Economics of Rainwater Harvesting for Crop Enterprises in Semi-Arid Areas

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Abstract
Rainwater harvesting (RWH) is being promoted widely as a way to improve the production of crops and livestock in semi-arid areas. However, there is very limited data on the performance of RWH in terms of productivity of water, land, labor and capital resources. This paper presents results from case studies in Tanzania where farmers are using RWH technology to produce maize, paddy and vegetables in semi-arid areas where it would otherwise be impossible or very difficult. The economics of these practices is analyzed in two contrasting districts over a period of five years. Results show that most farmers have invested heavily in terms of labor to establish and maintain earth structures for the capture of runoff without corresponding investment in nutrient management, leading to low yields for the cereal enterprises. When this is coupled with low farm-gate prices, the improvements of RWH for cereal systems did not lead to corresponding increase in returns to labor for the majority. However, high returns of 10 – 200 US$ per personday were obtained when rainwater harvesting was applied to vegetable enterprises. It is concluded that for RWH to contribute to improved incomes and food security, smallholder farmers should be assisted to change from subsistent to commercial objectives with marketing-oriented production of high value crops combined with processing into value-added products. This will require farmers to participate in food markets and thus increasingly depend on the market for food security as opposed to emphasizing self-sufficiency at household level.

Media summary
To contribute to poverty reduction, rainwater harvesting for crop production should be integrated with crop selection, adequate management of soil fertility, and marketing.

Key Words
Rainwater harvesting, returns to labor, poverty reduction, Tanzania.

Introduction
Nearly 40 % of the area of Eastern and Southern Africa (ESA) are semi-arid lands that experience inadequate and extreme fluctuations in the availability of water for plant growth (Fisher *et al.*, *1995*). The shortage of soil-water represents the most serious obstacle to poverty reduction because it is limiting the extent to which poor producers of crops and livestock, can take advantage of opportunities arising from emerging markets, trade and globalization. It is for this reason that the proportion of poor men and women in rural semi-arid areas is estimated to be 48% as compared to about 36% in rural humid areas, or 17% in urban areas (Leach and Mearns, 1997). Shortage of water limits the variety and quantity of products that a smallholder can produce, leading to a very narrow range of options for commercialization. Furthermore, poor smallholder producers, seldom use productivity enhancing inputs such as improved varieties, seed and fertilizer. This, together with the fluctuations in yields, makes it hard for the poor men and women in semi-arid areas to participate in the emerging market economies. It is perhaps for this reason that the New Partnership for Africa's Development (NEPAD) has recognized that (*one of the four*) *fundamental mutually reinforcing pillars on which to base the immediate improvement of Africa's agriculture, food security and trade balance, is extending the area under sustainable land management and reliable water control systems* (NEPAD, 2003).

Studies have shown that, although shortage of rainfall is an important factor, the most critical problem is often the inter- and intra-seasonal variability (Barron *et al.*, 2003). Thus, poor smallholder producers of crops and livestock in the semi-arid areas of Africa, face frequent food shortages and livelihood losses resulting from inter-seasonal droughts or floods. The catastrophic consequences of inter-seasonal variation have recently been experienced in Southern Africa, where in a space of four years, many parts of the region have gone from serious floods to serious drought and back to floods. A case study in

Tanzania has shown that historically, floods have caused about 38% of all declared disasters, while droughts caused 33% (Hatibu and Mahoo, 2000). Often the floods and droughts occurred in the same semi-arid area, and in the same season. The problem is that when it rains in the semi-arid areas, runoff response is very rapid and if not captured the water flows as a flood wave to sinks, from where it is often not economical to recover it for beneficial use. Often only a small fraction of the rainwater reaches and remains in the soil long enough to be useful. Up to 80% of the rainfall can be "lost" as evaporation, or runoff that causes erosion and flooding downstream (Figure 1). Therefore, both floods and droughts and their detrimental consequences result from this wastage of valuable rainwater. A clear win-win solution is to convert the erosion/flood causing runoff into the critically needed soil-moisture for crop and pasture growth.

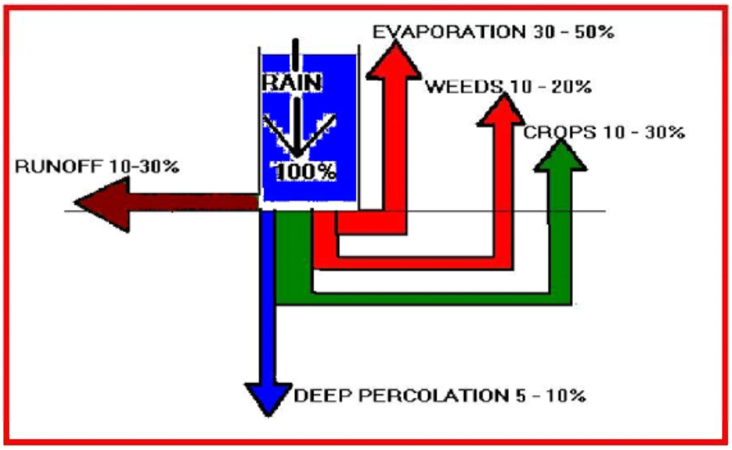

Figure 1: Schematic presentation of wastage of valuable rainwater in rain fed systems

The inadequate and extreme fluctuations in the amount of water available in the soil for plant growth, force most poor women and men farmers to remain at subsistent level and perpetual poverty. Furthermore, the consequent high risk of catastrophic crop and livestock failures, limits financing of investments in the semi-arid areas. This condemns the majority of inhabitants of these areas to precarious survival without savings, credit, investments, infrastructure and trading links. This predicament was captured in the WEHAB report as described in text Box 1 (WEHAB, 2002).

There is therefore a need to increase the capacity of the poor to manage and sustainably use the available rainwater, including effective means to deal with climatic variability. However, evidence of the performance of Rainwater harvesting (RWH) with respect to food and income security and thus reduction of poverty, is limited and far apart. The work reported in this paper is an attempt to fill this knowledge gap. Economic evaluation of the performance of different techniques of RWH varies between simple yield/productivity comparisons and more sophisticated risk analysis methods such as stochastic dominance analysis (Kunze, 2000). However, the highly sophisticated techniques are normally limited by data availability. The most commonly used methods are yield comparisons; gross margin analysis and investment analysis (Kunze, 2000). All the methods are capable of examining the 'with' and the 'without' RWH situations. Gross margin is the difference between gross value of outputs and the total variable costs used in the production process. The analysis is useful in comparing the situation "with" the project to that of "without" the project. Gross margin analysis is static, and does not take into consideration the time value of money. However, it is a useful tool, which can assist in improving the overall management as it addresses resource productivity in a given period of time. Investment analysis allows costs and benefits to be spread across the lifetime of the project, which for many RWH structures is always more than ten years.

This paper evaluates farmer-initiated and managed RWH systems in eastern Africa, with particular reference to Tanzania. These systems are briefly described in the following section. Gross margin analyses were used to assess economic performance of these systems with respect to return to labor and thus income generation. It then provides an analysis of the priority actions needed to enhance the performance of RWH in the semi-arid areas of the region.

Methods

Characteristics of the study area

Data was collected from two small watersheds selected to capture contrasting biophysical, socio-economic and farming conditions. The first is located in Maswa District in Northern Tanzania just south of Lake Victoria, and the second is in Same District within the Pangani River basin just south of Mount Kilimanjaro (Figure 2). Maswa District is located approximately between longitudes 33^o 30' and 34^0 15' East and latitude 2^o 50' and 3^o 38' South and at an elevation of 1230-1300 m above sea level. The rainfall is bimodal varying from about 1000 mm a year in the north-west to less than 800 mm a year in the south-east. The open water evaporation varies from 3.6 - 6.8 mm d^{-1}, leading to soil-water deficit for most of the growing season. The study area in Same District covered three villages located in the up-, mid- and down-stream of a single watershed extending to the Pangani River. This is located between latitudes 4^0 8$'$ and 4^0 25$'$ south, and longitudes 37^0 45$'$ and 37^0 54$'$ East. It lies along the Moshi – Dar-es-Salaam highway, about 140 km from Moshi town at an elevation between 600 m and 2500 m above mean sea level. The rainfall pattern is bimodal, with mean annual rainfall of approximately 400 – 600 mm. The short rains start in November and extend to January. The long rains start in March and extend to May and are more reliable. Evaporation varies between 3.0 - 5.4 mm d^{-1} with an annual long-term average of 1,575 mm y^{-1} (Barron *et al.* 2003).

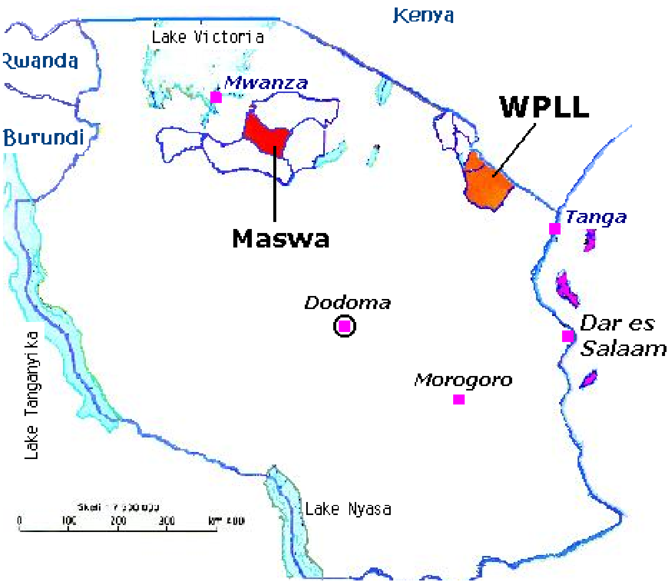

Figure 2: Map of Tanzania showing the location of the two study areas

The four types of rainwater harvesting described below were studied. The extent of adoption of these techniques in the study areas is shown in Figure 4.

In-situ rain capture systems normally defined as soil and water conservation (SWC) practices (Gowing *et al*., 1999). Capturing rainwater where it falls and storing it in the root zone is perhaps the most cost-effective means of increasing water availability for plants. For example, converting from plowing to sub-soiling and ripping in parts of semi-arid Tanzania led to doubling of yields in good years (Jonsson, 1996).

Micro-catchment systems improve the *in-situ* management with provisions for supplying extra water from adjacent catchments. These systems normally exploit the natural concentration of rainwater and nutrients flowing into the valley bottoms from the surrounding high grounds in the landscape. Using this approach, many farmers in semi-arid areas of Tanzania have changed from the cultivation of sorghum and millet, to paddy. This system is now widely used in nearly all the semi-arid areas of central Tanzania. The system accounts for over 70 % of the area cultivated with paddy and over 35% of the paddy produced in Tanzania (Meertens *et al.*). It has enabled farmers to grow a marketable crop in dry areas, providing opportunity for poverty reduction.

Macro-catchment systems are technically similar to the previous but are designed to provide more water for crop growth through the diversion of storm floods from gullies and ephemeral streams, into crop or pasture land. Large scale systems involve diversion of storm floods from steep slopes of vast areas. The requirement to construct strong diversion and conveyance structures makes these systems costly. However, in the study areas for this paper, farmers have managed to control huge volumes of water through large earth canals built over many years.

Small storage ponds have been adopted by few farmers to increase the effectiveness of rainwater harvesting systems, especially in the production of vegetables.

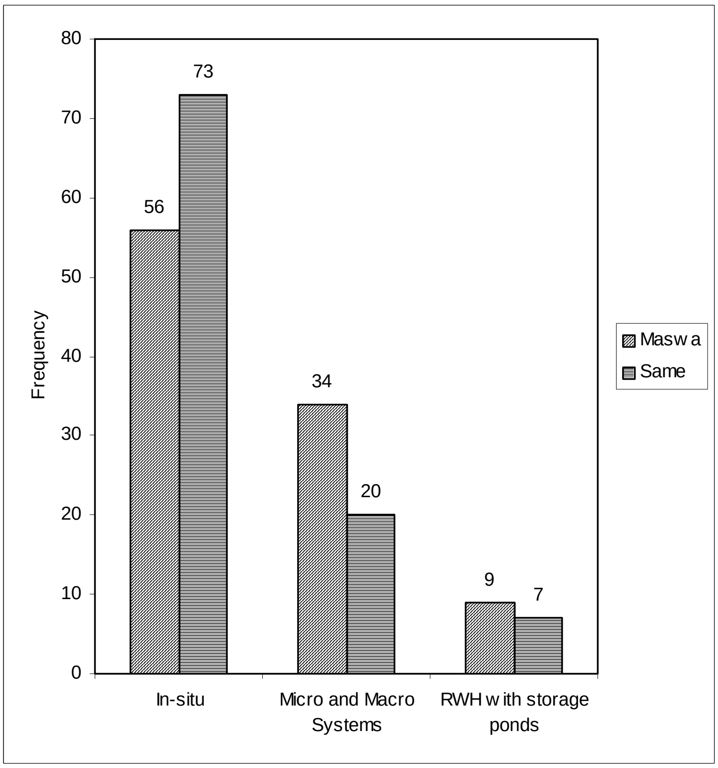

Figure 3: Extent of adoption of the different categories of RWH in the study areas

Data collection

Participatory poverty assessment (PPA) was undertaken to provide information on poverty definition and socio-economic categories that are perceived by the farmers. This sub-section describes the process and the major steps followed. Broad socio-economic groups were identified in each study area through workshops. Participants at these workshops were community development officers, divisional and ward leaders, village chairpersons and village opinion leaders. Each workshop was conducted in plenary and group discussion sessions. Then focus group meetings were held with the representatives from the different socio-economic groups at each village. The exercise led to participatory identification of three categories of poverty: better off, middle and poor and an estimated proportion of individuals falling under each. Data for assessing absolute poverty were obtained through a questionnaire survey of household annual expenditures. Past experience has shown that respondents provide more consistent information on expenditures. It formed part of the main survey as described below. The questionnaire survey involved interviewing samples of farming households proportionally selected to represent different locations along the topo-sequence, farming systems, and enterprises in the study watersheds. The sample sizes were 300 and 278 respondents for Maswa and Same watershed, respectively. The sample size was approximately 10% of the households in the respective sampled villages. Historical data was based on respondents' records and recall but was supplemented by actual measurements during the 2002/2003 season for purpose of evaluating the correctness of information from the respondents. Analysis of data was done using descriptive and qualitative analyses leading to means, ratios and frequencies data.

Results

Characteristics of Poverty

The results summarized in Figure 4 show that there is distinct difference in the poverty level of the two study areas. Nearly every body in Maswa spends less than one dollar per day, while in Same about half of population was found to be spending a dollar or more per day. There was no difference at all between male and female headed households with respect to the proportion who fell below the poverty line (Table 1). However, the lower quartile in Maswa is very poor with a mean per capita expenditure of only 0.09 US$ per day. The highest mean was for the upper quartile in Same District where the mean per capita expenditure was 1.79 US$ per day. There are two main reasons for the difference. First is the fact that households in Maswa tend to be very large in a remote district with only limited access to markets and consumer items, while the situation is reversed in Same District. Second is the good links to markets enjoyed in Same where the study area is connected by railway and highway to important commercial centres in East Africa, helps to raise incomes as well as expenditures. Yet even in Same District, only about a third of the population is above the poverty line.

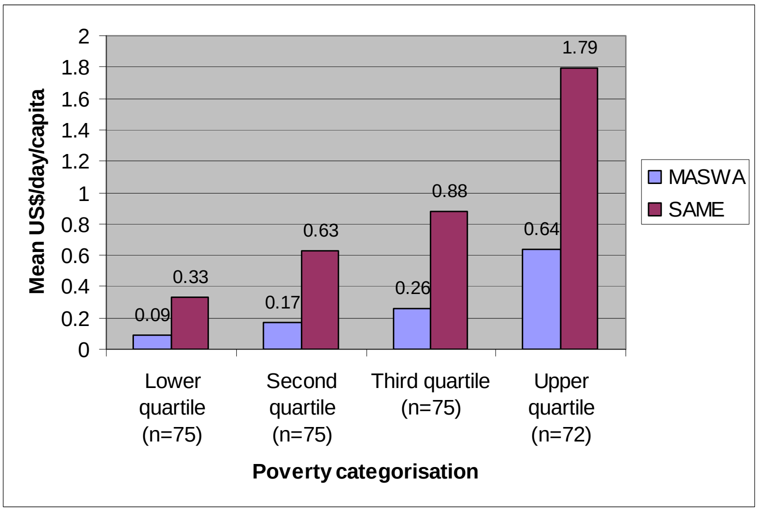

Figure 4: Poverty levels (US$ per capital) by poverty categorization

Table 1: Number of respondents who are above or below dollar poverty line by gender of head of household (HH)

		Proportion (%) above Poverty Line	Proportion (%) Below Poverty Line
Maswa	Male-headed HHs (N = 234)	2	98
	Female-headed HHs (N = 63)	2	98
Same	Male-headed HHs (N = 248)	32	68
	Female-headed HHs (N = 26)	31	69
Overall	Male-headed HHs (N = 482)	17	83
	Female-headed HHs (N = 89)	10	90

Economic Performance of Rainwater Harvesting

A comparison of the performance of the RWH for maize in Same District and RWH for paddy in Maswa District is summarized in Table 2 in terms of yields, gross margins and return to labor for the different levels of rainwater harvesting. The levels of water availability was divided into four main categories: (1) rainfed system where the farmer only captured and conserved the rainwater falling directly on the field without additional water from external sources; (2) poor RWH in which the farmers captures and conserve all direct rainfall (*in-situ RWH*) and also irregularly obtain some extra run-off from external (micro-catchment) sources with reliability of less than 25%; (3) medium RWH is where the reliability of obtaining runoff from external (micro and macro-catchment) sources is above 25% but less than 75%; and (4) the system was considered to have good RWH where the availability of runoff from external (macro-catchment) sources was above 75% - and where storage ponds are used.

Good rainwater harvesting for maize led to four fold increase in grain yields per hectare compared to rainfed systems. For paddy farming systems, good RWH led only to the doubling of yields above poor RWH. The benefits from RWH drop appreciably when assessed in terms of gross margins per hectare. Investment in good RWH led to only doubling of mean GMs in the maize farming system, and an increase by a factor of 1.6 for the paddy system. The situation is more serious with respect to return to labor in which the results show that it is not worthwhile to invest in good RWH systems for either of the two farming systems. The poor RWH for maize led to the highest benefits by doubling the returns to labor when compared to rainfed system.

These results show that even with good rainwater harvesting the yields per hectare are still too low at only 2 tons per hectare instead of 4 – 6 t/ha that are possible. This means that other factors of production especially fertility management has not been optimized. This situation is depicted in Figure 5 showing that less than half of the recommended nitrogen content is actually available in the crop fields under study. Therefore, improvement of RWH systems does not lead to corresponding increase in returns to labor. Apart from the low yields, the returns are depressed by the high labor requirement for constructing and maintaining earth structures necessary to ensure high reliability in the diversion of runoff into crop fields from external sources. Furthermore, the farm-gate prices are too low due to poor markets for cereals. The comparison of the performance of RWH for cereals and for vegetables given in Table 3 elaborates this point further.

Table 2: Performance of RWH in terms of yields, gross margins and return to labor
(a) Maize farming system in Same District

	Quality of RWH System				
	Rainfed	Poor RWH	Medium RWH	Good RWH	Mean
Yield (t/ha)	0.5	1.6	1.3	1.9	1.4
Gross Margins (US$/ha)	77.7	119.2	103.6	142.8	110.8
Return to Labor (US$/person day)	5.0	9.0	7.3	4.6	6.5

(b) Paddy farming system in Maswa District

	Quality of RWH System				
	Rainfed	Poor RWH	Medium RWH	Good RWH	Mean
Yield (t/ha)	N/A	1.2	1.4	2.1	1.6
Gross Margins (US$/ha)	N/A	182.0	195.0	294.0	224.0
Return to Labor (US$/person day)	N/A	4.5	5.9	5.2	5.2

Note: calculations of GMs excludes the cost of family labor

In Table 3 the performance of good RWH harvesting is compared across four different enterprises. It is evident that using rainwater harvesting for vegetable production is consistently very beneficial to the farmer with returns to labor exceeding US$ 10 per person day and in some years reaching nearly US$ 200 per person day. On the other hand, returns to labor for both maize and paddy rarely exceed US$ 10 per person day. This adds another dimension of enterprise choice to go with rainwater harvesting. However, the returns obtained from vegetable enterprises may be high because only a small percentage of the farmers are engaged in these enterprises and therefore markets and prices are not a big problem. Expansion of these enterprises without adequate expansion of markets and the marketing systems will most likely lead to sharp reduction in the returns. Furthermore, food self sufficiency at the household level is the priority objective of nearly all farmers. This coupled with lack of any alternative beneficial use for the labor, forces farmers to invest this labor towards household food sufficiency.

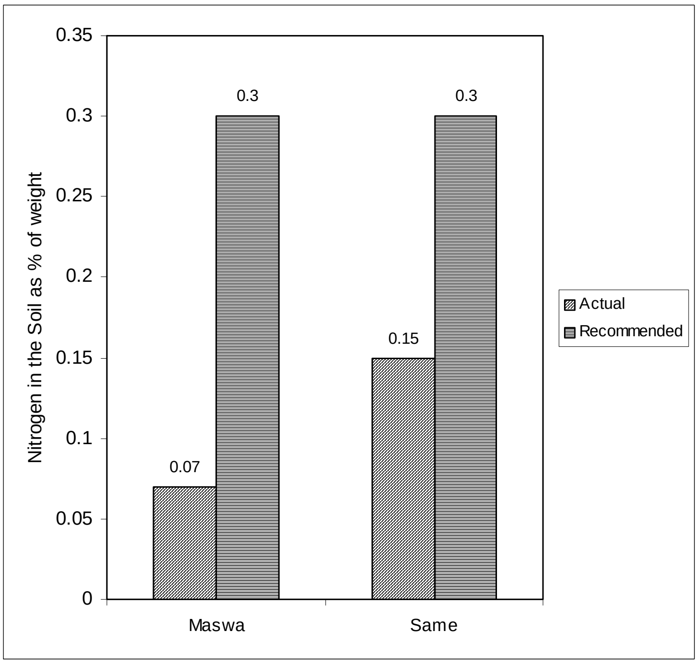

Figure 5: An example of the low fertility status in the study areas

Table 3: Comparison of the performance of good RWH for maize, paddy and vegetable enterprises over a period of 5 years

		2002	2001	2000	1999	1998	Mean
Gross Margins (US$/ha)	Maize	168	129	116	184	117	143
	Paddy	264	474	291	309	132	294
	Tomatoes	3,272	1,277	3,393	1,057	1,427	2,085
	Onions	2,278	2,248	2,213	2,692	1,803	2,247
Return to Labor (US$/person day)	Maize	2.9	1.7	14.4	3.0	1.0	4.6
	Paddy	5.7	6.8	5.3	5.4	2.7	5.2
	Tomatoes	16.0	10.0	12.0	14.0	13.0	13.0
	Onions	205.0	88.0	21.0	30.0	92.0	87.0

Conclusion

Farmers in the semi-arid areas of eastern Africa are already adapting and investing in RWH but efforts of most do not lead to adequate returns to labor for effective reduction of poverty. The main reason for this outcome is that most farmers have invested heavily in terms of labor to establish and maintain earth structures for the capture of rain runoff without adequate and corresponding investment in nutrient management, leading to low yields for the cereal enterprises. When this is coupled with low farm-gate prices the returns to labor are not attractive. The high performance observed with vegetable enterprises indicates that investments in rainwater harvesting make economic sense if coupled with the production of high value crops. However, it must be noted there is a limit to which the high value crop enterprises can be expanded without corresponding marketing development.

Linking the crop and livestock producers working in the semi-arid areas with markets and marketing systems to obtain high returns on their investments in RWH would be the most urgent action required to promote wider adoption of RWH for improved incomes and food security. This can be achieved by assisting smallholder farmers to change from subsistent to commercial objectives. This change requires a shift in focus from cereals production for self-sufficiency to marketing-oriented production of crops combined with processing into value-added products. This requires farmers to participate in food markets and thus increasingly depend on the market for food security as opposed to emphasizing self-sufficiency at household level.

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