga District. In this semi arid region of Tanzania, pits are typically about 30 cm diameter and 20 cm deep.

Fig. 3 Planting pits for water harvesting and conservation at a farmer's field in Zimbabwe

The system is well adapted to hand cultivation and is beneficial to most smallholder farmers who are usually resource constrained especially in areas where soil surface capping is a problem.

Benefits of In-Field Rainwater Harvesting

Utilization of RWH has the potential to conserve rainfall especially in threatened environments resulting in increase in crop yield and reduced risk of crop failure (Oweis et al. 2001; ATPS 2013). Increased crop productivity and yield among smallholder farmers due to adoption of RWH will motivate and incentivize them to invest in more soil nutrient enhancement. In- situ rainwater harvesting technologies often serves primarily to recharge soil water for crop and other vegetation growth in the landscape. Malesu et al. (2006) argues that in-situ technique emphasizes on water management and conservation which are mostly traditionally considered for soil moisture conservation. This approach aims at maximum infiltration and minimum surface runoff to achieve better yields where soil moisture is a constraint. Different strategy for in-situ water harvesting resulted in increased retention of moisture, through reduction in run-off from fields and improved infiltration enhancing groundwater recharge. Therefore, improved in-field water harvesting can increase the time required for crop moisture stress to set in and thus can result in improved crop yields, food security and livelihood among households (Nyamadzawo et al. 2013).

In Zimbabwe, infiltration pits dug in contours were found to increase soil moisture content significantly from the centre of the infiltration pits up to 3 m down the slope compared to contour ridges only (Nyakudya et al. 2014). Infiltration pits help reduce soil erosion and high value horticultural crops can be grown inside and close to the pits (Nyakudya et al. 2014). Ndlovu et al. (2020) studied climate change adaptation by smallholder farmers in Gwanda district, Zimbabwe and noted that water harvesting techniques such as planting pit, mulching, deep tillage, dead level contours, ephemeral stream diversion and ridges/furrows reduces surface runoff thereby promoting water conservation and soil fertility. However, the authors noted that although in-field rainwater harvesting techniques have the potential to improve yields and crop production, there are a number of pertinent factors that affect and influence the adoption of these water harvesting techniques by smallholder farmers in the study area. These include the availability of household labour, technical know-how and farmers' perceptions. Such factors should be taken into consideration while designing and implementing strategies for upscaling the adoption of water harvesting techniques.

In Dodoma, Tanzania, runoff water was harvested, stored and later used to irrigate during a serious drought year and resulted in rice yields of about 1.5 t/ha while no yield was observed in plots where there was no supplementary irrigation (Kaumbutho and Simalenga 1999). In Malawi, simulation results showed that tied-ridges reduce surface runoff and this increased rainwater retained in the field (Wiyo et al. 2000). However, the same study showed that tied-ridging is not likely to benefit maize crop grown in coarse-textured soils regardless of seasonal rainfall. In Kenya, tied-ridges coupled with soil fertility improvement were found to increase crop yields by 100–300% (Kathuli and Itabari 2014) which is a very significant increase. In a study in Niger, Olaleye et al. (2006) reported higher yields on zai treatments compared to flat planting and this was attributed to a build-up in the soil organic matter contents which may have increased the soil water holding capacity in the zai treatments. The common idea behind all these structures is to retain runoff water and increase water use efficiency.

Farmer Adoption and Knowledge of Rainwater Harvesting Strategies

According to Critchley and Siegert (1991), the main problems associated with adoption of the water harvesting structures are that they are difficult to construct, have high labour requirements and have no room for mechanization. A clear example on effects of labour issues on adoption of rainwater harvesting strategies in Zimbabwe were pronounced on the basin tillage system (makomba), which are a modification of the zaipits which were widely promoted under Precision Conservation Agriculture

(PCA), half moon basins and shallow planting furrows using a hand hoe (Twomlow et al. 2008). Though these basin tillage were adopted by some farmers, challenges still persist due to perennial high labour demand required on establishment to the extent that they have been given a nickname, “digaufe” in vernacular language which translate to “dig and die” (Nyamadzawo et al. 2015). This clearly shows that to promote farmer adoption, technologies should be cautiously promoted to avoid stigmatization. However, a study done by Mutekwa and Kusangaya (2006) in Chivi district in Masvingo Province showed some encouraging levels of adoption with infiltration pits being the most commonly adopted RWH techniques adopted by 61% of the household respondents while tied ridges were adopted by 27%. The same authors also quoted a farmer’s perception about RWH technonologies as follows. ‘*These technologies have taught us to work together. We learn from each other, share labour and tools. We have already formed permanent labour clubs. Otherwise as individual households, we would not manage*’. About 89% of the RWH farmers indicated that they are now able to grow at least 2 crops on a rotational basis in one calendar year showing that the farmers are now able to intensively utilise their land (Mutekwa and Kusangaya 2006). This also shows that farmers know that these technologies work and to be successful and effective, they need to work together due to limited availability of the tools and labour required to make these structures. This assertion was also observed by Munamati and Nyagumbo (2010) whose study found that resource ownership is also a key factor in farmers’ ability to scale out water harvesting technologies with performance significantly linked to resource status. This is also a clear indication that with proper promotion, adoption of RWH strategies by many farmers is a great possibility. Literature showed that farmers tend to adopt more of permanent rainwater harvesting structures. Hagmann and Murwira (1996), reported that farmers in semi-arid areas showed more interest in large, semi-permanent to permanent water harvesting structures. Nyamadzawo et al. (2013) also expressed that more permanent water harvesting technologies may be a solution to the problems of perennial high labour requirements and there is a need to promote them. Semi-permanent to permanent water harvesting structures helps to harvest the runoff after in-situ soil moisture storage and stores it for providing supplemental irrigation to crops using efficient water application methods to save the crops during prolonged dry spells which are very common in recent years due to the impacts of climate change.

In Kenya, variability of rainfall due to climate change has triggered a sprout of a myriad of RWH strategies to mitigate drought and water shortages (Aroka 2010). However, despite many efforts being put in place to adopt RWH projects there is lack of tangible evidence on the significance of RWH on human welfare and sustainable development (Ngigi 2003). Moreover, RWH projects have not received enough attention to warrant widespread adoption and implementation (Kenya Rainwater Association 2010). There is need for twin effort by researchers and policy makers to promote efforts for adoption of different RWH strategies by smallholder farmers who are more prone to climate change in different cropping regions of Kenya. A complimentary study done by (Mang’era, 207) noted many deterrents to effective RWH in Kenya that include poor technical designs for rainwater capture and storage, inadequate investment, failure to apply water supply standards, perceptions about the non-potability of rainwater, and poor linkage and coordination of efforts at local through national levels of social organization. The researcher also identified some key factors responsible for successful RWH projects which included: social capital, local knowledge and capacity, and establishment and enforcement of property rights. Therefore, there is need for efforts to promote effective rainwater harvesting strategies through building capacity of project groups at the local level, developing effective RWH policies, institutions and creating RWH coordination networks at local level through national and international collaborations.

In Tanzania, it was observed that farmers already know the importance of water conservation and harvesting and interestingly they have been implementing these practices. Farmers effectively utilize soil moisture through proper cropping system with less water demanding crops such as millet being cropped on upper slope while maize and other crops that require more water were planted on lower slope positions. Adoption of these water harvesting practices was found to improve farmer's income and reduced poverty (Kaumbutho and Simalenga 1999). Another study done by Gowing et al. (1999) assessed the extent to which different RWH are used in Tanzania and reported widespread adoption of RWH techniques. However, the authors noted that farmers are faced with shortage of appropriate technologies and knowledge suitable for their areas. They concluded that there is a need to identify and disseminate appropriate technologies that will reduce vulnerability to rainfall variability and scarcity especially in the semi-arid areas of Tanzania. Therefore, specific regulations are imperative for guiding and enforcing the adoption and attainment of the targeted technology potential. These should be recognizable at national level through national RWH technology guidelines and standards (Mwamila et al. 2016).

Conclusions

Many farmers in selected areas of SSA observed significant benefits by adopting different RWH strategies. This clearly shows that in-field RWH can be acritical climate change adaptation strategy in Zimbabwe. In-field rainwater harvesting coupled with good soil fertility management practices can help to increase crop yields significantly through increased water use efficiency and thereby, helping in climate change mitigation and adaptation. Furthermore, for rainwater harvesting to be effective and successful, there is need for farmers to work collectively taking into consideration of the farmers' resource endowment. The problem of resource endowment can be countered through formation of labour working groups in order to reduce the amount of time spent during the initial establishment of the RWH technologies. More studies need to be done to explore the benefits of rainwater harvesting in Zimbabwe in order to come up with proper more adaptable strategies for climate change adaptation. Moreover, advocacy for adoption of different rainwater harvesting strategies to smallholder farming communities, both at policy and lower levels should be done for adaptation to climate change.

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