Economics of Rainwater Harvesting for Crop Enterprises in Semi-Arid Areas: The Case of Makanya Watershed in Pangani River Basin, Tanzania

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Abstract

Contrary to irrigated agriculture that use blue water, rainwater harvesting that use green water in forms of the direct rain and runoff, has been accorded little importance in terms of economic research, investment, technology transfer and management. This bias happens whereas 60-70 per cent of food production is rainfed and based on green water. The perception by majority of our water planners has been that, water harvesting in the upper watersheds would reduce blue water flows downstream. Improved management of rainwater in the upper watersheds for agriculture, livestock and domestic use would reduce pressure on the blue water downstream. However, the promotion of rainwater harvesting in the upper watersheds requires an ex-ante *analysis related aspects of economic benefits, eco-hydrology and human dynamics. This paper demonstrates the economic benefits of rainwater management for crop production in a semi-arid Makanya Watershed in the Pangani river basin. The results from a two-seasons yield monitoring done between 2002 to 2004 for maize and lablab show that, rainwater harvesting has the potential for poverty reduction through improved yields, returns to land and labour. These findings justify investment and technology transfer in rainwater harvesting for crop production in the upper watersheds of our major river basins.*

Keywords: Rainwater harvesting, Semi-arid Makanya watershed, Pangani River Basin, Economic benefits, Poverty reduction

Introduction

Background information

The Accra Declaration of Africa's Regional Stakeholders' Conference for Priority Setting (2002) states "water can make an immense difference to Africa's development if it is managed well and wisely (Van Koppen, 2002). Given clear policies and strategies and real commitments to its implementation, sustainable water utilization can help eradicate poverty by revamping the performance agriculture, industry, fishery, and energy sectors at the same time maintaining ecosystem integrity. An estimated 38% of the population in SSA (roughly 260 million people live in drought prone drylands (Rockstrom, 2000). And, nearly 40% of the area of Eastern and Southern Africa (ESA) are semiarid lands that experience inadequate and extreme fluctuations in the availability of water for different uses including agriculture (Hatibu, *et al.*, 2004). Nearly two thirds of Tanzania with a total of 939,701 km2 can be described as semiarid on the basis of having a probability of less than 25% of receiving 750 mm of rainfall per year (Bourn and Blench, 1999; Mascarenhas; 1995). The onset and duration of rainfall in semiarid areas are inherently stochastic, and the probability of occurrence of acute dry spell during a growing period is high (Anschutz *et al.*, 1997; Mahoo et al., 1999; Hatibu, 2000; Gowing *et al.*, 2000; Kisanga, 2002).

In semi-arid areas of SSA where water is the most critical constraint to development, critical manifestations of poverty such as food and income insecurity are apparent. In view of this, the battle against poverty would be won or lost in these areas. To feed almost 2 billion more people in the next 25 years some say that most of the increase will have to come from irrigated agriculture involving withdrawal of blue water from rivers and lakes. Others, however, see irrigation expansion as a more limited option, since a certain amount of water must remain in rivers to protect aquatic ecosystems. This leaves us with the fundamental question as to what degree rainfed agriculture especially in the tropics could be made much more productive (Falkenmark and Rockstrom, 2004). Therefore, upgrading the predominant rainfed dryland agriculture through better management of rainwater resources (direct rain and the runoff) is a fundamental step in poverty reduction. However, efforts to utilize the green water resources in forms of rain where it falls and the generated runoff are inadequate. Some attempts by smallholder farmers in rainwater management for agriculture is sternly constrained by lack of efficient technologies and capital, and there is little or no support from the government and other development agencies. As a result, most of the rainfall is still lost as surface evaporation and runs as flash floods into swamps, rivers, lakes and saline sinks before it is used for agricultural production (Hatibu *et al.*, 1997, Van Koppen, 2002). The rainfall lost by surface runoff in semi-arid tropics is estimated at 69% (Christianson *et al.*, 1991).

In the tropics, rainwater management can bring to use a large part of the falling rain which is lost through surface evaporation (30-50% of falling rain) before it is either taken-up by the plants, recharging the groundwater or flowing to the rivers and lakes, and ultimately to the sea (Falkenmark and Rockstrom, 2004). Furthermore, rainwater management can productively utilize the runoff (10-20% of falling rain) lost as flash floods, which are currently left to cause the land erosion, displacement and demolition of infrastructure in the downstream. Moreover, rainwater harvesting for wildlife and improvement of the pasture in the rangelands is a feasible option. However, the promotion of rainwater harvesting in the riparian watersheds requires an *ex-ante* analysis of the economics, climate, hydrogeology, terrestrial and aquatic ecosystems, environmental flows and dynamics of humans. Among such prerequisites, this paper is a modest attempt to demonstrate the economics of rainwater management for crop production in a semi-arid watershed of Makanya River in the Pangani River Basin.

Methodology

The study area

The research was conducted in the Makanya river watershed (MRW). The Makanya River is an ephemeral stream which drains in the major Pangani river basin. MRW is located in the Western Pare Lowlands (WPLL) of the Same district. The WPLL is in North East Tanzania (Fig. 1).

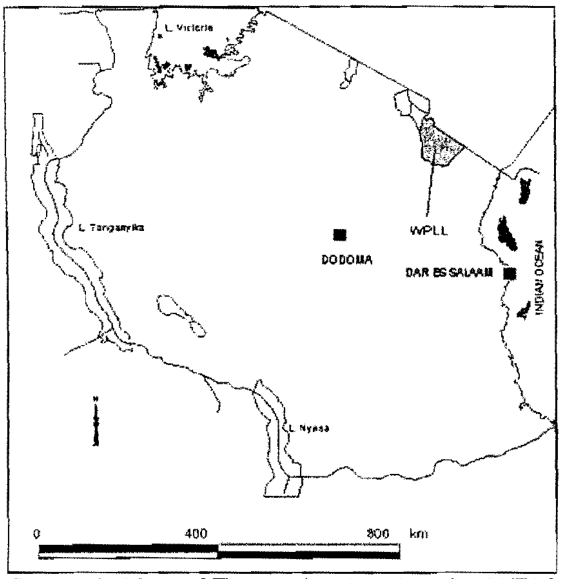


Figure 1: Map of Tanzania showing the WPLL

The Makanya river watershed extends from a sub-humid dryland climate in the Pare mountains (constituting the famous Eastern Arc Mountains) to the semi-arid western lowland in the leeward. The Makanya village where yield monitoring was under taken is part of the semi-arid western lowland referred to in this paper as the Western Pare Lowland (WPLL). The Pare Mountains are located to the South East of Mt. Kilimanjaro, between 600 and 2,424 m above mean sea level and receives about 1,000 mm of rainfall. The western side of the mountains constitutes the leeward side and thus receives low amount of rainfall. The extensive catchments of the steeply sloping mountains yield runoff that flows into the adjacent lowlands before joining the Pangani River. In the WPLL, annual rainfall is in the range of 500 to 800 mm with bimodal pattern, with about 200 mm in the short rainy season from November – January (locally called 'vuli') and 400 mm in the long rainy season from March – May (locally called 'masika'). Potential evapo-transpiration is over 2,000 mm per year. On top of being erratic, such seasonal rainfall is not adequate to provide the water requirement for drought resistant crop such as sorghum, however runoff farming has enabled small farmers in the WPLL to grow crops with high water requirements such as maize and legumes.

Yield monitoring exercise was carried out in the Mkanya village traditional rainwater harvesting scheme in the Makanya river watershed. The scheme is traditional in a sense that it has existed for decades where farmers are used to divert the runoff generated several kilometers in the Pare Mountains. After diverting the runoff from the main gully into distribution canals further water management practices are done within individual fields (*insitu*). Such a rainwater harvesting system involving a macro-catchment enables farmers to it utilize the runoff generated very far from the cropped area even if no rain has fallen in the farm vicinity. However, the major challenge associated with macro-catchment system is the need of a watershed/catchment-focused management approach of the runoff that becomes a common pool resource utilized beyond micro-political territories such as village or wards. The yield monitoring exercise done for two growing seasons (2002/03 and 2003/04) involved thirty farmers with maize and lablab fields located differently relative to the runoff source. The participatory mapping done by SWRG (2003) classified three biophysical classes of land based on the relative location from the runoff source. Such cropland suitability classes being high, medium and low (Figure 2) referred to as head, middle and tail in this paper.

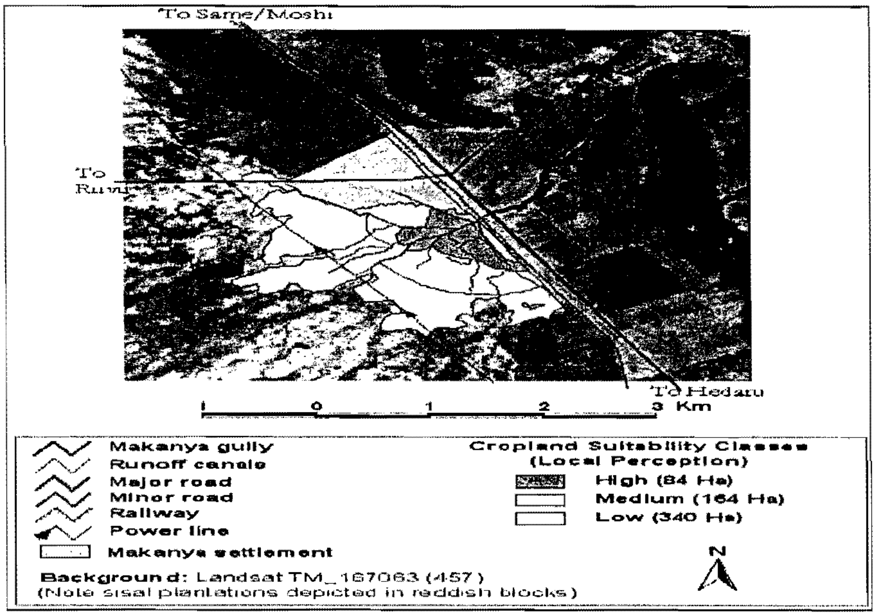


Figure 2: Map of showing the Makanya river watershed cropland classes

Data collection

A sample of 30 farmers in the Makanya traditional rainwater harvesting scheme was randomly drawn from the village household roaster. Selection of fields was randomly done in the beginning of every production season. The fields that a pilot farmer is determined to cultivate were listed and assigned numbers from which only one field was then chosen. The areas of the chosen fields in different locations in the scheme were measured using GPS. Field monitoring involved recording the frequencies of receiving runoff in each field. Yield measurements were taken by a research associate with assistance from a local field attendant and in the presence of respective pilot farmers. At the end of every week, the research associate visited all the pilot farmers to record the costs and labour input for that particular week. The maize lablab enterprises included sole maize, sole lablab and intercropping of the two.

Three plots of 30 square meters in each field of maize and lablab beans were harvested and the yields were then sun-dried in order to attain moisture levels similar to those obtained by farmers. Production costs and labour inputs for the selected fields and sun-dried weight from the small plots were extrapolated and reported as tons per hectare. Performance of crop enterprises was assessed based on the scenarios of above average (a-average) and below average (b-average) seasons. The variability of rainfall is high in semi-arid areas and the mean season is seldom a reality. The b-average seasons are those dominated by the negative characteristics such as rainfall amount that is below the long-term mean and highly variable, while a-average season is the one with an amount of rainfall that is above long term mean and also more evenly distributed. The minimum and maximum producer prices used to compute the revenues were acquired by asking key informants in the village.

Data analysis

Parameters used to express the performance of crop enterprises under rainwater harvesting included yield (tons per hectare), returns to land (gross margin per hectare) and returns to labour (gross margin per personday). In order to compute revenues, dry weights were multiplied by an average market unit price for a particular year (mean of prices immediate after harvest and that at the end of the season). Gross margins (returns) were computed by subtracting the recurrent costs from the gross revenue. The gross margins were divided by the number of persondays of the family labour employed in the production process. One personday is equivalent to one person working for 8 hours in a day. The monetary unit used in this report is the US $ at an exchange rate of TAS 1000 to US $ 1.

Results and discussion

The performance of crop enterprises were analyzed based on locational difference and frequency of access to runoff during a particular growing season. For the two years of yield monitoring exercise, only the short rainy season 'vuli' of 2004 was rated a-average. During this season (of 'vuli' 2004), the lowland benefited from excessive runoff that was managed traditionally to enable bumper harvests of maize. Because during the short rainy season of 2004 (*vuli*) the runoff was not a limiting factor production in all pilot fields, crop performance was evaluated based on land suitability classes (location on the runoff gully). The performance of crop enterprise for other seasons (all b-average) apart from '*vuli*' 2004, were evaluated based on how frequent a particular field received the runoff.

Performance of maize at different locations on the runoff gully

The performance of maize enterprise with regard to biophysical location on the runoff gully was assessed only for the short rainy season of 2004 (rated a-average). During this season, the lowland received adequate runoff as a result of two to three consecutive rainfall storms in the highlands. Such single flooding was able to pass the crop to harvest without any other extra event of rainfall. Therefore, locational difference becomes a critical source of variation regarding the performance of crop enterprises rather than frequency of runoff access in respective fields. Through participatory GIS mapping, cropland served by the runoff gully has been delineated into high (head), medium and low (tail) suitability classes. Locational advantage of access and easiness of diverting the runoff from the gully into crop fields diminishes as from the head toward the tail in the scheme.

Yield of maize with location (tons per hectare)

Figure 3 shows that, the yield of maize enterprise during the short rainy season of 2004 (a-average) decreased gradually from head, middle to the crop fields on the tail of the main runoff gully. However, the levels of yield for the three regions do not vary appreciably. While farmers believed that, land at the tail is a waste and very unproductive, the findings from this study show that, physical productivity of the land at the tail of the scheme was a question of water rather than any other thing else. This is because the yield of 2.6 tons/ha does not vary appreciably from 3 tons/ha between with plots in the head and middle locations. Moreover, because soil moisture was not a limitation throughout the scheme, it seems the basis used to classify the land suitability envisages other factors in addition to runoff access. Such factors could be soil fertility and within field runoff management infrastructures such as micro-channels and runoff control ditches that are well developed at the head of the scheme. However, the results suggest that, with improvement in water management and equitable water allocation much of the land can be put into productive use irrespective of biophysical position.

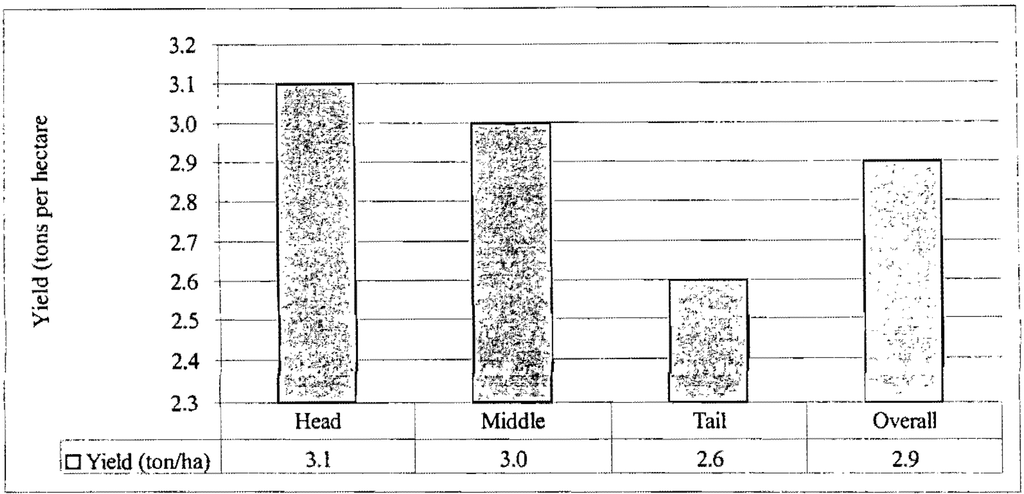


Figure 3: Yield ton/ha for maize along the runoff gully (Vuli 2004: a-average)

Returns to land from of maize with location (tons per hectare)

After taking into account prices and costs of production, the yields of maize realized during the short rainy season 'vuli' of 2004 were expressed into financial returns to land with respect to biophysical location. This reveals the relative special advantage or disadvantage in relation to poverty impact of traditional rainwater management. Figure 4 shows that, during short rainy season 'vuli' of 2004 (a-average), farmers with maize plots at the head, middle and tail of the main runoff gully realised returns to land amounting to US $ 762.4, 737.9 and 656.3 per hectare respectively. Such returns to land do not vary much from each other because during a-average season the runoff is able to reach the end plots. With respect to the income poverty impact of traditional rainwater management, the overall average turnover of US $ 718.9 per hectare realized within three months of the 'vuli' season is substantial in the context of rural economy.

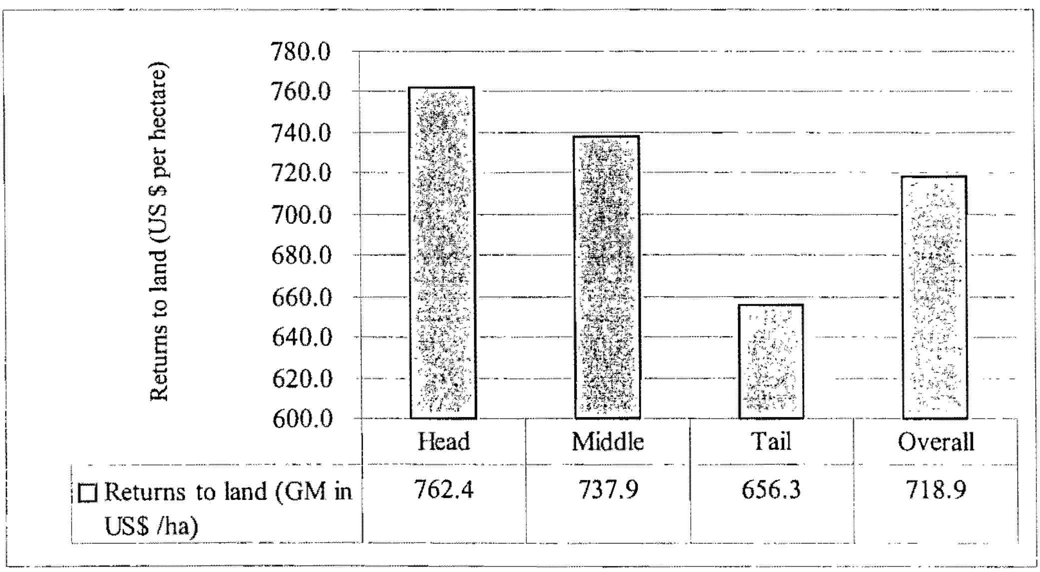


Figure 4: Returns to land from maize along the runoff gully (Vuli 2004: a-average)

Returns to labour from of maize with location (tons per hectare)

Return to labour reflects the level of reward for each personday of the household workforce engaged in the production process. In income poverty analysis, return to labour indicates the magnitude of daily income that can be gauged on absolute poverty thresholds to reflect the depth of poverty. During the short rainy season 'vuli' of 2004 (a-average), farmers with maize plots located on the head, middle and tail of the main runoff gully realized US $ 20.7, 19.7 and 18.0 for each personday of the household workforce involved in the producing maize. The overall mean return to labour realized by maize producers in the scheme irrespective of biophysical location was US $ 19.5 per personday. Such daily earnings in return to family labour input reflect the daily impact of runoff farming in poverty reduction.

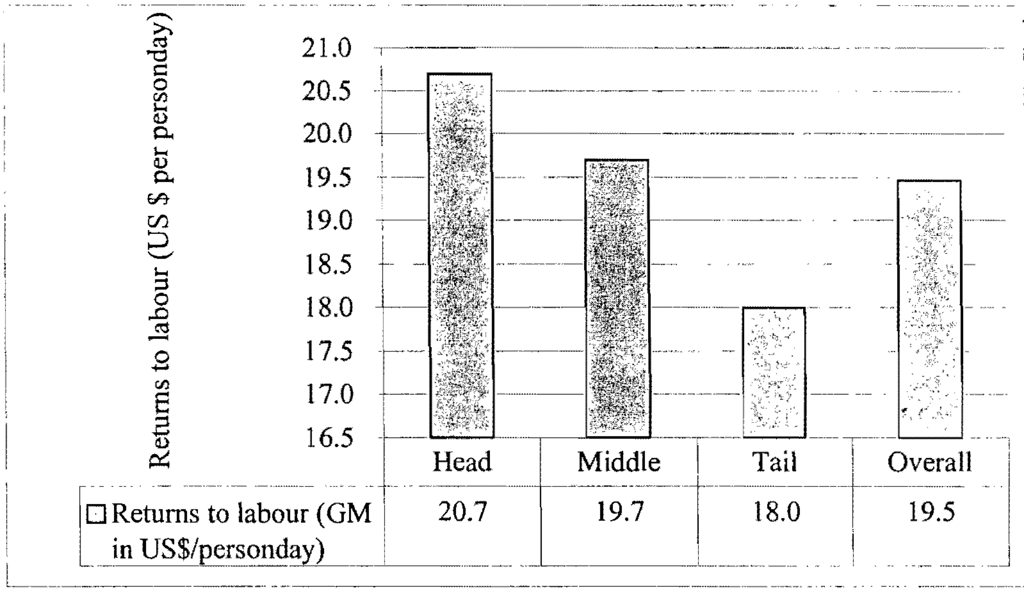
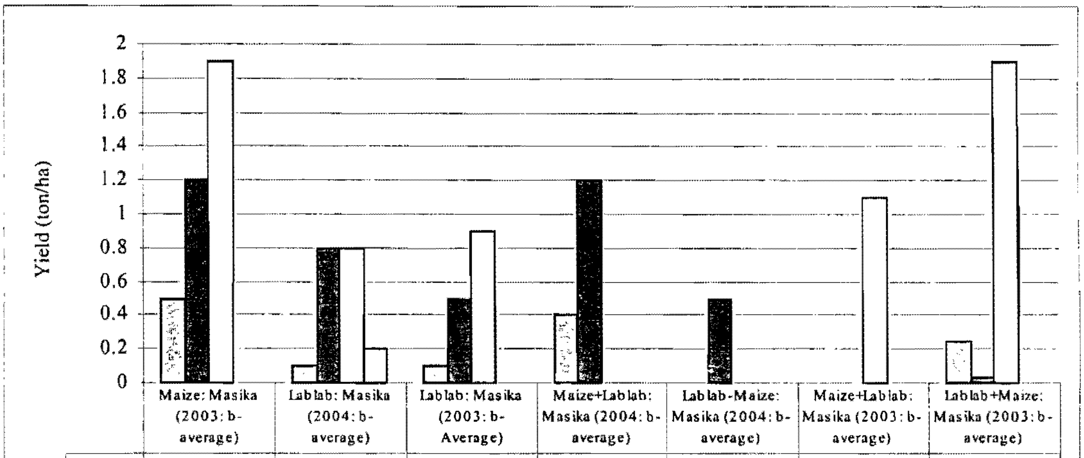


Figure 5: Returns to land from maize along the runoff gully (Vuli 2004: a-average)

Yield levels at different frequencies of runoff receptions

Production per unit land of farms that received no runoff was the worst in all the enterprises (Figure 6). Yield of sole maize, maize intercropped with lablab and sole lablab increased remarkably with inputs of one to two runoff events. Generally, rainfed system (no runoff reception) performed poorly in terms of production per unit land. Apparently, sole lablab realized very poor yield when the frequency of spate irrigation exceeded two times, i.e. with three receptions of runoff. During the 2004 long rainy season (*masika*), which was a b-average, rainfed, one and two runoff receptions realized 0.1, 0.8 and 0.8 tons of lablab per hectare respectively. Moreover, during 2004 long rainy season, the farmers who allowed the runoff to enter their fields more than twice realized the lowest yield of sole lablab beans (0.2 tons/ha). This is because lablab is sensitive to water logging which reduces yield tremendously. It is shown that, undertaking spate irrigation twice during b-average season resulted into relatively high production of both sole maize and maize intercropped with lablab beans. Moreover, lack of runoff during long rainy seasons of 2003 and 2004 had more adverse effect on the yields of intercropped maize and lablab than when the two crops were planted as separate stands. Also, one runoff event during the long rainy season of 2003 (b-average) resulted into zero yield and 0.03 tons per hectare for intercropped maize and lablab respectively.

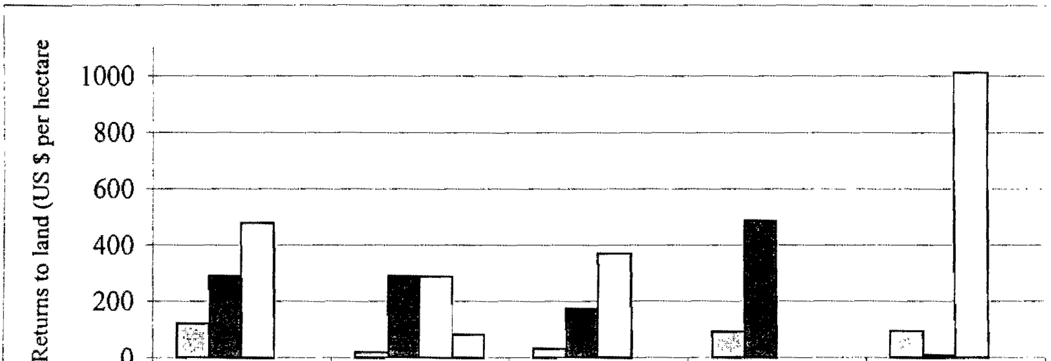


	Maize: Masika (2003: b-average)	Lablab: Masika (2004: b-average)	Lablab: Masika (2003: b-Average)	Maize+Lablab: Masika (2004: b-average)	Lablab-Maize: Masika (2004: b-average)	Maize+Lablab: Masika (2003: b-average)	Lablab+Maize: Masika (2003: b-average)
0: freq.	0.5	0.1	0.1	0.4	0.0	0.0	0.3
1: freq.	1.2	0.8	0.5	1.2	0.5	0.0	0.03
2: freq.	1.9	0.8	0.9			1.1	1.9
3: freq.		0.2					

Figure 6: Yield (ton/ha) of crop enterprises with frequencies of runoff access

Returns to land at different frequencies of runoff receptions

Returns to land from sole maize during 'masika' season of 2003 (which was b-average) were, US $ per hectare 122.5, 289.8 and 476.7 for rainfed (no runoff), one runoff event added, and two runoff events added respectively. Despite of seemingly low yields per unit land and poor seasonality, the two runoff events added in maize intercropped with lablab realized impressive returns to land of US $ per hectare amounting to 1,011.9 (Figure 7). Even with a single event of runoff, returns to land from intercropping maize and lablab beans during the short rainy season of 2004 (b-average) was as much as US $ 487.5 per hectare. However, due to very low yields of intercropped maize and lablab beans realized during the long rainy season of 2003, respective returns to land are also very low. Generally, high returns from intercropping maize and lablab beans would be the attribute of improved marketing of maize grain and lablab beans that fetch remunerative producer prices. The marketing efficiency is improved by being very close to the big marketing center such as Dar es salaam, Arusha and Nairobi which are linked by the Dar es salaam-Arusha -Nairobi highway. Maize is also the major staple food in the WPLL and neighboring areas of Northern Tanzania, which are inherently food-deficit. Due to high domestic and export demands, producer prices of maize and lablab are expected to improve during b-average seasons where the produce from other supply areas is in short supply. Lablab is a high value crop grown purposely for commercial export to Kenya fetching as high farm-gate price of US $ 400 per ton. Therefore, improving the yield of maize - lablab beans intercrop through better management of rainwater and agronomy would tremendously boost small farmers' incomes.

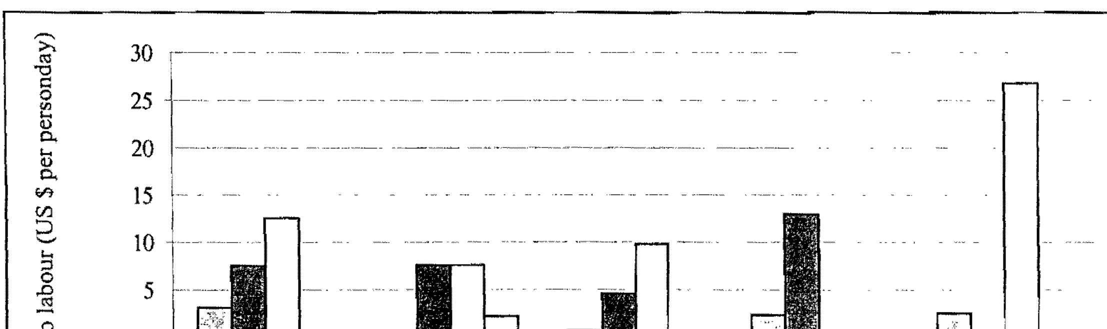


	Maize: Masika (2003: b-average)	Lablab: Masika (2004: b-average)	Lablab: Masika (2003: b-average)	Maize+lablab: Masika (2004: b-average)	Maize+Lablab: Masika (2003: b-average)
□0: freq.	122.5	20.3	34.2	90.6	95.8
■1: freq.	289.8	288.8	172.6	487.5	9.4
□2: freq.	476.7	287.5	369.5		1,011.9
□3: freq.		82.0			

Figure 7: Returns to land from crop enterprises under RWH

Returns to labour at different frequencies of runoff receptions

Returns to labour is a good indicator of income poverty reduction as a result of the employment created through farming. With exceptions of sole lablab enterprise during long rainy seasons of 2003 and 2004 under rainfed condition (no runoff event), and intercropped maize and lablab with a single runoff event, each personday of the household workforce engaged in producing maize and lablab beans was rewarded with more than one US dollar. Such levels of daily earnings are above the global poverty line of one US dollar per person per day. As in case of returns to land, during long rainy season of 2003, intercropped maize and lablab beans realized a much higher return to labor (US $ 26.9 per personday) compared to other crop enterprises.



	Maize: Masika (2003: b-average)	Lablab: Masika (2004: b-average)	Lablab: Masika (2003: b-Average)	Maize+lablab: Masika (2004: b-average)	Maize+Lablab: Masika (2003: b-Average)
□0: freq.	3.3	0.5	0.9	2.4	2.6
■1: freq.	7.7	7.7	4.6	13.0	0.3
□2: freq.	12.7	7.6	9.9		26.9
□3: freq.		2.2			

Figure 9: Returns to labor from crop enterprises under RWH

Conclusions

We can make four main conclusions from the results obtained from the yield monitoring exercise:

- Rainwater harvesting for crop production has a great potential of poverty reduction given impressive returns to land and labour even during b-average seasons. However, physical yields of maize and lablab beans are still low, although the crops realized higher prices due to good markets. This implies that, interventions to improve productivity of rainwater (more crop out put per drop) would result in tremendous economic benefits. This remains to be an avenue of interventions for a robust and sustainable market-focused watershed development (MFWD). The MFWD emphasizes on achieving the food and income security of farmers while maintaining the integrity of the eco-hydrology and other natural systems in the watershed.
- Lablab grown during *masika* is the high value crop that can be grown as sole stand or intercropped with maize. Despite of relatively low yields, intercropping of maize and lablab beans under rainwater harvesting revealed much higher returns to land and labor compared to sole crops. This implies that, efforts that can increase physical yields of intercropped maize and lablab beans would result into tremendous financial earnings. Such efforts could be in empirical knowledge of which best agronomical practices could optimize physical yields for the intercrop.
- On top of economic justification, the promotion of rainwater harvesting projects in the riparian watersheds of the major basins requires an *ex-ante* analysis of, among other aspects, the eco-hydrogeology and human dynamics. This paper has demonstrated the economic potential of rainwater management for crop production in a semi-arid riparian watershed in the Pangani Basin. However, the major challenge is still on how to balance the use of water for improving human livelihood while maintaining the nature functional.

Acknowledgement

This paper is an output from a project funded by the UK Department for International Development (DFID) for the benefits of developing countries. The views expressed are not necessarily those of DFID

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