Land Degradation &
Development Group

Rain on the menu:

Rainwater harvesting for small-scale irrigation of maize in the Central Rift Valley, Ethiopia

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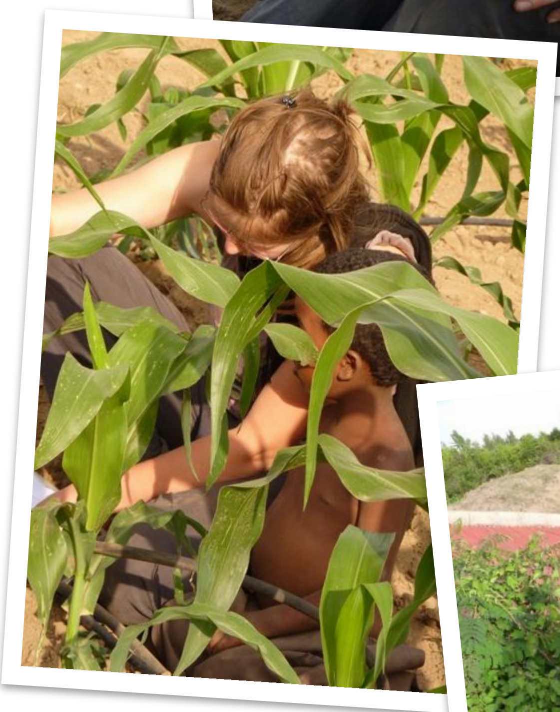
Abstract

In the Central Rift Valley of Ethiopia, small scale farmers mostly rely on rainfall for crop production. The erratic nature of rainfall causes frequent crop failures and makes the region structurally dependent on food aid. Rainwater Harvesting (RWH) is a technique to collect and store runoff that could provide water for livestock, domestic use or small scale irrigation. Usually, such irrigation is promoted for high value crops, but in the light of regional food security it may become interesting to invest in irrigation of maize. In this research, two cemented RWH cisterns were investigated to determine their economic and social potential for supplemental irrigation of maize using drip irrigation. For this, data from test fields with irrigated maize and monitoring of water levels of the cisterns were used, as well as a survey under 30 farmers living close to the experimental site. The results show that catchment size and management should be in balance with the designed RWH system, to prevent too little runoff or flooding. An analysis with Cropwat 8.0 was used to investigate the possibility of irrigating maize with the observed amounts of water in the RWH cisterns. This would suffice for 0.3-0.8 ha of maize. For a RWH cistern with a drip irrigation system to be economically viable, the production on this acreage should become 3-4 ton/ha; 2.5 times higher than the current yield. But the biggest challenge would be to change the perception of respondents, who don't find it logical to spend precious water on a common crop like maize. Therefore, if the Ethiopian government considers the irrigation of maize to be important for regional food security, it is recommended to either subsidize the construction of RWH cisterns or provide credit on favourable terms.



Acknowledgements

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Contents

Abbreviations

API	Antecedent Precipitation Index
AU	Animal Unit
CC	Canopy Cover
CRV	Central Rift Valley
ETB	Ethiopian Birr, 22 ETB ≈ €1,-
IPMS	Improving Productivity and Market Success of Ethiopian Farmers
IWMI	International Water Management Institute
IWR	Irrigation Water Requirement
RAM	Readily Available Moisture
RWH	Rainwater Harvesting
TAM	Total Available Moisture
Shilshalo	Second ploughing of maize fields to break the superficial crust of the soil between the maize rows.

Chapter 1

Introduction

"Smallholder farmers are the mainstay of African agriculture. They have to be right at the heart of Africa's green revolution. We need to ensure they are given the knowledge and support to play their full part in the transformation of food production through access to seeds, fertilizers and other resources."

Kofi Annan, chair of 'Alliance for a Green Revolution in Africa' – February 19, 2011

The above words are part of a speech that Kofi Annan delivered at the International Fund for Agricultural Development in Rome. In this speech, he describes how agricultural development in Africa has been undermined by a lack of access to the fruits of science and technology, an unfavourable (global) economic environment, poor infrastructure and more recently by the impact of climate change. The importance of agriculture for development becomes clear when one considers that '... four out of five Africans depend on farming and related activities to provide for their families'. Four thousand kilometres away from this gathering of intellectual visionaries, the reality in Ethiopia tells a similar story. Agriculture is with 47.7% an important contributor to the economy (World Bank, 2008a). Food insecurity is a recurrent problem (Devereux, 2000). Although Ethiopia is sometimes called the "water tower of Northeast Africa" (e.g. NSMA, 2001), water is an important restricting factor to food production.

This thesis will investigate a system that is developed to adapt to periods of water shortage. The research for this thesis was executed in the Central Rift Valley (CRV) of Ethiopia, during April, May and June 2012. Part of it took place on an experimental site of Alemayehu Muluneh Bitew, who is currently undertaking a PhD research project, partly aiming at assessing the possibilities of optimizing the use of farm rainwater harvesting for field crops.

This introduction explores the reasons for water scarcity in the CRV of Ethiopia and its impact on food security (Section 1.1). After this, the concept of rainwater harvesting is introduced and discussed in terms of opportunities, restrictions, economic viability and adoption in Ethiopia (Section 1.2). Section 1.3 describes small-scale and low cost drip irrigation. The state-of-the-art overview of these three sections leads to the problem statement of the current thesis and the research goals that follow from this (Section 1.4). Chapter 2 presents the study area and Chapter 3 the materials and methods. The results of the research are described in Chapter 4 and discussed in Chapter 5. The final chapter draws conclusions and gives recommendations.

1.1 Agricultural water scarcity

The Central Rift Valley of Ethiopia is a region that experiences water stress regularly. Seasonal shocks cause variability and unreliability of rainfall (Awulachew *et al.*, 2005). This is one of the reasons why agricultural water is often scarce. With regard to climate change, the forecasted change in rainfall is not uniform. The World Bank (2008b) identifies Ethiopia as one of the countries that are most at risk from drought. Trend analysis of the meteorological agency of Ethiopia (NMSA, 2001) showed that from 1961-1999, annual rainfall has declined in the North and Southwest of the country, while in central Ethiopia an increasing trend was observed. These data do not show the variability of the rain within a year, which makes them less useful for agricultural analysis (Barron, 2003).

Another source of water is groundwater, that is extracted by shallow or deep community wells. According to IWMI reporting, this is the main water source for the majority of the Ethiopian rural population (Awulachew *et al*., 2007). People walk many kilometres to get this water and bring it to their homes. In the CRV, due to high concentrations of fluoride and sodium, groundwater is not always suitable for agricultural use, and the risk of over-exploitation is always looming (Hengsdijk & Jansen, 2006).

On top of the erratic rainfall and limited availability of groundwater, agricultural water scarcity is worsened by large non-productive water flows. This includes soil evaporation, surface runoff and deep percolation (Rockström *et al.*, 2002). The effect of drought on water availability for crops depends on the capacity of the soil to retain water: "... when soil and crop conditions were incorporated with rainfall and evapotranspiration in an agricultural dry spell analysis, occurrence of dry spells affecting yields negatively were highly dependent on soil water storage capacity (Barron *et al.*, 2003)."

As noted by Kofi Annan, smallholder farmers play a major role in African agriculture. In Ethiopia, this group constituted 89% of the labour force in 1997 (Devereux, 2000). Smallholders are particularly vulnerable to water scarcity, as they have little capital to deal with shocks like crop failure. In good years, the limited water availability still restricts the productivity of the land because there is no irrigation applied.

Because smallholder farmers face a high risk of crop failure, they are less intend to invest in fertilizers and other inputs, so that no intensification takes place (Kahinda *et al.*, 2007). In view of Ethiopia's population growth of 3% per year (NMSA, 2001), the food security situation will become worse without an increasing food production. Furthermore, the economic situation of smallholder farmers will not improve, which leaves them at their vulnerable position. Since food insecurity is closer linked to poverty than to a low food production (Love *et al.*, 2006), this last issue could be the most important.

1.2 Rainwater harvesting

One way to confront the problem of water scarcity is the concept of rainwater harvesting (RWH), defined as 'any practice that collects runoff for productive purposes (Rockström *et al.*, 2010)'. There are two ways in which rainwater can be harvested: in-situ, capturing the rainfall on the farmland itself e.g. by constructing bunds; and ex-situ, capturing rainfall from outside the farmland (Rockström *et al.*, 2010). This thesis focuses on the second type of RWH, especially on the construction of ponds or cisterns to harvest rainwater from a relatively big catchment.

The first thing that becomes clear when considering the concept of rainwater harvesting, is that the difference between ‘rainfed’ and ‘irrigated’ agriculture makes little sense in this context (Rijsberman & Manning, 2006; Rockström *et al.*, 2010). The opportunity of RWH for crop production lies in the combination of making use of rainfall events and managing the available water to increase the productivity of the water. In a research from Zimbabwe, Kahinda *et al.* (2007) found that supplemental irrigation of maize from RWH mitigates the dry spells during the rainy season and reduces the risk of complete crop failure.

In an IWMI report on Ethiopia, it is mentioned that many RWH ponds are mainly used for livestock (Awulachew *et al.*, 2005). The mixed system of livestock and crops reduces the risks that come from livestock rearing; in case of drought it takes a lot of time to recover from loss of cattle, while crop production recovers relatively quickly (Biazin & Sterk, in press). RWH ponds and cisterns are also used for household purposes.

In some regions of Ethiopia, RWH ponds are associated with negative health effects, like malaria outbreaks. The environmental sustainability of the interventions are also questioned, on grounds of soil salinization through micro dams (Awulachew *et al*., 2005). Rijsberman and Manning (2006) mention the risk that RWH on a large scale can cause water shortage in downstream areas. Furthermore, there needs to be enough runoff, which is restricted by the available catchment area (Ngigi *et al.*, 2005). This will probably be a factor that becomes important with increasing scale of RWH.

It is widely recognized that RWH as an intervention targeted at increased production should be part of an integrated approach. In particular, fertilizer is an important element of this (Awulachew *et al.*, 2005; Kahinda *et al.*, 2007). A study in Zimbabwe (Maisiri *et al.*, 2005) found that fertilizer use, not irrigation, was determining for final yield. To use supplemental irrigation in a good way, it is crucial to have knowledge of the impact of water shortage during critical growing stages (Kahinda *et al.*, 2007). Water management also includes choosing the right planting date (Ngigi *et al.*, 2005)

The benefit-cost ratio of RWH for supplemental irrigation is different for every particular situation. One determining factor is the choice of crop that is irrigated. Cash crops will provide a relatively rapid payback of the investment, since they are marketed and exchanged for money. In contrast, staple crops are consumed by the household and do not contribute to cash income, but are the basis of household food security. Ngigi *et al.* (2005) report a positive economic outcome for supplemental irrigation of maize by using RWH farm ponds in central, semi-arid Kenya.

Rainwater harvesting at household level has been promoted in Ethiopia, but both adoption and performance of the systems is currently low. This is stated by Moges *et al.* (2011), who studied three RWH systems in Oromiya region and found that the water availability was low in relation to crop water needs, particularly for maize.

1.3 Drip irrigation for small-scale farmers

When it comes to applying the harvested water to the field, drip irrigation is a method to apply precise amounts on the spots where it is needed, while minimizing evaporation losses. El-Hendawy *et al.* (2008) define a proper drip irrigation rate as one that "both minimizes the amount of water leached from the rootzone and maintains a high soil matrix potential in the rhizospere to reduce plant water stress." Drip irrigation is often associated with commercial farming, since it involves relatively a lot of technique and costly materials. But there has been a lot of research on the development of these systems for smallholders.

Polak *et al.* (1997) describe a low cost drip irrigation system, where the low cost is obtained by making some modifications to the original design: no emitters but holes in the lines; moveable lines, so 10 crop rows can be irrigated with one line; simple containers with cloth filters for the water. Postel *et al.* (2001) mention four criteria for a drip irrigation system for smallholder farmers: affordability, rapid payback of the investment, divisibility and expandability, water efficiency.

A point of critique on such low cost drip systems comes from Maisiri *et al.* (2005), who note that compared to surface irrigation with siphons, drip irrigation offers no labour saving, because the water is manually lifted into the irrigation container.

The potential for low cost drip irrigation or other forms of micro irrigation is high in Ethiopia, because they can already be successful at an individual level (Awulachew *et al*., 2005). The drip kits that were available in 2005, cost about US $174 per kit. This is still very expensive compared to the kits made in India that cost about US $1-65 in India (Awulachew *et al.*, 2005).

1.4 Problem description and research goals

Rainwater Harvesting in the form of individual cisterns is practiced in the study area, and mainly used for small-scale vegetable cropping, livestock and household. At the same time, the staple crop that is grown for household consumption is maize. Maize is sensitive to dry spells (Barron, 2003) and the erratic rainfall pattern in the area results in frequent crop failure (IPMS, 2007). A stabilized maize yield would increase food security, and so the hypothesis of this thesis is that RWH cisterns could be used for irrigation of maize. This contributes to the current discussion about RWH, since most research about RWH from macro-catchments is about cash crops.

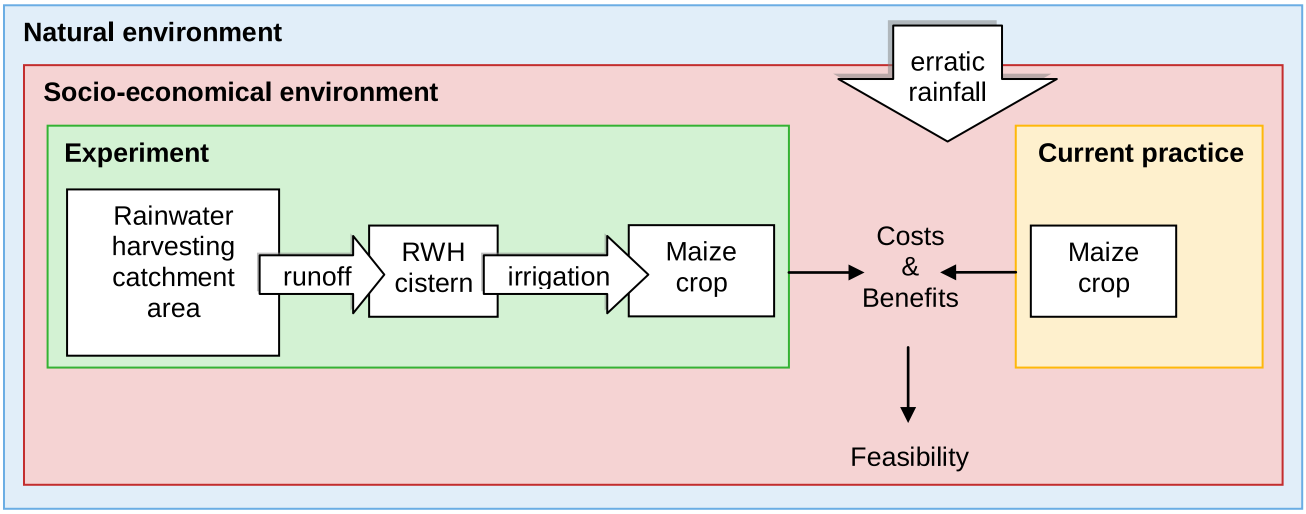

Figure 1 Schematic representation of the logic of the thesis.

Figure 1 represents the logic of the thesis, that is reflected in the research goals. The central part of the research is a field experiment (green box), consisting of two RWH cisterns that are used for supplemental irrigation of maize. Using the data that are collected on the experimental site, an estimation can be made of the efficiency of the two RWH cisterns and the amount of water needed for irrigation. The next step is to determine the yield that is normally produced by farmers living close to the experimental site (orange box). After this, these agro physical factors can be integrated into a broader assessment of socio-economic costs and benefits. Finally, the question will be addressed if the system that is developed in the experiment has potential for current farming practice in the area.

Summarized, there are three research goals:

1. Construct a water balance for the experimental fields.
    a. Determine the efficiency in water harvesting of two RWH cisterns at the test field.
        - Monitor the water level of the two cisterns.
        - Determine the volume of water inflow for the two cisterns.
    b. Determine the irrigation water requirement for supplemental irrigation of maize.
        - Calculate the Crop Water Requirement of maize (variety: *Awasa BH 540*) in Guba.
        - Theoretically compute the irrigation water requirement.
2. Assess the current practice of maize cropping in Guba.
    a. Make an overview of the consequences of water shortage in the different stages of the lifecycle of maize.
    b. Compare these consequences with farming practice and rainfall conditions during the maize season of 2011.
3. Assess the economic and social feasibility of irrigation maize with a cemented individual RWH cistern.
    a. Calculate the total costs of a RWH cistern and drip irrigation.
    b. Determine the yield increase that should be achieved with irrigation to make RWH and drip irrigation economically viable.
    c. Investigate statistical correlations between farmers with RWH pond and farm features.
    d. Investigate rationale of farmers about irrigation of maize.

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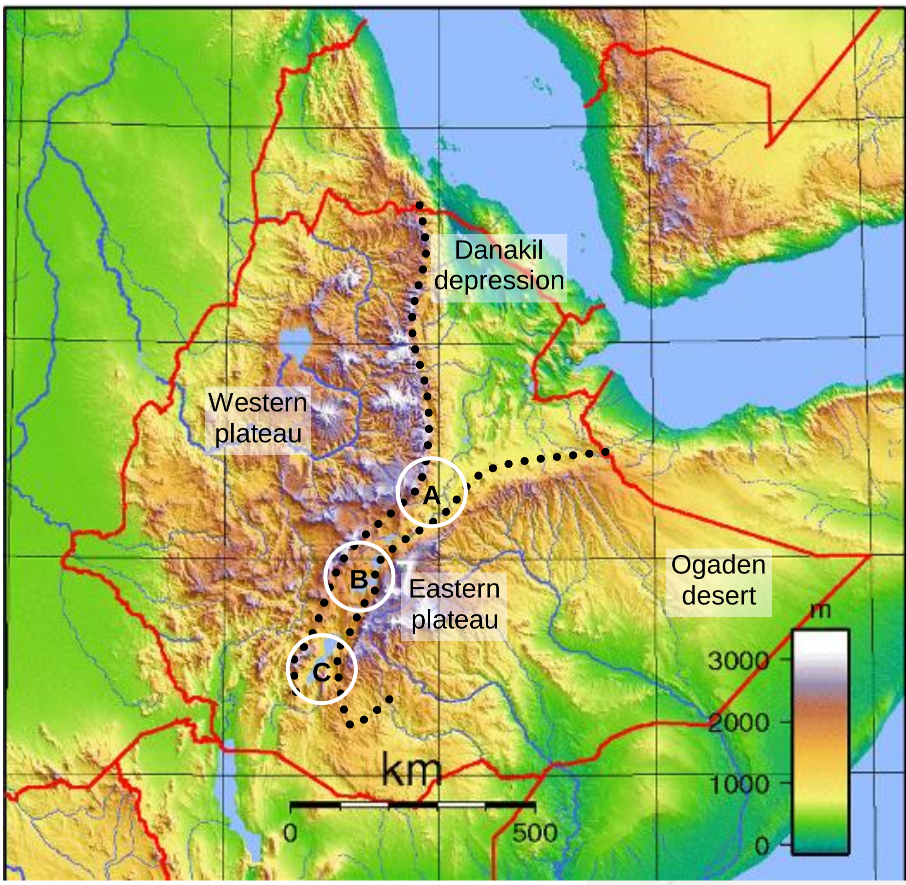

Figure 2 Topography of Ethiopia

Between the dotted lines lies the Rift Valley, divided in:

A. **Awash basin**
B. **Central Ethiopian Rift Valley**
C. **Southern basin**

(Sources: mapsof.net, ny; Hengsdijk & Jansen, 2006)

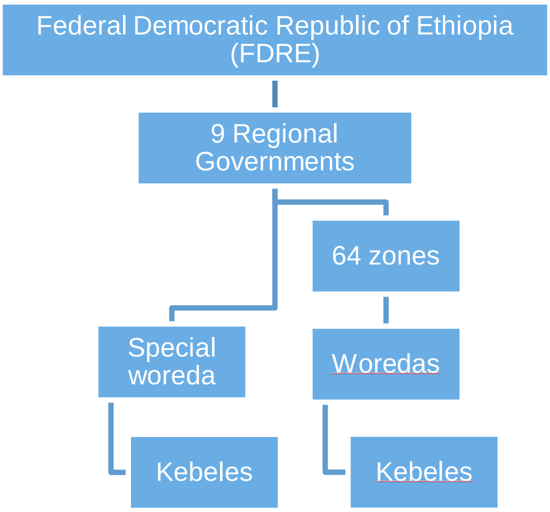

Figure 3 Administrative levels of Ethiopia.

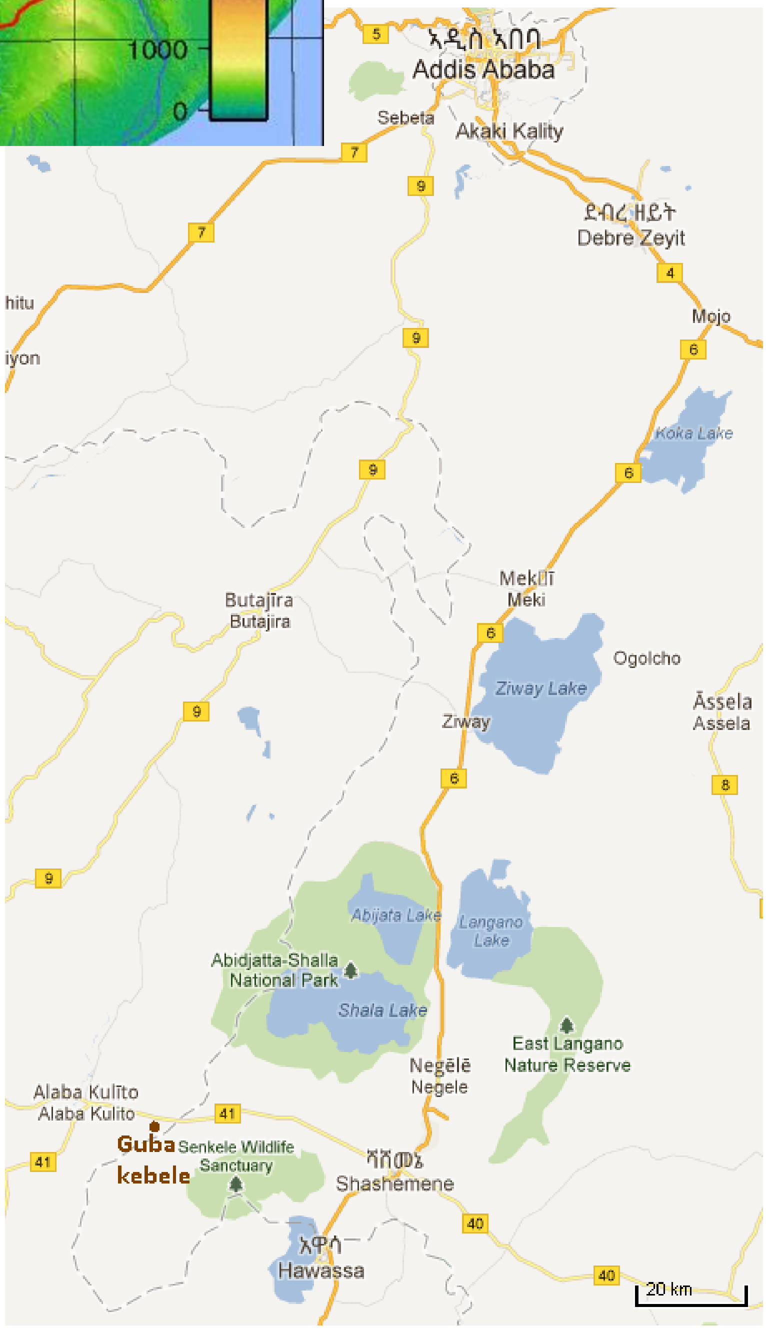

Figure 4 Location of the research area in Ethiopia (Source: Google maps).

Chapter 2

Study area

2.1 Regional information

2.1.1 Location

Ethiopia is administratively divided in 9 regions. The research area lies in Southern Nations, Nationalities, and Peoples Region, in Alaba woreda. *Woreda* is the second smallest administrative unit, as shown in Figure 3. Alaba woreda used to be part of the zone KAT: Kembata, Alaba and Tembaro, until Alaba became a special woreda. This means that it is not part of a zone, but falls directly under the regional government. The size of the woreda is 64,000 ha, further divided into 64 kebeles (IPMS, 2007). The research area is located in the Guba kebele, 7°16' N latitude and 38°13' E longitude (Figure 4).

2.1.2 Physical features

The topography of Ethiopia is dominated by a high plateau, intersected by the East African Rift Valley. Within the Rift Valley, three water basins can be identified, see Figure 2:

A. The Awash basin, roughly north of Addis Ababa;
B. the Central Rift Valley (CRV), with the conglomerate of lakes: Ziway, Langano, Abyata and Shala;
C. the Southern basin, starting from lake Awassa.

(Hengsdijk & Jansen, 2006).

Alaba woreda is located in the CRV. Classifying the climate of this region is a complicated effort, because of the high spatial and temporal variability of rainfall. This is caused by the interplay of several pressure systems and varying topography of the region (Walker *et al.*, 2003). According to the traditional classification, using altitude and mean daily temperature, the CRV belongs to the *weina dega* or temperate zone (Walker *et al.*, 2003). The elevation of Guba Kebele is 1829-1910 meter above sea level, with vitric andosols (IPMS, 2005).

At the research location, the average rainfall is 1017-1056 mm/year and the mean annual temperature 18°C (IPMS, 2005).

The research location has three seasons:

- The *belg* season: light rainy season, from February/March to May. The rains are produced by moist easterly and southeasterly winds.

- The *kiremt* season: the main rainy season, from June to September.
- The *bega* season: the dry season, from October to December/January/February. Warm and cool northeasterly winds bring dry air, but are very occasionally interrupted when low-pressure systems from the Mediterrean interact with the equatorial/tropical systems, resulting in rainfall over parts of central Ethiopia.

(Seleshi & Zanke, 2004)

2.1.3 Socio-economic features

The information used for this section is mainly derived from a report of the project 'Improving Productivity and Market Success of Ethiopian Farmers' (IPMS), that was initiated in 2004 by the International Livestock Research Institute and the Ethiopian Ministry of Agriculture and Rural Development.

The rainfall pattern in Alaba woreda is problematic for food production. This is not due to an insufficient amount of total rainfall, but caused by the unfavourable and unpredictable distribution of it. During the *belg* season, the reliability of rain is low. Farmers usually do not grow any crops in this time, except for pepper seedlings (IPMS, 2005). Crops that are grown during the main rainy season are maize, teff, wheat, pepper, haricot bean, sorghum and millet (IPMS, 2005). In this time the occurrence of rain is still erratic, so that the woreda experiences crop failures as often as once per three years.

Irrigation is not a common practice in the area, although the relatively flat landscape would be suitable for it. Two irrigation schemes are active, using rivers as water sources. There are four rivers in the woreda. The biggest of them is Bilate river, that is at the same time a problematic source, because it borders another woreda (IPMS, 2005). The groundwater table of Alaba woreda is very deep, with water wells of 300 meter (IPMS, 2005). These wells are developed by NGO's and form the main source of water for the majority of the rural population, that live far from the rivers (see Figure 6).

Water harvesting is practiced at household level, mainly used for livestock, and community level (IPMS, 2005). Around the year 2009, the agricultural NGO Sasakawa Africa Association (SAA, n.d.) constructed several individual cemented RWH cisterns as part of the program 'Sasakawa Global 2000'. A cheaper alternative are plastic lined RWH ponds, that have also been distributed in the area. However, these are proven to be deconstructed after being received, due to the high value of the geomembrane and the fact that it is a mobile asset (van Hulst, 2012).

The cropping of maize usually starts at the beginning of the main rainy season, coinciding with sowing of haricot bean and transplanting of the pepper seedlings. About two weeks after sowing the maize, a technique called *shilshalo* is carried out, which consists of ploughing the field to turn over the soil (Figure 5). In some cases this is combined with applying urea. The purpose of *shilshalo* is to break the superficial crust of the soil between the maize rows, to enhance infiltration (Biazin *et al.*, 2011). It also restores the ridges that are an effect of the ploughing.

Figure 5 Bateno, the owner of Cistern 1, who is performing *shilshalo* (second ploughing) on a field with maize and chat.

Figure 6 A woman on a road in Guba, on her way to fetch water.

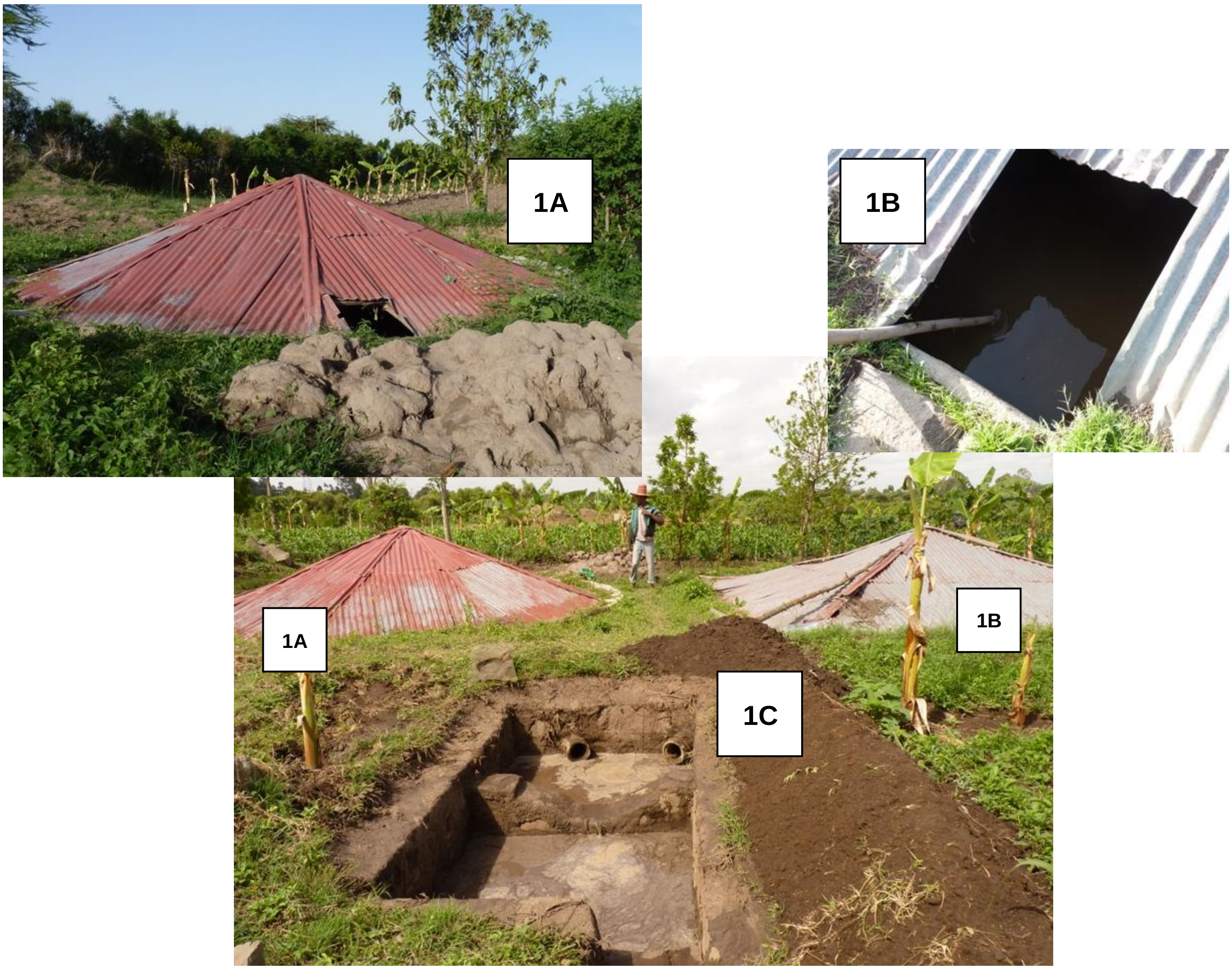

Figure 7 Pictures of the two Rainwater Harvesting cisterns (1 and 2), each with a round basin (A), a square basin (B) and a silt trap (C).

2.2 Experimental fields

2.2.1 Description of experiment

As mentioned in the Introduction, part of the research took place at the experimental site of the PhD project of Alemayehu Muluneh Bitew. The farm where the research takes place is located south of Road 41 (Shashemene - Alaba Kulito), 10 km east of Alaba Kulito, the administrative centre of the woreda (see Figure 4). The research fields are schematically drawn in Annex I. The experiment is laid out as a Randomized Complete Block design, with a plot size of 4 x 5 meter and three replications. This results in three experimental fields/farms each with an area of 200 m^2.

On the research site, two Rainwater Harvesting cisterns are present, see the pictures in Figure 7. In this report, they will be indicated as 'Cistern 1' and 'Cistern 2'. The cisterns consist of a silt trap and two basins. The silt trap is designed to allow the silt that is carried by the water to settle down. Two pipe inlets lead to the basins, with a wire mesh in front of their opening to prevent contamination of the pond water.

Figure 8 Sowing of maize on field 1 of the experiment, 2 May 2012.

A drip irrigation system that uses water from the two RWH cisterns was installed and functioning about a month after sowing. The plots were all sown with maize (*Zea Maize* L.), variety *Awasa BH540* , that has 145 days to maturity (EARO, 2004). Sowing was done in four different densities: D1, 30 000 plants/ha; D2, 45 000 plants /ha; D3, 60 0000 plants/ha; D4, 75 000 plants/ha. Figure 8 shows how the sowing was done with different distances between the seeds. This took place at 2 May 2012.

There are also four irrigation treatments:

- I1, only rain fed without supplemental irrigation;
- I2, supplemental irrigation when the water content drops 50% below the threshold water content level (the level at which the crop begins to experience water stress);
- I3, supplemental irrigation when the water content drops 25% below the threshold water content level;
- I4, supplemental irrigation throughout the growing season before the water content drops below the threshold water content.

Because it is not probable that a planting density higher than D1 is feasible in an I1 situation, only the combination I1-D1 is tested. The same accounts for I2-D1/D2, etcetera. The experiment aims at finding an optimum combination of planting density and irrigation rate. A high irrigation rate will limit the area that can be cropped, while it allows a high plant density. A high density can also limit light availability. On the other hand, a lower irrigation rate allows the cropping of a larger area with a lower density. Nutrient availability was not a limiting factor, as fertilizer was supplied at a rate of 150% of normal application. The timing of the irrigation events was determined by monitoring the soil water content.

2.2.2 Soil characteristics

Table 1 presents the soil properties of the research fields, that had been established previously by means of soil sample analysis. They have a loamy texture, which is favourable in terms of water retention. No soil samples were taken at farms of survey respondents, but it can be assumed that the soil texture was close to that of the experimental fields.

Table 1 Soil characteristics of the three experimental fields, for soil depth of 0-40 cm.

	Texture [%]				Water content [m^3/m^3] at:	
	Clay	Silt	Sand	Class	Wilting point	Field capacity
Field 1	22	30	48	Loam	0.13	0.42
Field 2	21	30	49	Loam	0.13	0.43
Field 3	24	36	40	Loam	0.13	0.45

Chapter 3

Materials and methods

This chapter will present the materials and methods that have been used in this research. The first three sections describe the different types of data that were collected at the experimental site. These measured data were analyzed every day using Microsoft Excel. Section 3.4 and 3.5 describe how Cropwat 8.0 was used and Section 3.6 introduces the socio-economic survey.

3.1 Efficiency of RWH ponds

The efficiency of the water harvesting ponds was determined with the use of the following water balance equation (adapted from Yazaw *et al.*, 2006):

$$V_{final} = V_{initial} + V_{inflow} - V_{evaporation} - V_{seepage} - V_{used}$$

The parameters that cannot be measured are evaporation and seepage. Therefore the equation can be written like:

$$V_{evaporation} + V_{seepage} = V_{initial} + V_{inflow} - V_{used} - V_{final}$$

To establish values for $V_{initial}$ and V_{final}, the water level in the pond was measured by a tape meter and converted to volume by an equation depending on the shape of the reservoir. These equations are presented in Annex IV. V_{used} was obtained from the irrigation records and record keeping of household use. Water levels in the cisterns were measured from May 10 to June 28. To evaluate the amount of harvested water, this period was divided into 24 periods based on the moments of measurements. The average length of these periods was 48 hours, ranging from 20 to 67 with one outlier of 172 hours (period 5). Per period, the amount of harvested water was calculated with the following equation:

$$V_{harvested} = V_{final} - V_{initial} + V_{evaporation} + V_{used}$$

The equation shows how the change in volume was compensated for water use and evaporation from the opening in the tin roof to obtain the amount of harvested water. To relate this volume to rainfall amounts, it was divided by the catchment surface which resulted in a figure in mm.

This study does not empirically estimate values for $V_{evaporation}$, which makes it impossible to determine the exact amount of seepage. However, some assumptions can be made about evaporation. The research of Yazaw *et al.* (2006) in Tigray region (northern Ethiopia) shows that for the water harvesting ponds they investigated, evaporation loss had little impact on the amount of water eventually harvested. Evaporation was small related to the other factors (1.7 - 6.4% of total inflow) and also related to the surface area of the ponds. It is not clear if the investigated ponds were covered. If this was not the case, the importance of evaporation becomes even smaller, as covering the surface minimizes evaporation. The two RWH ponds of the current research both have a tin roof. Based on the size of the openings in the roof, an estimation of the evaporation loss was made.

The other part of the loss is represented by the parameter $V_{seepage}$. Moges *et al.* (2011) set seepage losses at zero for a RWH pond that is lined with cement. However, Yazaw *et al.* (2006) found a seepage loss of 57% for the concrete pond they investigated; caused by cracks in the concrete lining. So it cannot be assumed that seepage will be zero in this case. It can be approached by comparing the measured V_{final} with a calculated figure, that represents the amount of water that theoretically should be left in the cistern:

$$V_{final\ calculated} = V_{initial} - V_{used} - V_{evaporation}$$

The difference between V_{final} (as measured) and $V_{final\ calculated}$ is an indication of the seepage rate. This difference was calculated was done with a correction for the possible measuring inaccuracy of 1 cm of the tape meter that was used to measure water levels of the cisterns. The volumetric figure ($V_{difference}$) was subsequently converted to a seepage rate in m^3/week.

V_{inflow} is determined by the amount of runoff that is caused by the rain that falls on the catchment of the ponds. As mentioned by Hendriks (2002), the relation between rainfall and runoff is determined by fixed and time-varying factors. The fixed factors have to do with features of the catchment area: the size, shape, slope, soil type and distribution of stream channels. In this case, the catchment area was estimated from empirical assessment of runoff after a rainstorm. Other factors are time-varying, such as the type of vegetation cover. Another time-varying factor is precipitation. There is a threshold rainfall amount that is required before any runoff occurs, because the first rain is intercepted by plants, soil infiltration and depression storage like surface puddles or ditches. The time between two rainfall events will influence runoff, because right after a rainstorm the soil is more saturated with moisture than after some dry hours. A way to take this into account, is the Antecedent Precipitation Index (API). This index uses daily rainfall data and assumes that soil moisture content decreases exponentially when no rainfall is occurring (Shaw, 1983). The equation used in this thesis is:

$$API = 0.85 * API_{t-1} + P_{t-1}$$

Where API_{t-1} is the index on the previous day, P_{t-1} the rainfall of the previous day and 0.85 is a value for the factor that depends on the potential loss of soil moisture. The value of this factor can vary between 0.85 and 0.98 (Shaw, 1983). For this region, 0.85 was chosen because the climate is semi-arid which facilitates high levels of evapotranspiration.

3.2 Plant growth

The potential yield of the experimental plots was assessed by monitoring the growth of the maize plants and the Canopy Cover (CC). For the height of the plants, every 10 days a random sample of four plants per plot, so 120 in total, were measured and averaged.

The CC is estimated by the line-transect method (Eck & Brown, 2004), using the amount of shadow under the crop. A rope is stretched diagonally across the crop rows. This cord has knots at intervals of

10 cm. The knots that are shaded from sunlight are counted. For every plot, six diagonals are measured, as in Figure 9. For every transect, the number of shaded dots is divided by the total number of knots on the transect. The resulting average number is an estimate of the percentage of soil that is covered by the crop. The accuracy of this method was empirically tested, see Annex II. This measurement was also carried out every 10 days. For this way of estimating the CC, there should be a clear sky and the sun should be around its highest point. In April and May, solar noon is around 12:22 hour, while in June it shifts to an average of 12:26 hour (data for Addis Ababa). For the period of assessment, the CC measurements were taken between 11:20 and 13:30 hour.

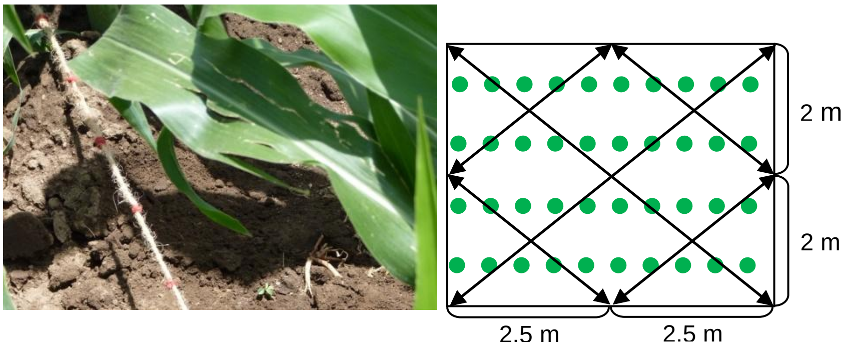

Figure 9 Estimation of Canopy Cover by six line transects (arrows) stretched diagonally across the crop rows (green dots).

3.3 Weather data

A meteorological station was present at the research location, to provide data on wind speed, wind direction, precipitation, radiation, temperature and air humidity.

3.4 Irrigation Water Requirement

Due to delay in installing the irrigation system and absence of frequent soil moisture measurements, it was not possible to exactly carry out the different irrigation regimes on the experimental site. Therefore, the amount of water that would be needed to sustain a maize crop was calculated rather than using the records of irrigation at the fields. This calculation of the Irrigation Water Requirement (IWR) was done with Cropwat 8.0, a program that uses the Penman-Monteith method (Allen *et al.*, 1998) to determine the reference crop evapotranspiration.

A simulation of maize cropping was carried out in Cropwat 8.0. For this, meteorological and soil data were used. The experiment had three different fields, but for the simulation their characteristics (see Table 1) were averaged. Soil data were computed for a soil depth of 0-40 cm, since this is the depth from which the maize mainly extracts soil water (Panda *et al.*, 2004). The Total Available Moisture (TAM) was calculated with values of Table 1 to be 300 mm/m. Initial depletion of soil moisture was measured at sowing time and averaged 29% of TAM. The maximum rain infiltration rate was estimated according to a FAO standard Cropwat value of 40 mm/day for a medium texture soil, that fits the texture properties of the experimental fields (see Table 1).

Table 2 shows how the TAM in mm depends on the rooting depth, that develops during crop growth. The Readily Available Moisture is a measure for soil moisture that a plant can readily abstract from the soil. It is a fraction of TAM: RAM = TAM * p, in which p is the critical depletion fraction. For maize this is 0.55, changing to 0.80 in the last growth stage. The Cropwat simulation irrigates at critical depletion: every time the soil moisture level drops below RAM, an irrigation event is indicated.

Table 2 Total Available Moisture (TAM) and Readily Available Moisture (RAM) as determined by rooting depth and p-factor throughout the growth stages of maize (FAO, 2002).

Crop stage	Rooting depth (m)	p: critical depletion fraction	TAM (mm)	RAM (mm)
Initial	0.3	0.55	90	50
Development	↓		↓	↓
Mid-season	0.6		180	99
End		↓ 0.80		↓ 144

The irrigation efficiency was estimated to be 80%. El-Hendawy *et al.* (2008) mention 90% as efficiency rate for drip irrigation, but the system used on the research location had some leaks and not every dripping hole was located exactly at a plant. Therefore, an efficiency rate of 80% was used.

3.5 Additional Cropwat simulations

Cropwat 8.0 was also used to test the Irrigation Water Requirement in case of a dry spell. For this, the recorded weather data were used, but adapted to simulate the desired situation. Simulations also included shifting of the sowing date.

3.6 Socio-economic survey

To gather information on farming practice and the (perceived) cost-benefit ratio of RWH, a socio-economic survey was held under 30 people living in Guba kebele. This is the minimum sample size for statistical analysis of a homogeneous group.

The survey was about cropping of maize. Since all the farmers in Guba are growing maize, this was not a restriction for sampling. The sample was selected based on geographic location, to limit the spatial differences/variations in access to water sources, market access, soil types, etcetera. This was done because these things could have an untraceable influence on the survey results. Since the potential system of irrigating maize was developed on the experimental farm, the socio-economic analysis should be based on comparable circumstances. The final sample consisted of respondents who all live within an area with a 2 kilometre radius.

An additional criterion was if the respondents had a RWH cistern or not. Because these cisterns are less widespread than the cropping of maize, the target was to interview all the owners of a RWH cistern within the radius of the sample. This resulted in eight respondents who owned an individual RWH cistern.

The survey questionnaire can be found in Annex III. The questions were about the 2011 season of maize. SPSS was used to analyse correlation between the use of RWH and other agricultural assets.

Chapter 4

Results

4.1 Water balance of RWH for irrigation of maize

This section presents the results of the experiment. First (Section 4.1.1) the water harvesting efficiency is indicated as the relation between rainfall and amounts of harvested water. This includes an analysis of the seepage rate and the antecedent precipitation index. Section 4.1.2 gives the Irrigation Water Requirement of the experimental maize crop. Additional Cropwat simulations that provide dry spell analyses are presented in Section 4.1.3. Subsequently, the water availability from the RWH cisterns is calculated in Section 4.1.4. Results on the effect of irrigation are given in Section 4.1.5.

4.1.1 Efficiency in water harvesting

The first element to be considered when evaluating the rainwater harvesting efficiency, is the amount and intensity of rainfall. Figure 10 presents these data, that were obtained from the meteorological station at the field, also showing the start and end of the period in which the rainfall data can be connected to RWH. The total amount of rainfall was 484 mm, of which almost half (221 mm) fell in July.

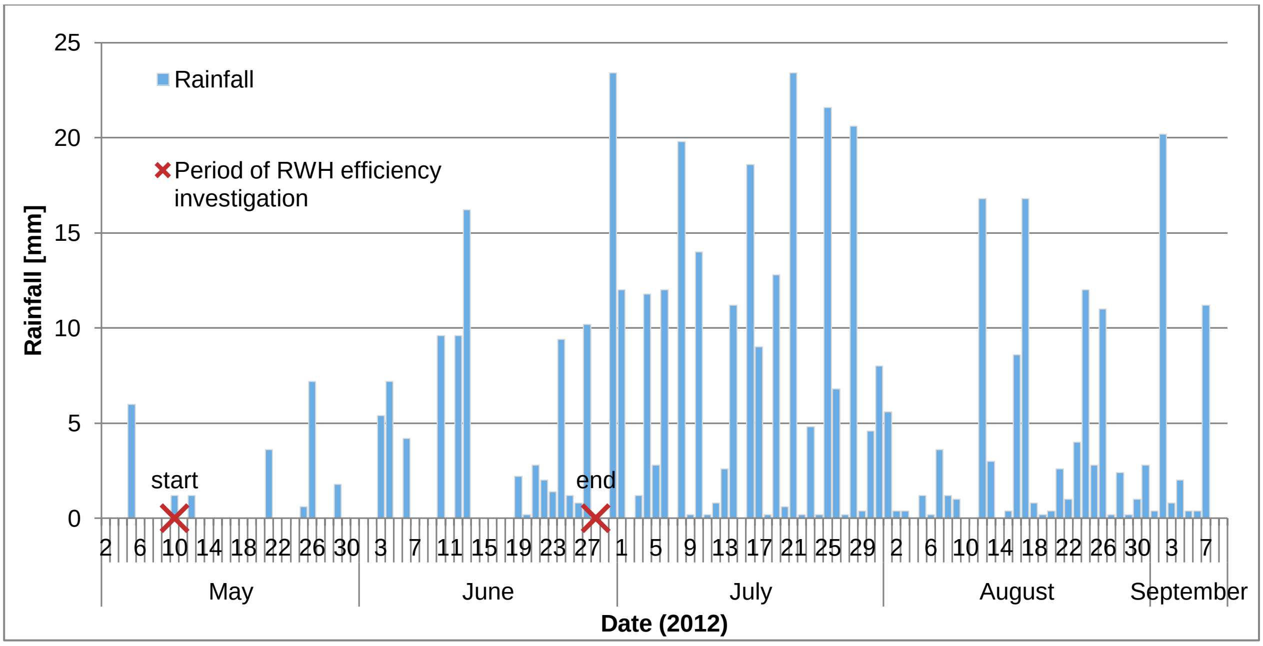

Figure 10 Daily rainfall from May 2 to September 9, 2012 (recorded by meteo station), with indication of start and end of the period of RWH efficiency investigation.

The other part of the analysis consists of measurements on the two RWH cisterns. The catchments are schematically drawn in Figure 11. The catchment of Cistern 1 measures 1.8 ha, consisting of agricultural lands. The maize fields in this catchment were sown at the end of May, the pepper was planted at the end of June and the teff field was fallow during the period of investigation. Cistern 2 has a catchment of 0.4 ha, that has a steeper slope than that of Cistern 1. The maize field at the top of the slope was installed in April. Figure 12 presents the trends in water levels of the RWH cisterns.

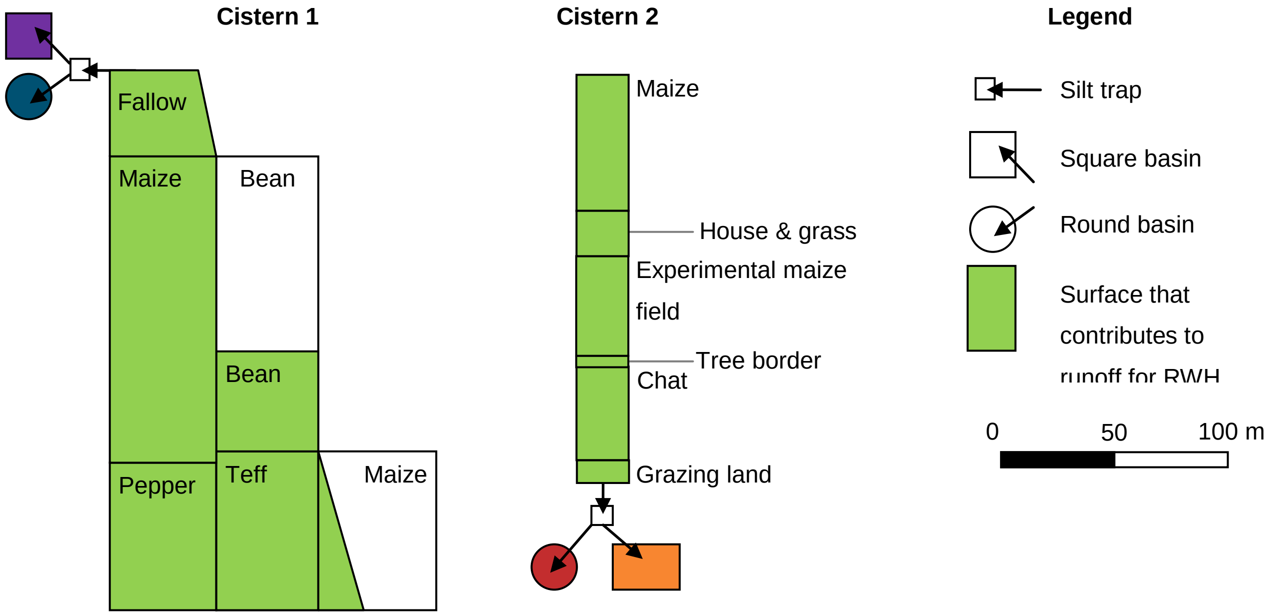

Figure 11 Schematic map of the catchments of the two Rainwater Harvesting cisterns. Cistern 1 has a catchment of 1.8 ha, Cistern 2 of 0.4 ha.

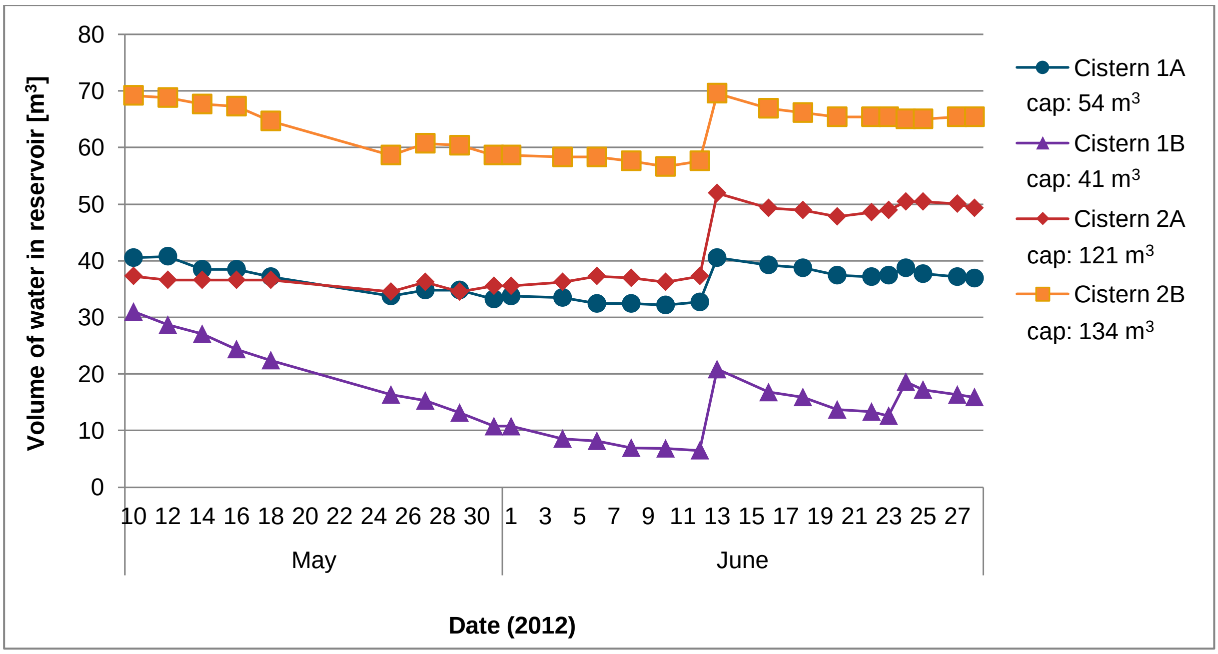

Figure 12 Trend of water volume contained by the different basins of the two cisterns, derived from water level measurements. In the legend, the capacity ('cap') of each basin is indicated.

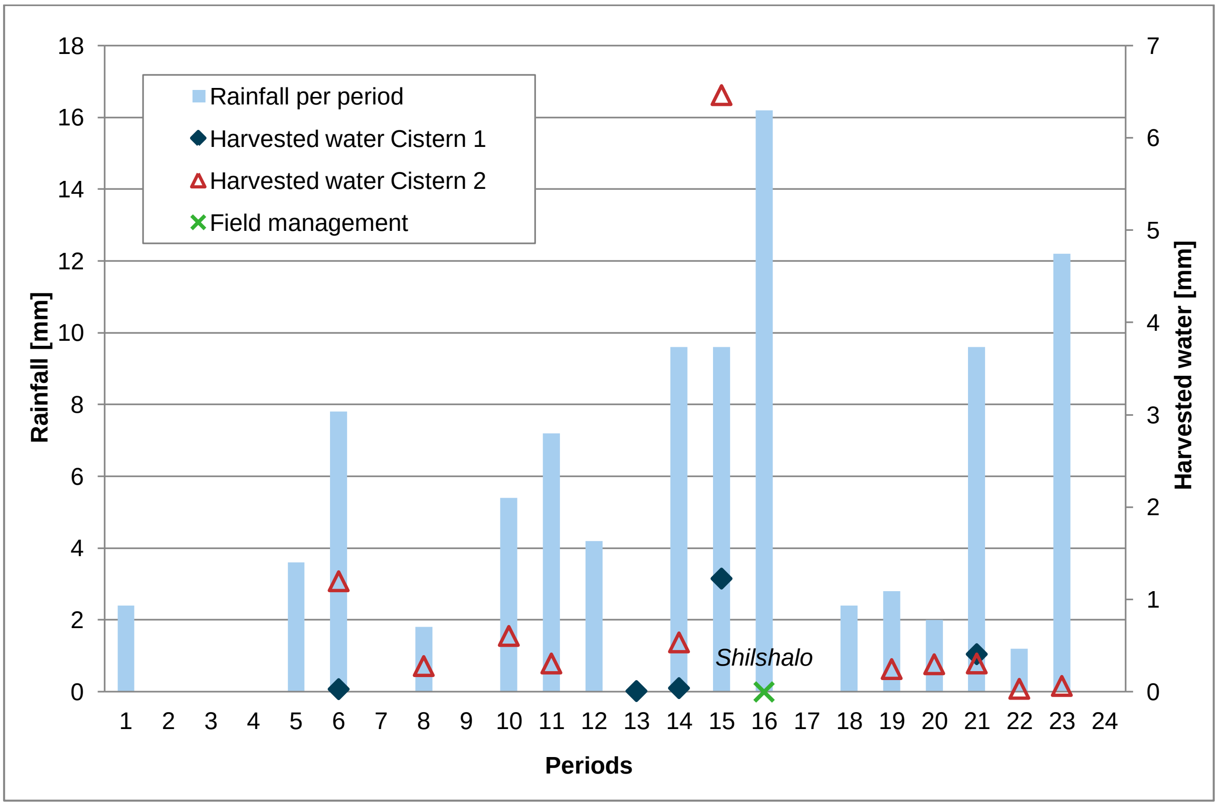

Figure 13 Comparison of rainfall and inflow in RWH cisterns.

The change in volume as measured in the cisterns was combined with the catchment surface area which resulted in an amount of harvested water in mm. Figure 13 shows the rainfall per period together with the amount of water that was harvested during that period. Period 6 was the first time during the research period that RWH took place. The rain in this period consisted of a small shower (0.6 mm, one hour) and 24 hours later a bigger shower of 7.2 mm in one hour. A rainstorm in period 5 (June 12: 9.6 mm in two hours) resulted in a total RWH of 7 mm. This rainstorm lead to flooding of the silt trap of Cistern 1. This caused substantial erosion of the bordering field. After this event, the owner of this pond used the disposed silt to create a small dike; this is visible in Figure 7 (1C). In total, Cistern 1 harvested 32 m^3 and the second cistern 44 m^3.

The amount of seepage was approached by comparing the measured trends of water volume (V_{final}, as in Figure 12) with the theoretical trends ($V_{final\ calculated}$). The result of this is visually represented in Figure 14. As explained in Chapter 3, the inaccuracy of measurements was taken into account. Analysis of the measurements showed that on average a difference in water level of 1 cm was equal to 0.3 m^3 of water. This amount of 0.3 m^3 has been subtracted from the difference V_{final} - $V_{final\ calculated}$. Table 3 shows the resulting rates of unexplained water losses, including seepage, in m^3/week.

Table 3 Unexplained water losses of the four reservoirs of Cistern 1 and Cistern 2, averaged over May 10 to June.

Cistern	1A	1B	2A	2B
Unexplained water loss [m^3/week]	0.5	2.8	-0.9	-0.1

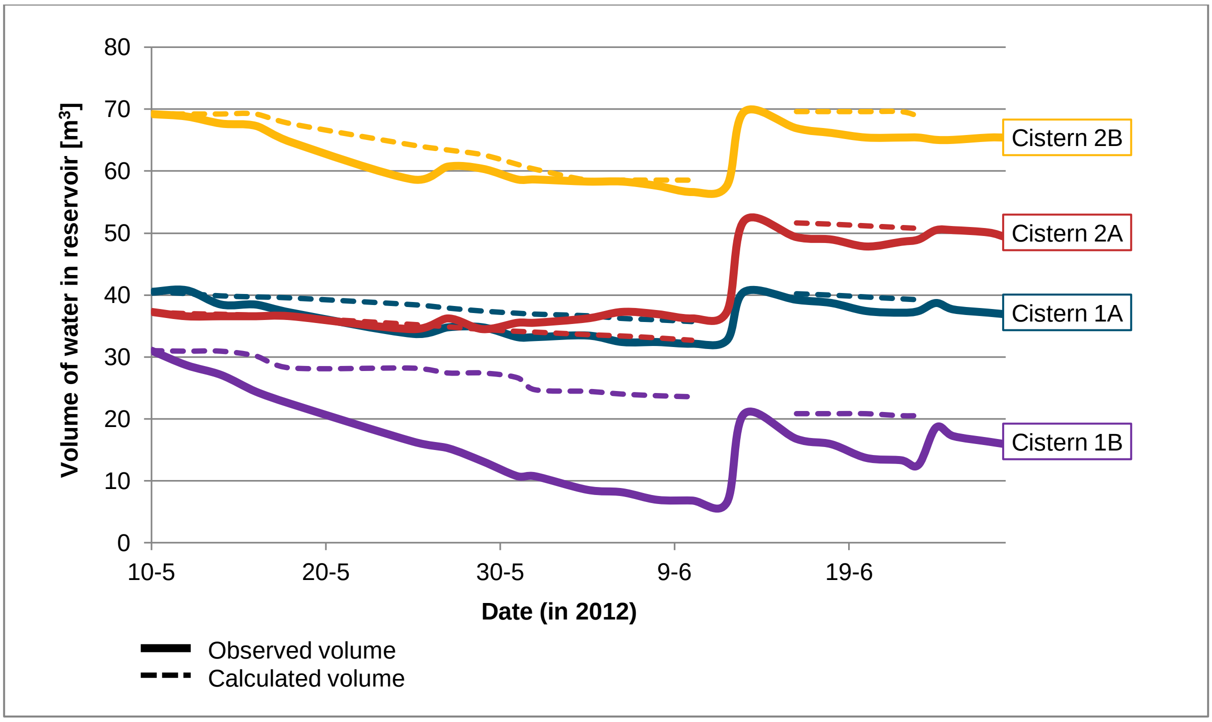

Figure 14 Graph of volume of water in the four reservoir (m^3), measured (solid lines) and calculated (dotted lines).

Figure 15 shows the outcome of the antecedent precipitation index (API) analysis: the development of API values over time, together with soil moisture values.

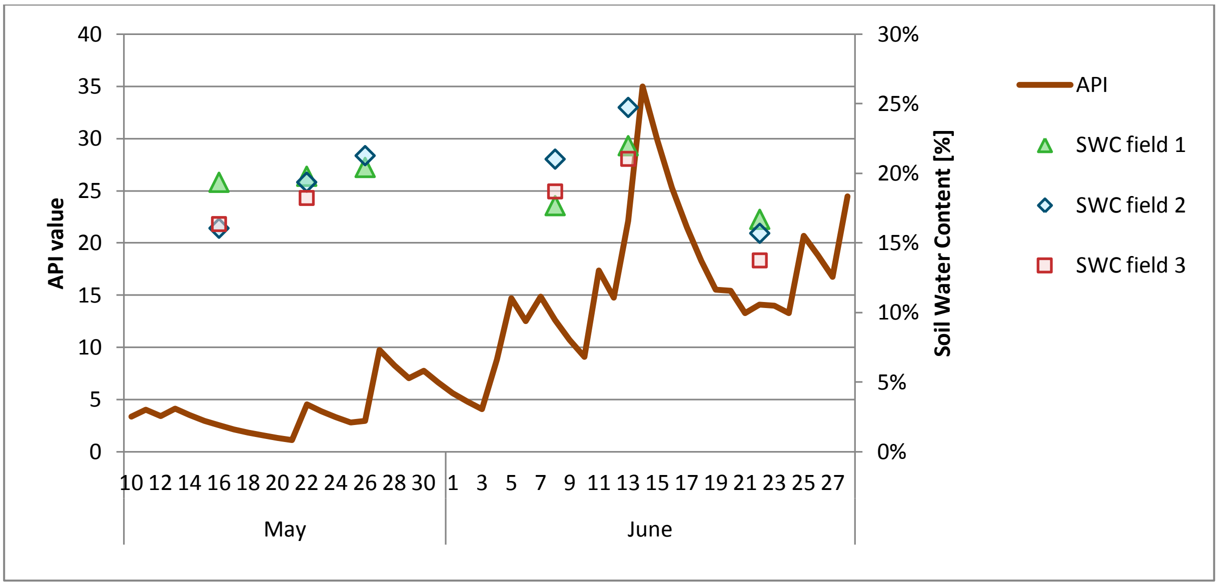

Figure 15 Antecedent Precipitation Index (API) compared to Soil Water Content (SWC) measurements of the three experimental fields at 0-20 cm soil depth.

4.1.2 Irrigation Water Requirement

The Cropwat analysis of the observed weather data resulted in two possible irrigation schemes for the maize cropping as it was done in the experiment, sown on May 2. One has a fixed net irrigation depth of 1 mm and one of 2 mm. The complete irrigation charts can be found in Annex V. They are summarised in Table 4. The schedule with 1 mm has 12 irrigation events of 1.3 mm (gross irrigation depth) each, which means 12 x 1.3 = 15.6 mm. The schedule of 2 mm uses 8 x 2.5 = 20 mm of water.

Table 4 Summary of two irrigation schedules for maize cropping simulated in Cropwat.

	Schedule 1	**Schedule 2**
Net irrigation depth (mm)	1	2
Gross irrigation depth (mm)	1.3	2.5
Number of events	12	8
Irrigation Water Requirement for 1 hectare (m^3)	156	200

4.1.3 Additional Cropwat simulations

A simulation with a later date of sowing, May 11, resulted in a schedule with no need of irrigation. This graph is also presented in Annex V. A variation of this simulation, simulating a prolonged dry spell starting from July 26 (when soil moisture depletion was only 2%), showed that the crop has no water stress until 18 days after the start of the dry spell. After this, the amount of irrigation should be 5 mm per event to keep the moisture depletion under the critical level. Figure 16 shows this in a graph.

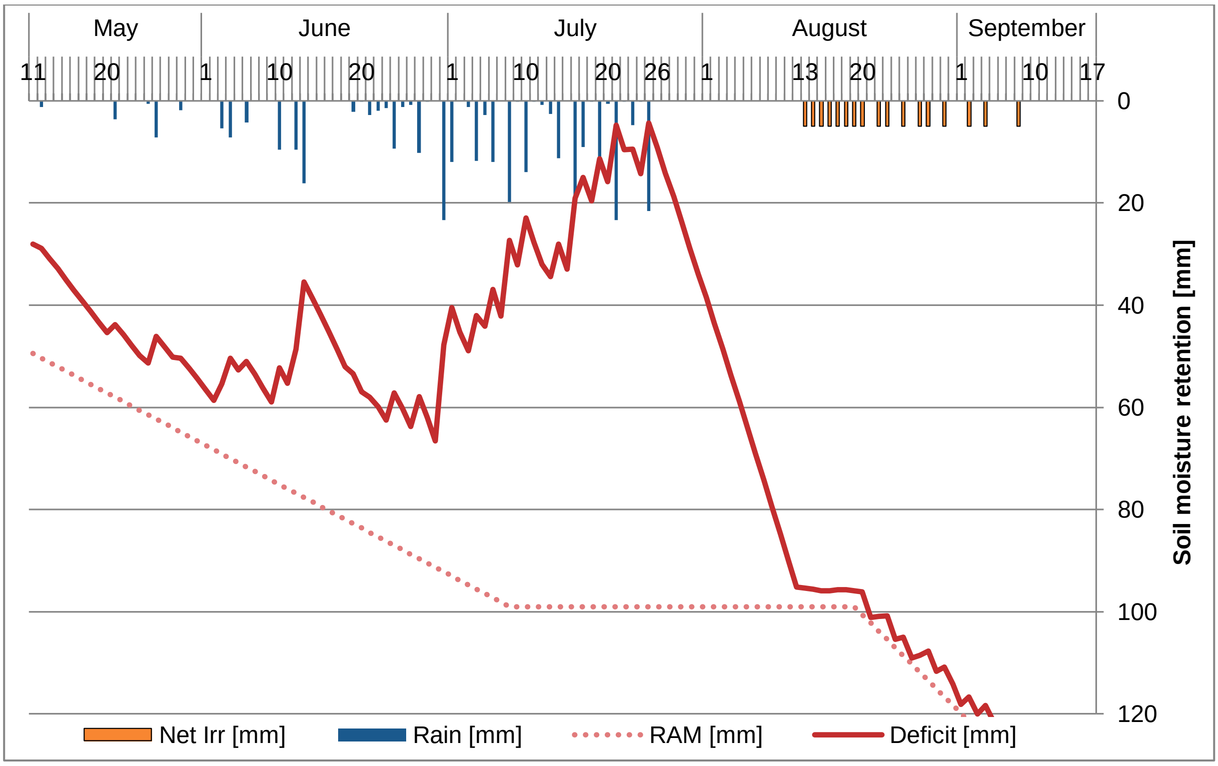

Figure 16 Irrigation chart for maize sown on May 11, with a simulated dry spell starting on July 26. First irrigation event is indicated at August 13.

4.1.4 Water availability from Rainwater Harvesting

The Irrigation Water Requirement that was calculated in Section 4.1.2 can be combined with the RWH data to find out the acreage for which supplemental irrigation is available. A simplified simulation was carried out, presented in Table 6 and Table 7. The measured volume of the basins was corrected for the volume used for actual irrigation (columns 2 and 3). For simulation, the volume was rounded down to whole numbers. For the periods where water was harvested, a certain amount of water was added to the volume. Because the cisterns have different sizes, the water availability was calculated for each cistern. The results are presented in Table 5. The table shows how much maize could be irrigated with the observed amount of water that was harvested by the two RWH cistern.

Table 5 Water availability from the two RWH cisterns under two different irrigation schedules.

	Irrigation depth 1 mm		Irrigation depth 2 mm	
	C1	C2	C1	C2
Optimal volume per irrigation event (m^3)	4.7	10	7.5	15
Irrigable acreage (ha)	0.4	0.8	0.3	0.6

Table 6 Simulation of maize irrigation according to Cropwat schedule of 1 mm/event. Optimal volume per irrigation event is 4.7 m^3 for Cistern 1 and 10 m^3 for Cistern 2.

	C1	C2
m^3:	4.7	10
ha:	0.4	0.8

Days of irrigation events	Volume water in cistern $V_{measured} + V_{irrigation}$		Volume water for simulation		Volume with Cropwat irrigation	
	C1 [m^3]	C2 [m^3]	C1 [m^3]	C2 [m^3]	C1 [m^3]	C2 [m^3]
31-5-2012	47.5	102.3	45	100	40	90
1-6-2012	48.3	103.1	45	100	36	80
2-6-2012	50.2	104.8	45	100	31	70
8-6-2012	50.2	104.8	45	100	26	60
9-6-2012	46.6	105.2	45	100	22	50
+			10	20		
20-6-2012	58.5	123.8	55	110	24	60
21-6-2012	58.5	123.8	55	110	19	50
22-6-2012	57.9	124.6	55	120	15	40
23-6-2012	57.7	125.7	55	120	10	30
+			5			
25-6-2012	62.6	126.8	60	120	10	20
26-6-2012	62.6	126.8	60	120	6	10
29-6-2012	60.5	126.1	60	120	0.80	0.00

Table 7 Simulation of maize irrigation according to Cropwat schedule of 2 mm/event. Optimal volume per irrigation event is 7.5 m^3 for Cistern 1 and 15 m^3 for Cistern 2.

	C1	C2
m^3:	7.5	15
ha:	0.3	0.6

Days of irrigation events	Volume water in cistern $V_{measured} + V_{irrigation}$		Volume water for simulation		Volume with Cropwat irrigation	
	C1 [m^3]	C2 [m^3]	C1 [m^3]	C2 [m^3]	C1 [m^3]	C2 [m^3]
31-5-2012	47.5	102.3	45	100	37.5	85
1-6-2012	48.3	103.1	45	100	30	70
2-6-2012	50.2	104.8	45	100	22.5	55
9-6-2012	46.6	105.2	45	100	15	40
+			10	20		
22-6-2012	57.9	124.6	55	120	17.5	45
23-6-2012	57.7	125.7	55	120	10	30
+			5			
26-6-2012	62.6	126.8	60	120	7.5	15
29-6-2012	60.5	126.1	60	120	0.00	0.00

4.1.5 Effect of irrigation

To indicate the influence of irrigation on maize yields in the experiment, the CC and plant heights measurements of plots with the same crop density (30 000 plants/ha) and different irrigation regimes are compared in Figure 17. The CC of the fully irrigated plots at 53 days after sowing is 1.4 times higher than that of the plots without irrigation. For the plant height, this is 1.2 times.

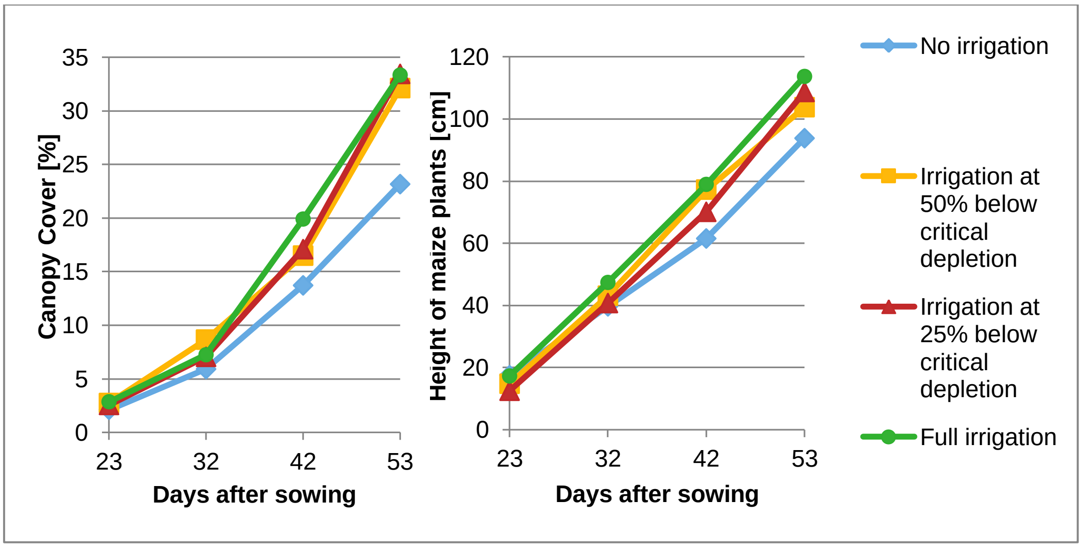

Figure 17 Canopy Cover and plant height measurements, averaged over three replications.

4.2 Current practice of respondents

This section, together with Section 4.3, presents the results of the socio-economic survey. The relation between maize cropping and perception of rainfall is presented in Section 4.2.1. Section 4.2.2 describes the farming systems and their production.

4.2.1 Maize and water shortage

Data from the survey provided an overview of the nature and timing of activities that are normally carried out for the cropping of maize. This is graphically presented in Figure 18. Sowing is mainly done in May. S*hilsalo* takes place about a month later. In November and December the maize is harvested.

The month of May is still part of the light rainy season. The green line in Figure 18 shows that in 2011 rainfall was unreliable in that month, since about one third of the respondents said there was not enough rain for their maize crop in May. The effect is aggravated because most of the maize is sown in this month.

To see in which crop stages the respondents perceived water deficiency, Figure 19 lists the maize cropping cycles that were reported in the survey. It is visible that most of the respondents leave their crop on the land after the official lifecycle of 180 days. The information for the figure was obtained per 15 days, like: “we have sown the maize in the first half of May, and in the second half of July there was not enough rain”.

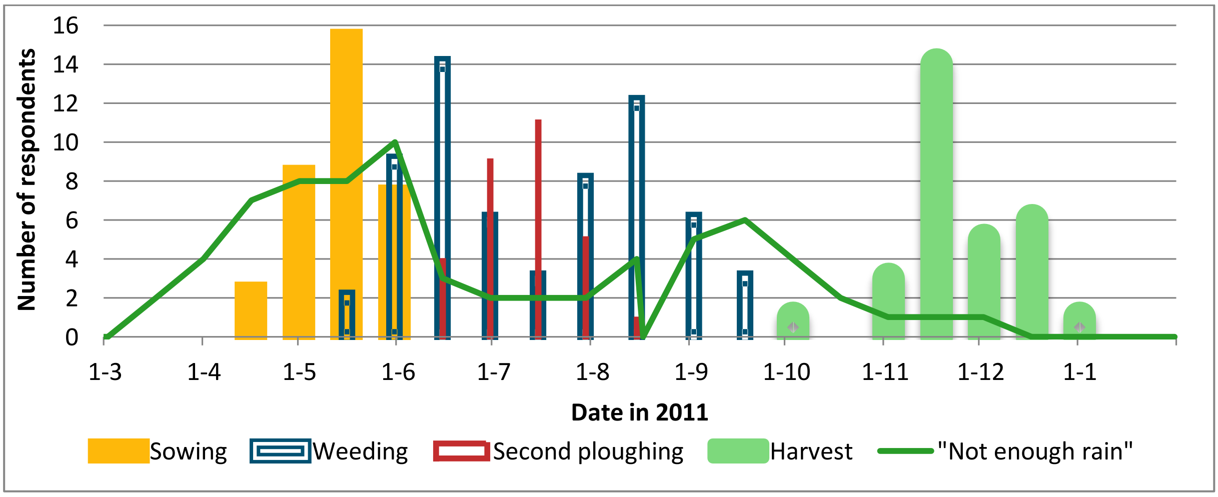

Figure 18 Graph with the distribution of maize cropping activities through the season.

Days after sowing:	0–15	15–30	30–45	45–60	60–75	75–90	90–105	105–120	120–135	135–150	150–165	165–180	180–195	195–210	210–225	225–240
FAO	Initial		Crop development			Mid-season				Late season						
				W1	P			W2	N	N	N	H				
		W1						N	N	N				H		
			W1;P						W2;N	N	N		H			
		W1;N	W2;P			N							H			
		W1	N		P			W2	N	N	N					H
		N	W1			W2	N	N	N	N						H
		N			W1	P	W2		N	N					H	
Irr.		N	W1;N		P		W2	N	N			N	N	N	N	H
		W1		P			W2						H			
			W1	P	W2							H				
		W1			P		W2					H				
			W1	P	W2									H		
			W1		P			W2								H
			W1			P		W2								H
			W1;N	P;N	N	W2								H		
		N	W1;N		P		W2						H			
		N	N	W1			P		W2				H			
			W1		P			W2							H	
	N		P	W1			W2				H					
		N	W1		P;N	N	W2					H				
			W1		P		W2						H			
				W1	P	W2							H			
			W1		P		W2						H			
			W1		P		W2						H			
	N		W1	P					W2				H			
			W1		P		W2						H			
	N	N	W1			P		W2					H			
			N	N	P		W2								H	
		W1		P			W2					H				
			W1		P		W2						H			
N	3	**8**	**6**	2	2	2	1	3	**7**	**6**	3	1	1	1	1	0

Figure 19 Comparison of crop cycles of the 2011 maize season from respondents (n=30) and FAO growth stages for East-African maize with a lifecycle of 180 days (Allen *et al.*, 1998). N = 'not enough rain' as indicated by respondents. Cropping activities are weeding (W1, W2), second ploughing (P) and harvest (H).

Figure 20 An example of the combined cropping of maize and chat on a homestead field.

4.2.2 Yields of farmers in Guba

According to the documentation of the maize variety *Awasa BH540* (EARO, 2004), the attainable on-farm yield is 5 - 6.5 ton/ha. From the survey data it becomes clear that yields of farmers in Guba are much lower. The survey respondents often have one field of maize, combined with chat (*Catha edulis*), close to the house (as in Figure 20), and another field with only maize at some distance. Besides this difference in location, there are also differences in the kind of fertilizing. The two types of maize cropping that are most common are the maize-chat combination with only natural fertilizer, and pure maize with chemical fertilizer. Table 8 gives the average size and production of these two types of cropping.

The 12 respondents that had a field with maize and chat where only natural fertilizer was applied, were all using manure from their animals. This was applied in two different forms: compost and separate manure. The compost, with or without manure, was applied once or twice during the season, often at seeding and second ploughing. Separate manure was applied at least once a week, often daily.

On the fields where only maize was grown and only chemical fertilizer was applied, all the respondents used DAP (diammonium phosphate). The average amount used per hectare of maize was 120 kg. About half of the respondents also applied urea (source of nitrogen) at an average rate of 80 kg/ha. The survey results do not point to a correlation between use of chemical fertilizer and production (Figure 21).

Table 8 Average size and production of maize plots from 20 survey respondents.

Cropping pattern	Average size of plots [ha]	Average production of maize [ton/ha]
Maize and chat, natural fertilizer (n=12)	0.4	1.3
Pure maize, chemical fertilizer (n=17)	0.6	1.6

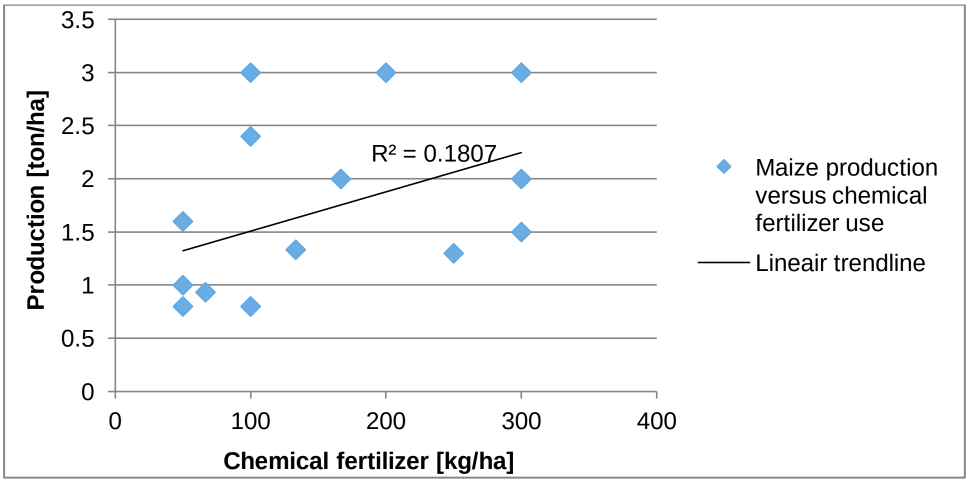

Figure 21 Maize production versus chemical fertilizer use of survey respondents on fields with only maize and receiving only chemical fertilizer (n=14).

4.3 Economical and social feasibility of a RWH cistern

The third research question puts the system of irrigating maize with water from a RWH cistern in the economical and social context of Guba kebele. The first section presents the costs and revenues of this system. In Section 4.3.2, the survey results are statistically analyzed. The last section (4.3.3) reports on the perception of respondents of the proposed system.

4.3.1 Costs and revenue

This section will first look at the costs of a RWH cistern with an irrigation system. Next, the revenue that can be obtained from an increased maize production is determined as Ethiopian Birr (ETB)/kg. These two amounts are compared to see how much extra production the system should generate to be economically viable for a farmer.

The reference case that is used is a farm with 0.5 hectare of homestead fields where maize and chat are grown. This is the average size of these kind of fields according to the survey. Other maize fields are further away. The RWH cistern that is built, is located close to the house since it is also used for cattle and household water use. This is why the fields at some distance from the house are not suitable for irrigation from the cistern without a mechanical pump. The 0.5 hectare of homestead maize fields are the only ones getting irrigation, which is not the maximum acreage (as seen in Table 6 and Table 7). 0.1 ha of those fields have chat and maize combined, and 0.4 ha is only maize.

The first step is to determine the costs of the proposed system. The construction of the RWH cisterns that are used in the experiment costs 16 480 ETB, about € 750,-. The composition of this amount can be found in Table 9. Additional maintenance costs are much lower. Once in 4-5 years the wooden roof structures need replacement; this costs 800 ETB (oral information from cistern owner). The yearly dredging and improvement of the cemented walls costs about 100 ETB.

Table 9 Costs of construction of a cemented RWH cistern (Source: oral information, Agricultural Office Alaba Woreda).

Cost	Unit price [ETB]	Number of units	Unit	Total price [ETB]
Cement	2	2100	kg	4200
Sand	700	4	trucks	2800
Stone	600	6	trucks	3600
Labour	14	420	man-days	5400
Total				**16480**

In addition to this, an irrigation system has to be installed. A drip irrigation system with a metal tanker on a cemented base to create height difference, costs 15000 ETB for a half hectare. So the total costs are 16480 + 15000 = 31480 ETB. Normally, a farmer will have to borrow this money. In Alaba, credit can be obtained from the Omo Micro Finance Institute. Loans from this institute have an interest rate of 18% (IPMS, 2005). If 31480 ETB is borrowed, the payback should be about 6000 ETB per year to solve the debt in 10 years. Add to this the yearly maintenance costs of 260 ETB and the yearly charge becomes 6200 ETB (≈ € 282,-).

In order to see whether it is possible for a farmer to pay 6200 ETB per year, we will look at the benefits. The benefits consist of two components: Money that is saved because no maize has to be bought, and money that is gained from selling surplus maize.

For the potential revenue from maize production, data from the survey is used. Farmers buy more maize than they sell: out of the 30 respondents, 15 only bought maize, 6 only sold it and 2 did both in 2011. The quantities that were bought and sold are displayed in Figure 22, which also shows the prices.

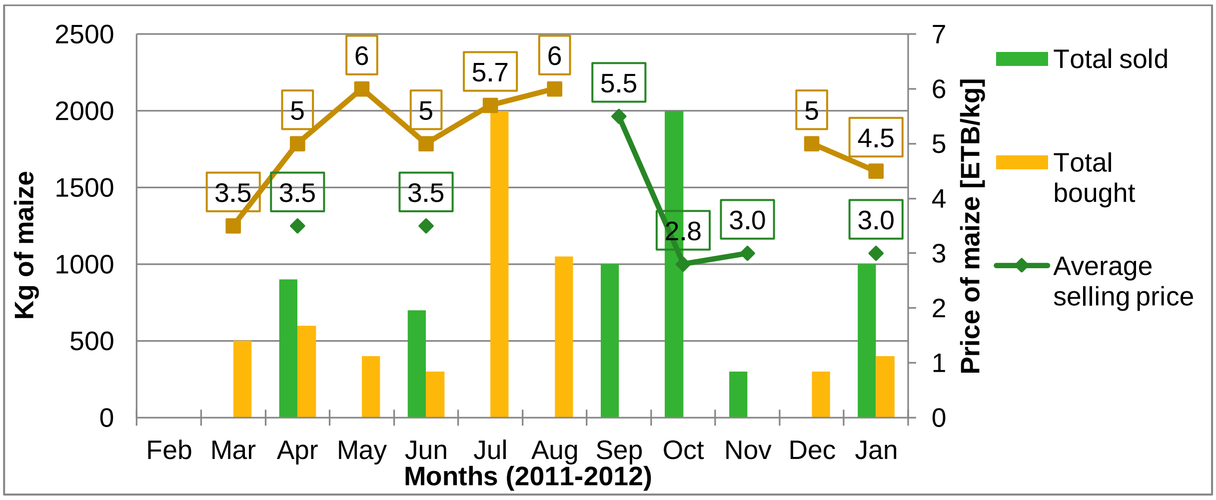

Figure 22 Maize trading by survey respondents (n=30).

Most of the respondents buy maize in July or August, for an average price of 5.9 ETB/kg. The average amount of maize that is bought throughout the year is 330 kg. Thus, from the additional maize production resulting from irrigation, 330 kg can be used for consumption which saves the household 330 x 5.9 = 1947 ETB. The rest of the surplus can be sold for a price of 5 ETB/kg. This is the selling price in September, which is a reasonable assumption since the experimental plots will also be harvested in September.

Table 10 Extra production needed per year to pay off investment in RWH cistern and irrigation system.

	Household consumption	Surplus for sale	Total
Amount [kg]	330	851	1181
Price [ETB/kg]	5.9	5	
Revenue [ETB]	1947	4253	**6200**

Table 10 shows that to pay back the loan, the increase in yield should be 1181 kg (1.18 ton). This amount can be applied to the reference farm described above.

The reference farm has 0.5 ha of irrigated maize fields, of which 0.1 ha also has chat plants. In Table 11 the required increase in production is used to calculate the productivity increase that should take place. To achieve a yield increase of 1.18 ton, the productivity should become 2.5 times higher than it is at the moment.

Table 11 Production increase that should be achieved with irrigation to yield 1.18 ton extra, calculated for reference farm size.

	Pure maize	Maize with chat	Total
Number of hectare	0.4	0.1	0.5
Normal productivity [ton/ha]	1.6	1.3	
Normal production [ton]	0.64	0.13	0.77
Required production [ton]	1.62	0.33	**1.95**
Required productivity [ton/ha]	4.1	3.3	
Required productivity increase factor	2.5	2.5	

4.3.2 Statistical analysis of survey results

In this section, five farm features are compared. They were chosen on the basis of the statistical analysis; only the correlations that were found significant are described, so only features that were part of these correlations are introduced in Table 12.

Table 12 Farm features that are part of the statistical analysis.

Feature	Range of values		Remarks
1. Owning a RWH cistern or not	no (n=22)	yes (n=8)	
2. Number of irrigated crops	0	12	
3. ETB spent on chemical fertilizer for maize	250	3800	Only one respondent did not buy any chemical fertilizer at all in this year.
4. Surface of fields with only maize	0	1.25	
5. Animal Unit (AU) used for manure	0	21	Cows, donkeys and horses: 1 animal = 1 AU; goats and sheep: 6 animals = 1 AU.

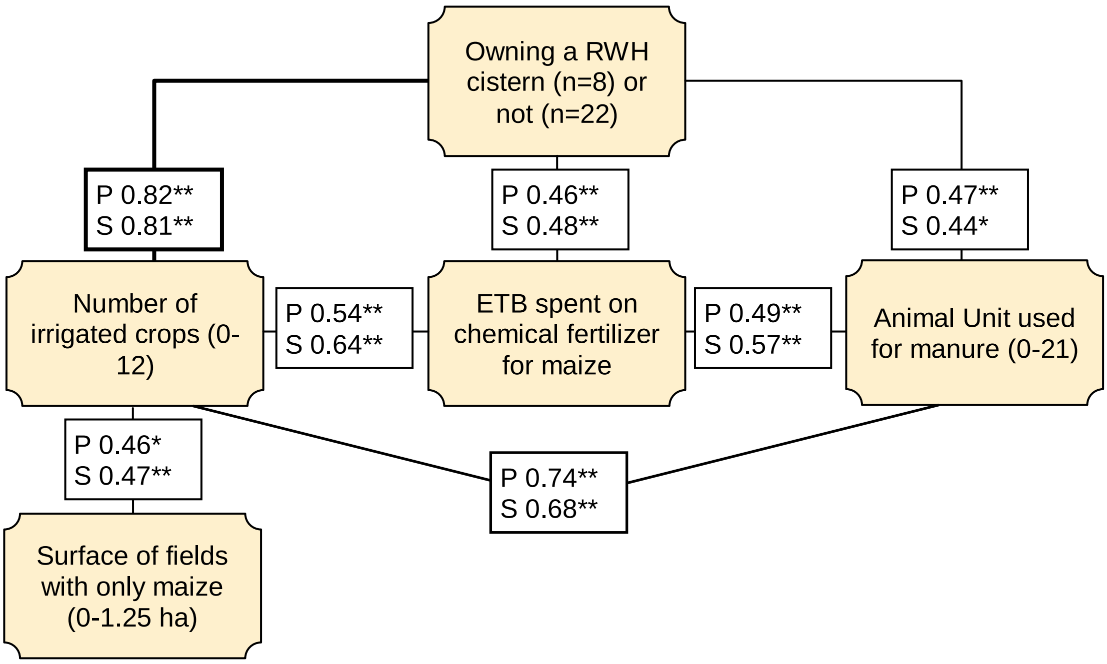

Figure 23 Results of statistical analysis of survey results (30 respondents). P=Pearson correlation. S=Spearman's rho. Significant correlations are flagged: ** for significance at 0.01 level and * at 0.05 level (2-tailed).

Figure 23 presents the results of statistical analysis of the farm features. Owning a RWH cistern is positively related with three farm features. The strongest of these is the correlation with the number of crops that are irrigated. The different crops and the percentage of respondents that irrigated them in 2011 are presented in Figure 24. These percentages are always for the total group, so if only 40% irrigated cabbage, it is likely that the other 60% did not grow cabbage at all since this crop mostly needs additional water. On the other hand, maize is grown by 100% of the respondents, so irrigation by one person (3%) means 97% of the people cropped maize without irrigation.

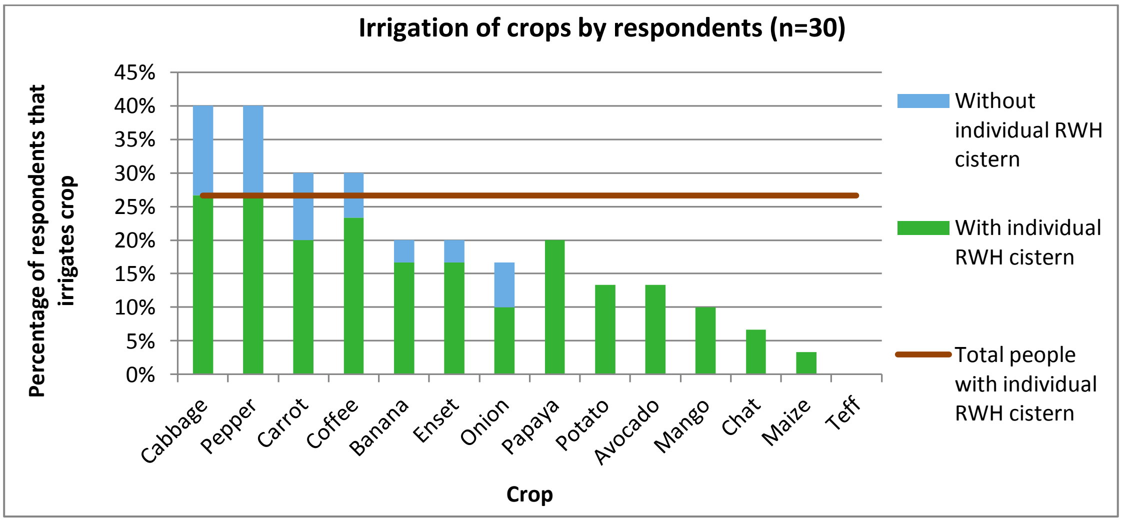

Figure 24 Graph of the percentage of respondents (n=30) that irrigated different crops in 2011.

The other two features that are related to having a RWH cistern are the amount spent on chemical fertilizer and the AU that is used for manure. The three features associated with a RWH cistern also strongly correlate amongst themselves. The number of irrigated crops and the AU can both be seen as wealth indicators, since they are so linked to each other.

The size of maize cropping, as expressed in the surface of fields where maize was grown without an added crop at the same time, does not have a correlation with the presence of a RWH cistern. It is however related to the number of crops that are irrigated, which is also an indicator of the size of a farm.

Figure 25 Manuda, a respondent who has a cemented RWH cistern, with his wife and a son. They show the maize plants that grow between the irrigated onions.

4.3.3 Perception about irrigation of maize

Only one of the respondents, Manuda (Figure 25), reported that he had applied water to his maize crop in 2011. In Figure 19 he is indicated with 'Irr'. Manuda irrigated the maize every three days in October, and once a week in November. The water came from his individual cemented RWH cistern.

None of the other respondents had irrigated their maize. In Table 13, all the mentioned reasons for this are listed.

Table 13 Reasons that are mentioned for not irrigating maize.

Reasons	Number of respondents that mentions this reason		Percentage of respondents that mentions this reason	
	From group with RWH (n=8)	From group without RWH (n=22)	From group without RWH (n=22)	Total average (n=30)
1. Water source is far away	0	15	68%	50%
2. Not enough water in cistern	5	1*	5%	20%
3. A pump would be needed	2	0	0%	7%
4. It is not common/instructed	2	0	0%	7%
5. Not enough labour for irrigation	1	0	0%	3%
6. The soil is sandy; does not retain the water	1	0	0%	3%
7. Enough rain	0	3	14%	10%

*) This respondent has a hand-dug earthen RWH pond

Chapter 5

Discussion

5.1 Water balance of RWH for irrigation of maize

The first research question is about the water balance of a RWH cistern that is used to irrigate maize. This section discusses the results that have been presented in Section 4.1. It starts with the efficiency in RWH (Section 5.1.1) and next looks at the use of this water for maize in terms of the Irrigation Water Requirement (Section 5.1.2), the water availability (Section 5.1.3) and the effect of irrigation (Section 5.1.4).

5.1.1 Efficiency in water harvesting

This section will discuss the results of the RWH efficiency analysis. First the characteristics of the catchments of the two RWH cisterns are analyzed. Then the relation between rainfall and water volumes in the cistern is discussed, including the question if seepage is taking place.

The size of the contributing area is quite different for both cisterns (Figure 11). Cistern 1 has smaller basins than Cistern 2 (see Figure 12), contrasting with its larger catchment area. The catchment of Cistern 2 has the steepest slope. This could lead to a higher flow velocity of runoff, and in that way to more erosion.

Figure 26 Maize field that contributes to run-off for Cistern 1.

Another difference is the land use on the two catchments. Cistern 1 has a maize field (Figure 26) followed by a fallow field close to the RWH silt trap. The catchment of Cistern 2 ends with a chat field, which is a perennial shrub crop. Fallow land and ploughed maize land is susceptible to erosion if overland flow is taking place. If they are located at the end of the catchment, the sediment has no possibility to settle down and the runoff that ends up in the silt trap will carry a lot of sediment. The chat field of Cistern 2's catchment could provide a more suitable location for sedimentation, because it is not ploughed and is covered with shrubs.

In short, there are two possible explanations for the fact that Cistern 2 has harvested the highest amount of water (44 m^3 versus 32 m^3) in spite of its smaller catchment. 1) Its catchment is steeper, facilitating a quick runoff of rainwater and 2) The chat field at the end of the catchment can allow the sediment to settle down, so that the silt trap does not get flooded. As mentioned in the results, the silt trap of Cistern 1 flooded once. This can point to excessive sediment delivery or too much overland flow.

Something that did seem to have an influence on the RWH process is the *shilshalo* practice. In period 16, the rainfall was more heavy than in the previous period, but no RWH could be observed. This could be related to a field management practice that took place on June 13, seven hours before the rainstorm. On the experimental field that is part of Cistern 2's catchment *shilshalo* was carried out. One of the targeted effects of this technique is to increase moisture conservation in the soil. The ridges also increase infiltration and ponding of rainwater on the field, and in this way hinder RWH. So the *shilshalo* of June 13 can be responsible for the absence of RWH in period 16.

On the scale of household RWH systems, it is likely that part of the catchment area is also receiving irrigation from the RWH cistern. If there is rainfall occurring, ridging the field through *shilshalo* could be the most efficient way to harvest rainwater (in situ). But a reservoir with stored water will then still be needed to bridge the times when there is no rainfall. For staple food grains, Awulachew *et al.* (2005) recommend in situ RWH, because according to them "... the high costs of irrigation can often be justified only if farmers grow high value crops for the market (Awulachew *et al.*, 2005)".

The second part of this section discusses the relation between observed rainfall and water volumes in the cisterns. The results as presented in Figure 13 do not show a pattern in the relation between rainfall and harvested water. The fact that the main rains did not fall during the period of RWH efficiency investigation (Figure 10) can explain why a real relation between rainfall and the amount of harvested water could not be found. During the period of RWH investigation, the transition from the light to the main rainy season took place. Remarks from farmers point out that the month of May had less rain than expected. The observed rainfall (Figure 10) corresponds with the *kiremt* season, that was indicated to run from June to September (Seleshi & Zanke, 2004).

An analysis of the antecedent precipitation index (API) does not explain the irregular pattern of RWH. Figure 15 shows that the soil moisture is notably constant in relation to the changing API. This means that soil moisture values are not influencing RWH fluctuations.

From Figure 14 it can be seen that the graph of the square basin of Cistern 1 (1B) is much steeper than its corresponding 'calculated' line. Unexplained water loss takes place at a rate of 2.8 m^3/week. The volume of the other basins also differs from the theoretical trend, calculated on the basis of water use and evaporation. These differences can be accounted to a number of things. The measuring of water levels or the conversion to volume can contain mistakes. The record keeping of water use by the households is also not totally reliable. The fact that Cistern 1B is showing a significant amount of unexplained water loss could indicate that seepage is taking place from that basin. The owner of the pond also confirmed that even during heavy rainfall the volume of water in this cistern did not increase, which suggests a crack in the cement.

5.1.2 Irrigation Water Requirement

The second point of attention was the irrigation of maize as a possible way of using the harvested water. This will be discussed in this and the coming sections.

The irrigation charts resulting from the Cropwat analysis in Annex V show that soil moisture drops during May, because of the little rainfall in this month. In June, irrigation events are indicated. From July onwards the rain is sufficient to sustain the crop until harvest. There are two possible irrigation schemes; one of 1 mm net depth per irrigation event and one of 2 mm. The drip irrigation system that is most widely used in the region does not include a pump, so the barrels at the start of the irrigation lines are filled manually with watering cans (Figure 27). This limits the amount of water that can be applied during one irrigation event. Because of this, a fixed application depth was used. 1 mm is the minimum amount that can be processed by Cropwat, so a smaller amount could not be investigated.

Figure 27 Irrigation of one of the experimental fields.

The schedule with 1 mm is most efficient, since it uses 15.6 mm in total. The advantage of the second schedule is that it has less irrigation events, which makes it more feasible to actually carry out.

If the sowing would have taken place 9 days later, on May 11, no irrigation would have been needed. This shows how the planting date is an important factor in determining the Irrigation Water Requirement for a crop. Farmers usually sow later in the month, which would have been a good choice for this year.

The soil texture is also influencing the IWR. Barron *et al.* (2003) found that for a sandy soil, a maize crop underwent more frequent and prolonged dry spells than meteorological rainfall analysis suggested, because the water holding capacity of this soil is low. In this sense, the farmers in Guba have the advantage of a good soil texture, namely loam.

5.1.3 Water availability from Rainwater Harvesting

Calculating from the observed volumes of water in the cisterns, they could support 0.3-0.8 ha of maize during the observed period (see Table 5). This scenario uses minor irrigation events of 1 or 2 mm depth per event.

From simulations of a dry spell, it turned out that the initial moisture depletion of the soil determines the period that a crop can go without water. Working with the observed data and a simulated dry spell starting on July 26, the maize plants did not need irrigation until 18 days after the drought started. This can be explained by the fact that on July 26, soil moisture depletion was only 2%. After this period, the irrigation that is needed is 5 mm per event, with a frequency of one event per day. Assuming that the cisterns are filled up to their capacity and there is 0.5 ha of irrigate maize, Cistern 1 could provide water for 3 events and Cistern 2 for 8 events. This means it can get the crop through a dry spell of 18+8= 26 days.

The paradox that occurs, is that supplemental irrigation is needed when there is little rain, in this case mainly in June. But when there is little rain, there is also little RWH. This limits the opportunity for supplemental irrigation. Moges *et al.* (2011) mention this as one of the inherent limitations of RWH systems: water availability is still dependent on rainfall conditions. Their simulations based on data from the CRV showed that these systems "can only provide supplementary irrigation water needs in or near to the rainy season (Moges *et al.*, 2011)".

5.1.4 Effect of irrigation

The different irrigation regimes have not been applied very strictly during the period of investigation, but what can be seen is the difference between plots without irrigation and those with irrigation. Figure 17 shows that irrigation does positively influence plant growth, but it cannot be concluded what the effect of this will be on final yield.

5.2 Current practice of respondents

The results of the socio-economic survey will be discussed in this section and the next (Section 5.3). This section is divided into the perception of water shortage (Section 5.2.1) and the farming systems (5.2.2).

5.2.1 Maize and water shortage

Most of the perceived rain shortage was at the beginning of crop development and in the late season. That last result is somewhat surprising, since the maize plants do not need a lot of water once they are mature. Water stress during the vegetative phase is also not critical (Barron *et al.*, 2003). Payero *et al.* (2009) found that at 12-14 weeks after crop emergence, maize is sensitive to water stress. Figure 19 shows that about this time (mid-season: the reproductive period between full cover and maturity), respondents did not experience a lot of rain shortage. Nyakudya and Stroosnijder (2011) also mention the reproductive stages of the crop as being sensitive to water deficiency: the flowering and grain filling stages.

5.2.2 Yields of farmers in Guba

The results describe the different farming systems of growing maize: homestead fields combined with chat and larger fields at some distance. Growing chat between the maize plants influences cropping density and nutrient availability, but seems to cause only a minor decrease in production of maize. This can partly be explained by the observation that the chat plants on these fields only occupy a minor part of the surface. Furthermore, these plants grow close to the house and are well supplied with natural fertilizer.

The local production of maize in normal years is circa 1.5 ton/ha. The gap between the official attainable yield and the production of the survey respondents can be attributed to a lot of different aspects, like the optimal use of fertilizers, the influence of soil type and crop management (ploughing, weeding).

5.3 Economical and social feasibility of a RWH cistern

The combination of the foregoing discussions takes place in this third section. Section 5.3.1 discusses the costs and revenues of this system. In Section 5.3.2, the statistical analysis of the survey results is discussed. The last section (4.3.3) discusses the perception of respondents of the proposed system.

5.3.1 Costs and revenue

For a RWH cistern with a drip irrigation system to be economically viable, the productivity of irrigated fields should become 2.5 times higher than the current yield. This is a big increase, although the production would still be well below the officially attainable on-farm yield. If this increase cannot be achieved, it is a logical choice for a farmer to just buy maize every year. But in regard of the harvest failures that occur regularly due to the erratic rainfall pattern, there should also be another view on this choice. In case of a harvest failure, buying maize is not a solution because there hardly will be maize on the market. As suggested by Awulachew *et al.* (2005), increased productivity of staple grains is an important element contributing to the achievement of food security in Ethiopia. “To meet future increased food demand in SSA, current farming systems need to be more efficient in both farm water and nutrient management. (Barron & Okwach, 2005

5.3.2 Statistical analysis of survey results

The survey statistics show that a RWH cistern facilitates crop diversification. Respondents that own a RWH cistern also spend a relatively big amount of money on chemical fertilizer for maize and have more animals that are used for manure. These last two factors can be seen as wealth indicators. If a farmer is well-off, he can afford to buy enough fertilizer to feed his crops and he will have a relatively big stock of cattle. These two correlations are notable weaker than the number of irrigated crops. It is likely that the three features that correlate with the presence of a RWH cistern are more influenced by the cistern than the other way around. This is deducted from the fact that the eight respondents having a cistern got it for free from Sasakawa Global 2000 (oral information from respondents). Thus, their wealth status before they had the RWH cistern did not necessarily influence the presence of the cistern, since they did not have to invest. However, this scenario also cannot be excluded, since wealth and social status may lead to preferential treatment during an NGO programme.

When asked about the reason why people do not irrigate their maize, the answer most often heard was that their source of water, either a community RWH pond or a deep groundwater well, is too far away to get enough water for irrigation (Table 13). Looking at Figure 24, it is clear that there is a relation between irrigating crops and having an individual RWH cistern, so the proximity of a water source is an important element. But this obstacle may not be the decisive one since respondents that do have a source of water nearby, an individual RWH cistern, are also not irrigating their maize crop. This group is mainly saying that irrigating the maize fields consumes a lot of water; either their cistern does not hold enough water, or a pump would be needed to deliver such an amount of water to the plants. Because maize is a staple crop, the plots are much bigger than those where vegetables are currently cropped with irrigation. So even if the water source is at hand in the form of a RWH cistern, the irrigation of maize is not perceived as a feasible option.

Currently, if RWH cisterns are used for irrigation in Guba it is almost exclusively cash crops and vegetables for home consumption that are grown with it. The cisterns are also important for domestic use (Figure 28), a benefit that is shared with the neighbouring households.

Something that does not show in Table 13, is the first reaction of respondents when the possibility of irrigating maize came up in the questions. This was perceived as a strange idea; regardless of the practical reasons not to irrigate maize, it is just almost unthinkable to spend precious water on a common crop like maize. This could be because they see maize as a ‘low-value’ crop (Barron & Okwach, 2005).

Figure 28 A woman fetching water from Cistern 2.

Chapter 6

Conclusions & Recommendations

In this thesis, we have looked at several aspects of Rainwater Harvesting (RWH) in the context of smallholder farming in the Central Rift Valley of Ethiopia. This final chapter will present the conclusions of the research an give some recommendations. It is divided into the issue of Rainwater Harvesting efficiency (Section 6.1), water availability from RWH for irrigation (Section 6.2) and the socio-economic feasibility of using RWH cisterns for irrigation of maize (Section 6.3).

6.1 Rainwater Harvesting efficiency

The study area is a village called Guba in Alaba woreda. The first part of the research aimed at investigating the efficiency in rainwater harvesting of two RWH cisterns at an experimental field. The cistern with the smallest and most steep catchment had the highest amount of harvested water. The other cistern experienced flooding of the silt trap one time. If the practice of *shilshalo*, second ploughing of the field, is carried out on a field that contributes to runoff for RWH cisterns, the runoff can decrease.

From the results, the following recommendations can be made for the design of RWH cisterns:

- Take into account the sediment load that comes with the runoff from the catchment. For example by creating a sedimentation zone where the water slows down and the sediment can settle before it reaches the RWH silt trap.
- Increase the size of the silt trap if the sediment still causes flooding.
- Consider the effect of management practices that will be carried out on fields that are part of the catchment.

An issue for further research is how in situ RWH (like *shilshalo*) and ex situ RWH (like the investigated cisterns) can best be combined.

6.2 Water availability for irrigation

The second point of attention was the irrigation of maize as a possible way of using the harvested water. A simulation was carried out in Cropwat, with meteorological data from May - July 2012. It followed that the water from the two investigated cisterns would be enough to irrigate 0.3-0.8 ha of maize. The results confirmed the observation of Moges *et al.* (2011): an inherent limitation of ex situ RWH systems is the dependence of water availability on rainfall.

6.3 Socio-economic feasibility

Finally, we will give some conclusions on the question if the irrigation of maize from a RWH cistern is a feasible option for the farmers of Guba. The results of the survey show that a strong effect of the use of a RWH cistern is irrigation of various crops. The revenue that is obtained from selling these extra crops was not taken into account in this thesis, since the analysis was only about traditional cropping of maize versus maize with supplemental irrigation. Maize that is grown on homestead fields could be irrigated with water from a RWH cistern, since these cisterns are usually located close to the house. If a RWH cistern is installed for the irrigation of 0.5 ha maize and should be paid back in ten years, the productivity of this crop should become 3-4 ton/ha, which is 2.5 times higher than current yields. If this cannot be achieved, it would not be economically feasible for the individual farmer to irrigate his maize. The general social perception is also not positive towards irrigating maize. In this case, if the Ethiopian government wants to stimulate supplemental irrigation of maize in the context of regional food security, it will have to take subsidiary measures. The following measures are recommended:

- The construction of cemented RWH cisterns would be a good choice, as opposed to the plastic lined ponds that are mobile and can be deconstructed (van Hulst, 2012) or the drip irrigation tubes, for which the same could be true.
- Provide credit for it at a lower interest rate than the current 18%. In this way, the choice to invest in this system can be facilitated.

Hopefully, this thesis has given insight about the role of RWH harvesting in the ongoing quest to improve the livelihoods of smallholder farmers. I follow Kofi Annan in his search for viable options that increase food production and will indeed lead to a green revolution in Africa.

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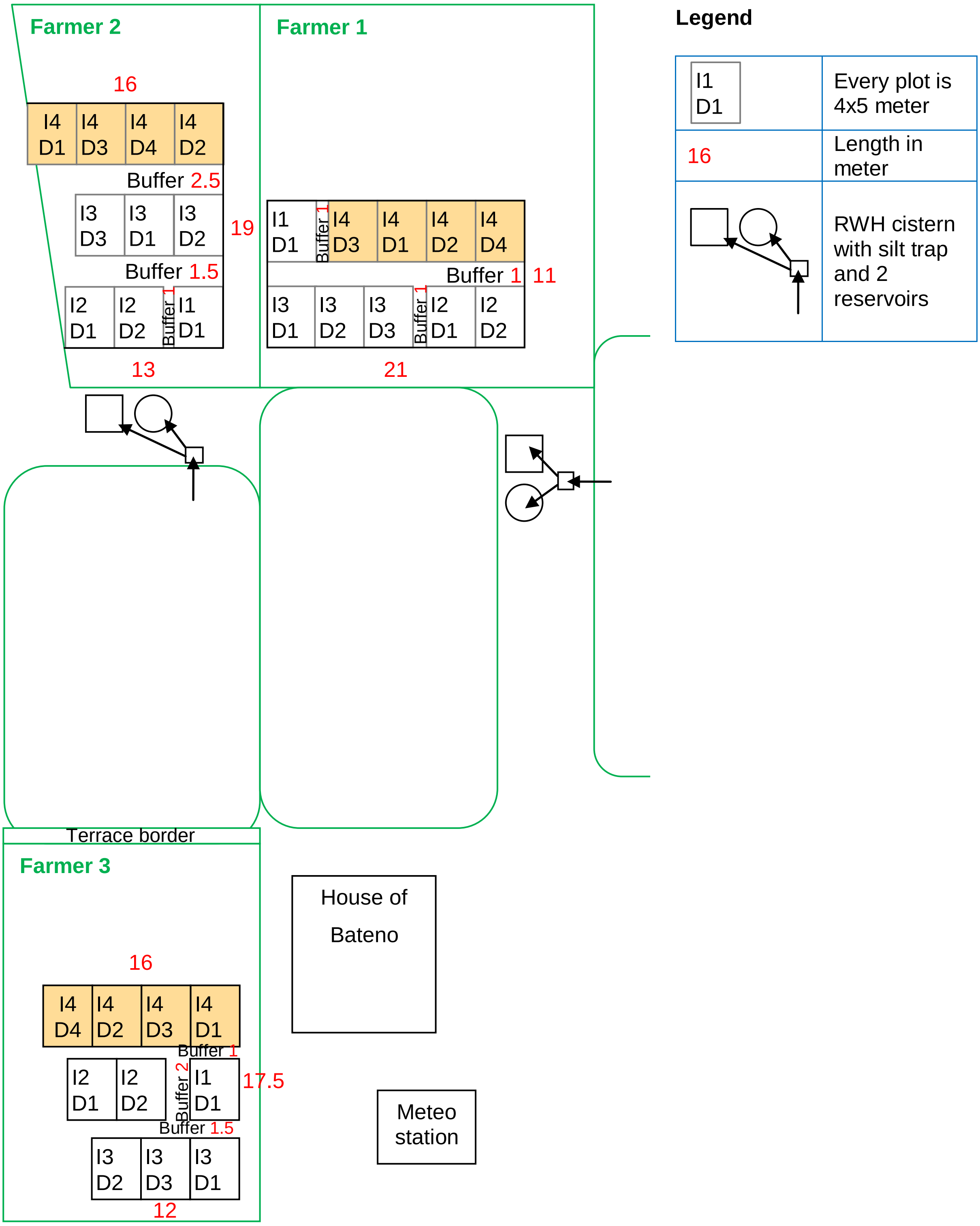
Annex I Schematic map of research plots



Annex II   Determination of method for estimating Canopy Cover

In order to choose a method for estimating the Canopy Cover (CC) of the maize on the different plots, a short test was done on paper. On a sheet of 25x18 cm (surface area 450 cm^3), random blocks were drawn, see Figure 29. Compared to the plots of the experiment, the scale is about 1:20. The area occupied by the blocks represents the part of the soil that is shaded by the crop. This was determined to be 110 cm^3, which leads to a CC of 100*(110/450) = 24.4%. Five different methods, summarized in Table 17, were compared. In this Annex, the methods and their results will be described.

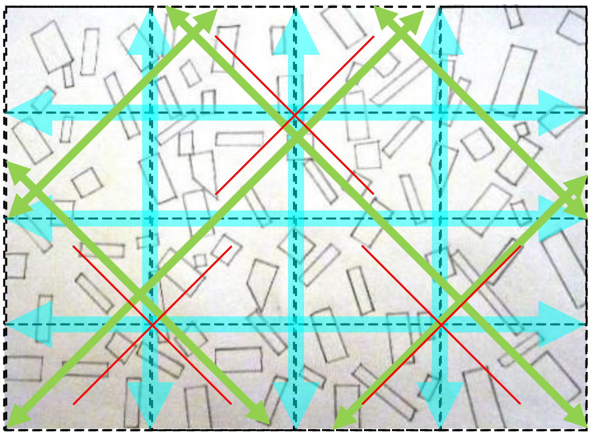


Figure 29 Test sheet for testing different CC methods. The red crosses are used for method 1, the blue arrows for methods 2-4 and the green arrows for method 5.

Method 1

This method tested the option of using a stick of 2 meter to determine the CC, as described by Mhirza (year). On this scale, a line of 10 cm was used. Three crosses were made as indicated in Figure 29. On these 6 lines, the mm that were shaded were counted. As can be seen in Table 14, the resulting CC was 32.5%, which is too high.

Table 14 Result of method 1

Line	Counted mm
1	42
2	19
3	36
4	17
5	47
6	43
Total	**195**
CC	195/6 = **32.5 %**

Method 2, 3 and 4

Method 2 was a simulation of a transect line with knots every 0.5 cm. Six transects were made horizontally and vertically, as the blue arrows in Figure 29. The result was a CC of 23.7%. To test the accuracy of the knots-method, method 3 used the same lines but measured the exact amount of mm that were shaded. The result was satisfactory: the CC was also 23.7%. Method 4 simulated the use of a rope with knots every 1 cm. This resulted in a CC of 30.4%. All the results can also be found in

Table 15.

Table 15 Results of method 2-4

Transect	Method 2			Method 3			Method 4		
	Shaded knots (A)	Total knots (B)	A/B	Shaded mm (C)	Total mm (D)	C/D	Shaded knots (E)	Total knots (F)	E/F
1	11	50	Average: 0.237	42	250	Average: 0.237	6	25	Average: 0.304
2	12	50		54	250		7	25	
3	9	50		52	250		9	25	
4	11	36		58	180		7	18	
5	9	36		51	180		5	18	
6	8	36		40	180		5	18	
CC [%]			23.7			23.7			30.4

Method 5

This method made six diagonal transects like the green arrows in Figure 29. ´Knots´ were made every 0.5 cm. The result can be found in Table 16.

Table 16 Result of method 5

Transect	Shaded knots (A)	Total knots (B)	A/B
1	6	28	Average: 0.235
2	14	52	
3	5	36	
4	8	36	
5	18	52	
6	8	36	
CC			23.5

Conclusion

Table 17 lists the outcomes of the five methods that were tried. The method with the stick scores worst, it overestimates the CC by more than 8%. This can be explained by the fact that this method covers a relatively small part of the plot. Although it is very exact in measuring the precise length of the shadow in mm, this does not lead to a credible estimation of CC. A transect method with a rope is able to cover much more of the plot. At the scale of the test sheet, a distance between the knots of 0.5 cm represents 10 cm. Seeing the result of method 2 and 3, this is a good way of estimating CC. It is important to not increase this distance, as this leads to much less accurate CC estimates (method 4). In the end, the orientation of the transect lines seems not to matter, as the diagonal lines give a comparable result to the vertical and horizontal lines. In a field with maize, it will be important to take the transect lines diagonally to the crop rows.

Table 17 Tested methods for estimation of CC

Nr	Method	Direction of transects	Distance between knots	CC [%]
Exact determination of surface blocks				24.4
1	Stick	n.a.	n.a: exact mm	32.5
2	Transect	Horizontal + vertical	0.5 cm	23.7
3	Transect	Horizontal + vertical	n.a: exact mm	23.7
4	Transect	Horizontal + vertical	1 cm	30.4
5	Transect	Diagonal	0.5 cm	23.5

Annex III Socio-economic survey questionnaire

Date:
Kebele & cluster:

Enumerator & Translator:
Name of Household Head:

General questions

1. Do you have an individual cemented pond? □ Yes □ No

   If yes: Do you use the water for… □ Drinking □ Household □ Animals □ Crops ?

2. In the last year, did you use water for any crop? If yes, which crops?

   □ Cabbage □ Chat □ Onion □ Carrot □ Coffee □ Banana
   □ Berbera □ Potato □ Enset □ Maize □ Teff □ Other:

Can we see the plot(s) where you have grown maize?
→ Go to calendar (other page)

3. Did you have shortage of workforce for the maize?	□ Yes □ No		
4. How much compost did you use for the maize?	________Kg		
5. Was there manure in the compost?	□ Yes □ No		
6. Did you use separate manure for the maize? If yes: a. How often? b. For how many hectares?	□ Yes □ No		
7. How much of these animals did you have in 2003? Did you use it for manure?	Animal:	Number in 2003:	Manure used:
	Cattle (oxen+cow)		□ Yes □ No
	Goat		□ Yes □ No
	Sheep		□ Yes □ No
	Donkey		□ Yes □ No
	Horse		□ Yes □ No
8. How much chemical fertilizer did you use for the maize? How much money did that cost you?	Name fertilizer:	Amount (kg):	Price:
9. From where do you buy chemical fertilizer?			

10. Did you use extra water for the maize? □ Yes □ No
    If yes: How many times?
    If no: Why not?

Information about <u>maize</u> production and trading in the agricultural year 2003-2004

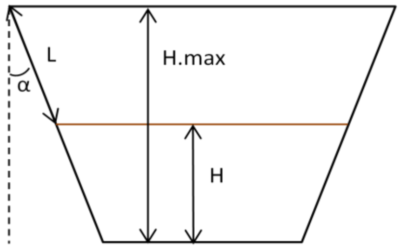
Fields:	1	2	3
Together with chat/bean			
Size (ha)			
Type(s) fertilizer (compost/chemical)			

				Activities on the field: 1Ploughing 2.Sowing 3.Weeding 4.Harvesting 5.Fertilizing **N=not enough rain**		Maize sold (Q and price)		Maize bought (Q and price)
2011	Febr	2003	Yäkatit					
	March		Mägabit					
	April		Miyazya					
	May		Gənbot					
	Jun		Säne					
	July		Ḥamle					
	Aug		Nähase					
	Sep	2004	Mäskäräm					
	Oct		Ṭəqəmt					
	Nov		Ḫədar					
	Dec		Taḫśaś					
2012	Jan		Ṭərr					
	Feb		Yäkatit					
Fresh harvest (Quintal)								

Annex IV Method of converting water level RWH cisterns to volume

Coloured fields are directly measured, others are calculated.

	Half spheroid shaped basins		Trapezoidal shaped basins	
	Cistern 1	Cistern 2	Cistern 1	Cistern 2
Total volume [m^3]	54	121	41	134
surface area [m^2]	30	46	50	54
surface opening [m^2]	0.4	0.4	0.5	0.6
Formula volume	2/3 π * x^2 * (Max.y-y)		H/3 (AB + √(AB+ab) + ab)	
	x = radius, y = depth		H = depth, A = length, B= width, ab: see below.	
	y = [Average y/L] * L (see next tab)		H = H.max - L*cos(α) --> see figure -->	
	x = √(Max.x^2-(y(Max.x/Max.y))^2)		A = (A.max/H.max)*H B = (B.max/H.max)*H	

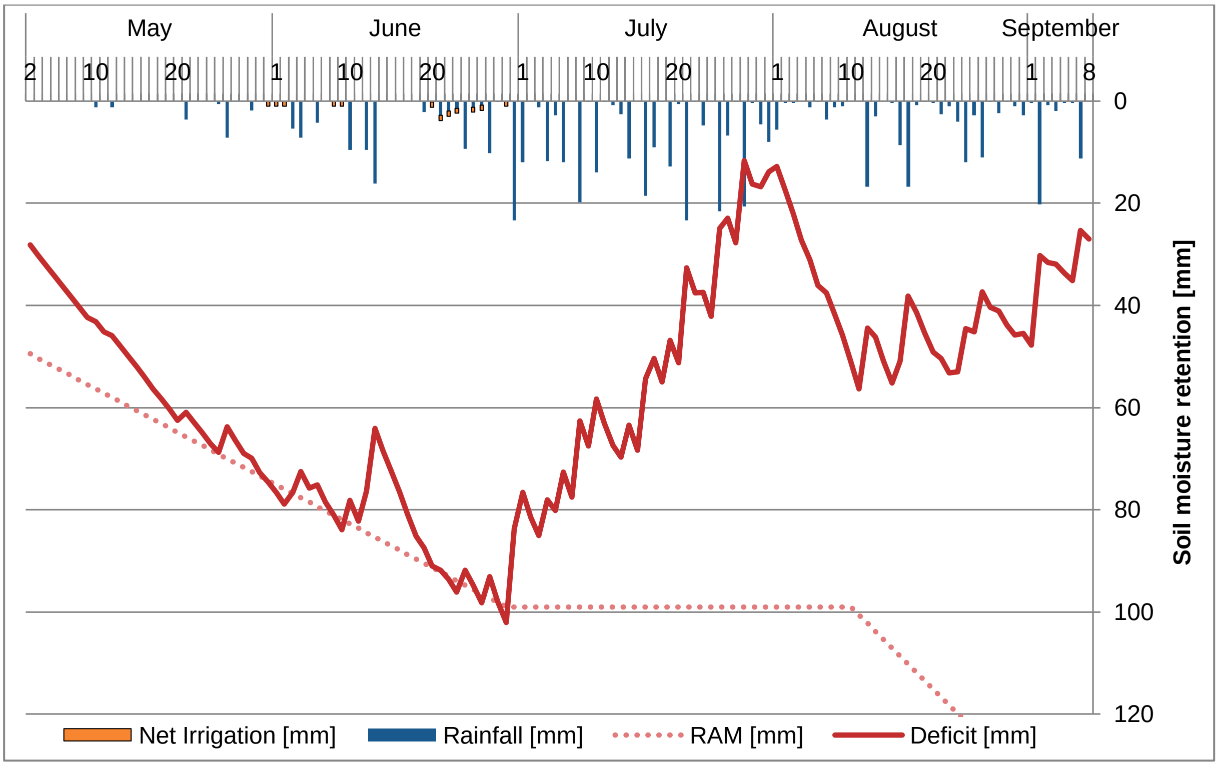


Half spheroid shaped basins		
	Cistern 1	Cistern 2
Circumference [m]	19.45	24
Diagonal	4.1	5.5
Radius of top [m] = Max.x	3.1	3.8
Max depth [m] = Max.y	2.7	4.0
Max.y/Max.x	0.87	1.04

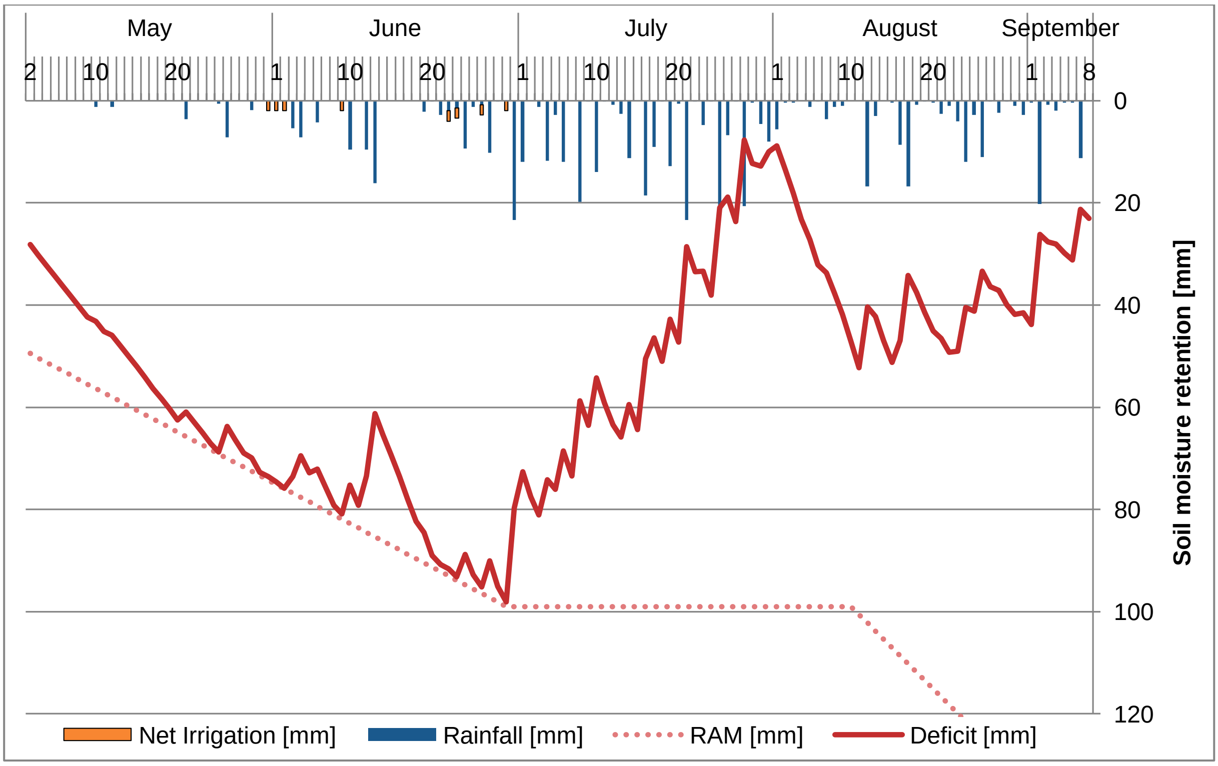
Trapezoidal shaped basins		
	Cistern 1	Cistern 2
straight part before trapezoidal [m height]	0.45	not
Length top (A.max) [m]	7.1	7.5
Width top (B.max) [m]	7.1	7.2
Length bottom (a) [m]	3.64	4.5
Width bottom (b) [m]	3.64	4.3
a*b	13.2	19.4
Max depth (H.max) [m]	1.73	4.9
hoek α (degr.)	45	17.0

Annex V Irrigation charts from Cropwat simulation

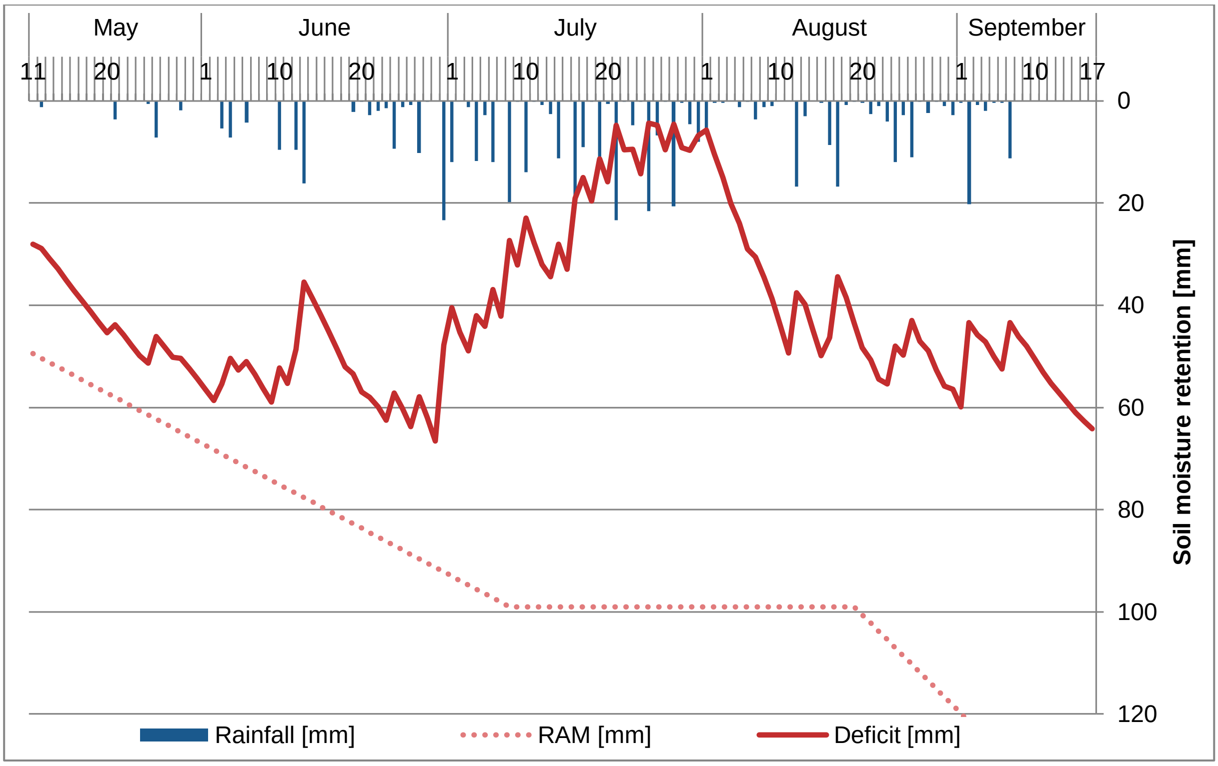
Net irrigation depth of 1 mm per event:



Net irrigation depth of 2 mm per event:



Changed date of sowing, from May 2 to May 11:



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