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 Basin (CB).

In situ Rainwater Harvesting

In-situ RWH, otherwise known as soil-water conservation, comprises a group of techniques for preventing runoff and promoting infiltration. The aim is to retain moisture that would otherwise be wasted as runoff from the cropped area. Rain is conserved where it falls, but no additional runoff is introduced from elsewhere.

This approach is appropriate where the main constraints are soil-related, but rainfall is adequate. Water acceptance may be hindered by low rate of infiltration caused by surface crusting (capping). Alternatively, the problem may be attributable to low percolation rate caused by restrictive layers in the soil profile. These problems may be due to inherent soil characteristics or to previous mismanagement (e.g. formation of plough pan, compaction by trampling).

The following techniques can be identified:

i) Conservation Tillage

Conservation tillage is a generic term for the use of tillage techniques to promote in-situ moisture conservation. This can be achieved by creating micro-relief to increase retention storage (e.g. tied ridges), by breaking subsurface pans by deep cultivation (e.g. chisel ploughing), or by contour ridges. Figure 1 illustrates effect of tillage on these characteristics. Recent research in semi-arid areas of sub-Sahara Africa (SSA) has been well documented in Kenya (Kiome and Stocking, 1993), in Zimbabwe (Twomlow and Hagmann, 1998) and more generally by Morse (1996). Experience in Tanzania is discussed by Rwehumbiza et al. (1999). These systems are well adapted to tractor and/or draught animal cultivation.

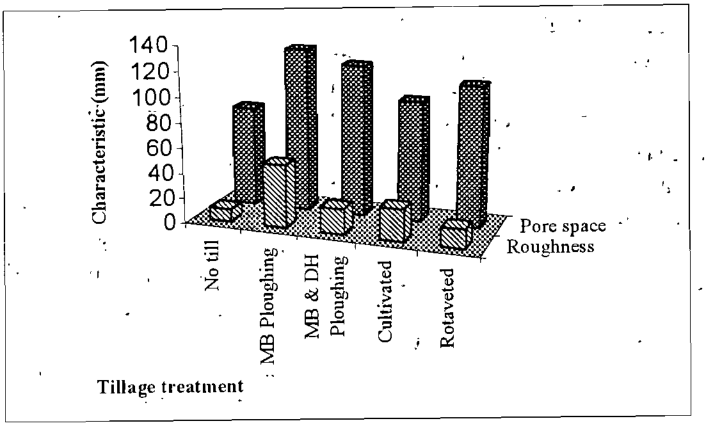

Figure 1: **Effect of tillage on porosity and surface roughness**

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.

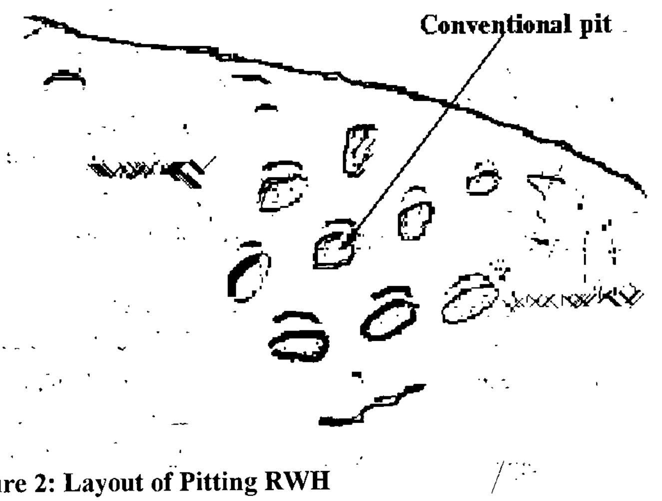

Figure 2: Layout of Pitting RWH

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

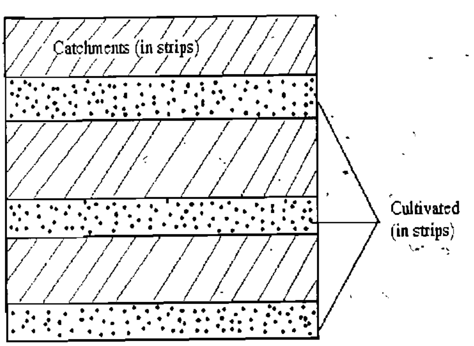

Figure 3: RWH with strip catchment tillage

ii) Contour barriers

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

Contour bunds have been advocated widely in the past as a method of soil erosion control on slopes up to 5%. They are generally constructed manually with soil either being thrown upslope (*fanya juu*) or downslope (*fanya chini*). The former system has been successfully adopted in Machakos District of Kenya, but the latter system is more common in steep slope areas in Arusha, Morogoro, and Tanga Regions in Tanzania. Bunds are usually closely spaced (2 to 5 m). There are many reported experiences of failure due to breakage or overtopping of bunds, which may lead to progressive downslope damage due to flow concentration. This problem is generally associated with poor alignment and poor maintenance of the bunds. The risk is reduced if intermittent structures rather than continuous contour bunds are created. These structures (sometimes described as demi-lunes or lunettes) are found as a traditional practice in parts of West Africa (e.g. Niger). They are similar to water-spreading structures described below.

Stone barriers offer advantages over earth bunds in certain circumstances. In particular, the risk of overtopping and progressive failure due to flow concentration is reduced. There is a long tradition of their use in parts of West

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%.

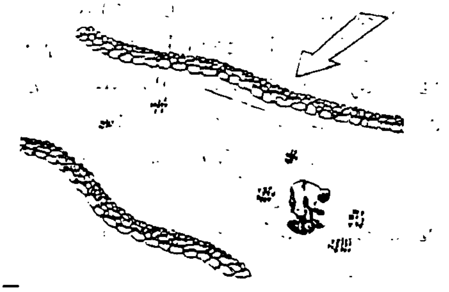

Figure 4: RWH with contour bunding (IFAD, 1992)

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.

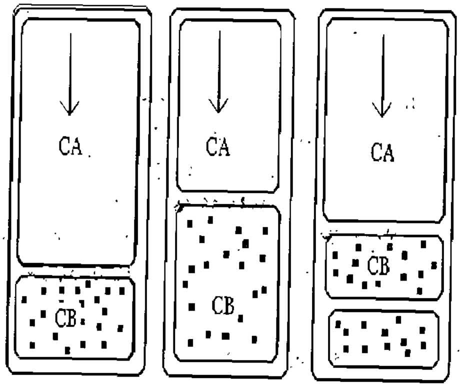

Figure 5 **RWH with Meskat-type Bunding**

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 gives rise to problems over management of water distribution.

The following techniques can be identified:

i) Hillside systems

These systems exploit hillslope runoff processes by which runoff from stony outcrops and grazing lands in upland areas tends to flow naturally downslope. Some farmers grow their crops in wetter lowland areas, which receive runoff in this way without any active manipulation or management. Farms in these areas are called *mashamba ya mbugani* and are found throughout semi-arid Tanzania grown with maize, rice, sugar cane, vegetables and bananas. They are attractive not only for their improved moisture regime, but also because of higher fertility levels due to enrichment. In some villages there is high demand for such land and favoured areas which also have good access and low risk of flooding tend to be fully exploited.

One technique for improving the capture of hillslope runoff involves the construction of cross-slope barriers and basins using earth bunds to intercept and store runoff. In principle, these systems are similar to contour barriers and basin-type micro-catchment systems, but they involve larger external catchments (Figure 6). In Tanzania the *majaluba* system of Sukumaland is the best known example. It is used primarily for production of rainfed lowland rice (Meertens *et al.*, 1999). It is arguably not a traditional practice (Shaka *et al.*, 1996), but its introduction can be traced to the colonial era (Thornton and Allnut, 1949) and its rapid adoption and spread indicates the potential of RWH in semi-arid areas.

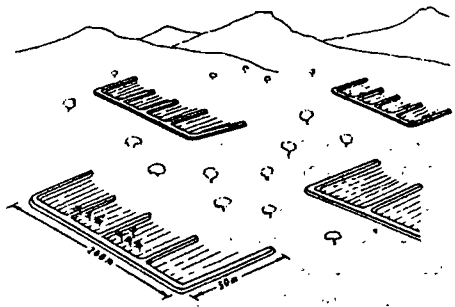

Figure 6: **Example of hill sheet flow RWH (After Reij, 1991).**

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.

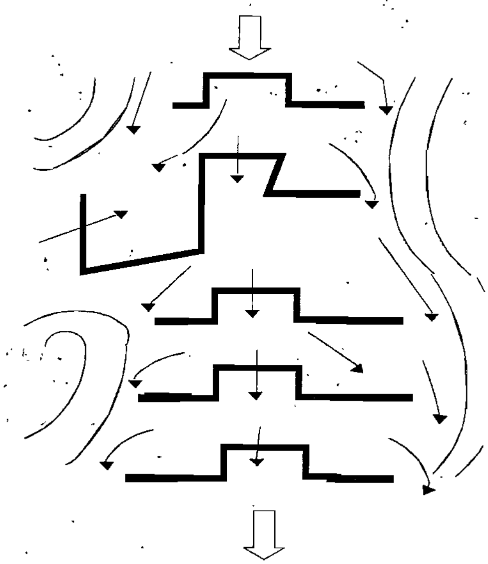

Figure 7: **Flood water harvesting within the streambed**

iii) Ephemeral stream diversion

These systems are also difficult to distinguish from spate irrigation, since they involve diverting water from an ephemeral stream and conveying 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).

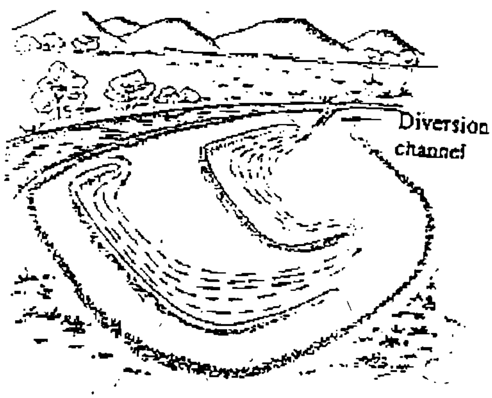

Figure 8: **Ephemeral stream diversion (After Reij, 1991)**

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, suggests that water harvesting for various purposes is a widespread practice in Tanzania. In most instances the practice is opportunistic, but there are a number of traditional techniques in which runoff collection and distribution is actively managed. Some documented studies exist, but knowledge is patchy. Rainwater harvesting has been largely neglected by research and extension services, but 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 vulnerability to rainfall variability and scarcity in the semi-arid areas.

References

Barrow, C.J., 1999. Alternative Irrigation: the promise of runoff agriculture. Earthscan Publications, London. 240pp

Boers, T.M. and Ben-Asher, J., 1982. A review of rainwater harvesting. *Agric. Water Management* 5: 145-158.

Carter, D. and Miller, S., 1991. Three years experience with an on-farm macro-catchment water harvesting system in Botswana. *Agric. Water Management* 19: 191-203.

Critchley, W. and Siegert, K., 1991. Water harvesting: a manual for the design and construction of water harvesting schemes for plant production. Report ACL/MISC/17/91, FAO, Rome. 133pp

Evenari, M., Shanan, L. and Todmore, N.H., 1971. The Negev: the challenge of a desert. Harvard University Press, Cambridge, USA.

Hudson, N., 1991. A study of the reasons for success and failure of soil conservation projects. FAO Soils Bulletin 64. FAO, Rome. 65pp

Hudson, N., 1992. Land Husbandry. Batsford, London. 192 pp.

International Fund for Agricultural Development (IFAD), 1992. Soil and Water Conservation in sub-Saharan Africa: towards sustainable production by the rural poor. IFAD, Rome. 110 pp

Kiome, R. and Stocking, M., 1993. Soil and Water Conservation in Semi-Arid Kenya, Bulletin 61, Natural Resources Institute, Chatham.

Kolakar, A.S., Murthy, K.N.K., Singh, N., 1983. Khadin: A method of harvesting water for agriculture in the Thar Desert. Journal of Arid Environments 6 (1): 59-66.

Meertens, H., Ndege, L.; and Lupeja, P., 1999. The cultivation of rainfed lowland rice in Sukumaland, Tanzania. Agriculture, Ecosystems and Environment 76: 31-45.

Morse, K., 1996. A Review of Soil and Water Management Research in Semi-Arid areas of Southern and Eastern Africa. Report LR14, Natural Resources Institute, Chatham.

Oweis, T.Y. and Taimeh, A.T., 1996. Evaluation of small basin water harvesting system in the arid region of Jordan. Water Resources Management 10 (1): 21-34.

Pacey, A. and Cullis, A., 1986. Rainwater harvesting: the collection of rainfall and runoff in rural areas. Intermediate Technology Publications, London. 216 pp

Pike, A.H., 1939. Soil Conservation amongst the Matengo tribe. Tanganyika Notes and Records 6: 79-81.

Pretty, J. and Shah, P., 1999. Soil and Water Conservation: a brief history of coercion and control. In: Fertile Ground: the impacts of participatory watershed management. Hinchcliffe, H.; J. Thompson, J. Pretty, I. Guijt and P. Shah (eds). IT Publications, London.

Prinz, D., 1995. Water harvesting techniques in the Mediterranean region. In: Berndtson, R. (ed) Rainwater harvesting and management of small reservoirs in arid and semi-arid areas. Proceedings of an expert seminar, Lund University, Sweden.

Reij, C. 1991. Indigeneous soil and water conservation in Africa. Gatekeeper Series No. 27, IIED, London, 35 pp.

Reij, C., Mulder, P. and Begemann, L., 1988. Water Harvesting for Plant Production. World Bank Technical Paper 91. World Bank, Washington D.C. 123 pp.

Reij, C.; I. Scoones and Toulmin, C., 1996. Sustaining the soil: indigenous soil and water conservation in Africa. Earthscan Publications, London.

Scoones, I.; C. Reij and Toulmin, C., 1996. Sustaining the soil: indigenous soil and water conservation in Africa. In: Reij, C., I. Scoones & C. Toulmin (op cit)

Shaka J.M., Ngailo, J.A., and Wickama, J.M., 1996. How rice cultivation became an indigenous farming practice in Maswa district, Tanzania. In: Reij et al. (1996) op cit.

Srivastava, J.P.; Tamboli, P.M., English, J.C., Lal, R. and Stewart B.A., 1993. Conserving soil moisture and fertility in the warm seasonally dry tropics. World Bank Technical Paper 21. World Bank, Washington D.C.

Stenhouse, A.S., 1944. Agriculture in the Matengo Highlands. East African Agricultural and Forestry Journal, 10: 22 - 27

Tauer, W. and Humborg, G., 1992. Runoff Irrigation in the Sahel Zone. CTA Wageningen, Netherlands.

Thornton, R.J., 1980. Space, time and culture among the Iragw of Tanzania. Academic Press, New York.

Thornton, D. and Allnut, R., 1949. Rice. In: Rounce N. (Ed) The Agriculture of the Cultivation Steppe of the lake, Western and Central Provinces. Longman, Cape-Town.

Tiffen, M., Mortimore, M. and Gichuki, F., 1994. More people less erosion: environmental recovery in Kenya. J. Wiley, Chichester. 311 pp.

Twomlow, S. and Hagmann, J., 1998. A Bibliography of references on soil and water management for semi arid Zimbabwe, Report IDG/98/19. Silsoe Research Institute, UK.

van Dijk, J. and Ahmed, M.H., 1993. Opportunities for expanding water harvesting in sub-Saharan Africa: the case of the teras of Kassala. Gatekeeper Series No. SA40. IIED, London.

Willcocks, T.J., and Gichuki, F. (Eds), 1996. Conserve water to save soil and the environment. Report IDG/96/15. Silsoe Research Institute, UK.

Rwehumbiza F.B., N. Hatibu, and Kishebuka, S.R, 1999. Evaluation of contour barriers for soil and water conservation in Western Pare Low lands. *Tanzania J. Agric. Sc, 2(2)*: 181 - 192