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 uses blue water, rainwater harvesting that uses green water as direct rain (in-field management) and runoff (spate irrigation) has been accorded little importance in terms of economic research, investment, technology transfer and management. 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 two seasons (2003 to 2004) of yield monitoring for maize and lablab show that rainwater harvesting for crop production has the potential for poverty reduction. During the short rainy season of 2004, which was good (above average) in terms of runoff access, maize enterprise under macro-catchment rainwater harvesting realized yield, returns to land and labour amounting to 2.9 ton/ha, US $718/ha and US $19.5/person-day respectively. For the long rainy season of 2003, which was bad (below average), the performance of maize in terms of yield, returns to land and labour improved appreciably with increasing frequency of runoff reception for spate irrigation. Performance of maize and maize-lablab intercrop improved with increasing frequency of runoff access. Respective returns to land and labour under rain-fed (no runoff) were only US $122.5/ha and US $3.3/person-day compared to US $1,011.9/ha and US $26.9/person-day with three incidences of runoff reception. Seasonal returns to land and labour exceed the national annual per caput income of US $280 and the global poverty line of US $1/person/day. These findings justify investment and technology transfer in rainwater harvesting for crop production in the upper watersheds of our major river basins.

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

Introduction

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 commitment to its implementation, sustainable water utilization can help eradicate poverty by revamping the performance of agriculture, industry, fishery, and energy sectors at the same time as maintaining ecosystem integrity. An estimated 38% of the population of sub-Saharan Africa (SSA) (roughly 260 million people) live in drought-prone drylands (Rockstrom, 2000). About 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 different uses, including agriculture (Hatibu *et al*., 2004).

Nearly two thirds of Tanzania with a total area of 939,701 km^2 can be described as semi-arid on the basis of having a less than 25% probability of receiving 750 mm of rainfall per year (Mascarenhas; 1995; Bourn and Blench, 1999). The onset and duration of rainfall in semi-arid areas are inherently stochastic, and the probability of the occurrence of acute dry spells during a growing period is high (Anschutz *et al*., 1997; Mahoo *et al*., 1999; Hatibu, 2000; Gowing *et al*., 2000; Kisanga, 2002).

Globally, dryland or rain-fed agriculture produces 80% of total farm production and irrigated agriculture 20%, but in SSA, dryland agriculture makes up more than 95% of farm output (Kauffman *et al*., 2003). 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 of to what degree rain-fed agriculture, especially in the tropics, could be made much more productive (Falkenmark and Rockstrom, 2004). The bottom line is that dryland agriculture will have to feed most people in SSA for the foreseeable future, and there is much room for improvement in rainwater use. However, efforts to utilize green water resources, specifically rainfall and the generated runoff, are inadequate. Some attempts by smallholder farmers in rainwater management for agriculture are strictly constrained by lack of efficient technology and capital as a result of inadequate support from the government and other development agencies. Consequently, 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).

There is no easy answer to the question of whether the focus of agricultural development in SSA should be on irrigated (blue water based) or dryland (green water based) agriculture. Ironically, the focus should be on both. However, the history of irrigation in most countries within SSA over the past decades has not been good, and most of the existing schemes have performed below their potential (Kauffman *et al*., 2003). Rainwater management can productively utilize the direct rain and the runoff, which are currently underutilized and left to cause land erosion, displacement and demolition of infrastructure in the downstream. 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. Contrary to green water management, and rainwater harvesting in particular, significant research is documented on the economics of water productivity and livelihood in the blue water management context, especially by the International Water Management Institute (IWMI) (http://www.iwmi.org). In Eastern Africa, research on the economics of rainwater harvesting is a relatively recent initiative, a few of these include those reported by Lazaro *et al*. (2000), Kunze (2000), Fox *et al*. (2000), Senkondo *et al*. (2004), and Hatibu *et al*. (2004). This paper is a modest contribution to the limited knowledge of the economics of rainwater management for crop production in a semi-arid watershed of 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 into the major Pangani river basin. The MRW is located in the Western Pare Lowlands (WPLL) of Same district. The WPLL is in North Eastern Tanzania (Fig. 1).

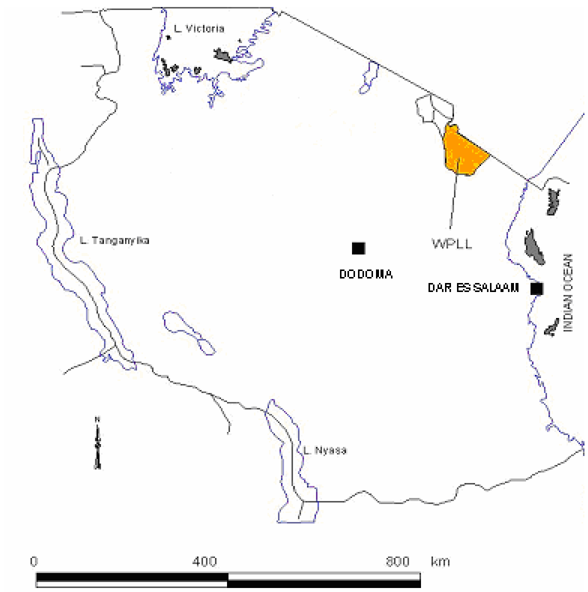

Figure 1. Map of Tanzania showing the WPLL

In the WPLL, annual rainfall is in the range of 500 to 800 mm with a bimodal pattern. Of the total rainfall, about 200 mm are received 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. Apart from being erratic, such seasonal rainfall is not adequate even for drought-resistant crops 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.

A yield-monitoring exercise was carried out in the Makanya village traditional rainwater harvesting scheme in the MRW. The scheme is traditional in the sense that it has existed for decades, where farmers have diverted the runoff generated several kilometers away in the Pare Mountains. After diverting the runoff from the main gully into distribution canals, further water management practices are done in individual fields. Such a rainwater harvesting system involving a macro-catchment enables farmers to utilize the runoff generated very far from the cropped area even if no rain has fallen in the farms' vicinity. However, the major challenge associated with a macro-catchment system is the need for a watershed-focused management approach to the runoff that becomes a common pool resource utilized beyond micro-political territories such as villages 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 at different places relative to the runoff source. The participatory mapping done by Soil and Water Management Research Group - SWMRG (2003) classified three biophysical classes of land based on their location relative to the runoff source. Such cropland suitability classes are high, medium and low (Figure 2), referred to as head, middle and tail in this paper.

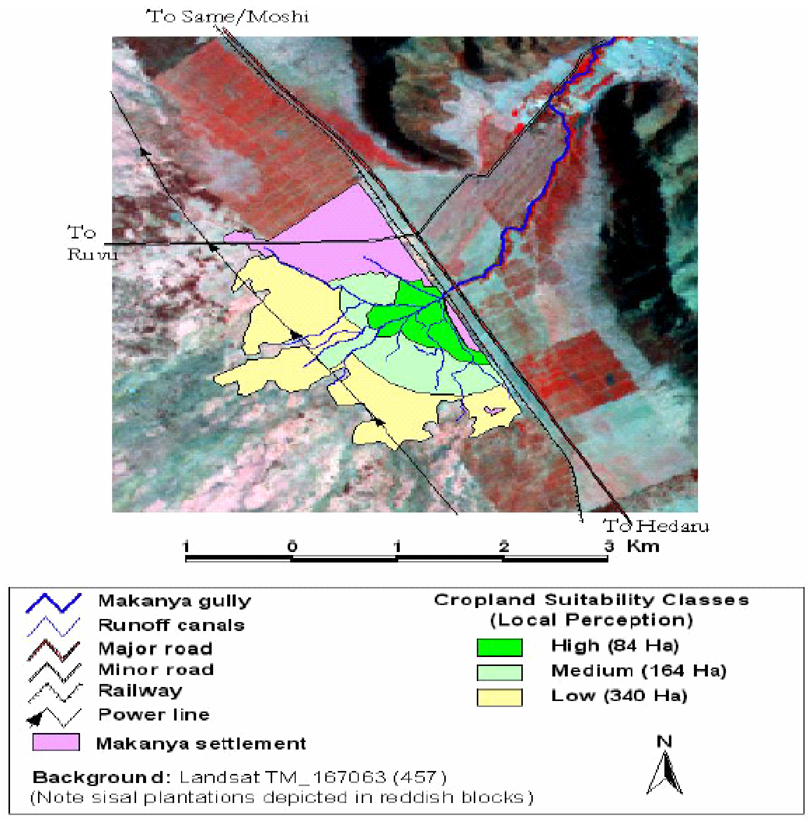

Figure 2. Map showing the Makanya river watershed cropland classes

Data collection

A sample of 30 farmers in the Makanya traditional rainwater harvesting scheme was randomly drawn from the village household register. Selection of fields was randomly done at the beginning of every production season. The fields that a pilot farmer 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 a global positioning system (GPS). Field monitoring involved recording the frequency of receiving runoff in each field. Yield measurements were taken by a research team in the presence of pilot farmers. Three plots of 30 m^2 in each field of maize and lablab were harvested. At the end of every week, the research associate visited all the pilot farmers to record their costs and labour input for that particular week. Every incidence of runoff event, if any, in each of the pilot fields was recorded immediately following an incidence of a rainfall storm in the upper catchment. The maize/lablab enterprises included sole maize, sole lablab and intercropping of the two.

Production costs and labour inputs for the selected fields and crop yields 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 b-average seasons are those dominated by negative characteristics, such as rainfall amount below the long-term mean and highly variable, while a-average seasons are those with rainfall amount above the long-term mean and also more evenly distributed. The minimum and maximum producer prices used to compute the revenues were acquired based on information provided by respondents 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 person-day). In order to compute revenues, crop yields were multiplied by an average market price for a particular year (mean of prices immediately after harvest and at the end of the season). Gross margins (returns) were computed by subtracting the recurrent costs from the gross revenue. Returns to labour were expressed as the gross margins divided by the number of person-days of the family labour employed in the production process. One person-day 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 1,000 to US $1. Location of relative runoff source and frequency of runoff access were used as references for depicting the effects of location and extent of runoff access on the performance of RWH-based crop enterprises.

Results and Discussion

Assessment of rainfall in the runoff-producing catchment

The lowland part of the watershed where the yield monitoring study was undertaken is on the leeward side and hence receives very low rainfall compared to the sub-humid highlands in the upper part of the watershed. For the two years of the yield-monitoring exercise, only the short rainy season '*vuli*' of 2004 was rated by farmers as above average (a-average). In agreement with farmers' perception, during the months of October 2003 to February 2004, which coincide with the 2004 '*vuli*', the representative meteorological station in the upper catchment (Suji Mission) recorded cumulative seasonal rainfall of 580 mm (Figure 3). This amount of rainfall was almost twice the long-term seasonal mean rainfall experienced in the lowland during short rains. Farmers rated the long rainy seasons of 2004 and 2003 as below average, in agreement with seasonal rainfall recorded in the runoff-yielding catchment of 353.5 and 136.6 mm respectively. The recorded seasonal rainfall in the upper catchments that yield the runoff used in the lowland was lower compared to the long-term seasonal mean rainfall experienced in the lowland during the long rains.

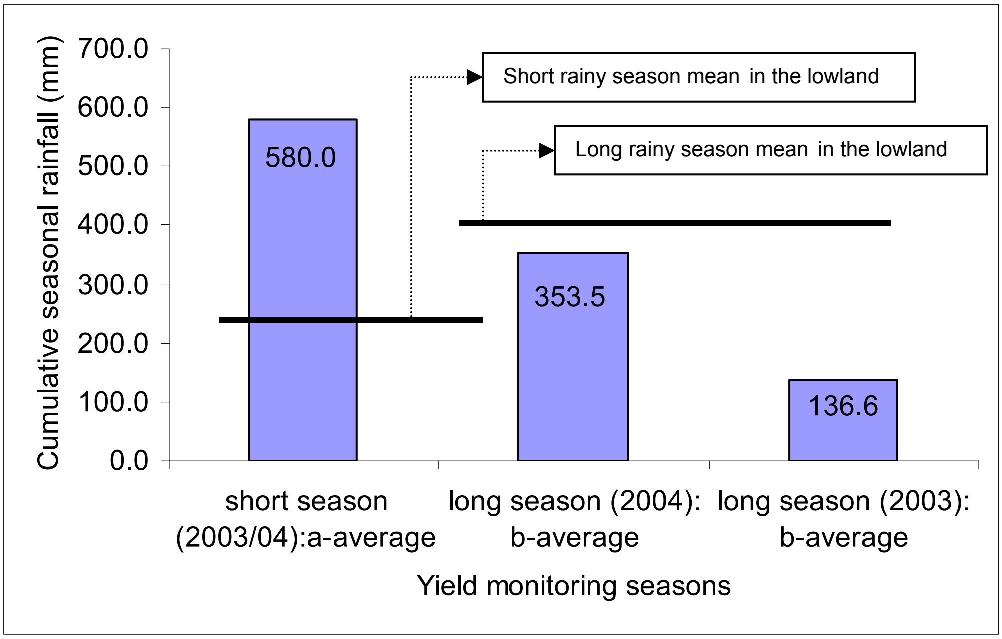

Figure 3. Cumulative rainfall in the runoff-yielding catchment for the study years

Maize performance as a function of locational difference

The performance of the 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 resulting from two to three consecutive rainfall storms in the highlands. Such single flooding was able to support the crop to harvest without any other extra 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 was delineated into high (head), medium and low (tail) suitability classes (SWMRG, 2003). Locational advantage of access and ease of diverting the runoff from the gully into crop fields diminishes from the head towards the tail in the scheme.

Maize yield

Beforehand, it is important to note that the reported yields were attained under 'no external input' farming, as none of the pilot farmers applied organic or inorganic fertilizers. Figure 4 shows that the yield of the maize enterprise during the short rainy season of 2004 (a-average) decreased gradually from the head to the tail of the main runoff gully. The levels of yield for the three regions do not appear to vary appreciably. While farmers believed that land at the tail is a waste and very unproductive, the findings from this study show that the physical productivity of the land at the tail of the scheme was essentially a question of water. This is because the yield of 2.6 tons/ha does not vary appreciably from 3 tons/ha between plots in the head and middle locations. Because soil moisture was not a limitation throughout the scheme during the short rainy season of 2004, the likely source of yield variation in the scheme was due to improved in-field runoff management practices, such as micro-channels and runoff control ditches, that are better developed at the head of the scheme than in the middle and tail parts. The overall mean yield of 2.9 tons/ha for RWH-based maize realized during an above average short rainy season of 2004 exceeds the national and regional (Kilimanjaro) average of 1.4 and 1.7 tons/ha respectively, computed based on seven seasons from 1985 to 1992 (URT, 1993). This yield is slightly higher than the yield of 2.7 ton/ha for irrigated maize in the Mkoji sub-catchment in the Rufiji basin in the southern highlands of Tanzania reported by the FNPP study by FAO-SWMRG (2003). These results reveal the potential of rainwater harvesting for upgrading crop yields in semi-arid watersheds.

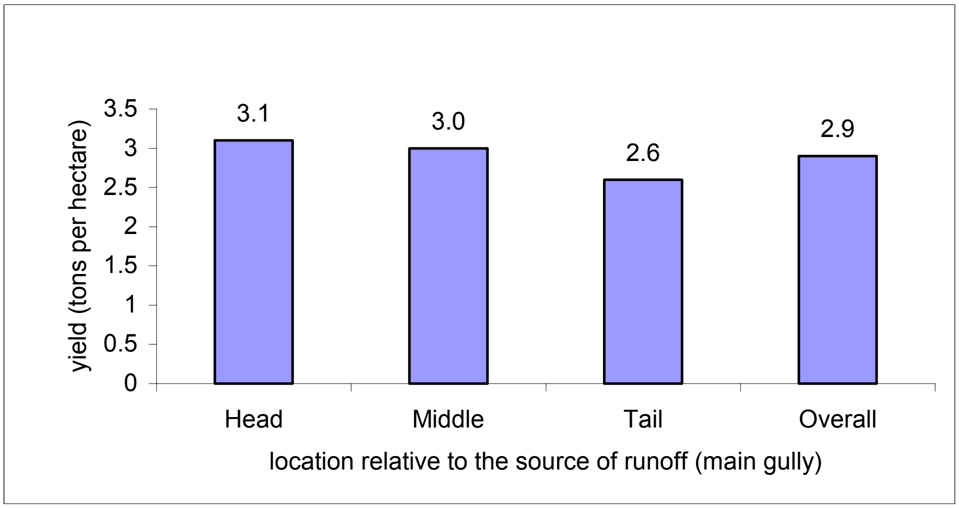

Figure 4. Yield ton/ha for maize along the runoff gully (Vuli 2004: a-average)

Returns to land

After taking into account prices and costs of production, the yields of maize realized during the short rainy season '*vuli*' of 2004 were expressed in financial returns to land with respect to biophysical location. Figure 5 shows that during the short rainy season '*vuli*' of 2004 (a-average) farmers with maize plots at the head, middle and tail of the main runoff gully realized 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 the a-average season the runoff is able to reach the end plots. The overall average return to land of US $718.9 per hectare realized within three months of the '*vuli*' season is substantial in the context of a rural economy. Such a level of return to land realized in a duration of three months of '*vuli*' season is about three times the 2003 national annual per caput GDP of US $280 (at current prices) (see http://www.tanzania.go.tz/economicsurveyf.html).

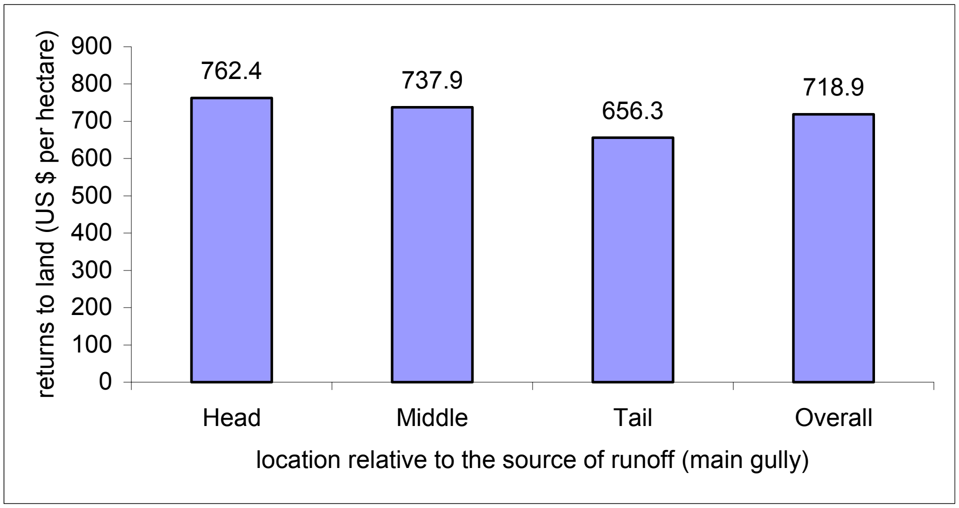

Figure 5. Returns to land from maize along the runoff gully (*Vuli* 2004: a-average)

Returns to labour

Return to labour reflects the level of reward for each person-day 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 person-day of the household workforce involved in producing maize (Figure 6). The overall mean return to labour realized by maize producers in the scheme, irrespective of biophysical location, was US $19.5 per person-day. As such the level of return to labour is almost twenty times above the global poverty line of US $1 per person-day, and reflects the daily impact of runoff farming on poverty reduction.

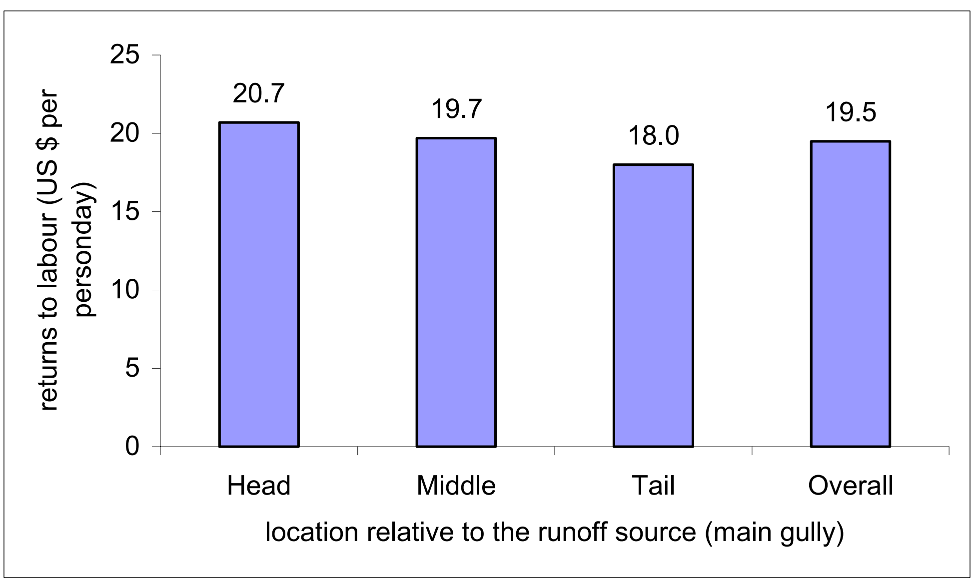

Figure 6. Returns to labour from maize along the runoff gully (*Vuli* 2004: a-average)

Maize performance as a function of runoff events
In order to assess the responsiveness maize and lablab beans on the level of spate irrigation, the frequency of runoff events in each of the pilot fields was monitored. Events of spate irrigation following runoff reception ranged from zero (no runoff/rain-fed) to a maximum of two.

Yield levels at different frequencies of runoff receptions:
Maize and lablab (sole stand) for 2003 and 2004 long rainy seasons

Yields of sole maize and lablab during the long rainy seasons of 2003 and 2004 improved with increasing frequency of runoff reception for spate irrigation (Figure 7). The two seasons were rated as below average by farmers due to low rainfall and inadequacy of the runoff generated in the upper catchment. Under zero events of runoff (rain-fed) the yields of both maize and lablab were much lower compared to under one and two events of runoff. Apparently, maize yield increased more responsively (almost twice) with increasing frequency of runoff reception. Yields of lablab during the long rainy seasons of 2003 and 2004 improved with more events of runoff compared to the rain-fed situation. Regardless of bad seasonality, the maize yield of 1.9 tons/ha realized with two incidences of runoff still exceeds the national average of 1.4 tons. Likewise, the yield of 0.8 tons/ha of lablab realized with one/two events of runoff exceeds the national average yield for pulses of 0.7 tons/ha (URT, 1993: 39-40). Generally, the yields of maize and lablab grown under single stands during the below-average seasons of 2003 and 2004 improved with the increasing number of runoff events.

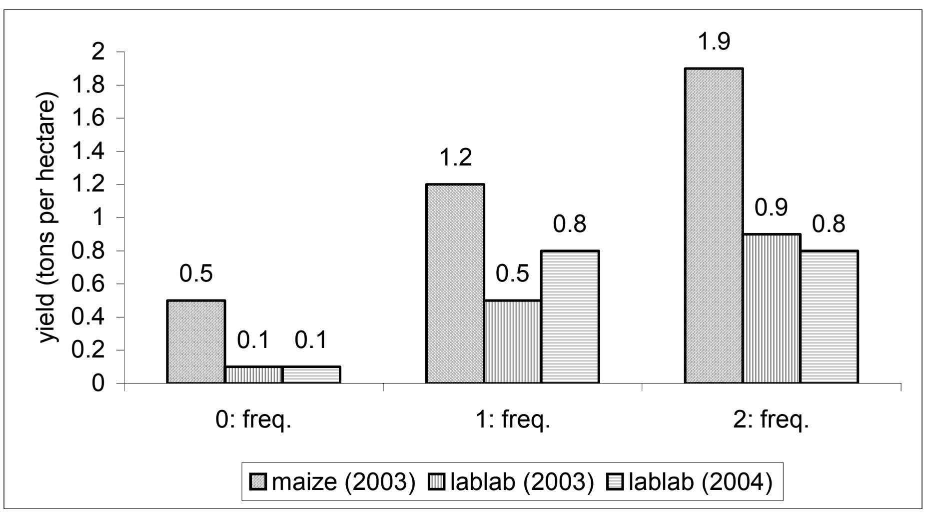

Figure 7. Yield of sole maize and lablab during long rainy seasons, 2003 and 2004 (b-average)

Maize and lablab intercrop for 2003 and 2004 long rainy seasons

Results in Figure 8 (a) show that during the long rainy season of 2003, no yield of maize intercropped with lablab was realized for both rain-fed conditions and with one event of runoff. However, in the same season, the yield of sole maize was 0.5 tons/ha (Figure 7). Apparently, during the long rainy season of 2003, the yields of intercropped maize and lablab improved substantively with two events of runoff (Figure 8 (b)). During the long rainy season of 2004 only one runoff was received. For this season, the yields of intercropped maize and lablab beans under rain-fed conditions (no runoff) were 0.4 and 0 tons/ha, and with one runoff event, respective yields were 1.2 and 0.5 tons/ha. Again, yields of intercropped maize and lablab were better with at least one runoff than with the no runoff situation.

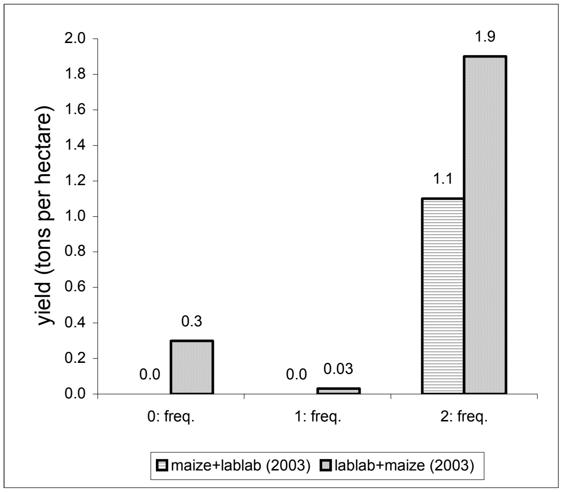

Figure 8(a). Yield of sole maize and lablab during long rainy season 2003 (b-average)

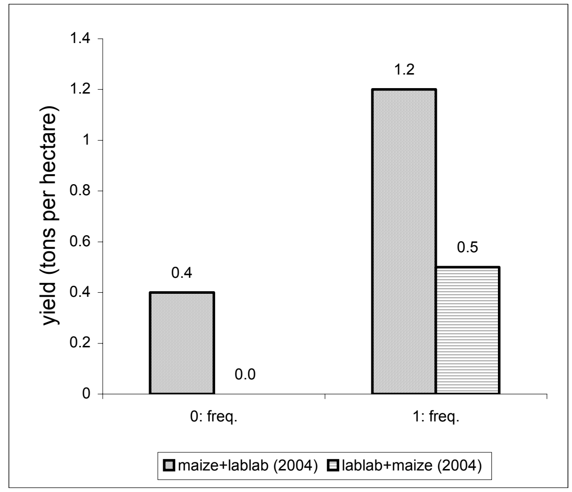

Figure 8(b). Yield of sole maize and lablab during long rainy season 2004 (b-average)

Returns to land at different frequencies of runoff receptions:
Maize and lablab (sole stand) for 2003 and 2004 long rainy seasons

As in the case of yields, returns to land for sole maize and lablab improved with increasing runoff events during long rainy seasons of 2003 and 2004, which were below average. With two events of runoff, such returns per hectare of land exceeded the national per capita income of US $ 280 (Figure 9).

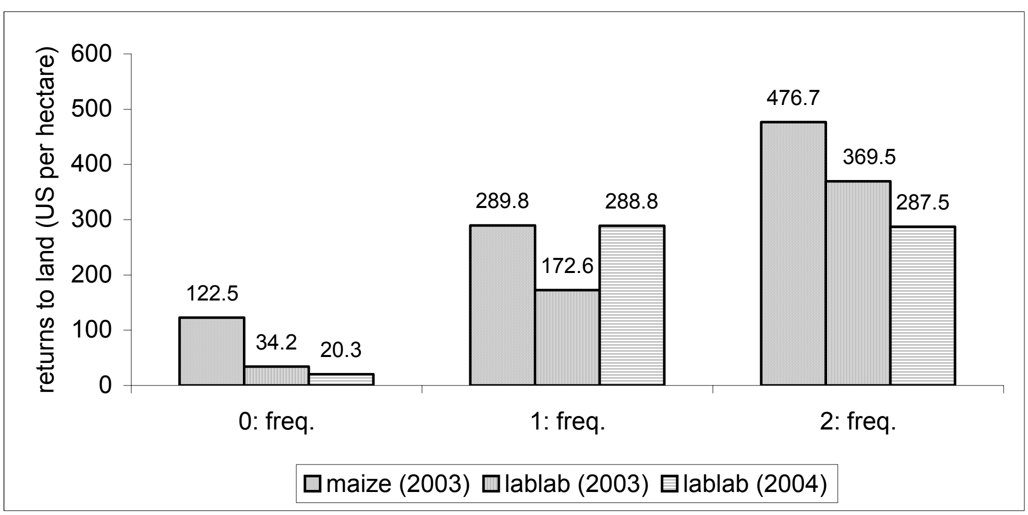

Figure 9. Returns to land of sole maize and lablab during long rainy seasons, 2003 and 2004 (b-average)

Maize and lablab intercrop for 2003 and 2004 long rainy seasons

Apparently, despite seemingly low yields per unit of land and poor seasonality, the two runoff events in maize intercropped with lablab gave impressive returns to land of US $1,011.9/ha (Figure 10). Because the long rainy season lasts for about three months, it means such income is attributed to this period and it is eloquent when compared to the national per caput income of about US $280. High returns from maize and lablab intercrop would be linked to good producer prices as a result of existing linkages to high local and export demands. Lablab beans are exported to Kenya (earning about US $400/ton) and maize grain is traded in local areas that are inherently short of maize grain supply. Makanya village, where the study was conducted, is close to big marketing centres such as Dar es Salaam, Arusha and Nairobi, which are linked by the Dar es Salaam-Arusha-Nairobi highway. Therefore, improving the yield of the maize-lablab bean intercrop through better management of rainwater and agronomy would boost small farmers' incomes tremendously.

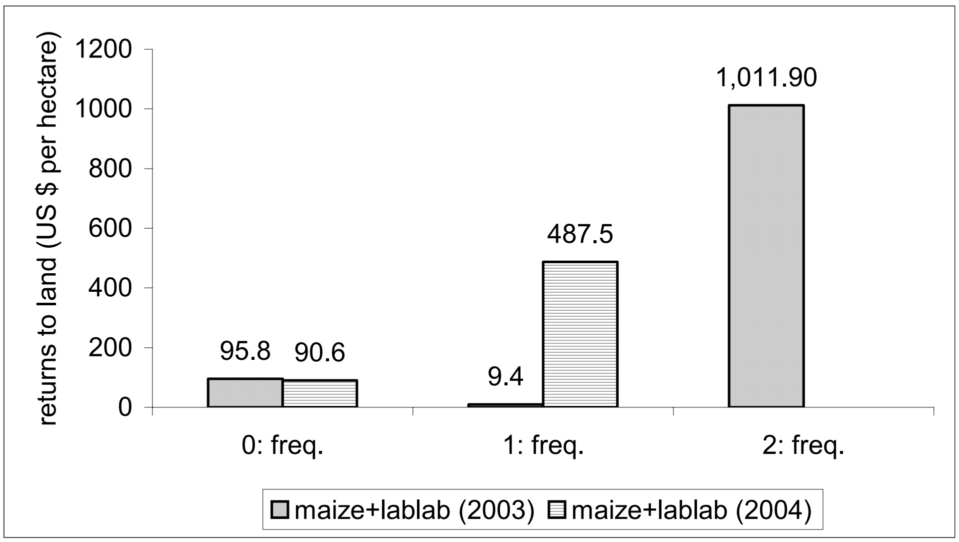

Figure 10. Returns to land of maize and lablab intercrop during long rainy season 2003 and 2004 (b-average)

Returns to labour at different frequencies of runoff receptions:
Maize and lablab (sole stand) for 2003 and 2004 long rainy seasons

Returns to labour is a good indicator of income and hence poverty reduction as a result of the employment created through farming. During the long rainy seasons of 2003 and 2004, with one to two events of runoff, sole maize and lablab enterprises realized returns to labour that exceeded the global poverty line of US $1. Apparently, the highest returns to labour realized, US $12.7 per person-day, was 12 times the global poverty line of US $1 per person per day.

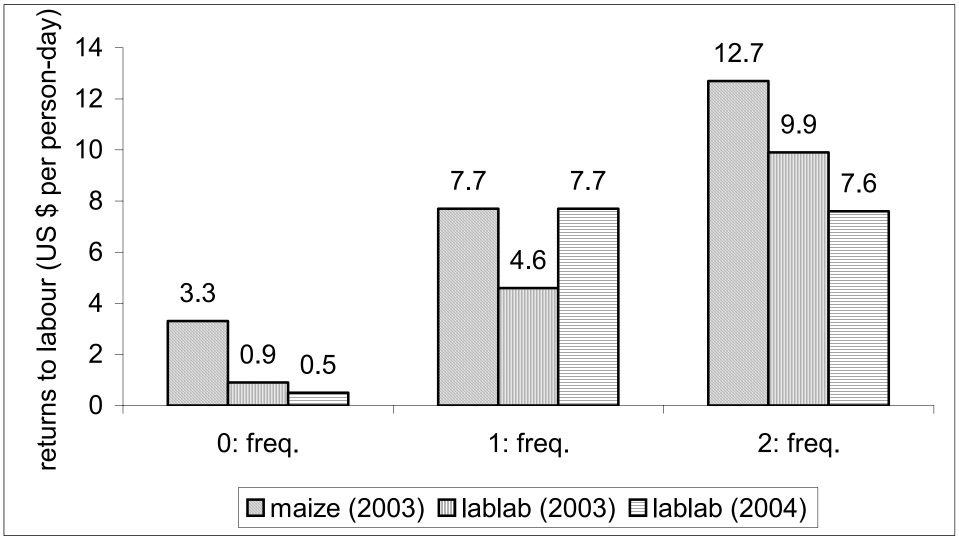

Figure 11. Returns to labour of sole maize and lablab during long rainy seasons 2003 and 2004 (b-average)

Maize and lablab intercrop for 2003 and 2004 long rainy seasons

The intercrop of maize and lablab under rainfed conditions during the long rainy season of 2003 gave higher returns to labour (US $2.6 per person-day), exceeding the same for one event of runoff (US $0.3 per person-day). This could be due to low yields of the crops in the mixed stand and more labour input for water management when at least one runoff was received. Apparently, returns to labour of US$ 26.9 per person-day is much higher than the global poverty line of US $1 per person per day.

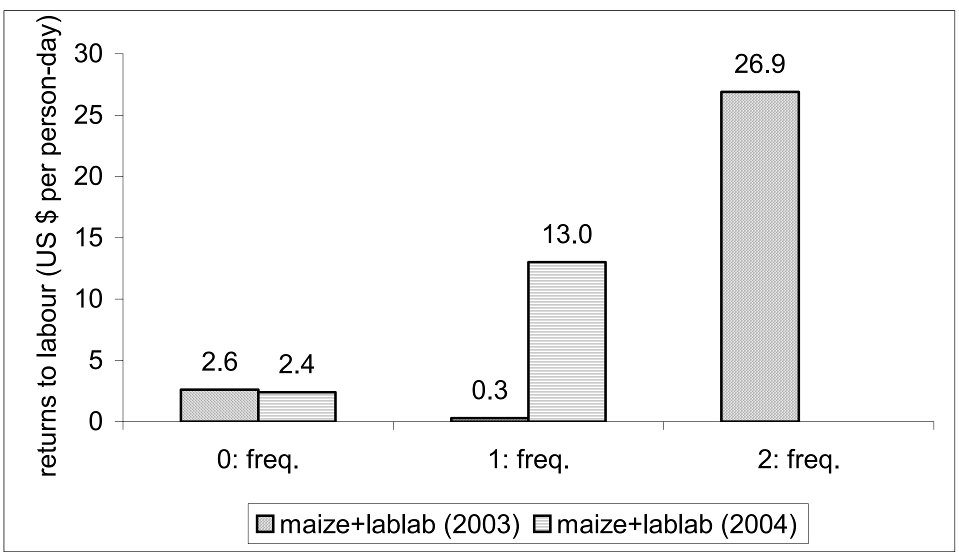

Figure 12. Returns to labour maize and lablab intercrop during long rainy seasons 2003 and 2004 (b-average)

Conclusions

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

1. Rainwater harvesting for crop production has great potential for poverty reduction by giving impressive returns to land and labour even during b-average seasons. However, physical yields of maize and lablab were still low, although the crops realized higher prices due to good markets. This implies that interventions to improve productivity of rainwater (higher crop output per drop) could result in tremendous economic benefits. This remains an avenue for interventions in a robust and sustainable market-focused watershed development (MFWD). The MFWD emphasizes achieving the food and income security of farmers while maintaining the integrity of the eco-hydrology and other natural systems in the watershed.

2. Lablab grown during *masika* is a high value crop that can be grown as a sole stand or intercropped with maize. Despite relatively low yields, intercropping of maize and lablab under rainwater harvesting gave much higher returns to land and labour compared to sole crops. This implies that efforts that can increase physical yields of intercropped maize and lablab would result in tremendous financial earnings.

3. 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 how to balance the use of water for improving human livelihood while releasing part of it for ecological services to maintain the functions of nature.

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