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Report on Adaptation and Performance of Water Harvesting Technologies

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Report on Adaptation and Performance of Water Harvesting Technologies

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WAHARA Project: Water Harvesting for Rainfed Africa: Investing in dryland agriculture for growth and resilience" (FP7-AFRICA-2010-1, grant agreement 265570)"

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Pictures previous page:

Burkina Faso: Banka (Hamado Sawadogo)

Tunisia: Gabion check dam (M. Ben Zaied)

Ethiopia: Hand-dug well (Kifle Woldearegay)

Zambia: Sorghum field (Silenga Wamunyima)

Acronyms

AHP	Analytical Hierarchy Process
REST	Relief Society of Tigray
RWH	Rain Water Harvesting
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa
SWC	Soil Water Conservation
TBoARD	Tigray Bureau of Agriculture and Rural Development
WAHARA	Water Harvesting for Rainfed Africa: Investing in dryland agriculture for growth and resilience.
WH	Water Harvesting
WHT	Water Harvesting Technologies
WP	Work Package

Summary

As part of the implementation of the project WAHARA (Water Harvesting for Rainfed Africa: Investing in dryland agriculture for growth and resilience": FP7-AFRICA-2010-1, grant agreement 265570)", a number of activities have been under implementation with an overall emphasis of: (i) participatory technology design, (ii) sustainable impact, (iii) integration and adaptability, and (iv) learning and action.

One of the major activities carried out was evaluation of the adaptation and performance of the implemented water harvesting technologies under Work Package 3 (WP3). It has been a continuation of the two work packages WP1 and WP2. The main objectives of WP3 were the following:

- Design and adaptation of selected WH technologies with stakeholders;
- Participatory monitoring and evaluation of the performance of selected WH technologies under different biophysical conditions (including variations in use of agricultural inputs);
- Assessment of synergies with and impact on existing farming systems and environmental services.

The adaptation and performance of the different WHT were tested in four countries of Africa: Tunisia, Burkina Faso, Ethiopia, and Zambia. In all the sites, different WHT were selected by the stakeholders and implemented for adaptation. Monitoring has been on-going in all the study sites for two years. Results of the adaptation and performance evaluation of the WHT show the following:

- ***In the case of Tunisia***: Jessour and Tabias contributed a significant role in ensuring crop production but recourse to supplemental irrigation will be needed in case of prolonged droughts. Moreover, combined Zai with Jessour/Tabia help the installation of young trees. In addition, recharge structures have a positive impact on groundwater replenishment but accumulation of silt can reduce significantly this effect.
- ***In the case of Burkina Faso:*** Zai with compost manure + microdosingwa is found to be the best technology; the sorghum grain yield for this technology varied from twice to three times to that of the yield obtained on the control plots. The introduced Magoye ripper gave significant results on grain yield compared to control and stone bunds. But the technology needs too much organic matter use according to the

farmers. The cowpea experiment was well appreciated by the women during the post evaluation of the experiment. Moreover, runoff water harvesting using Banka coupled with improved seed variety and proper soil management resulted in an increase in grain yield: from 2640 Kg/ha to 7367Kg/ha in supplementary irrigated case.

- ***In the case of Ethiopia:*** Bench terraces, if integrated with water availability, are becoming among the highly accepted technologies used for creating land, enhancing food security as well as for reducing erosion/sediment transport. Check-dams have great contribution in a number of ways: (a) reducing gully erosion, (b) enhancing groundwater recharge, (c) storing sediments and buffering moisture/enhancing moisture availability at landscapes. Integrated, landscape level of intervention with several technologies at different parts of the landscapes (trenches, bench terraces, check-dams, afforestation) has improved groundwater availability (from dry to water level upto 3m below surface) and created a landscape which is resilient to rainfall variability. The effectiveness of the implemented technologies has been tested by the El-Niño related drought which hit the northern Ethiopia in 2015; a climate-resilient watershed is created. Soil improvement with Effective Micro-organisms (EM) as well as other amendments have proved to have a good potential for enhancing productivity.
- ***In the case of Zambia***: implementation of WHT is proven to one of the best options to overcome dry spells and enhance productivity. This is because of the water and soil conservative measures employed in the WHTs which enabled the crop to withstand long dry spells experienced during the second year of monitoring.

The research result has proven the fact that through implementation of appropriate and locally adaptive WHT it is possible to enhance agricultural productivity and address challenges of rainfall variability/climate change in SSA.

Table of contents

1. Introduction

In the framework of the implementation of the EU project (FP7-AFRICA-2010-1, grant agreement 265570): "**Water Harvesting for Rainfed Africa: Investing in dryland agriculture for growth and resilience" (WAHARA)**, a consortium from African countries and from Europe have been involved in the implementation of the project.

The WAHARA project consortium members include the following organizations:

(a) Stichting Dienst Landbouwkudig Onderzoek (DLO), Droevendaalsesteeg 4, 6708 PB, Wageningen, the Netherlands (Project leader: Dr. Rudi Hessel).

(b) University of Leeds, Woodhouse Lane, LeedsLS2 9JT, Leeds, UK (Coordinator: Dr. Luuk Fleskens).

(c) MetaMeta, Paardskerkhofweg 14, 5223 AJ 's-Hertogenbosch, the Netherlands (Coordinator: Dr. Frank van Steenbergen).

(d) Institut des Régions Arides (IRA), Route de Jorf Km22, 4119 Médenine, Tunisia (Coordinator: Dr. Mohamed Ouessar).

(e) INERA P.O. Box 8645, Ouagadougou, Burkina Faso (Coordinator: Dr. Sawadogo Hamado).

(f) Mekelle University, Ethiopia (Coordinator: Dr. Kifle Woldearegay).

(g) GART, along Great North Road, Chisamba, Zambia (Coordinator: Dr. Douglas Moono).

(h) Wageningen University (WU-LDD), Droevendaalsesteeg 4, 6708 PB, Wageningen, The Netherlands (Coordinator: Prof. Dr. Coen J. Ritsema).

(i) ACA, Zambia (Coordinator: Mr. Piet Stevens).

The overall emphasis of the project was: (i) participatory technology design, i.e. selecting and adapting technologies that have synergies with existing farming systems and that are preferred by local stakeholders, yet tap from a global repertoire of innovative options; (ii) sustainable impact, i.e. technologies that combine multiple uses of water, green and blue water management, and integrated water and nutrient management; (iii) integration and adaptability, i.e. paying attention to the generic lessons to be learned from local experiences, and developing guidelines on how technologies can be adapted to different conditions; and (iv) learning and action: designating a strategy to enable learning and action from successes achieved locally: within a region, to upscale from water harvesting technologies to water harvesting systems; and across regions, promoting knowledge exchange at continental scale.

The project is divided into several work packages. The first work package (WP1) dealt with the assessment/evaluation of the potential for WH in an array of biophysical and human environmental settings in rainfed Africa. The second work package (WP2) dealt with participatory selection of WH technologies in the study sites whereby different WH technologies were selected by stakeholders in the different study sites for further adaptation. The third work package (WP3) dealt with testing of the selected WH under various biophysical and socio-economic settings in four study sites in different representative settings in Africa: Tunisia, Burkina Faso, Ethiopia, and Zambia. This has been the input for further modeling under the fourth work package (WP4) “Modelling and impact assessment”. This was later integrated under the fifth work package (WP5) which deals with “Integration and scope for adapting WH technologies”.

This report presents the adaptation and performance of the implemented water harvesting technologies under **Work Package 3 (WP3)** of the WAHARA project. It is a continuation of the two work packages mentioned above (WP1, WP2). The report is organized into the following sections. Section 2 presents the objectives and tasks of the WP3. Section 3 summarizes the approaches used. The technologies implemented in each study site is given in Section 4. A summary of the major findings on the adaptation and performance evaluation of the implemented technologies is presented in Section 5.

2. Objectives and Tasks of the WP3

The main objectives of WP3 were the following:

- Design and adaptation of selected WH technologies with stakeholders;
- Participatory monitoring and evaluation of the performance of selected WH technologies under different biophysical conditions (including variations in use of agricultural inputs);
- Assessment of synergies with and impact on existing farming systems and environmental services.

This work package includes four major task/components:

- Task 1: Facilitation and documentation of the adaptation design process of selected WH technologies.
- Task 2: Award competition for the best documentation of design and adaptation process.
- Task 3: Develop participatory monitoring protocols for WH technology performance monitoring.
- Task 4: Participatory monitoring and evaluation.

3. Approaches used

Though different water harvesting technologies were implemented in the different study sites, the approaches used were similar and included: (i) selection of WHT through the involvement of stakeholders, (ii) setting-up of experiment sites, (iii) monitoring of the adaptation process, and (iv) adaptation design which fully involved the stakeholders in the different study sites.

To facilitate the adaptation and monitoring process a protocol on the adaptation and monitoring of the different WHT was developed which included the following, among others: (a) type of WHT, (b) economic, social and environmental considerations, (c) parameters to be monitored/measured including frequency, and (d) scale of application, etc. Every study site has adapted the commonly developed protocol, with some modifications, to suit the local context of the specific study sites (Annex I).

4. Technologies implemented in each study site

The study sites in this project are Tunisia, Burkina Faso, Ethiopia, and Zambia. The study sites are described in WAHARA deliverable 2.1 (Ouessar et al, 2012). In all the sites, different WHT were selected by the stakeholders and implemented for adaptation as described in deliverables 2.3 (Swadogo et al., 2013). Monitoring has been on-going in all the study sites for two years. The major monitoring tasks accomplished in each of the four study sites is discussed below.

Task 1: Facilitation and documentation of the adaptation design process of selected WH technologies

(a) ***Tunisia:*** The WHT implemented include: Tabia, Jessour, Recharge wells, Zai, Gabion check-dams, and Cisterns. Monitoring the performance of the WHT has been going-on as planned and with the designed protocol (Annex 1).

(b) ***Burkina Faso***: The WHT implemented include: Zaï (with compost manure plus microdosingwa), Magoye ripper, and stone line. Monitoring the performance of the WHT has been going-on as planned and with the designed protocol (Annex 1).

(c) ***Ethiopia:*** The WHT implemented include: Percolation ponds with hand-dug wells, Check-dams, bench terraces with hillside cisterns, and Soil improvement (like mulching, effective micro-organisms and others). Monitoring the performance of the WHT has been going-on as planned and with the designed protocol (Annex 1).

(d) ***Zambia:*** The WHT implemented include: Zero tillage, Strip tillage, and Ripping. Monitoring the performance of the WHT has been going-on as planned and with the designed protocol (Annex 1).

Task 2: Award competition for the best documentation of design and adaptation process

In order to encourage good documentation of the design and adaptation process, an award competition was implemented. This involved selection of an independent jury and selection of the study sites who provided the best documentation. As an outcome of this competition Burkina Faso became the lead with Ethiopia the second. The award given was a certificate with highly relevant books related to the research projects: the books were prioritized by the participants but approved by the project coordinator.

All the study sites have produced documents on the documentation and adaptation processes. With full participation of stakeholders and taking into consideration the local conditions (biophysical, socio-economic and political), the study sites have implemented an approach which is context specific but with similar general approach which includes the following:

- Assessment of existing and potential water harvesting in the study sites and the existing socio-economic and environmental settings.
- Identification of stakeholders who could be involved in WHT selection and adaptation processes including governmental, non-governmental, private sector as well as local communities.
- Participatory selection of WHT for adaptation with full involvement of stakeholders.
- Design and adaptation of selected WH technologies with stakeholders.
- Participatory monitoring and evaluation of the performance of selected WH technologies under different biophysical conditions (including variations in use of agricultural inputs).
- Assessment of synergies with and impact on existing farming systems and environmental services.

As a result each study site has produced reports and one study site has produced videos on the adaptation processes.

Task 3: Develop participatory monitoring protocols for WH technology performance monitoring

Proper documentation of the adaptation process is a pre-requisite for evaluating the performance and cost-benefit as well as for further up-scaling of the technologies. The whole process which includes selection of technology, implementation of the technologies and approaches used were documented by each site. The technology performance monitoring involved a sound field experiment including variations in biophysical conditions and/or variations in use of agricultural inputs as well as environmental services in addition to biomass production. In order to have scientific basis for adaptation and performance evaluation and compare the results from the different countries as well as upscale the innovations, it was necessary to develop a participatory monitoring and performance evaluation protocol. The mmonitoring protocols also specified the scale, frequency and duration of monitoring. The following points were considered:

- For field level technologies it was recommended to design the trials with the same crop for all technologies in one study site.
- For each of the WHT, it was arranged that the data to be collected during the adaptation and evaluation process was linked with the criteria used in the selection of the technologies.
- Data on weather condition of the specific site is needed and as much as possible these data should be generated.
- In order to have data for publications repetition of the trials is needed; at least 3 trials are required though more is better.

The following main points were included in the documentation process:

- Type of WHT to be adapted;
- Where to be applied or applicability/suitability of the WHT?
- How to implement it (technical info, principle, drawings, etc)?
- Information on implementation (that don't need monitoring);
- What data to measure?
- How to measure?
- How often (time/space)?

Taking into consideration the above approach, a commonly agreed protocol was developed and each study site has tried to adapt to its site/technology specific conditions (Annex 1). Based on this, each study site has adapted several WHT and has been doing monitoring work for two years.

Task 4: Participatory monitoring and evaluation

In the four study sites, adaptation as well as participatory monitoring and evaluation has been carried out in the period 2013 to 2014. The activities carried out in this line is summarized below.

(i) Participatory monitoring and evaluation in Tunisia

The field work and monitoring have concerned the following:

- Climate: The main parameters recorded were Temperature (Tmin, Tmax), Rainfall, wind velocity, and relative humidity.

- Water balance: three main sites have been selected for water balance representing the major WHT encountered in the different landscape units (upstream, middle stream, downstream) of the study site, namely: Jessour, Tabia, and groundwater recharge check dams. The Zai technique has been associated with Jessour and Tabia for establishment of new plantations.
- Hydraulic characterization of gabion check dams: field measurements have been done on 42 sites using double ring infiltrometer in order to estimate the saturated vertical hydraulic conductivity of retention basins in the Oum Zessar watershed. Measurements were done with small and large pairs of rings (Van den Bosch et al., 2014). On three reference sites outside the study area, measurements with small and large double ring infiltrometer sets, and measurements with a disk infiltrometer were conducted.
- Gabion check dams silting up: this study aimed at investigating the characteristics of gabion recharge and spreading check dams with a focus on silting up rates. Topographic surveys and systematic inventory of 283 units have been carried out in 2013. Results show that 25% are in poor condition, 15% are in fair condition and 60% are in good condition. It was found that more than 53% of check dams are silted up from 51 to 100%.
- Assessment and evaluation of WHT: the aim of this research was to design a scientifically-based and generally applicable methodology to evaluate and assess the performance of existing RWH techniques in (semi-) arid regions. The methodology was applied in the study site in 2013. Engineering, biophysical, and socio-economic criteria were taken into account to assess the performance of RWH using the Analytical Hierarchy Process (AHP) supported by Geographic Information System (GIS). The performance of 58 RWH locations (14 jessour and 44 tabias) in three main sub-catchments in the study watershed were assessed and evaluated. Based on the criteria selected, 60% of the assessed sites received scores indicating moderate performance, 36% of the sites showed low performance, and only 4% received good performance scores.
- Groundwater pollution risks: Groundwater aquifers in the study are mainly recharged through the various WHT. Two main sources of pollution are wastewater treatment plant in Médenine, used water effluents from industrial areas (Koutine, Road Ben Guerdane industrial area) and solid waste discharges in wadis where various WHT have been constructed. The study was conducted in 2015 and supported by two

surveys (February and June 2015) aimed to identify the hydrochemical quality of groundwater, the concentration of Nitrate and isotopes analyses (Sulfate, Nitrate and Oxygen). 43 water points have been selected based on their positions relative to pollution sources and on the geographical distribution.

- Socio-economic aspects of WHT: based on socio-economic and biophysical survey done in 2013 (Table 1), households were asked if they benefit from water harvesting techniques applied in their area, what type of water harvesting techniques have been implemented and who implements these techniques. The survey revealed that within the watershed gabion units are the more used technique (67%) followed by Tabias and Jessour (31%). The presence of recharge techniques is quite small (2%). Some difference between locations can be observed. In fact, preference given to Jesours and Tabias in the upstream and midstream areas is higher than in the downstream areas. In fact, in some location checks dams represent 100% of used WHT techniques. It was clear that technologies use depend largely on location in the watershed.

Table 1. Average yield with and without WHT (kg/ha/year) (Source: Surveys).

Crop	location	Dry year			average year			rainfall year		
		Without WHT	with WHT	% change	Without WHT	with WHT	% change	Without WHT	with WHT	% change
Olive	Bénikhdéche	0	0	0%	0	55	100%	0	120	100%
	Médenine Nord	0	0	0%	0	28	100%	0	38	100%
	Sidi Makhlouf	0	20	100%	50	50	0%	0	75	100%
	Overall	0	20	100%	50	47	-6%	0	91	100%
Almond	Bénikhdéche	0	0	0%	0	20	100%	0	58	100%
	Médenine Nord	0	0	0%	0	20	100%	0	32	100%
	Sidi Makhlouf	0	0	0%	0	20	100%	0	50	100%
	Overall	0	0	0%	0	20	100%	0	48	100%
Fig	Bénikhdéche	0	0	0%	0	22	100%	0	45	100%
	Médenine Nord	0	0	0%	0	33	100%	0	70	100%
	Sidi Makhlouf	0	5	100%	0	16	100%	0	41	100%
	Overall	0	3	100%	0	20	100%	0	47	100%
Cereal	Bénikhdéche	0	0	0%	150	150	0%	450	380	-16%
	Médenine Nord	0	0	0%	35	29	-17%	60	65	8%
	Sidi Makhlouf	0	0	0%	0	60	100%	0	207	100%
	Overall	0	0	0%	92	67	-27%	255	226	-11%

(ii) Participatory monitoring and evaluation in Burkina Faso

The participatory monitoring and evaluation in Burkina Faso involved experiments that included: Comparison of WHT (Experiment 1), and Cowpea experiment for women (Experiment 2). These experiments are summarized below.

Experiment 1: Comparison of WHT

Two local WHT (stones bunds and Zaï) were compared to a newly adapted WHT (Magoye Ripper from Zambia). The control did not include application of fertilisation, because if farmers apply fertiliser, they also used a WHT technique. Hence, the control and treatments used give the best representation of the options that are used by farmers in reality.

Treatments:

T0 = Control = no WHT, no fertilization.

T1= stones bunds + 5 tons of compost manure+ microdosing

T2= Zaï + 5 tons of compost manure+ microdosing

T3= Magoye + 5 tons of compost manure+ microdosing

Number of replication: 10 farmers for each site

Sites: Somyaga, Ziga, Masbore

The data collected during the experiment include:

- Dates of rains during the rainy season.
- Dates of ploughing, sowing, weeding, manure application, chemical fertilizer application, pesticide application, harvest.
- Evaluation of yield of grain and straw.
- Soil sample: before sowing, at harvest.

Results of the experiments for experiment 1 is given in Table 2.

Table 2. Results for Ziga site for experiment 1

	T0	T1	T2	T3
Grain (Kg/ha)	471	742	1036	773
Straw (Kg/ha)	2791	4258	5138	4778

Experiment 2: Soil fertility management

The Zaï is the WHT used in this experiment

Treatments:

T0 = Control = no WHT, no fertilization.

T1= Zaï + 5 tons of compost manure (common practice in the region).

T2= Zaï + 5 tons of compost manure+ microdosing.

T3= Zaï + 5 tons of compost manure+ recommended fertilizer.

Data collected: the same to the first experiment.

Results for Ziga site for soil fertility management is given in Table 3:

Table 3. Results for Ziga site experiment 2.

	T0	T1	T2	T3
Grain (Kg/ha)	545	795	855	1054
Straw (Kg/ha)	3405	4135	4515	4975

Experiment 3: Cowpea varieties for women

This experiment is only reserved to women and young people.

Number of farmers/site: 10

Two new varieties from research station are compared to the local variety of the farmer (Table 4).

T1= KVX 775

T2= local variety

T3= KVX 442

Table 4. Results for Ziga site experiment 3

	T1	T2	T3
Grain (Kg/ha)	620	377	506
Straw (Kg/ha)	521	339	479

The plates below (Plate 1) show some of the results of the experiment.

Plate 1. Some of the technologies implemented in Burkina Faso: (a) Cowpea experiment at Ziga, and (b) Plot of Zaï with sorghum in the WHT comparison experiment at Masbore study site (September 2014; Photo credit: Hamado Sawadogo).

Generally, it is understood that the effect of the different Zaï is positive irrespective of the year. It has also been reported that the age of the SWC technology has an impact on their efficiency. The results of the agronomic monitoring (Table 5 and 6) show a rapidly expanding production system with an increasing use of manure. SWC technology and the use of manure are means by which producers can get better crop yields in the region.

Table 5. Sorghum grain and straw yield (kg.ha^{-1}) at Somyaga, Burkina Faso.

Traitements	Year 2011		Year 2012		Year 2013	
	Grain	Straw	Grain	Straw	Grain	Straw
T1	28c	179d	336 c	1288c	268c	1212d
T2	433b	1326c	1079 b	2755b	787b	2169c
T3	1018a	2857b	1588 a	4621a	1253a	2972b
T4	1142a	3589a	1857 a	4837a	1400a	3486a

Means in the same column with the same letter are not differents according to the Newman Keuls test at 5% level. T1=control treatment; T2=Zaï+5t.ha^{-1}of compost manure; T3=Zaï +5t.ha^{-1}of compost manure+62kg.ha^{-1}of NPKSB+50kg.ha^{-1}of urea; T4 = Zaï +5t.ha^{-1} of compost manure +100kg.ha^{-1} NPKSB +50 kg.ha^{-1} of urea.

Table 6. Sorghum grain and straw yield (kg.ha^{-1}) at Ziga, Burkina Faso.

Traitements	Year 2011		Year 2012		Year 2013	
	Grain	Straw	Grain	Straw	Grain	Straw
T1	72c	409c	408c	1382c	341d	1321c
T2	316b	1275b	926b	2468b	819c	2346b
T3	827a	2988a	1422a	2892a	1114b	3478a
T4	908a	3017a	1609a	2958a	1552a	3631a

Means in the same column with the same letter are not differents according to the Newman Keuls test at 5% level. T1=control treatment; T2=Zaï+5t.ha^{-1}of compost manure; T3=Zaï +5t.ha^{-1}of compost manure+62kg.ha^{-1}of NPKSB+50kg.ha^{-1}of urea; T4 = Zaï +5t.ha^{-1} of compost manure +100kg.ha^{-1} NPKSB +50 kg.ha^{-1} of urea.

Experiment 4: Using banka (Run off capturing) to improve maize productivity by supplementary irrigation at Ziga, northwestern Burkina Faso

T1 : Control (0 soil ploughing) : Organic matter : 0 kg + NPK : 0 + Urea : 0

T2 : Zaï : Organic matter : 5t/ha + 200 kg/ha NPK in micro-dosing + 50 kg/ha Urea

T3 : Magoye : Organic matter : 5t/ha + 200 kg/ha NPK in micro-dosing + 50 kg/ha Urea

Table 7. Grain yield of maize in kg/ha (Banka grains) at Ziga, northwestern Burkina Faso

Site	***Producer***	***Mode***	***T1 (Control)***	***T2 (Zaï)***	***T3 (Magoye Ripper)***
Ziga	Ouedraogo Boukari	Non-irrigated	653	4000	4520
Ziga	Ouedraogo Boukari	Irrigated	2640	7367	8667

As can be noted from Table 7, as compared to control, the Zai and Magoye ripper have resulted in higher fields when irrigated than non-irrigated with water from a Banka. The Magoye ripper technology has resulted in higher yield than that of Zai technology. This shows that irrigated agriculture with Magoye ripper have a higher potential for enhancing productivity if properly implemented with appropriate soil management applications.

Policy-makers should use these results to open up discussion on the strategy that central and regional government should proceed with regarding the transition between immediate and long-term support for vulnerable food producers in Burkina Faso. An important component towards meeting the African Water Vision is the need for managing rainwater resources for "drought proofing" communities which are often subject to regular climatic variability and uncertainty. Rainwater harvesting and storage has been recognized as one way of achieving this and hence the need for up-scaling of appropriate WHT in the region.

(iii) Participatory monitoring and evaluation in Ethiopia

The main WHT implemented in the selected watershed include: Percolation ponds, Check-dams, Bench terraces, Shallow groundwater wells and Soil fertility improvement. Each of these technologies is summarized below.

- **Percolation ponds:** Several percolation ponds (4 in 2013, 5 in 2014, and 3 in 2015) were constructed in collaboration with Wukro Saint Mary College, REST and TBoARD (e.g. Plate 2). Monitoring has been going on for three years (one year before the implementation and two years after the implementation) to evaluate the hydrological effects of the percolation ponds on spring discharge at downstream areas. Results of the spring discharge measurement is given in Figure 1.

Plate 2. Percolation ponds: (a) 20m long, 15m wide and 2.5m deep, and (b) 12m long, 8m wide and 2m deep constructed to enhance spring discharge and shallow groundwater recharges, Ethiopia.

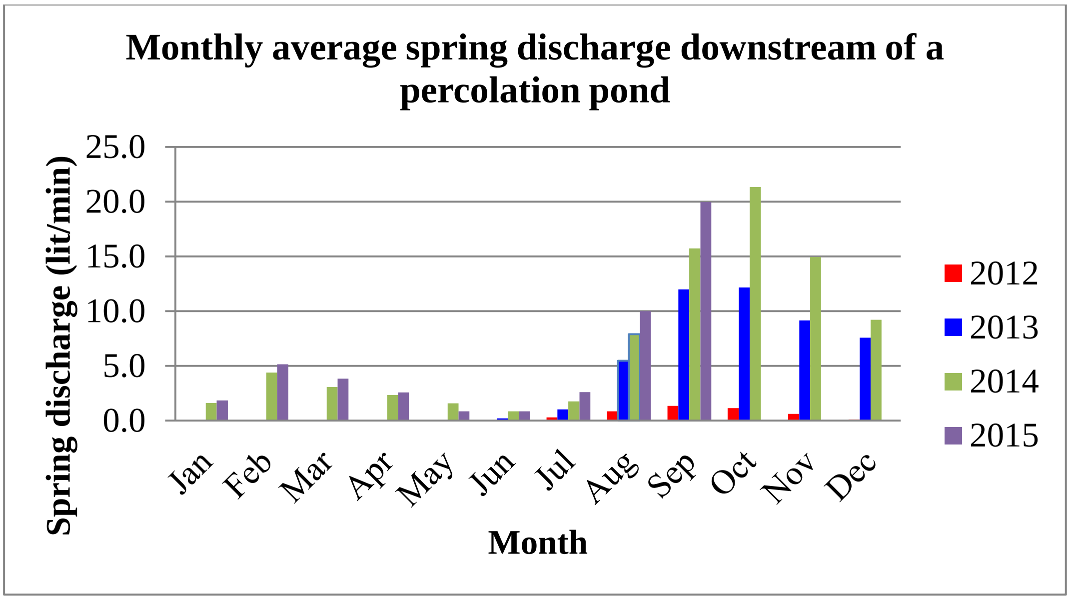

Figure 1. Monthly average spring discharge measurement at downstream of two percolation ponds in Gule sub-watershed, Ethiopia (for the years 2012-2015).

- **Check-dams:** A total of 15 check-dams were implemented in the Gule watershed with close cooperation with REST, Wukro Saint Mary College, Tigray Bureau of Agriculture and Rural Development, and the communities, and local administrative bodies. These check-dams are categorized into two major types: (a) gabion check-dams (e.g. Plates 3 and 4) which are designed to rehabilitate degraded gullies through accumulation of sediment and water, and (b) check-dam ponds (e.g. Plate 5), mostly constructed along the flat lying streams, designed to store water for irrigation purpose and for shallow groundwater recharge.

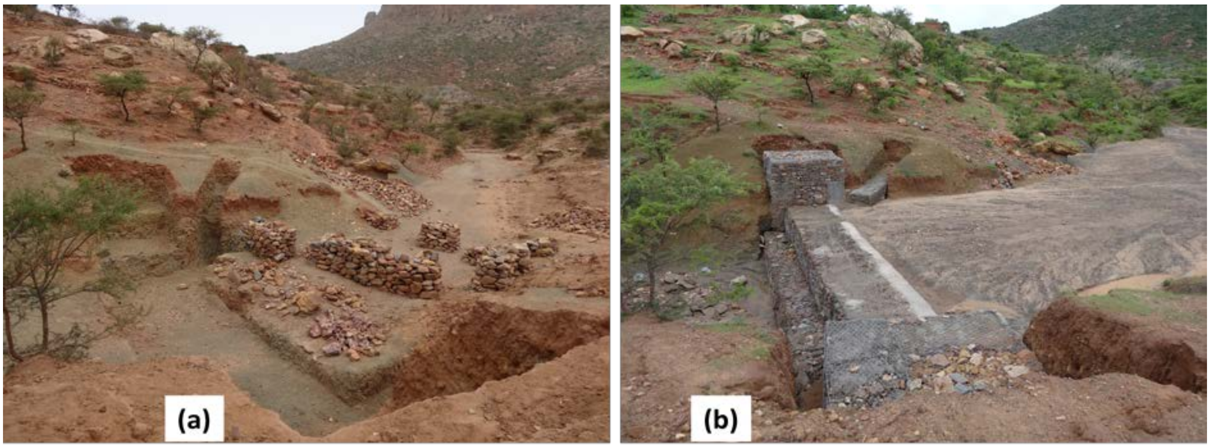

Plate 3. Gabion check-dams which are constructed to rehabilitate degraded streams and to enhance groundwater recharge in Gule watershed, Northern Ethiopia (project is funded by WFP and TBoARD).

Plate 4. Gabion check-dams which are constructed to rehabilitate degraded streams and to enhance groundwater recharge in Gule watershed, Northern Ethiopia (project is funded by Wukro Saint Mary College): (a) before biological treatment in July 2013 and (b) after biological treatment in July 2014.

Plate 5. Check-dam pond which is constructed to store/diver stream flow for irrigation and shallow groundwater recharge in Gule Watershed, Northern Ethiopia (project is funded by Relief Society of Tigray).

- ***Hand-dug wells downstream of check-dams :*** After the construction of check-dams and percolation ponds more than 15 hand-dug wells have been developed at downstream areas (e.g. Plate 6). Upstream soil/water conservation like deep trenches coupled with check-dam construction has resulted in an increase in groundwater recharge; wells have become more productive as a result. Monitoring has been carried out to evaluate the hydrological effects (mainly in terms of shallow groundwater level) and sediment concentration in streams in representative locations. Rainfall data from Wukro station of the Ethiopian National Meteorology Service Agency (ENMSA) and from WAHARA rain gauge stations were taken (Figure 2a). Results of the monitoring show that shallow groundwater level has improved due to the combined effects of the interventions (check-dams, percolation ponds, and previously done deep trenches) in the areas (Figure 2) despite a general reduction in rainfall in the years 2013-2015 as compared to that of 2010 and 2012. Sediment concentration was found to reduce downstream of areas where treatments have been carried out (Figure 3) while in areas where there is no treatment the sediment concentration was found to be high. In sites with no treatment the sediment concentration remained similar but in areas where treatments were done sediment concentration has reduced by more than 50%.

Plate 6. Shallow hand-dug well downstream of the gabion check-damps and percolation ponds: (a) during the excavation of the well, (b) the same hand-dug well which became productive throughout the year after, Ethiopia.

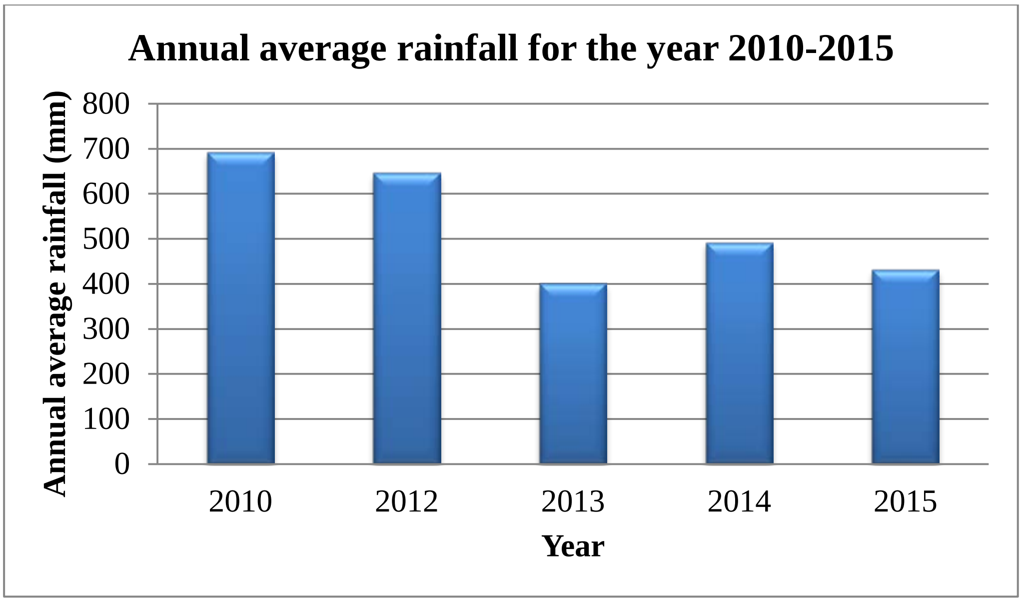

Figure 2a. Annual average rainfall for the year 2010-2015, Ethiopia. The annual average rainfall for the year 2010 and 2012 was taken from the Ethiopian National Meteorology Service Agency (Wukro station; 17Km from the research site) and the rainfall data for the 2013-2015 was taken from WAHARA project rain gauge station. For the year 2015 only rainfall until September is taken from Wukro station.

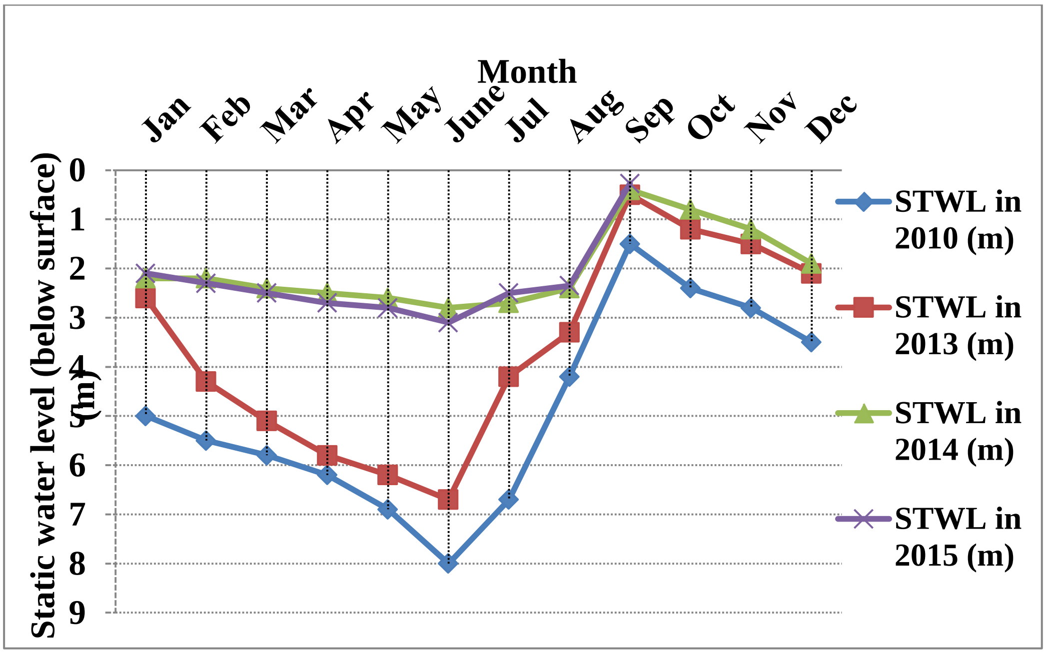

Figure 2b. Measurement of the Static Water Level (STWL) (m) of a representative hand-dug well in Gule watershed, Ethiopia.

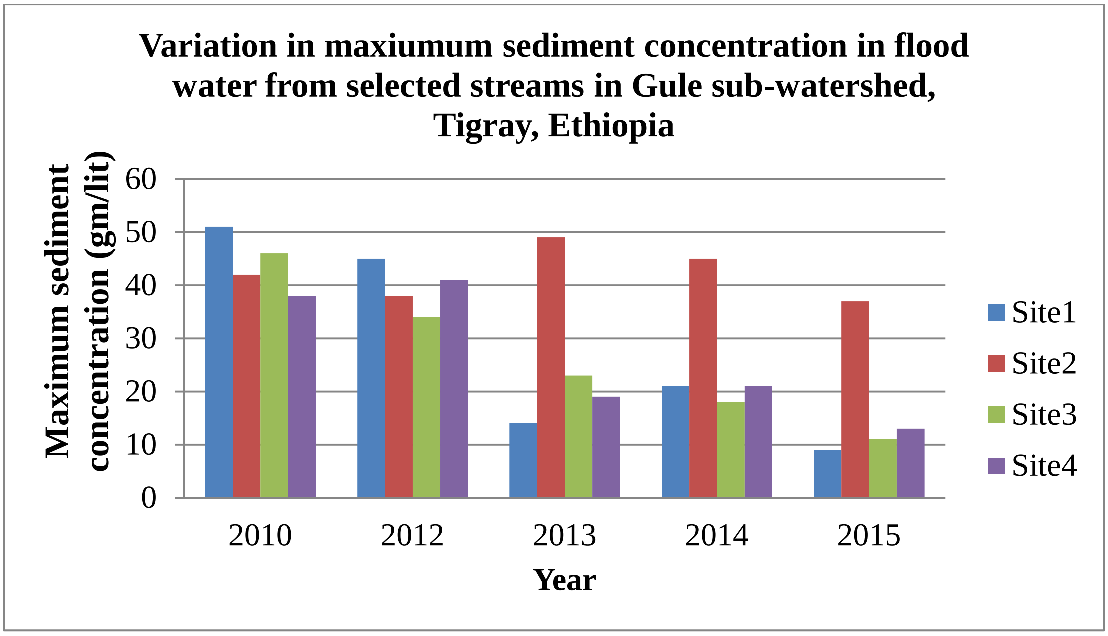

Figure 3. Sediment concentration (gm/lit) in stream water at different positions of the Guke watershed, Ethiopia. Site 1= Downstream of a treated gully; Site 2= Downstream of untreated gully; Site 3= Downstream of two percolation ponds; Site 4= Downstream of treated and untreated stream (main outlet of the sub-watershed). Note that implementation of the different WHT were implemented starting January 2013.

- **Bench terraces:** Starting the year 2013, a new development has emerged in Tigray, Ethiopia: creating new cultivable land from hilly terrains through bench terrace construction. During the stakeholder technology selection workshop (organized at the end of 2012 by EU-funded WAHARA project in Wukro town of Tigray, Ethiopia), the workshop participants have selected bench terrace with hillside cisterns as top priority of interventions. The participants of the workshop included representatives from Tigray Bureau of Agriculture and Rural Development (TBoARD), Relief Society of Tigray (REST), MERET project, SLM project, Wukro Saint Mary College, representatives of local farmers in the Suluh watershed, and Mekelle University. Immediately after the workshop, the Tigray Bureau of Agriculture and Rural Development has started constructing bench terraces in Tigray, Ethiopia. Though bench terrace is traditionally known in limited areas of Ethiopia (mainly Erobe in Tigray, and Konso in Southern Ethiopia), the technology has not evolved much in the country. The first bench terrace is constructed by the TBoARD in the year early 2013 in Zata watershed, Tigray, Ethiopia (Plate 7). In collaboration with Wukro Saint Mary and TBoARD, bench terrace is introduced at Gule watershed (Plate 8). Since then, the Tigray national regional government has given top priority to implement bench terrace development in all parts of Tigray whereby the newly developed cultivable land is integrated with water sources and distributed to landless youth (women and men) for multi-level crops: fruit trees and vegetables crops (e.g. Plate 9).

Plate 7. The first bench terrace constructed in Zata watershed in Tigray, Ethiopia (implemented by Tigray Bureau of Agriculture and Rural Development in the year early 2013) (Photo: Kifle Woldearegay).

Plate 8. A bench terrace constructed as a demonstration in Gule watershed (funded by Wukro Saint Mary College).

Plate 9. Bench terrace developed and distributed to local youth in Embahazti, Tigray, Ethiopia (note: bench terrace is constructed in 2013) (Photo: Kifle Woldearegay).

The experiences of bench terrace development in Tigray is now being shared to other regions of Ethiopia where bench terrace was not known before. The WAHARA project has been documenting the performance of the bench terraces in different topographical, geohydrological and agro-ecological zones in Tigray and in other parts of Ethiopia over the last two years. Results show that if integrated with any available sources of water (hand-dug wells, springs, reservoirs, pumping from rivers, etc) bench terraces could be among most important sources of income for youth in rehabilitated landscapes of Ethiopia. Considering the limited land size which is created by bench terrace development and high cost of construction and maintenance, land users need to focus on high value crops and implement soil improvements. There is also a need to give due attention towards optimum use of available water resources.

- ***Soil improvements:*** Two technologies of soil improvements were tried in the area. In the year 2013/2014, mulching with and without EM (Plate 10a), and use of Vermiculite (Plate 10b). The types of experiment (Table 8) and the results of the experiment is given in Figure 4 for grain yields and Figure 5 for biomass yield. As an extension of this, in the year 2014/2015, the research has focused on the effects of different amendments on yield was experimented (Table 9).

Plate 10. Field level stakeholders discussing on the technology introduced: (a) Soil improvement using EM, and (b) soil improvement using vermiculite.

Table 8. Eight different parameters (with and without EM) implemented in Gule sub-watershed, Ethiopia.

No	Soil amendments	+ EM	- EM
1	**Compost**		
2	**Compost and Orga**		
3	**Orga + Urea**		
4	**IF (DAP and UREA)**		
5	**IF and Compost (75:25)**		
6	**IF and Compost (50:50)**		
7	**IF and Compost (25:75)**		
8	**Control**		

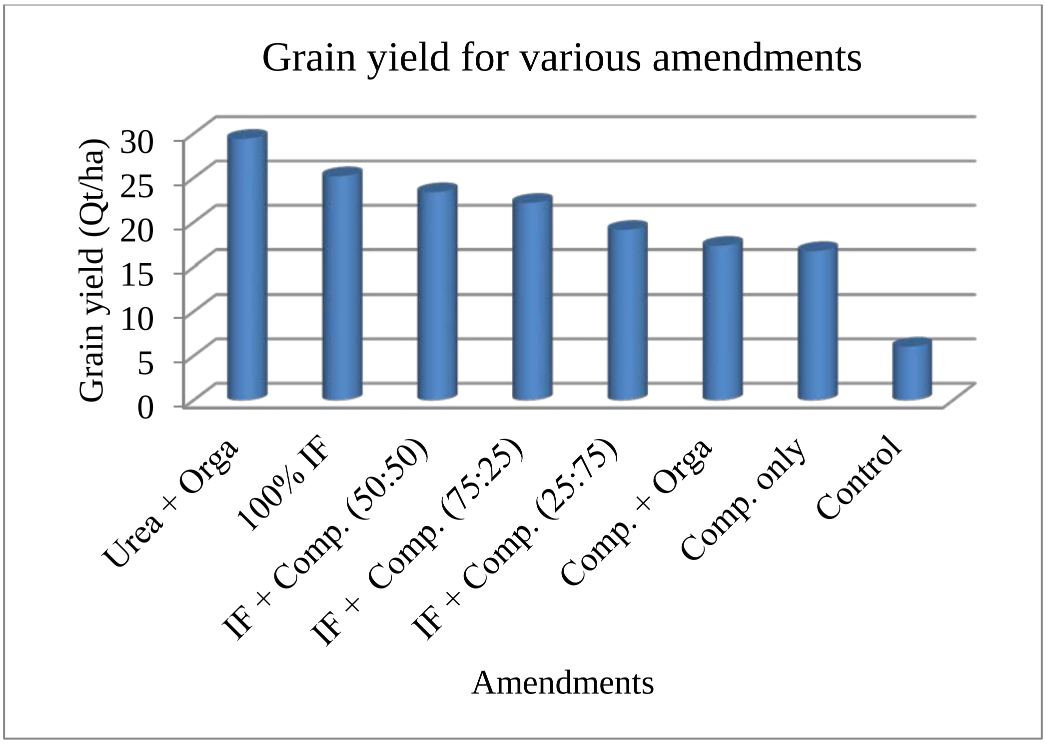

Figure 4. Variations in grain yield (Qt/ha) for various amendments in Gule sub-watershed in the year 2013/2014, Ethiopia.

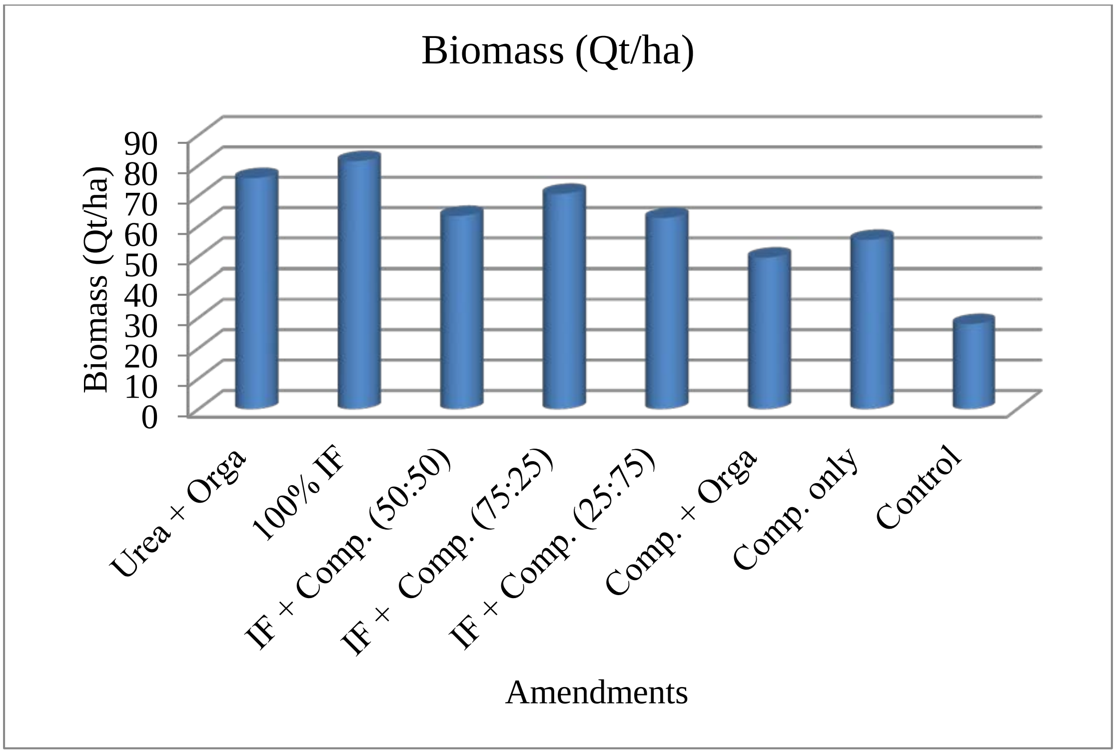

Figure 5. Variations in biomass yield (Qt/ha) for various amendments in Gule sub-watershed in the year 2013/2014, Ethiopia.

Table 9. Mean comparison of yield and yield components of bread wheat to various soil amendments in the year 2014/2015.

Soil amendment types	PH (cm)	NET (No/plant)	SL (cm)	SPS (No/spike)	DBM (t/ha)	GY (t/ha)	HI (%)	TGW (g)
DAP plus Urea with EM	61.33^{ab}	8.0^{a}	7.58^{a}	22.53^{a}	5.56^{a}	2.24^{a}	40.26^{a}	28.44^{abcd}
Compost with EM	56.68^{bcd}	6.47^{abcde}	6.37^{cd}	21.3^{ab}	4.11^{bc}	$1.61b^{c}$	38.82^{ab}	29.91^{abc}
Manure with EM	48.82^{ef}	4.7^{cde}	6.02^{de}	18.1^{abc}	1.89^{efgh}	0.69^{ef}	36.4^{ab}	26.76^{bcd}
Orga plus Urea with EM	53.65^{de}	7.67^{a}	6.64^{bcd}	23.07^{a}	4.22^{bc}	1.72^{b}	40.96^{a}	27.89^{abcd}
Control with EM	40.29^{gh}	3.93^{e}	5.29^{fg}	15.23^{bc}	1.22^{fh}	0.67^{ef}	37.61^{ab}	26.27^{bcd}
Compost plus Orga with EM	54.86^{cde}	6.87^{abc}	6.39^{cd}	22.13^{a}	3.67^{bc}	1.62^{bc}	44.05^{a}	30.79^{ab}
Manure plus Orga with EM	45.78^{fg}	4.25^{de}	5.6^{ef}	18.2^{abc}	2.00^{efgh}	0.8^{ef}	39.91^{a}	28.97^{abc}
Manure plus DAP with EM	51.48^{def}	4.93^{bcde}	6.24^{d}	22.73^{a}	2.67^{de}	1.00^{de}	37.5^{ab}	28.99^{abc}
DAP plus Urea without EM	63.29^{a}	7.97^{a}	7.98^{a}	22.1^{a}	6.11^{a}	2.42^{a}	39.65^{a}	28.53^{abcd}
Compost without EM	55.27^{bcde}	6.63^{abcd}	6.45^{bcd}	21.03^{ab}	3.67^{bc}	1.47^{bc}	39.91^{a}	30.53^{ab}
Manure without EM	49.82^{ef}	4.37^{cde}	6.11^{de}	18.83^{abc}	2.22^{ef}	0.8^{ef}	36.18^{ab}	27.17^{abcd}
Orga plus Urea without EM	56.36^{bcd}	6.83^{abc}	6.88^{bc}	22.7^{a}	4.56^{b}	1.82^{b}	39.81^{a}	24.91^{cd}
Absolute Control	35.32^{h}	4.0^{e}	4.77^{g}	13.33^{c}	1.33^{fgh}	0.42^{f}	31.58^{b}	23.75^{d}
Compost plus Orga without EM	60.60^{abc}	7.33^{ab}	7.06^{ab}	21.23^{ab}	4.11^{bc}	1.73^{b}	42.26^{a}	32.37^{a}
Manure plus Orga without EM	48.85^{ef}	4.27^{de}	6.01de	18.57^{abc}	2.22^{efg}	0.81^{ef}	36.7^{ab}	27.69^{abcd}
Manure Plus DAP without EM	49.78^{ef}	6.33^{abcde}	6.18^{de}	22.7^{a}	2.67^{de}	1.3^{cd}	38.98^{ab}	29.35^{abc}
CV (%)	6.5	22.3	5.3	16.9	16.2	16.1	10.2	9.5

Note: PH=Plant height, NET= Number of effective tillers, SL= Spike length, SPS=Seeds per spike, DBM=above ground dry biomass yield, GY=Grain yield, HI=Harvest Index, TGW=Thousand grain weight. Means with in columns followed by the same latter are not significantly different at $p<0.05$.

- Results of the experiment in soil improvement in the year 2013/2014 (Figures 4 and 5) show that:
    - Application of 100% compost plus orga, 100% compost and a combination of more OF with IF improved soil physical properties such as soil bulk density, soil moisture content, soil water holding capacity and soil available water.
    - Application of 100% compost plus orga, and 100% compost improved soil total nitrogen, available phosphorus, organic matter, CEC and exchangeable cations with more available phosphorus and exchangeable Calcium in 100% compost plus orga and 100% urea plus orga.
    - The highest numbers of soil micro-organisms (bacteria and fungi) were also obtained in treatments having more organic matter. EM application improved biological soil properties and total nitrogen.
    - Application of IF alone was inferior in the improvement of soil physical, chemical and biological properties with the same results as the soil with no soil amendment or slightly higher in most parameters. Whereas, plots treated with 100% Urea plus orga had moderate soil properties improvements.

- Results of the experiment in soil improvement in the year 2014/2015 (Table 6) show that:
    - Yield and yield components of bread wheat were affected by the application of organic and inorganic fertilizers amended with EM compared to the absolute control.
    - The highest yield was obtained in plots treated with the application of DAP plus Urea with and without EM (2.24t ha^{-1} and 2.42 t ha^{-1}, respectively). However, the lowest yield was obtained from absolute control (0.42 t ha^{-1}) followed by control plot with EM (0.67 t ha^{-1}). Intermediate yield between higher and lower was obtained from sole application of organic and in combination with inorganic fertilizers.
    - EM application did not play well on the increment of yield and yield components of bread wheat; this was due to lack of the recommended factors such as moisture, nutrients, soil organic matter in the soil. Yield results were strongly associated with the increments of agronomic traits such as plant height, dry aboveground biomass, seeds per spike, spike length and number of effective tillers per plant.

- From the overall results of the study, combined use of organic and inorganic fertilizers amended with EM has some distinct outcome over the full supply of organic or inorganic fertilizers. These outcomes confirm that besides increasing of yield and yield traits of bread wheat (inorganic fertilizers); they take part in improving soil fertility components (organic fertilizers) through saving SOM.

(iv) Participatory monitoring and evaluation in Zambia

The research centre lies on the frontage of two micro-catchment areas: Magoye river and Ngwezi stream. The stakeholders have selected and prioritized several WHT for further research and adaptation process. Several farmers have participated in the research.

Each of them have all provided 1 Lima of land on which the on-farm research has been undertaken. The farmers have also provided all the inputs required. However, it should be mentioned that not all farmers provided all necessary required inputs and rate of application.

It is worth mentioning that the following lessons are learned from the research work, especially with the costs associated with research experiments:

- The stakeholders had proposed Ex-situ WHT such as dam construction of which GART-WAHARA team had limited budget for construction of WHT for the research. This was also beyond the scope of GARTs expertise. Stakeholder involvement during the planning, experimentation and adaptation was crucial for successfully up-scaling of a certain WHT.
- The need exists to engage in ex-situ WHTs research in the near future. However, organizations involved in the natural resources management will have to be brought on board.

Monitoring of the WHTs started during the 2013/2014 farming season and the following data has been collected:

- Soil properties of the soil; soil pH, soil texture, S.O.M, soil respiration, bulk density and soil water infiltration rate.
- Economic data: production costs (labour input, weeding, fertilizer and seed inputs, harvesting costs and transportation costs), and yield data.
- Timing of operations: land preparation, planting, weeding and harvesting.

- Rainfall data: days of rainfall and amounts (mm).

Plate 11. Results of the adaptation: (a) maize crop in the zero till field, and (b) maize from the WHT Plot bagged separate from the main crop.

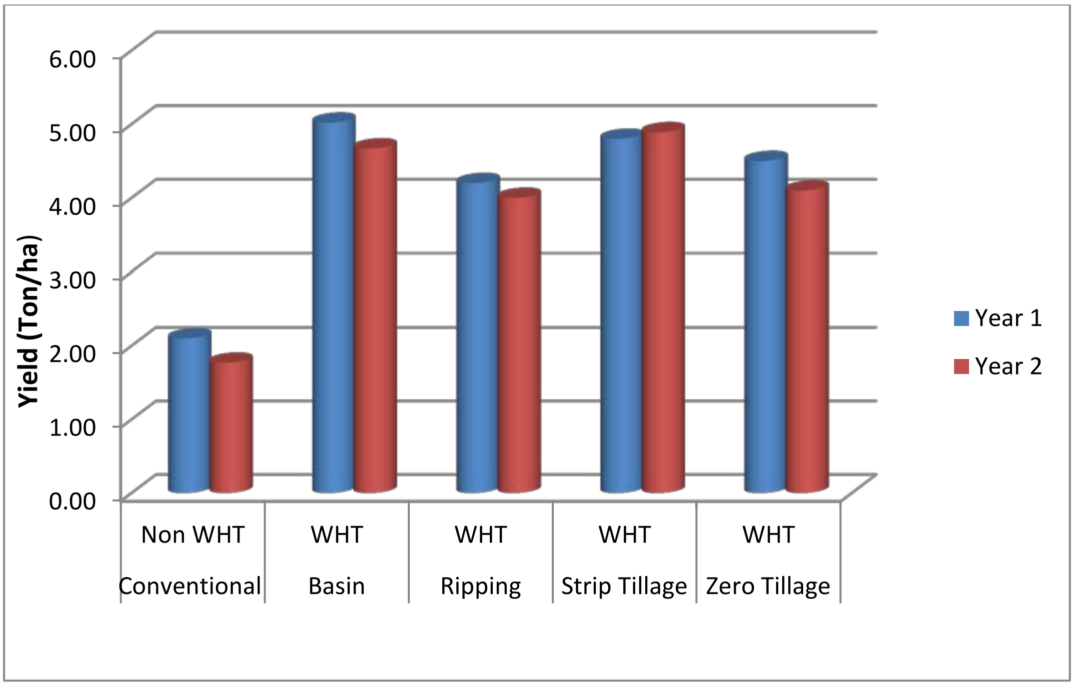

Figure 6. Maize yield with respect to the different water harvesting implemented in Zambia.

Generally all farming systems recorded lower yields in the second year of monitoring except for WHT Strip Tillage which showed a marginal increase in yield by 1.88%. The fall in yield in the WHTs was minimal compared to the fall in the None WHT. This is because of the water and soil conservative measures employed in the WHTs which enabled the crop to withstand long dry spells experienced during the second year of monitoring.

The reduction in yield could be attributed to the poor rainfall recorded in the second year (2014/15 Farming Season). The Conventional Method (None WHT) recorded worst yield losses by a value of 15.77%; this is because the method lacks water harvesting interventions. Crop damage due to poor rainfall (low rainfall) in 2014/2015 farming season was as high as 80 percent in some parts of Southern Zambia (Zambia National Farmers' Union, 2015), the Ministry of Agriculture and Livestock (MAL) reports that National Maize (*Zea mays*) production has fallen by 18 percent in 2015 due to low rainfall and drought in some instance (MAL., 2015).

5. Summary of main findings of the adaptation and performance evaluation of the implemented technologies

5.1 Results from Tunisia

The research which have been implemented in Tunisia has resulted in the following key findings:

- Jessour and tabias can continue play a significant role in ensuring crop production but recourse to supplemental irrigation will be needed in case of prolonged droughts,
- Combined Zai with jessour/tabia help the installation of young trees
- Recharge structures have a positive impact on groundwater replenishment but accumulation of silt can reduce significantly this effect. Therefore, direct recharge through improved recharge wells is under investigation.

5.2 Results from Burkina Faso:

The research which have been implemented in Burkina Faso has resulted in the following key findings:

- The zaï with compost manure + microdosingwa is found to be the best technology. The sorghum grain yield for this technology varied from twice to three times the yield obtained on the control plots.
- The introduced Magoye ripper gave significant results on grain yield compared to control and stones bunds. But the technology needs higher organic matter use according to the farmers.
- The Cowpea experiment was well appreciated by the women for its better productivity during the post evaluation of the experiment.
- Runoff water harvesting using Banka coupled with improved seed variety and proper soil management resulted in an increase in grain yield from 2640 Kg/ha to 7367Kg/ha in supplementary irrigated case. This shows the high potential for enhancing productivity through the integration of proper water harvesting, crop variety and land/soil management.

5.3 Results from Ethiopia

The research which have been implemented in Ethiopia has resulted in the following key findings:

- Integrated with water sources, the introduced bench terraces in Tigray are becoming among the highly accepted technologies used for creating new cultivable land and enhancing food security as well as reducing erosion.
- Check-dams are found to have great contribution in a number of ways: (a) reducing gully erosion, (b) enhancing groundwater recharge, and (c) storing sediments and buffering moisture/enhancing moisture availability at landscapes.
- Integrated, landscape level of intervention with different technologies along the landscape (trenches, bench terraces, check-dams, afforestation) has improved groundwater availability (from dry to water level upto3m below surface) and created a landscape which is resilient to rainfall variability. This is demonstrated by the fact that despite the El-Niño which occurred in northern Ethiopia in 2015, water availability is ensured and productivity has not declined in the watershed because of the landscape level of interventions linked with WAHARA research.
- Soil improvement with Effective Micro-organisms (EM) as well as other amendments have proved to have a good potential for enhancing productivity as these methods would increase soil moisture in soils and enhance soil nutrient.
- With the soil improvement, all treatments recorded higher yield and yield components than the control. Especially in treatments done in the year 2013/2014, they improved wheat productivity from lowest 1.65 times in 100% compost without EM to 4.29 times in 100% urea plus orga without EM. The highest yield was obtained in plots that received 100% urea plus orga without EM (32.03 qt/ha) followed by 100% IF without EM (29.44 qt/ha). These higher yields were associated with higher agronomic parameters such as number of tillers, plant height, and spike length, number of seeds/spike and above ground biomass. Although application of EM was insignificant in most of the agronomic parameters, its application with more organic matter (compost) resulted a significance increase in number of fertile tillers, plant height, panicle length, number of seeds/panicle and yield. But plots treated with 100% IF and 100% urea plus orga decreased the above agronomic parameters when applied with EM resulting 28.84% and 16.27% yield decline when compared without EM, respectively. In general term application of EM compost can increase the efficiency of normal compost (compost without EM) by 1.834 times in the case of area coverage.

This could be considered as a great success. Besides to this matured compost could be prepared within 2 months with the help of EM but without EM it took more than 80 days.

- The research has shown that organic soil amendments improve both soil fertility and crop productivity where as IF improve crop yield but without improving soil properties. Therefore investigation presented in this study indicates some distinct benefits of combined application of organic and inorganic nutrient sources together with EM over full supply of OM or inorganic fertilizer. The results confirm that besides increasing the crop yield, such practices save mineral fertilization and had potential effects on sustainable agricultural production in soils low in organic matter. In addition, the possibility of sustaining the soil ecology and the environment cannot be ignored.

5.4 Results from Zambia

The research which have been implemented in Zambia has resulted in the following key findings:

- Implementation of WHT is one of the best options to overcome dry spell and enhance productivity.
- This is because of the water and soil conservative measures employed in the WHTs which enabled the crop to withstand long dry spells experienced during the second year of monitoring.

Acknowledgement

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 265570 (WAHARA project).

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Annex I. WAHARA Project: Water Harvesting Adaptation Protocol

Adaptation and Performance Evaluation of WH Technologies: Protocol

1. Background

This document tries to outline the main processes to be followed for the adaptation and evaluation of different water harvesting technologies selected (to be introduced) in the four study sites of Africa (Tunisia, Burkina Faso, Zambia and Ethiopia) as part of the WP3 for the WAHARA project.

The main objective of this process includes the following:

- Design and adaptation of selected WH technologies with stakeholders.
- Participatory monitoring and evaluation of the performance of selected WH technologies under different biophysical conditions (including variations in use of agricultural inputs).
- Assessment of synergies with and impact on existing farming systems and environmental services.

In order to fulfil the above objectives, the following tasks are to be carried out:

- Facilitation and documentation of the adaptation design process of selected WH technologies.
- Award competition for the best documentation of design and adaptation process.
- Develop participatory monitoring protocols for WH technology performance monitoring.
- Participatory monitoring and evaluation.

2. Selected WHT and Parameters to be documented

Through the involvement of stakeholders, the four study sites have identified WHT for the adaptation process. The WHT selected and the parameters to be documented are summarized in Table 1. Though each study site is expected to design a detailed methodology on how to measure parameters in the field, it is necessary to note that:

- Depending on the WHT, it is necessary to evaluate the conditions before, during and after the introduction of the technologies.
- Involvements of stakeholders need to be encouraged at all levels of the adaptation process.

- If possible, partial financing of the installation of the WHT by the stakeholders could ensure the sustainability and further up-scaling of the technologies.
- It is advisable to use materials such as maps or sketches, films, recorded interviews, etc in the documentation of the adaptation process.

3. Format for WHT documentation

Proper documentation of the adaptation process is a pre-requisite for evaluating the performance and cost-benefit as well as for further up-scaling of the technologies. The following points need to be considered, depending on the WHT to be adapted:

- For field level technologies it is recommended do design the trials with the same crop for all technologies in one study site.
- In each of the WHT, the data to be collected during the adaptation and evaluation of should have a link with the criteria used in the selection of the technologies.
- Data on weather condition of the specific site is needed and as much as possible this date should be generated.
- In order to have data for publications repetition of the trials is needed; at least 3 trials are required though more is better.
- Financial scheme which includes who pays and how much for implementation and maintenance of the WHT need to be documented.

At least the following points need to be included in the documentation process:

- Type of WHT to be adapted
- Where to be applied?
- How to implement (technical info, principle, drawings, etc)?
- Information on implementation (that don’t need monitoring)
- What data to measure?
- How to measure?
- How often (time/space)?

Table 1. Summary of WHT and the parameters to be measured in each study sites.

WHT	Country	Economic	Social	Environ.	Technical	Scale	Repetition	Document	Frequency
Stone line	Burkina	- Dimension: length and width of the plots, - Slope of the plots, - Area of plots, - Cost and benefit, - Yield.	Land rehabilitation	- Soil moisture, - Organic matter, - Nitrogen content, - - Texture (once), - Infiltration rate, - Growth rate &phenol stage.	- Characteristics of the soil,	Field	10	- Soil moisture, - Organic matter, - Nitrogen content, - Texture (once), - Infiltration rate, - Growth rate & phenol stage.	From weekly to monthly
Zai	Burkina	- Dimension: length and width of the plots, - Slope of the plots, - Area of plots, - Cost and benefit, - Yield.	Land rehabilitation	- Soil moisture, - Organic matter, - Nitrogen content, - - Texture (once), - Infiltration rate, - Growth rate &phenol stage.	- Characteristics of the soil	Field	10	- Soil moisture, - Organic matter, - Nitrogen content, - Texture (once), - Infiltration rate, - Growth rate & phenol stage.	From weekly to monthly
Mango ripper (from Zambia)	Burkina		Land rehabilitation	- Soil moisture, - Organic matter, - Nitrogen content, -- Texture (once), - Infiltration rate, - Growth rate &phenol stage.	- Characteristics of the soil	Field	10	- Soil moisture, - Organic matter, - Nitrogen content, -- Texture (once), - Infiltration rate, - Growth rate & phenol stage.	From weekly to monthly

Percolation ponds with shallow wells	Ethiopia	-Construction cost (fixed), - Maintenance cost (variable), - Dimension: width, length, depth, - Materials used, - Labour (person days), - Who uses water, - Cost and benefit, - Yield, - Expected life WHT	- Shift in water us, - Shift in land use,	- Groundwater level, - Soil moisture, - Water quality, - Downstream discharge (springs) (quantity& quality), - Rate of water abstraction, - Sediment storage	- Dimension: length, width, and depth, - Excavability of the soils and rocks, - Best locations of percolation ponds, - Construction sequence of the ponds, - Designs for percolation ponds.	Sub-Catchment	At least two ponds	- Soil moisture, -GW level, - Yield - Sediment storage.	From daily to monthly
Check dams	Ethiopia	- Construction cost (fixed), - Maintenance cost (variable), - Dimension: length , width, depth and reservoir capacity, - Labour (person days), - Who uses water, - Cost and benefit, - Yield, - Expected life WHT.	- Shift in land use -	- Groundwater level, - Spring development, - Downstream discharge (springs) (quantity & quality), - Soil moisture, - Water quality, - Runoff, - River bank stabilization.	- Dimension: length, width, depth and capacity of the check dam, - Designs for specific soil condition, Spillways capacity, - Erosion protection measures, -Designs for check-dams.	Sub-Catchment	At least 3	- Sediment storage, - Runoff, - Groundwater level, - Spring discharge.	From weekly to monthly
Hillside cisterns with bench	Ethiopia	- Construction cost (fixed),	- Shift in land use	- Runoff reduction, - Sediment storage,	- Benches: detail design for the	Hillside	At least 3	- Productive area created,	From weekly to monthly

terraces		- Maintenance cost (variable), - Dimension: length and width of the bench terrace, - Slope of the terrace, - Area of bench created, - Labour (person days), - Who uses the bench terrace, - Cost and benefit, - Yield, - Expected life WH	(how to use hillslide)	- Groundwater recharge,	raiser, length, width, slope of the bench. - Cistern: design for the capacity and shape of the cistern.			- Soil moisture, - Organic matter, - Nitrogen content, -Abundance earth worms, - Bulk density, - Biomass on field, - Texture (once), - Infiltration rate, - Growth rate & phenol stage.	
Soil improvement I: Mulching with and without EM.	Ethiopia	- Dimension: length and width of the plots, - Slope of the plots, - Area of plots, - Cost and benefit, - Yield.		- Soil moisture, - Organic matter, - Nitrogen content, -Abundance earth worms, - Bulk density, - Biomass on field, - Texture (once), - Infiltration rate, - Growth rate &phenol stage.	- Characteristics of the Mulch, - Characteristics of the EM, - Methods of applying the trials (design)	Field	At least 3	- Soil moisture, - Organic matter, - Nitrogen content, -Abundance earth worms, - Bulk density, - Biomass on field, - Texture (once), - Infiltration rate, - Growth rate & phenol stage.	From weekly to monthly
Soil	Ethiopia	- Dimension: length and		- Soil moist,	- Characteristics of			- Soil moisture,	From weekly to

improvement II: use of Vermiculite		width of the plots, - Slope of the plots, - Area of plots, - Cost and benefit, - Yield.		- Organic matter, -Abundance earth worms, - Bulk density, - Biomass on field, - Texture (once), - Infiltration rate, - Growth rate &phenol stage.	the Vermiculite, - Methods of applying the trials (design).	Field	At least 3	- Organic matter, - Nitrogen content, -Abundance earth worms, - Bulk density, - Biomass on field, - Texture (once), - Infiltration rate, - Growth rate & phenol stage.	monthly
Zero tillage	Zambia	Labour Yield Cost&quantity fertiliser, insect etc. Timing operations	e.g. acceptability (if changing over time) conflicts about residue Spontaneous adoption	- Soil moist, - Organic matter, -Abundance earth, worms, - Bulk density, - Biomass on field, - Texture (once), - Infiltration rate(once?) - Growth rate &phenol stage - Pollution, - Decrease erosion		Field			From weekly to monthly
Strip tillage	Zambia	Labour Yield	e.g. acceptabili	- Soil moist, - Organic matter,		Field			From weekly to monthly

		Cost&quantity fertiliser, insect etc. Timing operations	ty (if changing over time) conflicts about residue Spontaneous adoption	-Abundance earth, worms, - Bulk density, - Biomass on field, - Texture (once), - Infiltration rate(once?) - Growth rate &phenol stage - Pollution, - Decrease erosion					
Ripping	Zambia	Labour Yield Cost&quantity fertiliser, insect etc. Timing operations	e.g. acceptability (if changing over time) conflicts about residue Spontaneous adoption	- Soil moist, - Organic matter, -Abundance earth, worms, - Bulk density, - Biomass on field, - Texture (once), - Infiltration rate(once?) - Growth rate &phenol stage - Pollution, - Decrease erosion		Field			From weekly to monthly
Tabia	Tunisia	-Construction costs -Maintenance costs -Olive yield		-Soil moisture -Runoff received -Sediment received	-Dimensions -Slope -GPS position	Hillside	At least three units	-Soil moisture -Yield	-At start -After each major rainfall event

		-Cereal yield -Other crop yields -Farming activities: ploughing, pruning, harvest, etc.							-During major farming operations
Jessour	Tunisia	-Construction costs -Maintenance costs -Olive yield -Cereal yield -Other crop yields -Farming activities: ploughing, pruning, harvest, etc.		-Soil moisture -Runoff received -Sediment received	-Dimensions -Slope -GPS position	Hill	At least three units	-Soil moisture -Yield	-At start -After each major rainfall event -During major farming operations
Recharge wells	Tunisia	-Construction costs -Maintenance costs Expected life Cost & benefit		-Waterlevel/ponding -Ponding time -Groundwater level -Silting up of the retention basin	-Dimensions -GPS position	Catchment	At least 5 units	-Ponding time -Groundwater level	-At start -After major flood events
Zai	Tunisia	-Construction costs -Maintenance costs -Olive yield -Cereal yield -Other crop yields -Farming activities: ploughing, pruning, harvest, etc.		-Soil moisture -Runoff received -Sediment received	-Dimensions -Slope -GPS position	Field	At least three units	-Soil moisture -Yield	-At start -After each major rainfall event -During major farming operations

Gabions check dams	Tunisia	Construction costs -Maintenance costs Expected life Cost & benefit		Runoff received -Sediment received	Dimensions -GPS position	Catchment	At least three units	Soil moisture -Yield	-At start -After each major rainfall event -During major farming operations
Cisterns	Tunisia	- Construction costs -Maintenance costs - Expected life - cost and benefit -Vegetation development (biomass ?) - blue (drinking) water use ? Animal watring ?		-Runoff received -Sediment received	Dimensions -Slope -GPS position	Field	At least three units	-water storage	At start -After each major rainfall event
Deep trench	Tunisia	-Construction costs -Maintenance costs -Vegetation development (biomass)		-Soil moisture -Runoff received -Sediment received	-Dimensions -Slope -GPS position	Field	At least three units	Biomass development	-At start -After each major rainfall event