Environment and Natural Resources Research; Vol. 4, No. 3; 2014
ISSN 1927-0488 E-ISSN 1927-0496
Published by Canadian Center of Science and Education

Participatory Planning of Appropriate Rainwater Harvesting and Management Techniques in the Central Rift Valley Dry Lands of Ethiopia

Birhanu Biazin[1], Geert Sterk[2] & Melesse Temesgen[3]

[1] International Livestock Research Institute, Addis Ababa, Ethiopia

[2] Department of Physical Geography,Utrecht University, Utrecht, Netherlands

[3] Department of Civil Engineering, Addis Ababa University, Addis Ababa, Ethiopia

Correspondence: Birhanu Biazin, International Livestock Research Institute P.O. Box, 5689, Addis Ababa, Ethiopia. Tel: 251-916-829-891. Fax: 251-461-109-9830. E-mail: birhanubiazin@gmail.com, b.biazin@cgiar.org

Received: December 11, 2013 Accepted: May 12, 2014 Online Published: June 20, 2014

doi:10.5539/enrr.v4n3p123 URL: http://dx.doi.org/10.5539/enrr.v4n3p123

Abstract

Despite the extensive efforts of rainwater harvesting and management (RWHM) interventions for moisture-stressed areas in Ethiopia, the adoption and wider dissemination of the newly introduced techniques have been generally meager. The objective of this study was, therefore, to develop appropriate RWHM techniques through a participatory planning process in the Central Rift Valley (CRV) dry lands of Ethiopia. To achieve this objective, a combination of literature reviews, focus group discussions, questionnaire surveys, agro-meteorological analyses and field experimentations were undertaken. Perceived agro-meteorological challenges were determined through the questionnaire survey and validated through meteorological data analyses. Potential *in situ* RWHM techniques were selected in a participatory process and field-tested for two consecutive growing seasons to evaluate their performances. Those techniques which were selected in a participatory process showed statistically higher crop yields than the existing practices under both low and normal rainfall years. The result of this study implied that the introduction of new RWHM techniques can be successful when they are adjusted and modified in accordance with the existing tillage, hoeing and related land management practices. It was concluded that participatory planning of *in situ* RWHM techniques allows both the utilization of existing knowledge and opportunities while empowering the farmers to select and introduce new practices as per the existing socioeconomic and environmental settings. The new participatory planning approach will augment the recent efforts of promoting various types of RWHM techniques for improved rainfed agriculture in the vast dry lands of Ethiopia.

Keywords: participatory, in situ, dirdaro, tied-ridges, Ethiopia

1. Introduction

Rainwater harvesting and management (RWHM) techniques hold a promising significance to exploit the full potential of the smallholder-based rain-fed agriculture in dry land regions (Biazin, 2012; Rockstrom et al., 2010; Rosegrant, 1997; Sachs et al., 2004). There are a range of RWHM techniques being practiced in sub-Saharan Africa (Biazin et al., 2012; WOCAT, 2010). The commonly applied RWHM techniques are either indigenous or modified from indigenous techniques (Critchley et al., 1994; Liniger et al., 2011; Reij et al., 1996). A review of the RWHM practices in sub-Saharan Africa revealed promising biophysical and socioeconomic performances (Biazin et al., 2012). As an example, micro-catchment and *in situ* rainwater harvesting techniques could improve the root zone's soil water content by up to 30% thus mitigating the adverse effects of dry spells during critical crop growing seasons (Abdulkadir & Schultz, 2005; Araya & Stroosnijder, 2010; Makurira et al., 2009; Motsi et al., 2004). Because dry land soils are mostly degraded and poor in fertility, the combined applications of rainwater harvesting and soil fertility improvements could improve the crop yields by up to 6 times as compared to traditional systems (Fatondij et al., 2006; Jensen et al., 2003; Zougmore et al., 2003). Socioeconomic assessments in Ethiopia and Tanzania revealed that economic circumstances were better for the users of rainwater harvesting techniques than the non-users (Awulachew et al., 2008; Hatibu et al., 2006).

There have been extensive efforts of RWHM interventions for dry land areas in Ethiopia during the last three decades. However, the adoption and wider dissemination of the externally introduced techniques has been generally meager. The introduction and myopic implementations of several micro-dams for runoff harvesting and small-scale irrigation were not successful in Northern Ethiopia (Abera, 2004). About 340,000 underground rainwater tanks (cisterns) were constructed in the four administrative regions of Ethiopia (Tigray, Amhara, Oromia and Southern Region) between 2003 and 2004 to promote supplemental irrigation of crops (Bekele et al., 2006). However, only 37% of these cisterns were operational by the end of 2004. In central and northern Ethiopia, where there has been continuous efforts of soil conservation and rainwater harvesting, many farmers have developed negative attitudes towards introduced measures (Abera, 2004; Amsalu & de Graaff, 2006). The introduced RWHM technologies were found to be: complex and unfit to the existing farming systems, labor demanding, difficult to construct and require high initial investments (Biazin et al., 2012; Bewket, 2006; Bewket & Sterk, 2002). There has been a lack of farmers' involvement at different levels of project planning and implementations.

On the other hand, although farmers are endowed with vast indigenous knowledge of RWHM, they have perceptible gaps in technical know-how (Critchley, 1996; Rajabu, 2005). They need to enhance their technical skills through supports from local institutions and scientific communities. Integrating indigenous knowledge with scientific approaches was found important for the successful planning and development of appropriate RWHM techniques in northern Ethiopia (Nyssen et al., 2000). Stone bunds could be effectively implemented and widely applied by the farmers of Tigray region only after integrating the bunds with the traditional knowledge of lynchets, locally called 'daget' (Nyssen et al., 2000).

Like other parts of the vast dry land areas of Ethiopia, agricultural production in the Central Rift Valley (CRV) is limited primarily by water scarcity. The annual rainfall variability and the non-productive loss of rainfall through soil evaporation and surface runoff are more limiting factors than the total annual amount in the CRV of Ethiopia (Biazin & Stroosnijder, 2012; Tilahun, 2006). Therefore, the objective of this study was to develop appropriate RWHM technologies in the CRV of Ethiopia through a participatory process. A participatory RWHM planning approach has been developed and validated. This approach can be aptly used in the future planning and development of RWHM techniques in other dry land parts of Ethiopia or elsewhere in sub-Saharan Africa, where rainfed agriculture continues to be the main source of livelihood.

2. Methods and Approaches of the Study

2.1 Description of the Study Area

This study was undertaken in the Central Rift Valley (CRV) of Ethiopia. The study area is geographically located around 7°33′ N latitude and 38°40′ E longitude. It is situated at about 190 km south of the capital, Addis Ababa. It has an altitudinal range of 1580-1660 m above sea level and an average slope of 2%. The area has a semi-arid climate with an aridity index (the ratio of mean annual precipitation to mean annual reference evapotranspiration) of 0.37, according to the UNCCD classification of dry lands (MEA, 2005; UNCCD, 2000). The annual rainfall varies between 270 and 960 mm (CV = 30%) with a mean value of 650 mm for the past 30 years. Agricultural water scarcity in the predominantly rain-fed agricultural system of the CRV is caused by annual rainfall variability and non-productive losses of precipitation in the form of evaporation and surface runoff. The soils of the study area are predominantly sandy loam soils (Biazin & Stroosnijder, 2012). These soils are liable to surface crusting after every wetting and drying cycle. The soils have poor fertility and are shallow with an impermeable calcite layer between 0.55 and 0.70 m (Biazin & Stroosnijder, 2012).

Although the area was previously covered with dense acacia woodlands, which was historically used by the pastoral Oromo people coming from the nearby highland areas, a significant proportion of the area is now subjected to cultivation and year-round grazing (Eshete, 1999). Major crops are maize (*Zea mays* L.) and haricot bean (*Phaseolus vulgaris* L.). Livestock mainly includes cattle and goats. Following each crop harvest, livestock freely graze on the crop residues. Although cattle manure is abundant around homesteads where the households corral their livestock, most of the local households did not apply any manure to their cultivated fields.

2.2 Methods

2.2.1 Participatory Processes

A combination of socioeconomic and biophysical data collection and analysis techniques were employed in this study during 2008 - 2010. Semi-structured interviews with key informants, focus-group discussions and questionnaire surveys were undertaken from March to September, 2008. Upon a participatory selection of potential *in situ* RWHM techniques, field experimentation and evaluation of the selected techniques was undertaken for two growing seasons during 2009 and 2010. The participatory processes of data collection and analyses that were followed in this study are summarized in 6 steps as follows (Figure 1).

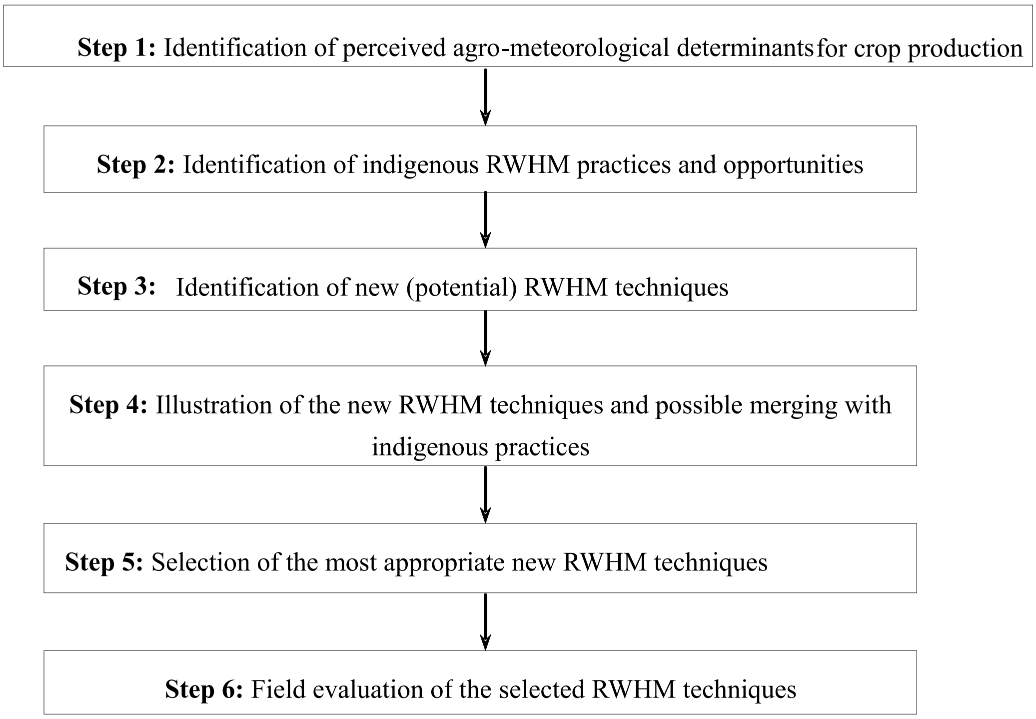

Figure 1. Schematic steps of the participatory rainwater harvesting and management planning process employed in this study

2.2.1.1 Identification of Perceived Agro-Meteorological Determinants for Crop Production (Step 1)

The perception of the local community to agro-meteorological determinants was assessed through key informant interviews, focus group discussions and a questionnaire survey. Four focus group discussions were conducted with both rich and poor household groups of 8-10 people each. Based on the outcome of the focus group discussions, a well thought out survey questionnaire was developed. The survey questionnaire was distributed to 66 households. Accordingly, the main causes of droughts and perceived frequencies of either moderate or severe droughts affecting crop production were examined. The lists of agro-meteorological factors that limit crop production were identified.

2.2.1.2 Identification of Indigenous RWHM Practices and Opportunities (Step 2)

Many of the rainwater harvesting techniques in sub-Saharan Africa are indigenous or modified from indigenous practices (Critchley et al., 1994; Lininger et al., 2011; Reij et al., 1996). Any attempt to improve water productivity and water-use efficiency of a given agricultural system should, therefore, start with an inventory of current land management and rainwater harvesting practices (FAO, 2005). As a follow up of the previous survey (step 1), key informants interviews, focus group discussions and survey questionnaire were undertaken. The number and types of households used in the second step of the survey were similar to the first survey. The second survey was applied to obtain the list of indigenous RWHM practices and related opportunities in the CRV of Ethiopia. All practices associated with tillage, land management, soil improvements and existing opportunities for improved crop productivity (possibility of using mulch, compost, manure, etc.) were assessed.

2.2.1.3 Identification of New (Potential) RWHM Techniques (Step 3)

The most commonly applied rainwater harvesting and management (RWHM) techniques and their performances in sub-Saharan Africa (SSA), Western Asia and Northern Africa were previously documented (Biazin et al., 2012; Oweis & Hachum, 2006; Oweis et al., 2004; Oweis et al., 2001).Therefore, the most applicable *in situ* RWHM techniques for the CRV of Ethiopia were identified from the aforementioned sources. Moreover, important toolkits like WOCAT (http://www.wocat.net), the works of Soil and Water management network (SWMnet), and International Water Management Institute (http://www.iwmi.cgiar.org) were explored. The performance of the techniques, the similarities with the indigenous practices in the CRV of Ethiopia, agro-ecological similarity, and affordability with the existing farming systems were important considerations during the identification of potentially applicable new techniques.

2.2.1.4 Illustration of the New Techniques and Possible Merging With Indigenous Practices (Step 4)

The identified techniques (Step 3) and their expected benefits were illustrated to the local farmers and representatives of potential stakeholder groups. A day-long workshop was held with 19 key informants (15 men and 4 women) including farmers from different wealth classes, village leaders, representatives from the offices of agriculture and local non-governmental organizations. Some of the new techniques were demonstrated and explained for better understanding of the implementation processes. The key informants suggested possible modification of the new practices and merging of them with the indigenous practices. The possibility of using local opportunities for RWHM development and possible combinations of RWHM techniques with soil improvement techniques was also discussed. Finally, the participants suggested appropriate procedure and mode of impelementations in accordance with their existing biophysical and socioeconomic settings.

2.2.1.5 Selection of the Most Appropriate RWHM Techniques (Step 5)

The selection of the most appropriate RWHM techniques was done by the key informants who attended the demonstration (Step 4). The key informants set their own selection criteria (constraints, advantages and opportunities) for each of the new RWHM techniques. The facilitator made sure that all the partcipants had equal chance of suggesting the selection criteria and voting for the ranking. Those techniques which were rated as more important than the existing traditional system were considered as accepted.

2.2.1.6 Field Evaluation of the Selected RWHM Techniques (Step 6)

Before attempting a wider dissemination of the agreed upon techniques, a field trial was carried out to evaluate the benefits of the selected techniques on crop yields and their implementation challenges. The trial was conducted for two consecutive years on plots provided by 4 volunteer (pilot) farmers. Farmer-driven experimentation allows farmers to systematically assess the value of the innovations they choose (Sturdy et al., 2008; WOCAT, 2007). It also provides researchers with a venue for learning about socioeconomic and biophysical influences of farmers' decisions. Crop yields from each of the RWHM techniques were measured at the end of each growing season and compared to the traditional system (control). Finally, the farmers rated the performances of the RWHM techniques as 'not good', 'good' and 'very good' based on the maize yields.

2.2.2 Biophysical Data Collection and Analyses for Validation

Precipitation and reference evapotranspiration data were obtained from the Langano Meteorological site (during 1981-2006) and an automatic weather station (during 2009-2010) that was installed during this study period. Onset of the rainfall season, dry-spells of different lengths, mean dekadal precipitation, coefficient of variability of the dekadal rainfall and crop water stress (CWS) were used to characterize the extent of drought in the CRV of Ethiopia. The onset of the rainfall season was calculated based on the definition stated previously (Biazin & Sterk, 2012). Hence, when the onset of the rainfall season was later than June 15, the year was considered as severe drought for Maize which is the staple crop in the CRV of Ethiopia. Dry-spells of length *m* are defined as a sequence of *m*-dry days preceded and followed by dry days whereby the lengths of successive spells are readily seen to be independent (Biazin & Sterk, 2012). The probabilities of dry spell lengths of 5, 7, 9, and 19 were determined for the months between March and September. The onset and dry spell analyses were done using INSTAT version 3.36 based on the method described by Stern et al. (2006). The CWS was estimated from the ratio of dekadal precipitation (RF) to dekadal reference evapotranspiration (RET) as described in the equation below.

$$CWS = \frac{RF}{RET}$$

The selected *in situ* RWHM techniques were evaluated in the field for two growing seasons (2009 and 2010) on maize. The field experiment was done in a split plot design where tied-ridges, sub-soiling and traditional tillage with the traditional *Dirdaro* were considered as the main plots. These main plots were further divided in to two sub-plots, with one unit treated with farmyard manure (4.5 $Mgha^{-1}$) and the other without manure. Surface runoff, soil water content of the maize rooting zone and root length density (RLD) were measured continuously throughout the maize growing seasons. The amount of surface runoff was measured after each rainfall event during the maize growing seasons in 2009 and 2010. Soil water content was determined using a Time Domain Reflectometer (TDR) instrument. The overall maize yields were determined at the end of each growing seasons. Finally, statistical analyses were done to examine the effects of the *in situ* RWHM techniques on hydrological and plant parameters mentioned earlier. Analysis of variance (ANOVA) was done using SPSS version 17 (Julie, 2007). Tukey's honestly significant difference test for equal variances and Dunnett's T3 test for unequal variances were used for mean separations.

Although it may be possible to introduce new potential RWHM techniques in to a given area, the expected benefits of each technique within a given agro-meteorological and soil conditions need to be simulated. Hence, the simulation of the different new RWHM techniques was done using the FAO's AquaCrop model. It was reported that there was a good fit between the simulated and observed values of maize yield in the CRV of Ethiopia (Biazin & Stroosnijder, 2012). Hence, the effect of tied-ridges on maize yield in response to different rainfall patterns (onset, amount and distribution) and fertility levels was simulated for validation of the farmers' qualitative evaluations and scientific explanations.

3. Results

3.1 Agro-Meteorological Determinants, Opportunities and Indigenous Practices (Steps 1 and 2)

According to the farmers' accounts, maize production in the CRV of Ethiopia is limited due to agricultural drought (100% of the respondents, N = 66), poor access to chemical fertilizers (72% of the respondents), and poor access to better seeds (55% of the respondents). There was a difference in the perception of rich and poor households regarding the occurrence of drought in the CRV. While rich households perceived the occurrence of drought every 7-10 years, the poor households perceived it within a range of 3-5 years. Long dry spells during the growing season and late onset of the rains were perceived as the major agro-meteorological determinants for crop production. Table 1 presents the perceived (N = 66) mean lengths of dry-spells that are critical to the growth of the local maize variety (*Awassa BH540*) at the crop's different developmental stages.

Table 1. Perceived mean lengths of critical dry spells during the different developmental stages of maize in the CRV, Ethiopia

Development stage (DAS)[†]	Critical lengths of dry spells
Emergence and establishment (1-25 DAS)	19
Vegetative developmental stage (26-60 DAS)	19
Flowering and grain filling (61-90 DAS)	7
Maturation stage and drying (91-120 DAS)	9

[†]DAS, days after sowing.

Indigenous land management practices that are used as *in situ* RWHM were identified in the CRV (Table 2). Most of these techniques are associated with tillage, hoeing and soil management. Tillage during planting is carried out carefully in such a way that moisture conservation is possible. Before the introduction of line sowing of maize, tillage during sowing was entirely made using the old *Malibes* technique, which is flat and without furrows. Recently, many farmers (67% of the respondents, N = 66) adopted a new type of tillage, *Dirdaro furrow*, in association with line sowing. The *Dirdaro* furrows are made with the traditional *Maresha* plough after every two planting rows with an average interval of 50-54 cm across the slope just after sowing. The furrows help to reduce runoff and enhance infiltration. Furthermore, the soils are inverted from the ridges to both sides of the planting rows, thus reducing soil evaporation from around the rooting zone. This practice is widely applied in northern Ethiopia (Nyssen et al., 2011). Removal of the surface soil crusts either by manual hoeing or *Maresha* plowing is necessary following wetting and drying cycles during the maize growing season. Because of this, the local farmers apply one or two hoeing operations. However, manual hoeing loosens only the thin soil surface. Therefore, about 35-45 days after planting, *Shilshalo* ridging is commonly practiced using the traditional *Maresha* plow on the furrows that were made for *Dirdaro*. It is normally practiced following rain events which otherwise is believed to dry up the crop. Despite the abundance of farmyard manure, the local farmers do not distribute it on their farmlands for soil improvements as they fear that it may dry up the crops. Few farmers (26% of the respondents) shift the location of corralling so that they can use the fertilized land for maize cultivation.

Table 2. Indigenous land management used as *in situ* rainwater harvesting techniques and level of application by the local households in the CRV of Ethiopia

Type of land management technique	Percentage of total respondents (%, N = 66)	Time of application	Perceived effects on water conservation
Dirdaro furrows	67	during sowing of maize	It reduces surface runoff and enhances infiltration; it inverts the soil from the ridges to the planting rows where it temporarily covers the seeds and later used to reduce soil evaporation.
First manual hoeing	95	14-20 days after sowing	It breaks the surface crusts and loosens the soils; it helps to pile soil around the root zone where soil evaporation can be reduced.
Second manual hoeing	71	21-35 days after sowing (usually applied as a replacement for *Shilshalo*)	It breaks the surface crusts and loosens the soils; it helps to pile soil around the root zone where soil evaporation can be reduced.
Shilshalo ridging	100	30-45 days after sowing	It breaks the surface crusts and enhances infiltration; it inverts the soil from the ridges to the root zone where soil evaporation can be reduced; helps to remove weeds.
Shifting the location of corralling	26	After 1-3 years of corralling	It enhances crop productivity due to increased fertility (with manure).

3.2 Identification and Illustration of Potential New Techniques and Their Expected Benefits (Steps 3&4)

Table 3 presents the most commonly applied *in situ* RWHM techniques in sub-Saharan Africa (SSA). The performances of these *in situ* RWHM techniques were found to be very effective when they were combined with soil improvement techniques such as addition of manure and compost (Jensen et al., 2003; Zougmore et al., 2003). Ridges can be left open, or closed (tied-ridges) at regular intervals for holding water and facilitating infiltration (Lal, 1990; Wiyo et al., 1999). Mulching can be done either with crop residues or stones and rock fragments. Sub-soiling, reduced tillage, zero tillage, and other conservation agriculture practices are done making use of different implements in different regions of Africa (Rockstrom et al., 2009; Walker et al., 2005).

Table 3. The new *in situ* RWHM techniques, their features and performances elsewhere as illustrated for the farmers in the CRV, Ethiopia

Type of techniques	Regions of wider application in SSA	Suitable climatic condition	Yield increment ¥		References
			Without fertilizer	With fertilizer	
Tied-ridges	Many parts of the SSA	Semi-arid, dry sub-humid	19-44%	100-600%	Hulugalle (1990); Lal (1990); Wiyoet al (1999); Jensen et al. (2003)
Sub-soiling	Western Africa	Semi-arid, dry sub-humid	1-25%	22-118%	Rockstrom et al. (2009)
Mulching	Western and Eastern Africa	Can be applied under wide climatic conditions	30-50%	-	Henseley et al (2000); Tengberget al(1998); WOCAT (2010)
Reduced tillage	Southern Africa	Semi-arid, dry sub-humid, humid	10-50%	20-95%	Rockstrom et al. (2009); Walker et al(2005)
Zero tillage	Southern Africa	Semi-arid, dry sub-humid, humid	2-50%	20-95%	Rockstrom et al. (2009); Walker et al(2005)

¥ Yield increment = (mean crop yield obtained when RWH is applied – mean yield with the control without any technology)*100/ mean yield with the control without any technology.

Direct application of these tillage techniques as used in other African countries may not fit the design of the Ethiopian traditional tillage implements. Recently, there have been encouraging efforts to develop modifications to the traditional *Maresha* plow in Ethiopia (Temesgen et al., 2007). On the basis of the traditional Maresha implement, the Maresha-modified ridger and sub-soiler were recently developed (Figure 2).

The aforementioned *in situ* RWHM techniques were demonstrated and discussed with the key informants in the field (Figure 3). Following a lengthy discussion, the key informants have suggested procedures for the implementations of tied-ridges and sub-soiling in their locality (Table 4). The key informants suggested that tied-ridges would be applied upon a simple modification of the traditional *Dirdaro* furrows. While the traditional *Dirdaro* tillage made 20 cm wide furrows, the *Maresha*-modified ridger made 26 cm wide ridges at the surface of the soil. Both the tied-ridges and the traditional *Dirdaro* furrows had a similar furrow depth of 16 cm. The key informants further suggested that the ridges should be tied at constant intervals of 4 m by the plow-man. This was approximately five paces while plowing. The distribution of farmyard manure was proposed to be undertaken before the primary tillage so that it would be incorporated in to the soil during tillage operations.

(a)

(b)

Figure 2. Maresha-modified ridger (a) and Maresha-modified sub-soiler (b) for in situ rainwater harvesting in the CRV of Ethiopia

Figure 3. Field demonstration and training on the Maresha-modified ridger in the CRV of Ethiopia

Table 4. Proposed procedures of land preparation & sowing according to the selected *in situ* rainwater harvesting and management techniques in the CRV of Ethiopia

Land preparation and sowing	*In situ* techniques		Traditional tillage
	Sub-soiling	Tied-ridges	
Primary tillage	Traditional *Maresha* plow followed by *Maresha* -modified sub-soiling on every other furrow	Traditional *Maresha* plowing	Traditional *Maresha* plowing
Secondary tillage	Traditional *Maresha* plowing followed by *Maresha*-modified sub-soiling on the previously sub-soiled furrows	A cross plowing using the traditional *Maresha* plow followed by tied-ridging using the *Maresha* -modified ridger on every other furrow. The ridges are tied every 4 meters.	A simple cross-plowing using the traditional *Maresha*-plow
Sowing	Sowing is undertaken on the previously sub-soiled rows after plowing by the traditional Maresha. The soil inversion is undertaken according to the traditional *Dirdaro* technique using the traditional *Maresha* plow	Sowing is undertaken on the previously ridged rows after plowing by the traditional *Maresha* plow. The soil inversion is undertaken according to the traditional *Dirdaro* technique using the *Maresha*-modified ridger. The ridges are tied every 4 meters.	Sowing is undertaken after plowing across the secondary tillage. The soil inversion is undertaken according to the *Dirdaro* technique using the traditional *Maresha* plow.

3.3 Selection of the Most Appropriate RWHM Techniques (Step 5)

Ranking of the different techniques was done by the key informants in a participatory process (Figure 4). Although the key informants were divided in to two groups of poor and rich, they came up with similar rankings as explained in Table 5. Hence, tied-ridges, addition of dry farmyard manure, sub-soiling, and compost were ranked better than the existing farming system. Among the presented techniques, mulching, minimum tillage, and zero tillage were put after the traditional system by the key informants. They put the major advantages and constraints of the different techniques in accordance with their biophysical and socioeconomic settings (Table 5).

Figure 4. Key informants ranking the new in situ rainwater harvesting techniques in order of acceptance in the CRV of Ethiopia

Table 5. Farmers' ranking of the *in situ* RWHM techniques and their possible constraints and advantages in the CRV of Ethiopia

Type of introduced technique	Order of ranking	Suggested advantages/opportunities	Suggested constraints
Tied-ridges	1	With the new Maresha-modified ridger, it is possible to make wider ridges than the D*irdaro* furrows; tying of the ridges will also help to reduce runoff.	It is difficult to apply *shilshalo* with the new ridger.
Dry farmyard manure	2	It improves crop yields; unlike other parts of Ethiopia, dry farmyard manure is not used as a source of household energy due to better access for firewood and charcoal from the woodlands.	It may initiate drying up of the maize crop when applied either in fresh or damped particularly during dry seasons.
Sub-soiling	3	It enables to loosen the soil deeper than the traditional tillage and enhance infiltration of rainfall.	It is difficult to apply cross-plowing during consecutive tillage operations; purchase of the sub-soiler incurs additional cost.
Compost	4	It improves crop yields; the ingredients (leaves and crop residues, manure, soil) are easily available.	Difficulty of getting water for the preparation of compost during the dry season; bad smelling may not be good for health.
Traditional tillage	5	It is easy to practice as they have already experienced it; There is no extra expense required.	It is not good enough to conserve moisture.
Mulching	6	Enhance infiltration of rainfall and cover the soil from the sun	Mulch is desperately needed as source of feed for livestock during the dry seasons.
Reduced tillage	7	It may be applied when onset is late	Without repeated tillage crop yields can be very low.
Zero tillage	8	No suggested advantage	Without tillage crop yields can be very low

3.4 Field Performances of the Selected RWHM Techniques (Step 6)

The farmers perceived that tied-ridges in combination with manure showed the largest maize yield (Table 6). However, tied-ridges and sub-soiling without soil fertility improvements were not good enough to improve crop yields during the very dry year in 2009. The use of farmyard manure has shown promising benefits under both very low and normalrainfall conditionswhen it was used in combinations with either the traditional tillage or the *in situ* RWHM techniques.

Table 6. Qualitative farmers' evaluation and measured maize yield according to the different *in situ* RWHM techniques during 2009 and 2010 growing seasons in the CRV, Ethiopia

Experiment Year	Type of technique	Farmers' evaluation		Measured maize grain yield (Mg ha^{-1})	
		With manure	Without manure	With manure	Without manure
2010	Traditional tillage (control)	Good	-	3.5	2.7
	Tied-ridges	Very good	Good	4.0	3.4
	Sub-soiling	Good	Not good	3.7	3.0
2009	Traditional tillage (control)	Good	-	0.5	0.3
	Tied-ridges	Good	Not good	0.5	0.3
	Sub-soiling	Good	Not good	0.5	0.4

"-" implies the reference (control).

4. Validations and Discussions

4.1 Agro-Meteorological Challenges and Opportunities (Steps 1 and 2)

Figure 5 depicts the probability of dry spells that are perceived as critical to maize during the different developmental stages. Particularly, dry spell lengths of 5 to 7 days are generally common during the maize growing season. Long-term meteorological analyses revealed that late onset of the rains caused 5 severe drought years for maize during the last 28 years, while long dry spells caused 6 moderate and 2 severe drought years (Biazin & Sterk, 2012). Moreover, there is a reasonable gap between the long-term mean dekadal (ten days) precipitation and Reference evapo-transpiration (RET), particularly during the months of May and June (Table 7). These months are either in the first or second developmental stages of maize in the CRV. According to Doorenbos and Kassam (1979), crop water stress becomes severe when the available water from the rainfall is less than half of the crop water demand. Based on long-term mean values, the first dekad of May, third dekad of May and first dekad of June have crop water stress (Table 7). The inter-annual variability of decadal rainfall is painfully high during the maize growing season implying unreliability of the rainfall (Table 7). All these support the perception of the farmers on drought.

Table 7. Long-term mean dekadal (ten days) rainfall (RF), dekadal Reference Evapotranspiration (RET) and crop water stress (CWS) index during the maize growing season in the CRV of Ethiopia

Month	Dekad of the month	RF		Mean RET (mm)	RF-RET (RF/RET)[€]
		Mean	CV (%)		
	1	25	136	51	-26 (0.49)
May	2	33	120	50	-17 (0.66)
	3	20	138	52	-32 (0.38)
	1	23	100	48	-25 (0.48)
June	2	29	125	47	-18 (0.62)
	3	33	96	45	-12 (0.73)
	1	47	65	43	4 (1.09)
July	2	45	85	42	3 (1.07)
	3	48	66	41	7 (1.17)
	1	42	74	42	0 (1.00)
August	2	41	78	43	-2 (0.95)
	3	37	66	44	-7 (0.84)
Total		423	-	548	-125 (0.77)

[€]Values in parenthesis are meant for the ratio of dekadal precipitation to reference evapo-transpiration.

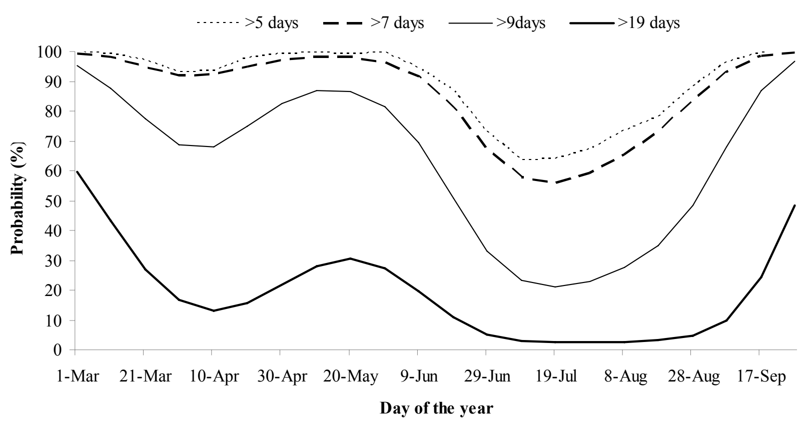

Figure 5. Probabilities of dry spells exceeding 5, 7, 9 and 19 days in Langano, the CRV of Ethiopia

Apart from this, field experiments during 2009 and 2010 growing seasons revealed that runoff is triggered when there is rainfall amount of at least 12 mm per day (Figure 6). The total rainfall during the growing season is more correlated (r = 0.89) with the number of days with a rainfall of greater than 12mm than with the total number of rainfall days (r = 0.4). Despite the severe agricultural water scarcity, the higher probability of different lengths of dry spells and the intensive nature of the rainfall infers that there is an opportunity to develop water conservation techniques associated with runoff harvesting.

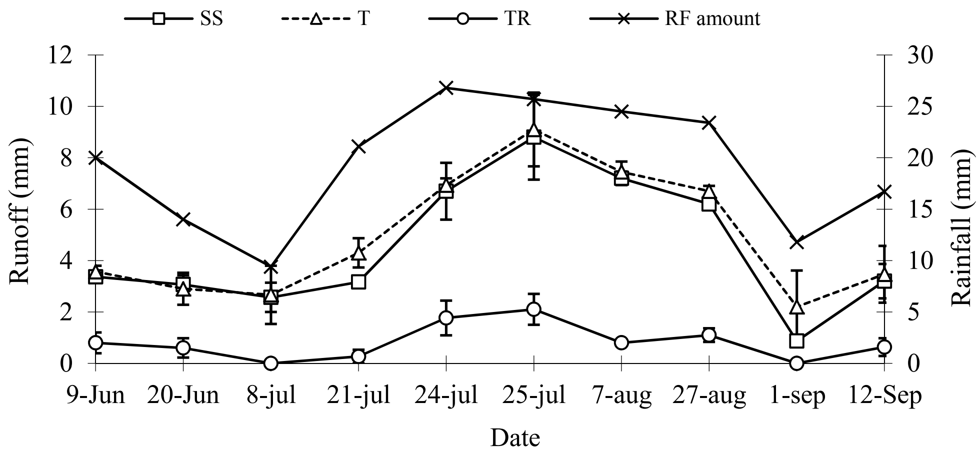

Figure 6. Runoff (mm) observed under Tied-ridges (TR), Sub-soiling (SS) and Traditional tillage with Dirdaro (T) from a maize field in 2010 in the CRV of Ethiopia. Standard error of the mean indicated as error bars for mean runoff. During the 2009 growing season, only three rainfall events could produce runoff. Hence, runoff amounts of 2.5 mm from rainfall of 14 mm (July 7), 4.5mm from rainfall of 27.1mm (July 14), and 2.3 mm from rainfall of 15mm (July 20) were measured from the traditional Dirdaro tillage

4.2 Review of Potential RWHM Techniques and Simulation of Expected Benefits (Steps 3 and 4)

An extensive review of the most commonly applied *in situ* and micro-catchment RWHM techniques along with their performances was made (Biazin et al., 2012). It was revealed that spectacular gains in crop yields could be obtained from appropriate combinations of RWHM and soil improvements. Simulation in response to planting of maize during differentmonths in the CRV of Ethiopia revealed that tied-ridges are more effective when applied forsowing in April than for sowing in May and June (Table 8). Simulations based on long-term meteorological data revealed that combining tied-ridges and soil improvements can increase maize yields by more than double. Although tied-ridges caused water logging effects during above normal rainfall years elsewhere in sub-Saharan Africa (Jensen et al., 2003), it is less likely to occur in the CRV of Ethiopia where consecutive wet days are least likely to occur and the soil is dominantly sandy loam.

Table 8. Simulated maize yield with tied-ridges and traditional tillage systems according to different planting months in the CRV, Ethiopia

Planting month (onset)	Simulated maize yield (Mg ha^{-1})					
	Traditional tillage			Tied-ridges		
	Current fertility level (46%)	Near-optimal fertility level (71%)	Optimum fertility level (96%)	Current fertility level (46%)	Near-optimal fertility level (71%)	Optimum fertility level (96%)
April	2.3	3.2	3.5	2.8	4.3	5.0
May	2.8	4.0	4.6	3.1	4.9	6.0
June	2.7	3.8	4.4	2.9	4.5	5.5

4.3 Field Evaluation of the New Techniques (Step 6)

Soil water content of the maximum rooting zone (0.6 m) was improved by 10.9% due to tied-ridges and 3.3% due to sub-soiling during the 2010 growing season. However, during the 2009 growing season, the effects of tied-ridges (2.3%) and sub-soiling (1.5%) on soil water improvements were negligible. The effect of the RWHM techniques on soil water improvements was different depending on soil depth. The soil water content of the top 0-15 cm soil depth was 15.4% higher under tied-ridges and 3.1% higher under sub-soiling than traditional tillage. In the 15-30 cm soil depth, the soil water content was 12.1% higher under tied-ridges and 3.7% higher under sub-soiling than traditional tillage. Within the 30-45 cm soil depth, the soil water status was 7.3% and 2.8% higher under the tied-ridges and sub-soiling as compared to the traditional tillage. Depending on the rainfall intensity and antecedent soil moisture, the proportion of the 2010 growing season rainfall that was lost in the form of runoff ranged between 8-30% (24% on average) from the traditional tillage, 15% - 28% (22% on average) from sub-soiling and 0-7% (3.5% on average) from tied-ridges (Figure 6). This is in line with a previous study by McHugh et al (2007) who reported that an average15% of the rainfall was lost as runoff from a traditional tillage system in the clay loam soils in Wollo province (Ethiopia). Araya and Stroosnijder (2010) revealed that 15-30% of the rainfall could be lost as runoff from slopes of 0-3% in the silt loam soils of Tigray region. Another study in the Rift Valley reported that up to 40% of the seasonal rainfall may be lost in the form of surface runoff non-productively, thus, reducing the productive 'green' transpiration (Welderufael et al., 2008).

Root length density (RLD, cm cm^{-2}) of maize was significantly ($\alpha < 0.05$) higher under tied-ridges than that under sub-soiling and traditional tillage at the 0-15 cm soil depth (Figure 7).At the 16-30 cm soil depth, the RLD under sub-soiling was significantly higher ($\alpha < 0.05$) than that under the tied-ridges and traditional tillage. However, there was little difference in the RLD below 30 cm soil depths. The application of dry farm manure (4.5 Mg ha^{-1}) improved the RLD by 43% on average.

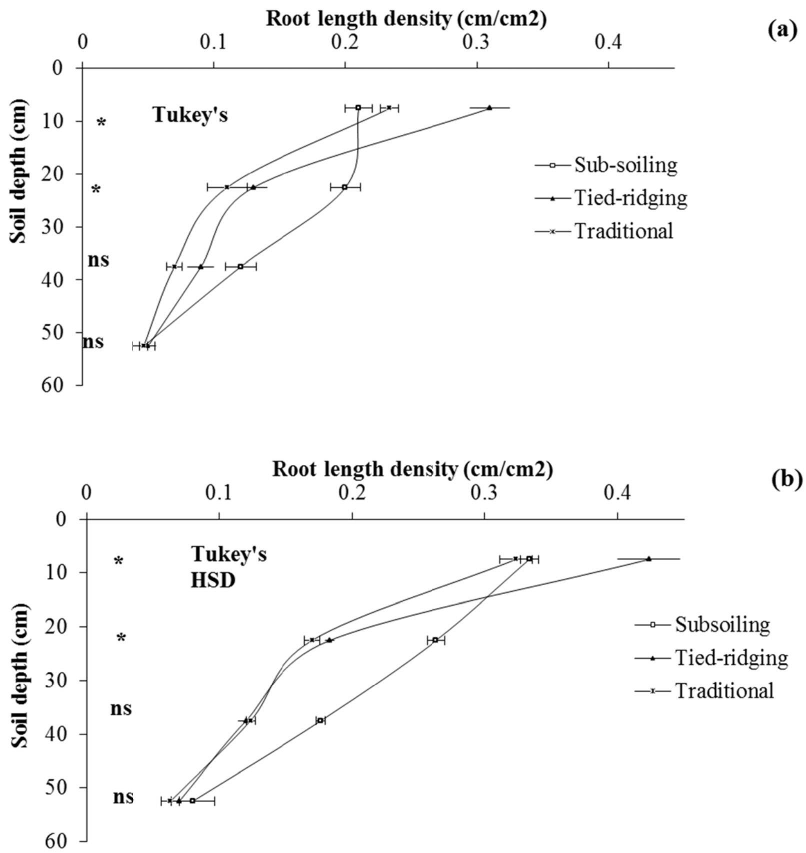

Figure 7. Effect of in situ RWHM techniques on root length density (cm cm^{-2}) at different soil depths (0-15 cm, 16-30 cm, 31-45 cm and 46-60 cm) without farmyard manure (a) or with farmyard manure applications (b) in the CRV of Ethiopia

Mean separations with the Tukey's HSD is implied by "*" for significant differences and by "ns" for no significant differences ($\alpha = 0.05$).

During the 2010 growing season (rainfall amount = 420 mm; 46 % probability of exceedance), maize yield was significantly ($\alpha < 0.05$) higher in plots treated with either farmyard manure or tied-ridges than the control with traditional tillage (Table 9). The interaction effect of manure application and tied-ridges on maize yield was also significant ($\alpha < 0.05$). During the very dry season of 2009 (rainfall amount = 230 mm; 96% probability of exceedance), the use of the *Maresha*-modified tied-ridges and sub-soiling did not improve maize productivity ($\alpha > 0.05$), while incorporating dry farmyard manure improved the maize productivity significantly ($\alpha < 0.05$). This implies that as long as the dry farmyard manure is evenly distributed during the offseason, the local perception that manure causes maize drying is unfounded.

Table 9. Statistical analyses on maize grain yield determined according to different *in situ* RWHM techniques during 2009 and 2010 growing seasons in the CRV, Ethiopia

Year and total rainfall*	Type of technique	Mean grain yield (Mg ha^{-1})		Benefits (percent)	
		With manure	Without manure	With manure	Without manure
2010 (420 mm)	Traditional tillage (control)	3.5(±0.12)bx	2.7(±0.10)by	30	-
	Tied-ridges	4.0 (±0.2)ax	3.4(±0.1)ay	48	26
	Sub-soiling	3.7(±0.28)abx	3.0(±0.14)aby	37	11
2009 (230 mm)	Traditional tillage (control)	0.5(±0.1)ax	0.3(±0.1)ay	67	-
	Tied-ridges	0.5(±0.09)ax	0.3(±0.1)ay	67	-
	Sub-soiling	0.5(±0.1)ay	0.4(±0.1)ay	67	33

*Values in parentheses refer to total rainfall during the growing season of maize from sowing to harvest. Standard error of the mean in parentheses and mean values followed by similar letters a-c along a column of a given year or x-y across a row are not significantly ($\alpha = 0.05$) different. Benefits were computed as

$$[(\text{yield from introduced technique} - \text{yield from the control}) / \text{yield from the control}] \times 100$$

5. Conclusions

The participatory RWHM planning approach enabled to examine the major challenges and utilize existing knowledge and opportunities thus empowering the farmers to introduce new RWHM techniques as per the socioeconomic and environmental settings. The application of this new approach in the CRV of Ethiopia showed that the introduction of *in situ* rainwater harvesting techniques needs to include an assessment of the major agro-meteorological challenges, existing tillage, hoeing and associated land management practices. In the CRV dry lands of Ethiopia, agricultural water scarcity is mainly caused by the long dry spells and associated non-productive losses via soil evaporation and surface runoff. This was confirmed by both the local people's accounts and agro-meteorological analyses. For an effective implementation of the new approach, the FAO's AquaCrop model, upon proper calibration and validation for different crops and regions of Ethiopia, could create a database explaining the expected benefits of the various rainwater harvesting techniques in response to different rainfall patterns and fertility levels. The RWHM techniques that were selected and modified as per the existing land management practices in a participatory process showed significantly higher maize yields than the traditional practices under both low and normal rainfall years. The new approach may augment the recent efforts of promoting various types of RWHM techniques for improved rainfed agriculture in the vast dry lands of Ethiopia.

Acknowledgements

This study was undertaken through the financial support of the Sweden International Development Agency (SIDA), International Foundation for Science (IFS) and the Wageningen University Sandwich PhD Fellowship. The Wondo Genet College of Forestry and Natural Resources, Hawassa University facilitated the logistical support. The authors are also grateful to the farmers of the Central Rift Valley of Ethiopia around Langano who were with us during 2008-2010 and voluntarily made their fields available for field experimentation during the 2009 and 2010 growing seasons. The authors are also thankful to Amlaku Bikss for his language editing support.

References

Abdulkadir, A., & Schultz, R. C. (2005). Water harvesting in a runoff catchment agro-forestry system in the dry lands of Ethiopia. *Agrofor. Syst., 63*, 291-298. http://dx.doi.org/10.1007/s10457-005-5746-1

Abera, Y. (2004). Problems of the solution: intervention into small-scale irrigation for drought proofing in the Mekele Plateau of Northern Ethiopia. *The Geogr. J., 170*, 226-237. http://dx.doi.org/10.1111/j.0016-7398.2004.00122.x

Amsalu, A., & de Graaff, J. (2006). Farmers' views of soil erosion problems and their conservation knowledge at Beressa watershed, central highlands of Ethiopia. Agric. *Human Values, 23*, 99-108. http://dx.doi.org/10.1007/s10460-005-5872-4

Araya, A., & Stroosnijder, L. (2010). Effects of tied-ridges and mulch on barley (*Hordeum vulgare*) rainwater use efficiency and production in Northern Ethiopia. Agric. *Water Manage, 97*, 841-847. http://dx.doi.org/10.1016/j.agwat.2010.01.012

Aune, J. B., Asrat, R., Asefa, D., & Tulema, B. B. (2011). *Zero Tillage or Reduced Tillage: The Key to Intensification of the Crop–Livestock System in Ethiopia*. International Food policy Research Institute. Retrieved December 25, 2011, from http://www.ifpri.cgiar.org/sites/default/files/pubs/pubs/books/oc53/oc53ch12.pdf

Awulachew, S. B., Hagos, F., & Loulseged, M. (2008).Agricultural water management and poverty in Ethiopia. In E. Humphreys, R. S. Bayot (Eds.), *Proceedings of the Workshop on Increasing the Productivity and Sustainability of Rainfed Cropping Systems of Poor* (September 22-25, 2008. pp. 245-258). Smallholder Farmers, Tamale, Ghana.

Awulachew, S. B., Merry, D. J., Kamara, A. B., van Koppen, B., Penning de Vries, F., Boelee, E., & Makombe, G. (2005). *Experiences and opportunities for promoting small-scale/micro irrigation and rainwater harvesting for food security in Ethiopia*. Columbo, Sri Lanka, IWMI. V.86p. (working paper 98).

Barron, J., & Okwatch, G. (2005). Run-off water harvesting for dry-spell mitigation in maize (*Zea mays L.*): results from on-farm research in semi-arid Kenya. *Agric. Water Manage., 74*, 1-21. http://dx.doi.org/10.1016/j.agwat.2004.11.002

Bekele, T., Kebede, H., Taddese, G., & Peden, D. (2006). *Small-scale irrigation practices and crop & livestock water requirements for better production by smallholder farmers: a cursory study on SG-2000 water harvesting and utilisation pilot project*. Addis Ababa, Ethiopia.

Bewket, W. (2007). Soil and water conservation intervention with conventional technologies in northwestern highlands of Ethiopia: Acceptance and adoption by farmers. *Land Use Policy, 24*(2), 404-416. http://dx.doi.org/10.1016/j.landusepol.2006.05.004

Bewket, W., & Sterk, G. (2002). Farmers' participation in soil and water conservation activities in the Chemoga Watershed, Blue Nile basin, Ethiopia. *Land Deg. Dev., 13*(3), 189-200.

Biazin B., & Stroosnijder, L. (2012). To tie or not to tie ridges for water conservation in the Rift Valley dry lands of Ethiopia. *Soil & Till. Res., 124*, 83-94. http://dx.doi.org/10.1016/j.still.2012.05.006

Biazin, B. (2012). *Ranwater Harvesting for Dry land Agriculture in the Rift Valley of Ethiopia*. PhD dissertation, Wageningen University, Netherlands.

Biazin, B., Sterk, G., Temesgen, M., Abdulkedir, A., & Stroosnijder, L. (2012).Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa – A review. *J. Phys. Chem. Earth, 47-48*, 139-151. http://dx.doi.org/10.1016/j.pce.2011.08.015

Biazin, B., & Sterk, G. (2012). Drought vulnerability drives land-use andlandcoverchanges in the Rift Valley dry lands of Ethiopia. *Agriculture, Ecosystems & Environment, 164*, 100-113. http://dx.doi.org/10.1016/j.agee.2012.09.012

Critchley, W., Reij, C., & Willcocks, T. J. (1994). Indigenous soil and water conservation: a review of the state of knowledge and prospects for building on traditions. *Land Degr. Rehab., 5*, 293-314.

Doorenbos, J., & Kassam, A. H. (1979). *Yield Response to Water*. FAO Irrigation and Drainage Paper No. 33. FAO, Rome, Italy.

Eshete, G., (1999). *Assessment of fuelwood resources in Acacia woodland in the Rift Valley of Ethiopia: towards the development of planning tools for sustainable management*. Doctoral Thesis, Swedish University of

Agricultural Sciences, Umeå, Sweden.

FAO. (2005). *Drought resistant soils; Optimization of soil moisture for sustainable plant production*. Food and Agricultural organization, Rome, Italy.

Fatondji, D., Martius, C., Bielders, C., Vlek, P., Bationo, A., & Gérard, B. (2006). *Effect of planting technique and amendment type on pearl millet yield, nutrient uptake, and water*.

Fox, P., & Rockstrom, J. (2003). Supplemental irrigation for dry-spell mitigation of rainfed agriculture in the Sahel. *Agric. Water Manage., 61*, 29-50. http://dx.doi.org/10.1016/S0378-3774(03)00008-8

Fox, P., Rockstrom, J., & Barron, J. (2005). Risk analysis and economic viability of water harvesting for supplemental irrigation in semi-arid Burkina Faso and Kenya. *Agric. Syst., 83*, 231-250. http://dx.doi.org/10.1016/j.agsy.2004.04.002

Hatibu, N., Mutabazi, K., Senkondo, E. M., & Msangi, A. S. K. (2006). Economics of rainwater harvesting for crop enterprises in semi-arid areas of East Africa. *Agric. Water Manage., 80*, 74-86. http://dx.doi.org/10.1016/j.agwat.2005.07.005

Hensley, M., Botha, J. J., Anderson, J. J., van Staden, P. P., & Du Toit, A. (2000). *Optimisingrainfall use efficiency for developing farmers with limited access to irrigationwater*. WRC Report No. 878/1/00. Water Research Commission, Pretoria, South Africa.

Hulugalle, N. R. (1990). Alleviation of soil constraints to crop growth in the upland Alfisols and associated soil groups of the Western African Savannah by tiedridges. *Soil Till. Res., 18*, 231-247. http://dx.doi.org/10.1016/0167-1987(90)90063-J

Jensen, J. R., Bernhard, R. H., Hanse, S., McDonagh, J., Moberg, J. P., Nielsen, N. E., & Nordbo, E. (2003). Productivity in maize based cropping systems under various soil-water-nutrient management strategies in a semi-arid, Alfisol environment in East Africa. *Agric. Water Manag.,* 217-237. http://dx.doi.org/10.1016/S0378-3774(02)00151-8

Julie, P., (2007). *SPSS Survival manual: A step by step guide to data analysis using SPSS for Windows Version 15* (3rd ed.). Open University Press, UK.

Krueger, R. A. (1994). *Focus Groups: A Practical Guide for Applied Research*. Newbury Park, CA: Sage.

Lal, R. (1990). Ridge-tillage. *Soil Till. Res. 18*, 107-111. http://dx.doi.org/10.1016/0167-1987(90)90053-G

Liniger, H. P., Studer, R. M., Hauert, C., & Gurtner, M. (2011). *Sustainable Land Management in Practice - Guidelines and Best Practices for Sub-Saharan Africa*. TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agriculture Organisation of the United Nations (FAO). pp. 243.

Makurira, H., Savenije, H. H. G., Uhlenbrook, S., Rockstrom, J., & Senzanje, A. (2009). Investigating the water balance of on-farm techniques for improved crop productivity in rainfed systems: a case study of Makanya catchment, Tanzania. *Phys. Chem. Earth, 34*, 93-98. http://dx.doi.org/10.1016/j.pce.2008.04.003

Malley, Z. J. U., Kayombo, B., Willcocks, T. J., & Mtakwa, P. W. (2004). *Ngoro*: an indigenous, sustainable and profitable soil, water and nutrient conservation system in Tanzania for sloping land. *Soil Till. Res., 77*, 47-58. http://dx.doi.org/10.1016/j.still.2003.10.003

McHugh, O. V., Steenhuis, T. S., Berihun, A., & Fernandes, E. C. M. (2007). Performance of in-situ rainwater conservation tillage techniques on dry-spell mitigation and erosion control in the drought-prone North Wollo zone of the Ethiopian highlands. *Soil and Till. Res., 97*, 19-36. http://dx.doi.org/10.1016/j.still.2007.08.002

MEA (Millenium Ecosystem Assessment). (2005). *Ecosystems and human well-being: Current states and trends* (p. 625). Washing, DC.

Motsi, K. E., Chuma, E., & Mukamuri, B. B. (2004). Rainwater harvesting for sustainable agriculture in communal lands of Zimbabwe. *Phys. Chem. Earth, 29*, 1069-1073. http://dx.doi.org/10.1016/j.pce.2004.08.008

Mupangwa, W., Love, D., & Twomlow, S. (2006). Soil-water conservation and rainwater harvesting strategies in the semi-arid Mzingwane Catchment, Limpopo Basin, Zimbabwe. *Phys. Chem. Earth, 31*, 893-900. http://dx.doi.org/10.1016/j.pce.2006.08.042

Ncube, B., Magombeyi, M., Munguambe, P., Mupangwa, W., & Love, D. (2008). Methodologies in the Limpopo

Basin. In E. Humphreys, R. S. Bayot (Eds.), *Increasing the Productivity and Sustainability of Rainfed Cropping Systems* (September, 2008. pp. 209-221). Tamala, Ghana.

Nyssen, J., Govaerts, B., Araya, T., Cornelis, W. M., Bauer, H., Haile, M., Sayre, K., & Deckers, J. (2011).The use of the Mareshaard plough for conservation agriculture in Northern Ethiopia. *Agron. Sustain. Dev., 31*, 287-297. http://dx.doi.org/10.1051/agro/2010014

Nyssen, J., Haile, M., Moeyersons, J., Poesen, J., & Deckers, J. (2000). Soil and water conservation in Tigray (Northern Ethiopia): the traditional daget technique and its integration with introduced techniques. *Land Degrad. Dev., 11*, 199-208. http://dx.doi.org/10.1002/1099-145X(200005/06)11:3%3C199::AID-LDR376%3E3.0.CO;2-Y

Okoba, B. O., Tenge, A. J., Sterk, G., & Stroosnijder, L. (2007). Participatory soil and water conservation planning using an erosion mapping tool in the central highlands of Kenya. *Land Degrad. Develop., 18*, 303-319. http://dx.doi.org/10.1002/ldr.778

Oweis, T., & Hachum, A. (2006).Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. *Agric. Water Manage., 80*, 57-73. http://dx.doi.org/10.1016/j.agwat.2005.07.004

Oweis, T., Hachum, A., & Bruggeman, A. (2004). *Indigenous Water-Harvesting Systems in West Asia and North Africa*. ICARDA, Aleppo, Syria.

Oweis, T., Prinz, D., & Hachum, A. (2001). *Water harvesting: indigenous knowledge for the future of the drier environments* (p. 40). ICARDA, Aleppo, Syria.

Rajabu, K. R. M. (2005). The role of participatory problem analysis in performance improvement and sustainable management of rainwater harvesting (RWH) systems: A case study of Makanyavillage, Tanzania. *Phys. Chem. Earth, 30*, 832-839. http://dx.doi.org/10.1016/j.pce.2005.08.027

Reij, C., Scoones, I., & Toulmin, C. (1996). *Sustaining the Soil: Indigenous Soil and Water Conservation in Africa, Earthscan, London*.

Rockstrom, J., Barron, J., & Fox, P. (2002). Rainwater management for increased productivity among smallholder farmers in drought prone environments. *Phys. Chem. Earth, 27*, 949-959. http://dx.doi.org/10.1016/S1474-7065(02)00098-0

Rockstrom, J., Jansson, P.-E., & Barron, J. (1998).Seasonal rainfall partitioning under run-on and runoff conditions on sandy soil in Niger. On-farm measurements and water balance modeling. *J. Hydrol., 210*, 68-92. http://dx.doi.org/10.1016/S0022-1694(98)00176-0

Rockstrom, J., Karlberg, L., Wani, S. P., Barron, J., Hatibu, N., Oweis, T., … Qiang, Z. (2010). Managing water in rainfed agriculture - The need for a paradigm shift. *Agric. Water Manag., 97*, 543-550. http://dx.doi.org/10.1016/j.agwat.2009.09.009

Rockstrom, J., Kaumbutho, P., Mwalley, J., Nzabi, A. W., Temesgen, M., Mawenya, L., … Damgaard-Larsen, S. (2009). Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. *Soil Till. Res., 103*, 23-32. http://dx.doi.org/10.1016/j.still.2008.09.013

Rosegrant, M. W. (1997). *Water resources in the Twenty-first century: Challenges and implications for action. Food, agriculture and the environment*. Discussion paper 20, IFPRI, Washington.

Sachs, J. D., McArthur, J. W., Schmidt-Traub, G., Kruk, M., Bahadur, C., Faye, M., & McCord, G. (2004). Ending Africa's poverty trap. *Brookings Papers on Economic Activity, 1*,117-240. http://dx.doi.org/10.1353/eca.2004.0018

Shiferaw, M. (2006). Keeping an eye on decentralization and specification of a resource policy: an overview of the policy study to the promotion of rainwater harvesting. Best practices and technologies for small-scale agricultural water management in Ethiopia. In *Proceedings of a MoARD/MoWR/USAID/IWMI Symposium and Exhibition Held*, 7-9 March, Addis Ababa, Ethiopia.

Spaan, W. (2003). Consuming the savings: water conservation in a vegetation barrier system at the Central Plateau in Burkina Faso. *Tropical Resources Management Papers, 42*, 14.

Steduto, P., Hsiao, T. C., Raes, D., & Fereres, E. (2009). AquaCrop - The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. *Agron. J., 101*, 426-437. http://dx.doi.org/10.2134/agronj2008.0139s

Sturdy, J. D., Jewitt, G. P. W., & Lorentz, S. A. (2008). Building an understanding of wateruse innovation adoption processes through farmer-driven experimentation. *Phys. Chem. Earth, 33*, 859-872. http://dx.doi.org/10.1016/j.pce.2008.06.022

Temesgen, M. (2007). *Conservation Tillage Systems and Water Productivity Implications for Smallholder Farmers in Semi-arid Ethiopia*. PhD thesis. Taylor & Francis/Balkema, Leiden, the Netherlands.

Temesgen, M., Hoogmoed, W. B., Rockstrom, J., & Savenije, H. H. G. (2009). Conservation tillage implements and systems for smallholder farmers in semi-arid Ethiopia. *Soil & Till. Res., 104*, 185-191. http://dx.doi.org/10.1016/j.still.2008.10.026

Tengberg, A., Ellis-Jones, J., Kiome, R., & Stocking, M. (1998). Applying the concept ofagrodiversity to indigenous soil and water conservation practices in eastern Kenya. *Agric. Ecosyst. Environ., 70*, 259-272. http://dx.doi.org/10.1016/S0167-8809(98)00153-4

Tenge, A. J., Okoba, B. O., & Sterk, G. (2007). Participatory soil and water conservation planning using a financial analysis tool in the west samara highlands of Tanzania. *Land Degrad. Develop., 18*, 321-337. http://dx.doi.org/10.1002/ldr.780

Tilahun, K. (2006). The characterisation of rainfall in the arid and semi-arid regions of Ethiopia.*Water SA, 32*(3), 429-436.

UNCCD, (2000). An introduction to the United Nations Convention to combat desertification. Retrieved June 10, 2011, from http://www.unccd.int

Walker, S., Tsubo, M., & Hensley, M. (2005). Quantifying risk for water harvesting under semiarid conditions. Part II. Crop yield simulation. *Agric. Water Manage., 76*, 94-107. http://dx.doi.org/10.1016/j.agwat.2005.01.007

Welderufael, W. A., Le Roux, P. A. L., & Hensley, M. (2008). Quantifying rainfall-runoff relationships on the Dera calcic fluvicRegosolecotope in Ethiopia. *Agric. Water Manage., 95*, 1223-1232. http://dx.doi.org/10.1016/j.agwat.2008.04.007

Wiyo, K. A., Kasomekera, Z. M., & Feyen, J. (1999). Variability in ridge and furrow size and shape and maize population density on small subsistence farms in Malawi. *Soil &Till. Res., 51*, 113-119. http://dx.doi.org/10.1016/S0167-1987(99)00033-1

WOCAT. (2007). In Liniger, Hanspeter, Critchley, William (Eds.), *Where the Land is Greener – Case Studies and Analysis of Soil and Water Conservation Initiatives Worldwide*. FAO, Rome.

WOCAT. (2010). WOCAT database on SLM technologies and SLM approaches. Retrieved April 13, 2010, from http://www.wocat.net

Zougmore, R., Mando, A., Ringersma, J., & Stroosnijder, L. (2003b). Effect of combined water and nutrient management on runoff and sorghum yield in semiarid Burkina Faso. *Soil Use Manage., 19*, 257-264. http://dx.doi.org/10.1079/SUM2003199

Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/3.0/).