Review of Rainwater Harvesting Techniques and Evidence for their Use in Semi-Arid Tanzania

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Abstract

Rainwater harvesting (RWH) should be regarded as a continuum of techniques that link in situ soil water conservation at one extreme to conventional irrigation at the other. In situ RWH, comprises a group of techniques for preventing runoff and promoting infiltration. Micro catchment RWH comprises a group of techniques for collecting overland flow (sheet or rill) from a catchment area and delivering it to a cropped area in order to supplement the inadequate direct rainfall. The transfer normally occurs over a relatively short distance entirely within the land holding of an individual farmer and the system is therefore sometimes known as an "internal catchment".. Macro-catchment RWH comprises a group of techniques in which natural runoff is collected from a relatively large area and transferred over a longer distance. Examples of each of these categories of RWH exist in parts of Tanzania, but their potential is largely neglected by research and extension services and they are under-exploited. The purpose of this paper was to assess the extent to which the different rainwater harvesting systems, are used in Tanzania. The findings show that there is a widespread practice of rainwater harvesting in Tanzania. Rainwater harvesting with storage of water for livestock has received government support in the past. However, many storage reservoirs have been destroyed by siltation. On the other hand rainwater harvesting for crop production has not received an adequate support from research and extension services. Therefore, although farmers are practicing rainwater harvesting, they are faced with shortage of appropriate technologies and knowledge.

Keywords: Rainwater harvesting, runoff agriculture, soil-water conservation, micro-catchments, macro-catchments

Introduction

In the semi-arid areas of Tanzania, agriculture and the livelihoods that depend upon it are greatly affected by the unreliable and highly variable rainfall regime. Any attempt to improve agriculture therefore must tackle the moisture constraint, but knowledge of appropriate techniques is surprisingly poor. It appears that a significant knowledge gap exists between two areas that have previously received far greater attention. On one hand, widespread concern about land degradation has led to a focus on soil erosion control. On the other hand, efforts to exploit water resources have led to a focus on irrigation. Between these two extremes, the middle ground of rainwater harvesting (RWH) has been largely neglected, although it represents the best prospect for sustainable intensification for the vast majority of dryland farmers. The challenge is to identify and disseminate appropriate technologies that will reduce their vulnerability to drought.

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Critiques of colonial and post-colonial soil conservation projects in sub-Saharan Africa began to appear in the late 1980s and various authors (Scoones *et al.*, 1996; Pretty and Shah, 1999) have pointed to the failure of approaches that attempt to impose technical "solutions" on unwilling farmers. A wide-ranging review by Hudson (1991) identified reasons for success or failure and defined what new farming practices should offer in order to be adopted by farmers. The well-documented experience of Machakos District in Kenya (Tiffen *et al.*, 1994) shows what is achievable when conditions are right. This is also made clear in the paper by Hatibu et al.(1999). The emergence of a new style of natural resource management, that is based on participatory approaches, provoked a re-evaluation of indigenous soil-and-water conservation techniques (Reij *et al.*, 1988; IFAD, 1992; Reij *et al.*, 1996). The question then became: how can external interventions transfer knowledge and facilitate technological innovation by farmers?

This review provides the context to the RWH research activity by first examining what is known about indigenous practices and introduced RWH techniques. Rainwater harvesting should be regarded as a continuum of techniques that links in-situ soil-water conservation at one extreme to conventional irrigation at the other. It can be defined as the practice of collecting rainfall run-off for cultivation (Pacey and Cullis, 1986; Boers and Ben Asher, 1982). Various attempts have been made to classify the different techniques according to the nature of the runoff process involved (Critchley and Siegert, 1991; Prinz, 1995; Barrow, 1999). For simplicity, this paper adopts a classification according to the size ratio and transfer distance between runoff producing normally called Catchment Area (CA) and the runoff receiving area, normally called Cropped Ba (CB).

In situ Rainwater Harvesting

In-situ RWH, otherwise known as soil-w conservation, comprises a group of technic for preventing runoff and promoting infil tion. The aim is to retain moisture that w otherwise be wasted as runoff from cropped area. Rain is conserved where it fa but no additional runoff is introduced f elsewhere.

This approach is appropriate where the n constraints are soil-related, but rainfall is quate. Water acceptance may be hindered low rate of infiltration caused by sur crusting (capping). Alternatively, the prob may be attributable to low percolation caused by restrictive layers in the soil pro These problems may be due to inherent characteristics or to previous mismanager (e.g. formation of plough pan, compactio trampling).

The following techniques can be identified:

i) Conservation Tillage

Conservation tillage is a generic term fo use of tillage techniques to promote in moisture conservation. This can be achi by creating micro-relief to increase rete storage (e.g. tied ridges), by breaking surface pans by deep cultivation (e.g. c ploughing), or by contour ridges. Figu illustrates effect of tillage on these charac tics. Recent research in semi-arid areas of Sahara Africa (SSA) has been well docum in Kenya (Kiome and Stocking, 1993), in babwe (Twomlow and Hagmann, 1998) more generally by Morse (1996). Experi in Tanzania is discussed by Rwehumbiza (1999). These systems are well adapte tractor and/or draught animal cultivation.

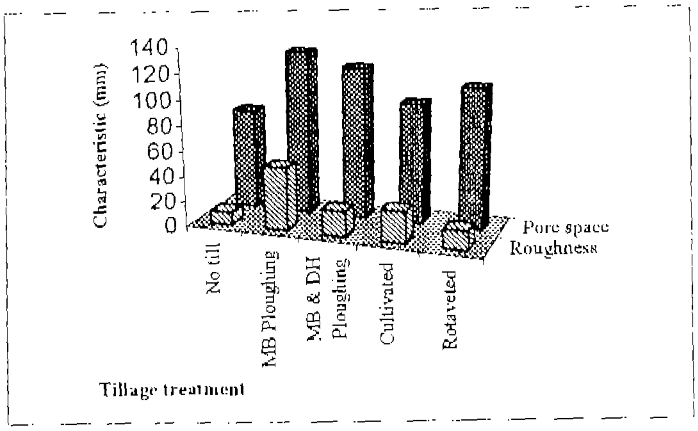

Figure 1: Effect of tillage on porosity and surface roughness

ii) Pitting

Planting pits (Figure 2) have been documented as an indigenous practice in Mali, Burkina Faso and Niger, where they are known as zay, zai or tassia (Reij *et al.*, 1996). In Tanzania, a notable example is the "ngoro" technique of the Matengo Highlands in Mbinga District. This system was documented during the colonial era (Pike, 1939; Stenhouse, 1944) and has received recent attention (Willcocks *et al.*, 1996). In semi-arid Tanzania, pits are typically about 30 cm diameter and 20 cm deep. The system is well adapted to hand cultivation and is beneficial especially when soil surface capping is a problem.

Micro-catchment RWH

Micro-catchment RWH comprises a group of techniques for collecting overland flow (sheet or rill) and delivering it to a cropped area in order to supplement the inadequate direct rainfall. This system involves a distinct division of CA and CB, but the two zones are adjacent. The transfer distance is typically in the range 5 m to 50 m. Both CA and CB are normally situated within the land holding of an individual farmer. The system is therefore sometimes known as an "internal catchment" system.

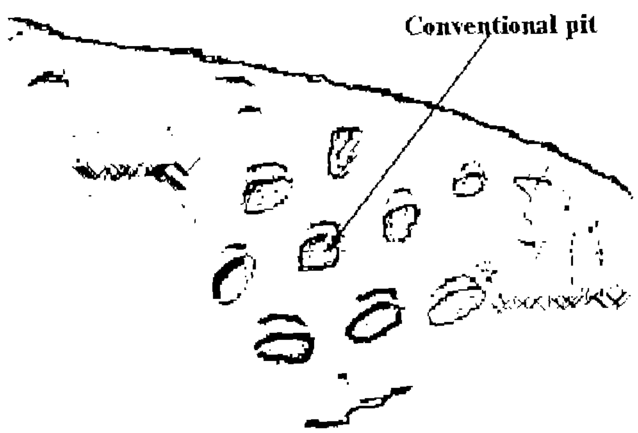

Figure 2: Layout of Pitting RWH

The short transfer distance ensures that the system offers relatively high runoff efficiency, possibly yielding as much as 50% of precipitation compared with as little as 5% contribution to streamflow in a natural catchment. The small catchment size ensures that the flow volume and speed are limited and soil erosion is therefore relatively easy to control. The main disadvantage of the system is that it involves leaving uncropped areas within the farmer's field. In evaluating the benefit therefore it is important to account for the opportunity cost of the cropped area.

The following techniques can be identified:

i) Strip catchment tillage

This technique (also known as contour strip cropping) involves alternating strips of crops with strips of grass or cover crops. Cultivation's are usually restricted to the row-planted crop strips. The uncultivated strips release runoff into adjacent crop strips (Figure 3). The system is normally used on gentle slopes (up to 2%) with the strip width being adjusted to suit the gradient. The CA: CB ratio is normally less than 2:1.

The system is widely practiced in many semi-arid areas, although farmers and extension workers may not recognise it as a RWH measure. Various studies have reported reduction in soil erosion and runoff, but little research has been done to evaluate improvement in crop

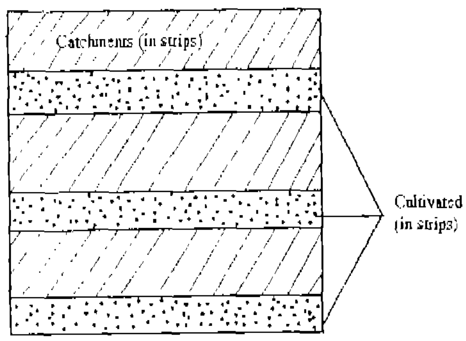

Figure 3: RWH with strip catchment tillage

performance (Kiome and Stocking, 1993). T system is suited to most crops and is easy mechanize.

ii) Contour barriers

This technique involves the creation of cr slope barriers, which may be vegetative (g strips, trash lines) or mechanical (stone li earth bunds). The barrier intercepts ru from upslope and promotes infiltration in cropped area. In the case of earth bunds, barrier is designed to be impermeable and ter is ponded behind it. Other barriers semi-permeable and aim to slow down filter runoff without ponding.

Contour bunds have been advocated widel the past as a method of soil erosion control slopes up to 5%. They are generally c structed manually with soil either being thr upslope (*fanya juu*) or downslope (*fanya chi* The former system has been successf adopted in Machakos District of Kenya, but latter system is more common in steep s areas in Arusha, Morogoro, and Tanga gions in Tanzania. Bunds are usually clo spaced (2 to 5 m). There are many repo experiences of failure due to breakage overtopping of bunds, which may lead to gressive downslope damage due to flow centration. This problem is generally ass ated with poor alignment and poor mainten of the bunds. The risk is reduced if intermi structures rather than continuous contour b are created. These structures (sometimes scribed as demi-lunes or lunettes) are four a traditional practice in parts of West A (e.g. Niger). They are similar to w spreading structures described below.

Stone barriers offer advantages over bunds in certain circumstances. In partic the risk of overtopping and progressive fa due to flow concentration is reduced. The a long tradition of their use in parts of

Africa (IFAD, 1992; Reij *et al.*, 1988) and they have been promoted widely as a RWH technique in recent years. Stone lines (Figure 4) are normally constructed manually approximately following the contour at spacing of 15 to 30 m depending largely on the amount of stones available. They are recommended for slopes up to about 2%.

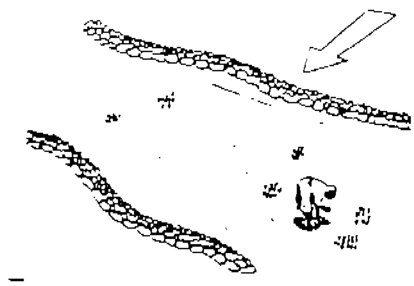

Figure 4: RWH with contour bunding (IFAD, 1992)

Semi-permeable barriers can also be formed using trash-lines (straw, crop residue, brushwood) or live barriers (grass strips, contour hedges). Trashlines are known to be in use as a traditional practice in Tanzania (Thornton, 1980). They have received little research attention, but Kiome and Stocking (1993) reported that they were successful as a RWH method in semi-arid Kenya. Grass strips are similar in principle to strip catchment tillage, but normally involve a narrower band (typically one metre) of a specially planted grass species. Particular emphasis has been given to vetiver grass but Srivastava *et al.* (1993) provide a full list of commonly used species. Contour hedges, possibly using leguminous perennials, can also provide an effective barrier (possibly combined with stone lines), but experience indicates that they are better suited to more humid environments, since competition for moisture is likely to be a problem in semi-arid conditions.

iii) Basin systems

This practice is commonly known as the "negarim" micro-catchment technique and 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 (Figure 5). The basin size is typically in the range 10 m^2 to 100 m^2 and is surrounded by an earth bund approximately 30 to 40 cm high. They are particularly well suited to tree crops, but other crops can be grown successfully under non-mechanised farming systems. There is a long tradition of using this system in arid regions with low-intensity winter rainfall (Evenari *et al.*, 1971; Oweis and Taimeh, 1996). There is no experience of systematically designed micro-catchment basin systems in semi-arid Tanzania other than the research reported later in this issue. However, it is apparent that some farmers recognise the natural redistribution of runoff that occurs in the farming landscape and adjust their management to reflect differences in land capability.

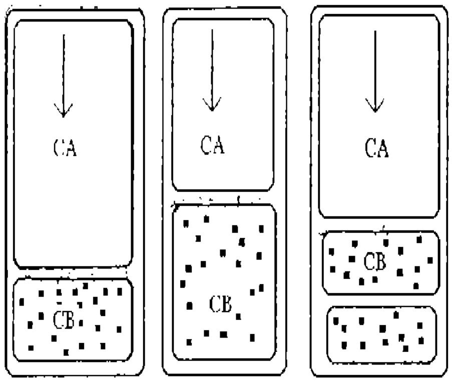

Figure 5 RWH with Meskat-type Bunding

Macro-catchment RWH

Macro-catchment RWH comprises a group of techniques for harvesting runoff from a catchment area (CA) and delivering it to a cropped area (CB), where CA and CB may have markedly different characteristics (e.g. slope and soil) and the transfer distance may be in the range 100 metres to several kilometres. The catchment generally lies outside the land holding of the farmer(s) using the runoff, so the system is sometimes known as an "external catchment" system. This distinct separation can be particularly beneficial if runoff events can be harvested at times when there is no direct rainfall in the cropped area.

The runoff efficiency is normally less than for a micro-catchment system, but the large catchment area ensures that the runoff volume and flow rates are high. This gives rise to problems in managing potentially damaging peak flows, which may lead to serious erosion and/or sediment deposition. Substantial channels and runoff control structures may be required and this usually involves collective effort amongst a group of farmers for construction and maintenance. This sometimes gi rise to problems over management of wa distribution.

The following techniques can be identified:

i) Hillside systems

These systems exploit hillslope runoff pr esses by which runoff from stony outcrops a grazing lands in upland areas tends to fl naturally downslope. Some farmers grow th crops in wetter lowland areas, which recei runoff in this way without any active mani lation or management. Farms in these areas called *mashamba ya mbugani* and are fou throughout semi-arid Tanzania grown w maize, rice, sugar cane, vegetables and nanas. They are attractive not only for th improved moisture regime, but also because higher fertility levels due to enrichment. some villages there is high demand for su land and favoured areas which also have go access and low risk of flooding tend to be fu exploited.

One technique for improving the capture hillslope runoff involves the construction cross-slope barriers and basins using ea bunds to intercept and store runoff. In prin ple, these systems are similar to contour bar ers and basin-type micro-catchment systen but they involve larger external catchme (Figure 6). In Tanzania the *majaluba* syste of Sukumaland is the best known example. It used primarily for production of rainfed lo land rice (Meertens *et al.*, 1999). It is arguab not a traditional practice (Shaka *et al.*, 199 but its introduction can be traced to the col nial era (Thornton and Allnut, 1949) and rapid adoption and spread indicates the pote tial of RWH in semi-arid areas.

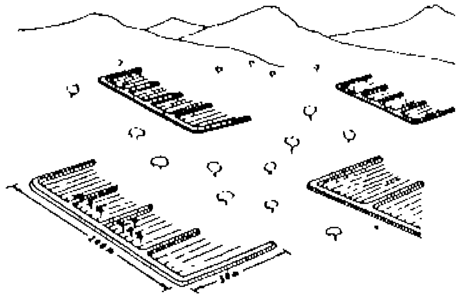

Figure 6: **Example of hill sheet flow RWH (After Reij, 1991).**

An alternative technique involves the construction of hillside conduits, which are dug along the contour to intercept runoff and convey it to an area suitable for crop production. The construction effort is justified if the hillslope runoff would otherwise not reach land that is suitable for cropping. This tends to be the case where low-intensity rain falls on stoney hillsides (Evenari *et al.*, 1971). Carter and Miller (1991) reported on experiments with similar systems in Botswana with CA:CB ratios between 17:1 and 50:1. Some *majaluba* systems receive runoff in a similar way by using cattle-tracks as channels and constructed conduits.

ii) Stream-bed systems

These systems use barriers, such as permeable stone dams or earth banks, to intercept water flowing in an ephemeral stream (wadi) and spread it across adjacent valley terraces to enhance infiltration (Figures 7). This technique is sometimes known as the *liman* system and is difficult to distinguish from spate irrigation. In north India (especially Rajasthan) the *khadin* system has received considerable attention (Hudson, 1992). In east Sudan a similar system, known locally as *teras* has also been studied extensively (van Dijk and Ahmed, 1993). The size of these structures varies a great deal, but some systems run for several kilometres with one structure spilling excess flow to another downslope and so on (Kolakar *et al.*, 1983). Normally, planting occurs at the end of the wet season using stored soil moisture.

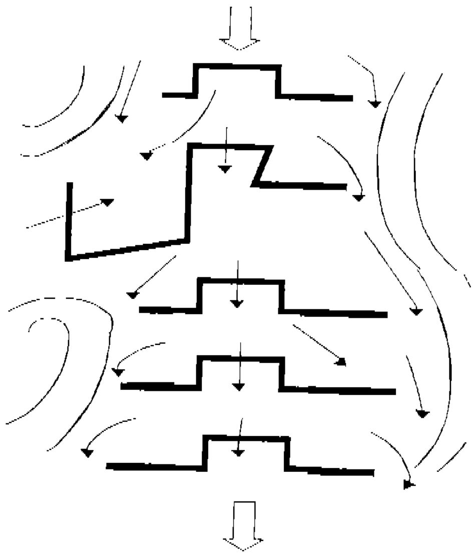

Figure 7: **Flood water harvesting within the streambed**

iii) Ephemeral stream diversion

These systems are also difficult to distinguish from spate irrigation, since they involve diverting water from an ephemeral stream and convèying it to a cropped area. There are two distinct ways of distributing the water in the cropped area. The first uses a cascade of open trapezoidal or semi-circular bunds (Figure 8). The water fills the top basin and spills around the end of the bund into the next basin (sometimes known as *caag* system). In the second system, the field is divided into closed basins and water is distributed either through a channel or in a basin-to-basin cascade using small spillways (as in the *majaluba* system).

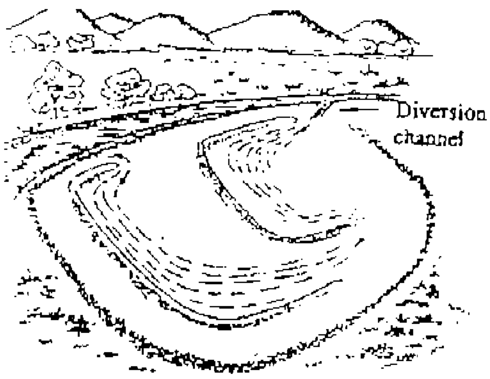

Figure 8: Ephemeral stream diversion (After Reij, 1991)

Traditional diversion structures may be earth banks, stone walls or brushwood barriers. They are subject to frequent damage and are likely to be washed away by large floods. Attempts to improve such systems by building "permanent" diversion structures concrete or stone-filled gabions have often encountered problems with flows by-passing the structure or with diversion of damaging flows during large floods. Similar difficulties occurred in Tanzania in the IFAD supported project to expand RWH systems for rice in Dodoma, Shinyanga, Mwanza, Tabora and Singida Regions. Considerable attention has been devoted to developing improved methodologies for planning and design of these systems (Tauer and Humborg, 1992).

iv) Storage systems

Macro-catchment RWH systems often yield high volumes of runoff and it may be advantageous to store it in a reservoir or use it to recharge groundwater. Simple reservoir systems have been used widely for livestock watering. They are sometimes known as "charco dams" or "haffirs". Siltation is often a problem and the labour requirement for sediment removal can be a considerable burden. Evaporation and seepage losses may also be high, but in some cases they are avoided by using sand dams as a method of small-scale groundwater recharge.

Conclusions

Evidence, that is largely anecdotal, sugge that water harvesting for various purposes is widespread practice in Tanzania. In most i stances the practice is opportunistic, but the are a number of traditional techniques in whi runoff collection and distribution is active managed. Some documented studies exist, b knowledge is patchy. Rainwater harvesting h been largely neglected by research and exte sion services, but represents the best prospe for sustainable intensification for the vast m jority of dryland farmers. The challenge is identify and disseminate appropriate technol gies that will reduce vulnerability to rainfa variability and scarcity in the semi-arid areas.

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