AMBO UNIVERSITY
SCHOOL OF GRADUATE STUDIES
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCE
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ASSESSMENT OF EFFECT OF MANAGEMENT PRACTICES AND AGRO-ECOLOGY ON WATER PRODUCTIVITY OF MAJOR CROPS IN MEJA WATERSHED, JELDU DISTRICT, OROMIA REGION, ETHIOPIA

M.Sc. THESIS

By:

ADDISU ASFAW DEBELA

DECEMBER, 2012
AMBO

ASSESSMENT OF EFFECT OF MANAGEMENT PRACTICES AND AGRO-ECOLOGY ON WATER PRODUCTIVITY OF MAJOR CROPS IN *MEJA* WATERSHED, JELDU DISTRICT, OROMIA REGION, ETHIOPIA

By:

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A Thesis Submitted to the School of Graduate Studies of Ambo University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Environmental Science

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As Thesis research advisor, I hereby certify that I have read and evaluated this Thesis entitled: ASSESSMENT OF EFFECT OF MANAGEMENT PRACTICES AND AGRO-ECOLOGY ON WATER PRODUCTIVITY OF MAJOR CROPS IN MEJA WATERSHED, JELDU DISTRICT, OROMIA REGION, ETHIOPIA prepared under my guidance by: **Addisu Asfaw Debela**. I recommend that it can be submitted as fulfilling the Thesis requirement.

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BIOGRAPHY OF THE AUTHOR

The Author was born in Ambo, West Shewa zone of Oromia region, on May 5, 1981. He completed his elementary and High School education in Addis Ketema Primary and Ambo Comprehensive Senior Secondary Schools, respectively. He joined the then Alemaya University in September 2000 and Graduated with B.Ed in Geography in 2003. He was employed by Ministry of Education in Gelemso Senior Secondary School in July 2003 as a teacher. In October 2005, he was employed in Madda Welabu (Private) College, Ambo, Ethiopia as instructor and Academic vice dean. In December 2006, he was transferred to Ambo Micro Business College and employed as Ambo Campus Dean. In 2009, he was re-employed in Medda Welabu College as academic vice dean with agreement to get educational opportunity.

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LIST OF ACRONYMS AND ABREVIATIONS

BM	**Biomass**
BMY	**Biomass Yield**
CPWF	**Challenge Program on Water and Food**
CWP	**Crop Water Productivity**
ECWP	**Economic Crop Water Productivity**
EIAR	**Ethiopian Institute of Agricultural Research**
ETB	**Ethiopian Birr**
ET_C	**Crop Evapotranspiration**
FAO	**Food and Agricultural Organizations**
FDRE	**Federal Democratic Republic of Ethiopia**
GIS	**Geographic Information System**
GPS	**Global Positioning System**
GY	**Grain Yield**
HI	**Harvest Index**
ILRI	**International Livestock Research Institute**
IR	**Irrigation Requirement**
IRRI	**International Rice Research Institute**
IWMI	**International Water Management Institute**
JDOA	**Jeldu District Office of Agriculture**
MoARD	**Ministry of Agriculture and Rural Development**
NBDC	**Nile Basin Development Challenge**
RS	**Remote Sensing**
SSA	**Sub Saharan Africa**
SY	**Straw Yield**
TECWP	**Total Economic Crop Water Productivity**
USDA	**United States Department of Agriculture**
USD	**United States Dollar**
WP	**Water Productivity**

ABSTRACT

Low water use efficiency is a challenge to crop production in Sub-Sahara African countries. Water is getting continuously scarce due to increased demand and shrinking availability induced mainly by climate change. As agriculture is the major consumer of water, improving crop water productivity is among the ways of overcoming the challenge. Crop production under rainfed system is the major livelihood strategy for smallholder farmers in Ethiopia. The major objective of this study is, therefore, to estimate water productivity of major crops grown under rainfed system in *Meja* watershed as influenced by management practices and local agro-ecology. The research work mainly depends upon house hold survey and field measurement conducted from July 2011 to February 2012. Agronomic practices used for major crops were monitored on randomly selected farmers' fields, and biomass and grain yield were determined at harvest. Crop water requirement was simulated by CROPWAT model from which the average consumptive water use (m^3) by each crop was calculated. In a mixed crop livestock farming system, farmers obtain benefit not only from grain but also from straw (primarily as animal feed). In line with this demand, the average biomass water productivity magnitudes for barley *(Hordeum vulgare)*, wheat *(Triticum Vulgare)*, teff *(Eragrostis tef)*, sorghum *(Sorghum bicolor)*, potato *(Solanum tuberosum)* and maize *(Zea mays)* were found to be 3.57, 4.82, 2.31, 6.45, 14.61 and 6.68kg/m^3, respectively while the corresponding grain water productivity were 1.32, 1.42, 0.65, 0.98, 14.25 and 1.42kg/m^3 in that order. Based on the local market values of the crops' biomass, economic water productivity of barley, wheat, teff, sorghum, potato and maize were determined to be 10.09, 10.84, 8.45, 8.05, 28.82 and 10.18 Birr/m^3, respectively. The mean biomass water productivity showed significant variation across the three local agro-ecological zones due to variations in seeding rate, tillage frequency, fertilizer rates and other agronomic practices. Hence, farmers can enhance economic benefit from the land and water resources they are endowed with rainfed by using improved technologies that could enhance grain and biomass yield. Moreover, implementation of integrated crop-soil-water management strategy is crucial to bring sustainable agricultural production and ensure food security in the long run. The correlation test between some management practices and major crops water productivity also indicated no significance but tended to correlate indicating a need to have detailed further study.

1. INTRODUCTION

1.1 Background and Justification

Globally, rainfed agriculture is very important as it constitutes 80% of the world's agricultural lands and generates 58% of the world's staple food (SIWI, 2001 in Singh *et al.* 2011). According to Singh *et al.* 2011, most food for poor communities in developing countries is produced in rainfed areas. For instance, in Sub-Saharan Africa (SSA) over 95% of the farm land is under rain fed. In Ethiopia, about 94% of the total 74.3 million hectare of arable land is rainfed (MARD, 2009).

As water is one of the most critical inputs to agriculture, rainwater is an essential resource to rainfed agriculture (Molden *et al*. 2003). In regions characterized by erratic rainfall, rainfed agriculture is subjected to inherent water related risks, which make farmers less likely to invest in production enhancing inputs (Singh *et al.* 2011). In these areas, rainfall is the most prominent random parameter beyond farmers' control. Hence, it is both a critical input and a primary source of risk and uncertainty for agricultural production (Rockström *et al.* 2009). On the other hand, agricultural water use is facing competition for water from industry, domestic uses, aquatic ecosystems and environmental services. Thus, water available for agricultural sector is expected to be reduced in the future despite the increasing pressure for more food production (Kijne *et al*. 2003). Yet, the rain fed agriculture practiced by most small holder farmers in developing countries is characterized by poor water management and low water use efficiency. The current rainwater use efficiency for crop production ranges between 30% and 45%, and annually 300 to 800 mm of seasonal rainfall is lost as surface runoff or deep drainage (Wani *et al*. 2003). In SSA, less than 30% of rainfall is used as productive transpiration by crops. On severely degraded land, this proportion can be as small as 5% (Rockström and Steiner, 2003)

Current irrigation water withdrawals are also causing stress in many of the world's major river basins (Molle *et al.* 2007). The world is therefore, facing a water crisis with little scope for further expansion of large-scale irrigation (Singh *et al.* 2011).

Thus, the best solution to alleviate these problems (water scarcity and low water use efficiency) lies on improving water management in rainfed agriculture not only to secure the water required for food production but also to build resilience for coping with the future water related risks and uncertainties (Molden *et al.* 2007; Rockström *et al.* 2010). Crop failures were commonly blamed on "drought''. This might also be prevented in many cases through better farm-level water management (Singh *et al.,* 2011). It was also predicted that there will be further decline in rainfall and amplification of extreme events (IPCC, 2007). Thus, the current and future state-of-affairs denote that increasing food demand due to increasing world population can be satisfied with more efficient use of the available water resources (Singh *et al.* 2011). One of the best mechanisms to attain this objective is improving crop water use efficiency or crop water productivity especially of rainfed (Cai *et al.* 2010). The Comprehensive Assessment of Water Management in Agriculture also pointed out that there is a large and unexploited potential for upgrading rain fed agriculture (Molden *et al.* 2007). An attempt was made by some experts to estimate water productivity (WP) status of major cereal crops and their future potentials for improvement. The result of WP investigation made by Cai and Rosegrant (2003) indicated that the average WP of cereal crops (except rice) in developing countries was lower than 0.56 kg m^{-3} as compared to an average of 1.0 kg m^{-3} for developed countries in 1995. More specifically, WP of cereal crops in SSA was the lowest in the world ranging from 0.1 to 0.3kg m^{-3}. It varied from 1.0–1.7 kg m^{-3} in China, the USA and Brazil; and 1.7–2.4 kg m^{-3} in Western European countries. This crop water productivity variation is attributed mainly to variations in non-water related factors such as environmental, agronomic, social and economic conditions of different localities (Kijne *et al.* 2003). Land degradation, poor soil fertility, soil salinity, lack of improved varieties, low rate of fertilizers used, poor weed management, shortages of labor, insecure land ownership, limited access to capital for investment, limited skill and abilities are among the determinant factors for low crop water productivity (Mulugeta, 2006; Singh *et el.* 2011). These are the potential problem area where interventions are required to improve crop water productivity in rainfed agriculture. By overcoming the limitations emanating from the 'none water factors', agricultural water productivity of small- holder farmers in developing countries like Ethiopia can be increased.

The Ethiopian Institutes of Agricultural Research (EIAR, 2004) suggested that water productivity improvements in crops, livestock and fishery can effectively address food insecurity and poverty. Ethiopian agriculture is small scale, subsistence-oriented dependent on rainfall and, characterized by low productivity. It is facing water shortages that will complicate the national efforts to attain agricultural transformation (EIAR, 2004). Thus, analysis of crop water productivity based on landscape positions and management practices at watershed level is essential to address the problem of water scarcity and food insecurity. Such studies help to examine the current state of crop water productivity and identify the principal factors which contribute to crop water productivity and suggest appropriate technological interventions at each agro-ecological zone for improvement in crop water use efficiency. Efficient on-farm rainwater management system recharges ground water and improves water productivity. According to Wani *et al*. (2001) efficient use of rainwater can be achieved by implementing appropriate crop and land management techniques. Restoration of degraded land and implementation of integrated crops, soil and water management interventions can contribute to the improvement of crop productivity.

1.2 Statement of the Problem

Underdevelopment, rapid population increase, land degradation, climate uncertainty and water scarcity are the major bottlenecks to achieving higher agricultural production and improved rural livelihoods in developing countries like Ethiopia (Singh *et al.* 2011). *Meja* watershed, being part of the Blue Nile (Abay) Basin, is predominantly characterized by subsistence, low yielding and rainfed agriculture. The cultivated land in the area is highly prone to sheet and rill erosion due to lack of appropriate soil and water conservation practices, deterioration of forest cover in the hilly areas and increasing human and livestock population pressure (Birhanu Ayana, 2011). As a result, big and active gullies are formed which decreased ground water infiltration, increased surface run-offs and soil nutrient depletion. Marginal lands and steep slopes are being cultivated that could also aggravate soil erosion, land degradation and reduce crop water use efficiency. Thus, in order to satisfy the needs of the growing populations in the area and restore productivity of the natural landscapes, land degradation should be reversed, rainwater should be properly managed and productivity should be improved. In line with this need, the study was

designed to assess how management practices and local agro-ecology could affect crop water productivity of major crops in the study area. Such studies are very rare in the country.

1.3 Significance of the Study

Limited studies have been conducted to understand the influence of management practices and local agro-ecology in *Meja* watershed and the Abay River Basin. This study attempted to reveal the current status of crop-water productivity, identify determinant factors affecting crop-water productivity and give directions for future improvement of water use efficiency. Thus, the result of this study is very much significant for the local community, development agents, agricultural experts, researchers (in the areas of agronomy, field crop, horticultural crop and soil and natural resource conservation) policy makers and other stakeholders in the area and beyond.

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of the study was to estimate water productivity of major crops based on management practices and local agro-ecological zones in the watershed.

1.4.2 Specific Objectives

The specific objectives of the study include:

1. To identify the cropping systems and existing crops management practices in the study area and relate to crop water productivity.
2. To produce map layers of land use and crop types of the study watershed.
3. To estimate biomass and grain yields of major crops in each local agro-ecology and,
4. To simulate crop water requirements and calculate consumptive water use (m^3) of the major crops.

1.5 Scope of the Study

The study was limited to *Meja* watershed which incorporates parts of *Ento Dalle, Sariti, Tullu Gurra, Chilanko, Bicho, Tullu Gurjji, Edensa Gelan, Kolu Gelan* and *Chobi Sirba* Kebele Administrations (KAs) and part of *Gojo* town. The watershed has been stratified into two local agro-ecological zones (upper and middle). However, *Gora Lalisa* Farmers' Association was purposely added from outside of the watershed as lowland so as to make samples representative of the district's agro-ecologies. The dominant crops cultivated in the study district across the three landscape positions were barley (*Hordeum Vulgera*), potato (*Solanum tuberosum*), wheat (*Triticum vulgare.*), teff (*Eragrostis tef*), sorghum (*Sorghum bicolor*) and maize (*Zea mays*). Minor crops include, faba bean *(Vicia faba L.)*, field pea *(Pisum sativum L.)* flax *(Linum usitatissimum)*, and niger seed *(Guizotia abyssinica)*. Therefore, the study was restricted to the assessment of water productivity of the major crops in their respective local agro-ecological zones based on management practices.

2. LITERATURE REVIEW

2.1 Concept and Definitions of Watershed

A watershed is defined as a geographic area where runoff resulting from drops of rain will be collected and drained through a common confluence point. The confluence point is a single body of water, such as a lake, river or simply a watershed outlet (Seleshi Bekele *et al.* 2009). A watershed can be small as a basin that drains to a tiny creek, or as large as the Nile River Basin (ibid). Hence, it comprises of a catchment area (recharge zone), a command area (transition zone) and a delta area (discharge zone). The top most portion of the watershed is known as the “ridge” and a line joining the ridge portions along the boundary of the watershed is called a “ridgeline”. A watershed is a logical unit for planning optimal development of its soil, water and biomass resources (Calling, 2004).

2.1.1 Characteristics of Watershed

A watershed can be characterized by its size and shape, topography, relief and soil. According to Calling (2004) size of a watershed ranges from less than 100 ha to that of greater than 50,000 ha. A watershed with areas ranging from 1 - 100 ha, 100 - 1,000 ha, 1,000 - 10,000 ha, 10,000 ha - 50,000 ha and above 50,000 ha are called mini watershed, micro watershed, milli watershed, sub-watershed and macro watershed, respectively. A watershed could be described as fan shaped (near circular) or fen shaped (elongated). Hydrologically, the shape of the watershed is important because it controls the time taken for the runoff to concentrate at the outlet. Watersheds may also be categorized as hill or flat watersheds, humid or arid watersheds, red soil watershed or black soil watershed based on criteria like soil, slope and climate. Depending on the land use pattern, watershed could be classified as highland watersheds, tribal settlements and watersheds in areas of settled cultivation (ibid).

2.1.2 Watershed Management

Watershed management is defined as the process of formulating and carrying out a course of action involving the manipulation of resources in a watershed to provide goods and services without adversely affecting the soil and water base. Usually, watershed management must consider the social, economic and institutional factors operating within and outside the watershed area (Seleshi Bekele *et al.* 2009).

The task of watershed management includes the treatment of land by using the most suitable biological and engineering measures in such a manner that the management work must be economical and socially acceptable. The various factors affecting watershed management are watershed characteristics (shape and size, topography, relief and soils); climatic characteristics (precipitation, and amount and intensity of rainfall); watershed operation; land use pattern (vegetative cover, density and state *i.e*, type and quality); social status of inhabitants; and water resources and their capabilities (Seleshi Bekele *et al.* 2009).

Watershed management involves the judicious use of natural resource with active participation of institutions, organizations, in harmony with the ecosystem. The three main components in watershed management are land management, water management and biomass management (Calling, 2004).

Water management: Water characteristics like inflows (precipitation, surface water inflow, ground water inflow) water use (evaporation, evapotranspiration, irrigation, drinking water) outflows (surface water outflow, ground water out flow) storage (surface storage, ground water storage, root zone storage) are the principal factors to be taken care of in sustainable water management (Calling, 2004). The broad interventions for water management are: Rainwater harvesting, ground water recharge, maintenance of water balance, preventing water pollution, economic use of water. Rainwater harvesting forms the major component of water management (ibid).

Land management: Land characteristics like terrain, slope, and formation, depth and texture, moisture and infiltration rate and soil capability are the major determinants of land management activities in a watershed. The broad category of land management

interventions can be as follows: structural measures, vegetative measures, production measures and protection measures (Calling, 2004).

Biomass management: The major intervention areas for biomass management are: eco-preservation, biomass regeneration, forest management and conservation, plant protection and social forestry, increased productivity of animals, income and employment generation activities, coordination of health and sanitation programs, better living standards for people, eco-friendly life style of people and formation of a learning community (Calling, 2004).

2.2 Water Productivity: Concept and Definitions

Water is one of the most critical inputs to agriculture. Currently however, the existing water resource has become scarcer due to fluctuation in local to global climatic conditions, increasing water demand with its low use efficiency (high wastage and deterioration in its quality). Hence, the concept of water productivity emerges with the view to improve water use efficiency (increase its consumptive water use) in agriculture especially in crop production. The concept was first presented by David Molden *et al.* 2003, as a robust measure of the ability of agricultural systems to convert water into food. Principally, it was designed to evaluate the function of irrigation systems as the amount of 'crop per drop'. Recently, however, extending this concept to include other types of livelihood support, such as mixed cropping, pasture, fisheries or forests has become reasonable (Steduto *et al*. 2007). In line with this, the Comprehensive Assessment of Water Management in Agriculture defined water productivity broadly as the ratio of the net benefits from crop, forestry, fishery, livestock, and mixed agricultural systems to the amount of water required to produce those benefits. In its broadest sense it reflects the objectives of producing more food, income, livelihoods, and ecological benefits at less social and environmental cost per unit of water used, where water use means either water delivered to a use or depleted by a use. Simply, it means gaining more benefits with less water) (Steduto *et al*. 2007). Water productivity can be either physical or economical. Physical water productivity is the ratio of the mass of agricultural output (in kg ha^{-1} or ton ha^{-1}) to the amount of water used in m^3, and economic productivity is the value derived per unit of water used (economic return or

nutrition, any other economic and social benefits). Water productivity can be measured for crops as crop water productivity and for livestock as livestock water productivity (Steduto *et al*. 2007) while the two can be integrated to generate system water productivity.

2.2.1 Crops Water Productivity

Crop water productivity is defined as crop yield per cubic meter of water consumption, including 'green' water (effective rainfall) for rain-fed areas and both 'green' water and 'blue' water (diverted water from water systems) for irrigated areas. Definitions of crop water productivity differ based on the background of the researcher or stakeholder. From all other options available; however, obtaining more kilograms per unit of transpiration is an important means of expressing crop productivity with respect to water (Molden *et al*. 2003).

There are different options to assess crop water productivity in rainfed agriculture. Rockström and Barron (2007) pointed out three kinds of considerations of crop water productivity (WP) assessment. These are water productivity with respect to rainfall (usually effective rainfall), evapotranspiration and transpiration. Each of them can be computed using the following formulae:

1. $WPR = \frac{\text{Average Crop Yield (Kg)}}{\text{Rainfall during the growing period (m3)}}$, Where WPR refers to water productivity with respect to rainfall.

It refers to the amount of dry matter or marketable yield produced per unit of rainfall received by the crop or cropping system. This is also known as rainfall use efficiency (RUE) (Singh *et al.* 2011).

2. $WPE = \frac{\text{Crop yield (kg)}}{\text{Actual Evapotranspiration (m3)}}$, Where WPE refers to water productivity with respect to evapotranspiration, and

Water productivity with respect to evapotranspiration is defined as the amount of dry matter or marketable yield produced per unit of evapotranspiration (ET) by the crop, where ET is the sum of soil evaporation and transpiration by the crop during the season (Singh *et al*. 2011).

3. $\text{WPT} = \frac{\text{Crop Yield (kg)}}{\text{Actual crop water use (Ta) (m3)}}$, Where WPT implies water productivity with respect to transpiration.

Water productivity with respect to transpiration is the amount of dry matter or marketable yield produced per unit of water taken up by plants. This is also known as transpiration efficiency or transpiration ratio (Singh *et al.* 2011). As mentioned earlier, this method is more appropriate to express crop productivity with respect to water. Singh *et al.* (2011) tried to summarize several other considerations of expressing crop water productivity from different literatures.

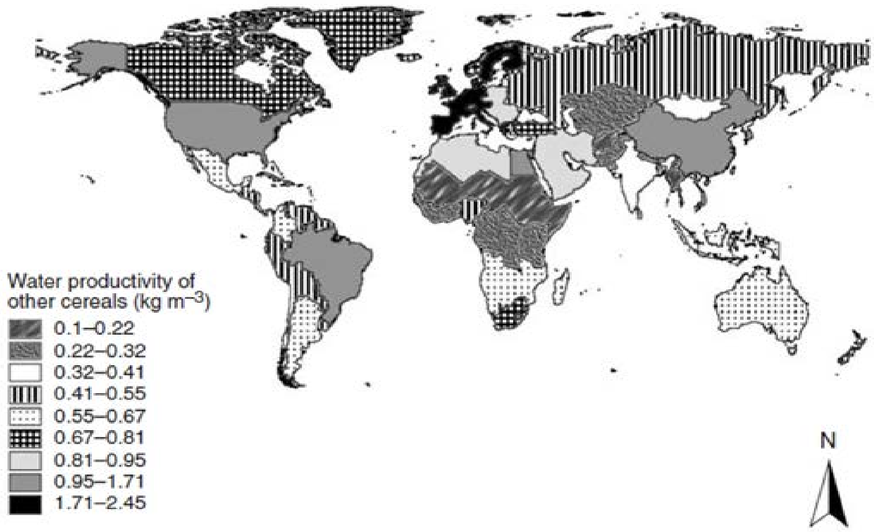
According to Cai and Rosegrant (2003) water productivity varies from region to region and from field to field, depending on many factors, such as crop and climate patterns and field water management, land and infrastructure, and input including labor, fertilizer and machinery.

For a comparative study of water productivity of different crops or cropping systems in response to various management practices, equivalent yields of different crops or net income per unit of ET, amount of irrigation, rainfall or rainfall plus irrigation received by the crop or cropping system may be considered (Singh *et al.* 2011).

2.2.2 The World's Cereal Crops Water Productivity Status

The research works that have been conducted worldwide so far, to assess the crops water productivity indicated the status of worlds' cereal crops water productivity. These research works have been carried out by grouping cereal crops in to two categories. These are rice and other cereal crops (except rice). According to Cai and Rosegrant (2003), it was found that the water productivity (WP) of rice ranged from 0.15 to 0.60 kg m^{-3}, while that of other cereals ranged from 0.2 to 2.4 kg m^{-3} in 1995. Since rice usually consumes more water than other crops, the WP of rice is significantly lower than that of other cereals. Figure 1 shows the WP of other cereals excluding rice. For both rice and other cereals, WP in sub-Saharan Africa is the lowest in the world. The WP of rice varied from 0.10–0.25 kg m^{-3} in this region, with an average yield of 1.4 t ha^{-1} and water consumption (WC) ha^{-1} is close to 9500 m^3. For other cereals in sub-Saharan Africa, the average yield is 2.4t ha^{-1}, the

WC is 7700 m^3 ha^{-1} and the average WP is 0.3 kg m^{-3} (ranging from 0.1 to 0.6 kg m^{-3}) (Cai and Rosegrant, 2003).



Source: Cai and Rosegrant (2003).

Figure 1: World Water Productivity of Total Cereals, excluding Rice, in 1995

It should be noted that, because of the level of aggregation, the values shown on the above maps do not show the variation of WP within individual countries. WP within individual countries like Ethiopia requires further study that should begin from watershed level and scaled up to basin level and finally to country level.

2.2.3 Water Productivity in Ethiopia: Potentials for Improvement

The performance of agriculture in Ethiopia is highly affected by natural and anthropogenic factors. Increasing human and livestock population pressure resulted in land degradation, deforestation, over cultivation, overgrazing and desertification. These factors being associated with climate change impacts are highly reducing soil fertility and crop productivity (FAO, 1984). The Ethiopian highland studies revealed that the Ethiopian highlands, which cover 44% of the country's total land area, are seriously threatened by soil and biological degradation. Some 27 million ha representing approximately 50% of the highlands are already significantly degraded. Of this area 14 million ha are badly eroded and if the present trend of soil degradation continues, per capita income in the highlands obtained from agriculture will fall by 30% in 20 years time (Bekele and Holden, 2000;

FAO, 1984). Fifty four percent of the remaining highlands are also highly susceptible to erosion. These evidences indicated that there are poor soil and water management practices all over the country.

Ethiopian agriculture is facing water shortages that will complicate the national efforts to attain agricultural transformation. According to Bekele and Holden (2000) agriculture is the predominant user (75% – 80%) of the available fresh water resource in many parts of the world. Ethiopian agriculture is also the largest water consuming economic activity (EIAR, 2004). Thus, researchers and development partners often acknowledge that increasing crop water productivity is a key researchable area to mitigate water scarcity. Improvements to agricultural water productivity especially in crop, livestock, and aquaculture help meet rising demands for food. Water productivity improvements can effectively address food insecurity and poverty alleviation (EIAR, 2004). According to EIAR (2004) Ethiopia has tremendous potential to improve water productivity through improved and known water management practices. Management practices that can increase agricultural yields also improve water productivity such as the choice of crop varieties, fertilizer, and pest and weed management, timely operations and post-harvest management. Integrated water and land management at the watershed scale is the key to improving water productivity and enabling sustainable water resource management (ibid).

2.2.4 The Need for Improved Crop Water Productivity

Fifty years ago the world had fewer than half as many people as it has today. They were not wealthy, consumed fewer calories and thus required less water to produce their food. The pressure they inflicted on environment was lower (Steduto *et al*. 2007). Recently, however the world population has been increasing rapidly with increasing demand for food and water. The ever-growing demand for food and feed in the world due to rapid increase in population and urbanization necessitates increased food production more than ever before. Among the important inputs for production are land and water, which are reaching scarce levels due to competing uses and degradation of their quality (Teklu Erkossa *et al*. 2010). In SSA, the bulk of increased food production came from the expansion of

agricultural land. Now there is limited new land that can be placed under agriculture as compared to the last three to four decades (McCalla, 1994; Young, 1999).

In SSA more than 95% of agricultural land is rainfed which will remain the dominant source of food production in the near future (Singh *et al.* 2011; Parr *et al*. 1990). However, yields from rain fed agriculture are often low, generally being around 1 t ha^{-1} in semi-arid tropical agro-ecosystems (Rockstro¨m, 2001). Studies indicated that the suboptimal performance of rainfed agriculture is related to management problems rather than low physical potential (Agarwal and Narain, 1997; Benites *et al*. 1998; Rockstro¨m and Falkenmark, 2000). Currently, there is increasing pressure in SSA to increase agricultural productivity substantially, without the option of expanding agricultural land and with limited amount of fresh water. This necessitates the generation of integrated land, water and crop management technologies that can enhance the productivity of rainfed agriculture (Teklu Erkossa *et al.* 2010). Water productivity improvement helps to get better net socioeconomic and environmental benefits through the use of water in agriculture, including fisheries, livestock, crops, agro forestry, and mixed systems. Generally, there are important reasons to improve agricultural water productivity throughout the world (Steduto *et al*. 2007):

- To meet the rising demand for food from a growing, wealthier, and increasingly urbanized population, in light of water scarcity.
- To respond to pressures to reallocate water from agriculture to cities and to ensure that water is available for environmental uses.
- To contribute to poverty reduction and economic growth.

For the rural poor more productive use of water can mean better nutrition for families, more income, productive employment, and greater equity. Targeting high water productivity can reduce investment costs by reducing the amount of water that has to be withdrawn. Globally, the additional amount of water needed to support agriculture directly will depend on the gains in water productivity. With no gains in water productivity current average annual agricultural evapotranspiration of 7,130 cubic kilometers could nearly double in the next 50 years (Steduto *et al*. 2007). With appropriate practices in livestock, aquaculture, rainfed, and irrigated systems the increase could be held down to 20% – 30%. Increases in withdrawals for irrigation, now at 2,664 cubic kilometers, could range from 0

– 55% depending on investments in increasing water productivity and on how much rain fed and irrigated agriculture expand (Steduto *et al*. 2007).

2.2.5 Factors Affecting Crop Water Productivity

Crop water productivity is a function of several factors. According to Kijne *et al*. (2000) differences in environmental, agronomic, social and economic conditions of different localities can always bring variation in agricultural productivity. Improved crop varieties increase yields together with the reduction in crop-growth duration. Drought escape and increasing drought tolerance have been identified as important strategies for increase water productivity. For instance, the modern 'IRRI varieties' of rice developed as part of the Green Revolution have about a threefold increase in water productivity compared with the traditional varieties (Tuong, 1999). Water evaporation and transpiration from weeds also influence water productivity through increasing non-beneficial water depletion. Thus, plant breeding for early shading will contribute to reducing evaporation while timely weed control reduces transpiration from weeds (Mulugeta, 2006).

According to Tuong (1999) and Rockstrom *et al*. (2003), there is an almost linear relation between yield and water productivity per unit water transpired. Hence, integrated crop-and resources–management practices that increase yield will effectively increase water productivity (WP). Improved nutrient application methods (using appropriate rate) can also enhance crop water productivity. Agricultural WP is also highly correlated with land degradation which is the depletion of soil quality. Generally, highly degraded lands result in lower productivity, although the impacts vary across production conditions and technologies employed. Lower productivity can be either due to decreasing yields or increased production costs associated with decreased input efficiency. Many cultural practices, such as row spacing, the use of mulches and plant residues have the potential to increase WP through their effects on partitioning evapotranspiration between evaporation and transpiration (Mulugeta, 2006).

2.4 Crop Water Requirement

All field crops need soil, water, air and sunshine to grow. The soil gives stability to the plants, stores water and nutrients. Without water, crops can not grow at the same time too much water is not good for many crops (Seleshi Bekele et.al, 2009). Optimum amount of water is requierd for helthy growth of crops. Crop water needs are the sum of crop transpiration (T) and soil evaporation (E) (Blaney and Criddle, 1950; Doorenbos and Pruitt, 1975). The plant roots extract water from the soil to live and grow. Almost all of this water doesnot remain in the plant, but escapes to the atmosphere as vepour through the plant's leaves and stem, the process called transpiration.

2.4.1 Determination of Crop Water Requirement

The crop water need mainly depends on three major factors:

1. **The climate:** in sunny hot climate crops need more water per day than in a cloudy and cool climate.
2. **The crop type:** crops like rice or sugar cane need more water than crops like bean and wheat.
3. **The crop growth stages:** Grown crops need more water than crops that have just been planted (Seleshi Bekele *et al.* 2009). Thus, during the initial and development stages crops need more water than the late season.

Table 1: Approximate range of values of seasonal crop water need

Crop	Crop Water Need (mm/total growing period)
Alfalfa	800-1600
Banana	1200-2200
Barley/oat/wheat	450-650
Bean	300-500
Cabbage	350-500
Citrus	900-1200
Cotton	700-1300
Maize	500-800
Melon	400-600
Onion	350-550
Peanut	500-700
Pea	350-500
Pepper	600-900
Potato	500-700
Rice (paddy)	450-700
Sorghum/millet	450-650
Soybean	450-700
Sugar beet	550-750
Sugar Cane	1500-2500
Sun Flower	600-1000
Tomato	400-800

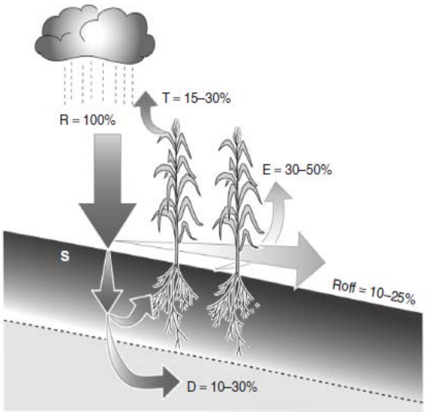
Source: Sileshi Bekele *et al.* (2009)

2.4.1.1 Reference Crop Evapotranspiration

Evapotranspiration (ET) comprises the simultaneous movement of water from the soil and vegetation surfaces into the atmosphere through evaporation (E) and transpiration (T). Reference crop evapotranspiration ETo is the evapotranspiration from a reference crop with the specific characteristics of grass, fully covering the soil and not short of water and represents the evaporative demand of the atmosphere at a specific location and the time of the year independently of crop type, crop development and management practices, and soil factors (Allen *et al*. 1998). The only factors affecting ET_0 are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data (Kassam and Smith, 2001). Relating ET to a specific surface provides a reference to which ET from other crop surfaces can be related. It obviates the need to define a separate ET level for each crop and stage of growth. ETo values measured or calculated at different locations or in different seasons are comparable as they refer to the ET from the same reference surface.

2.4.1.2 Effective Rainfall

The plant cannot use all the rainwater that fall on the soil surface. The rainwater is partitioned in the farming system in such a way that part of it percolates below the root zone of the plant and part of it flows away over the soil surface as run-off (Figure 2).



Where: R = Total Rainfall

T = Transpiration

E = Evaporation

Roff =Surface run-off

D = Drainage, and

S = Soil

Source: Rockström *et al.* (2003)

Figure 2: General overview of rainfall partitioning in farming systems in the semi-arid tropics of sub-Saharan Africa.

The plant cannot use deep percolated water and a part of water generated as surface run-off. In other words, part of the rainfall is not effective. The remaining part which is called effective rainfall is stored in the root zone and can be used by the plants.

The factor which influence how much rainfall is effective and not effective, include the climate, the soil properties and the depth of the roots zone. As it can be understood from Figure 2, when the rainfall is high, a relatively large part of water is lost through deep percolation and runoff.

In many countries, formulae have been developed locally to determine the effective precipitation. Such formulae take in to account factors like rainfall reliability, topography and prevailing soil type. If such formulae or other local data are available, they should be used. If such data are not available, the following table could be used to obtain a rough estimate of the effective rainfall (Seleshi Bekele *et al.* 2009).

Table 2: Precipitation (p) and effective Rainfall or Effective Precipitation (Pe) in mm/month

P (mm/month)	Pe (mm/month)	P (mm/month)	Pe (mm/month)
0	0	130	79
10	0	140	87
20	2	150	95
30	8	160	103
40	14	170	111
50	20	180	119
60	26	190	127
70	32	200	135
80	39	210	143
90	47	220	151
100	55	230	159
110	63	240	167
120	71	250	175

Source: Seleshi Bekele *et al.* (2009)

For example, from Table 2, when total rainfall is 80mm/month, the effective rainfall is 39mm/month. This means that out of 80mm/month, the plant can use 39mm and it is estimated that the remaining 41mm is lost through deep percolation and run-off (Seleshi Bekele *et al*. 2009).

2.4.1.3 Irrigation Requirement

The irrigation water needs of certain crops is the difference btween the crop water need (ETC) and the part of the rainfall that can be used by the crop (the effective rainfall). For each of the crops grown on an irrigation scheme, the crop water need is usually determined based on a monthly basis. The crop water need is expressed in mm water layer per unit, in this case mm/month. The effective rainfall is estimated on a monthly basis, using measured rainfall data, Table 11 or local information, if available (USDA 1962; Doorenbos, and Pruitt 1977; FAO 1977; Taffa Tullu, 2002; panda, 2005). For all crops and for each month of the growing season, the irrigation water need is calculated by subtracting

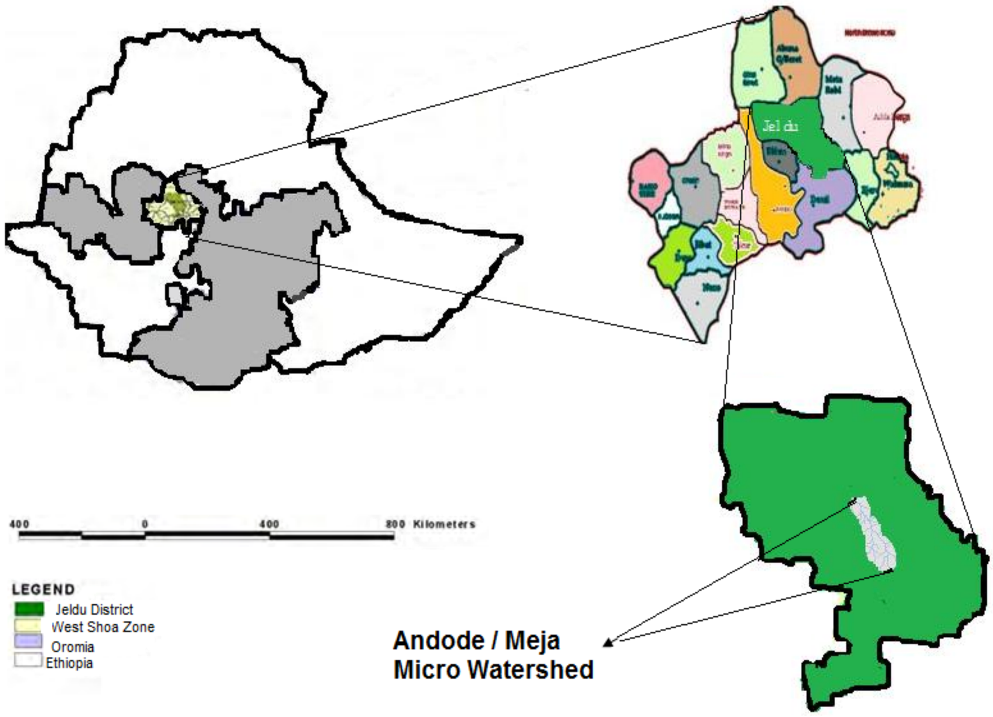
the effective rainfall from the crop water need. Crop evapotranspiration (ETC) is also called potential crop water need. Thus, in such areas, there is no need for supplemental irrigation in the rain fed system and water is not a limiting factor for agricultural production. Contrary to this, when the difference between crop water need and effective rainfall is negative, there is no sufficient amount of rainfall to fulfill the crop water need. Thus, there is rainwater scarcity and supplemental irrigation is required and hence, water is a limiting factors for crop production (Seleshi Bakele *et al*. 2009).

3. MATERIALS AND METHODS

3.1 Descriptions of the Study Area

3.1.1 Location

West Showa is one of the 18 Zones of Oromia Regional State. It has a total of 18 wereda, one city administration, 532 Kebele Administrations and 39 towns (West Showa Zone Office of Agriculture & Rural Development Work Plan, 2009, Unpublished). Jeldu is one of those 18 weredas of the zone where the study was conducted (Figure 3). It is located at a road distance of about 114 km, 72 km and 36 km from Addis Ababa, Ambo and Ginchi towns, respectively along the main road to Kachisi (Gindeberet District's Administrative town). Geographically, it is situated between 9° 02' 47" to 9° 15' 00" N latitude and 38° 05' 00" to 38° 12' 16" E longitude.



Source: Berhanu Ayana, (2011)

Figure 3: Map of the Study District and Meja watershed

The wereda shares boundary with Ilfeta in the South, Gindeberet in the North, Ejere and Meta Robi in the East and Abuna Gindeberet weredas in the West (Birhanu Ayana, 2011, Unpublished Thesis). The study watershed, which stretches from South to North direction to the left side of the main road to Gindeberet, is also located in Jeldu wereda. It is part of

the upper Blue Nile Basin and estimated to have an area of 92.6 Km^2. Its altitude ranges from 2,440 m - 3,200 m a.s.l (Zemadim *et al*. 2010).

3.1.2 Climate

The wereda has a total area of 139,389 ha with variable agro ecology. It is characterized by having undulating topographic feature. The altitude of the wereda ranges from 1800m to 3200m a.s.l which is predominantly highland. The area receives bimodal rainfall pattern with short rainy season from March to April and main rainy season from June to September. The mean annual rainfall varies from 1800 to 2200mm. The mean minimum and maximum annual temperature ranges from 17^{o}C to 22^{o}C (JDOA, 2010, unpublished report)

3.1.3 Geology and Soil

The geological history of the country indicates that central high lands of the Ethiopia were primarily formed from the oldest pre-Cambrian rocks known as basement complex rocks (Solomon Nigusie, 2006). The pre-Cambrian rock is overlaid by other rocks during the subsequent geological processes of Mesozoic and Cenozoic eras. Hence, all soil types are principally formed from these parent rocks.

3.1.4 Farming Systems, Crops Grown and Input Utilization

Mixed crop-livestock farming system is the most common livelihood strategy in the study area. Barley is the dominant crop cultivated followed by wheat, potato and enset (false banana). Farmers used UREA, DAP, compost, farmyard manure, improved seeds, pesticide and herbicides to threat soil fertility problem and enhance crop yield. Cattle, sheep and equines were the dominant livestock species reared by farmers (Birhanu Ayana, 2011). Small scale irrigation through traditional diversion of the major river is also common along the dawn stream regions.

3.1.5 Land Use Land Cover Conditions

Arable land comprised 43.4%, grazing land 15.3%, plantation forest 3.9% and others (barren degraded lands, buildings, grave yards, roads, etc) constitute 37.4% (ILRI, 2010, Unpublished Survey Report). According to Birhanu Ayana (2011), farmland constituted

70.37%, grazing land 3.43%, plantation forest 24.26% and riverine forest/vegetation 1.94% in 2010.

3.1.6 Vegetation and Water Resources

From 20 – 30 years ago there was natural forest in the study watershed around *Ento Dalle Kebele* and along the *Andode* River gorges (Birhanu Ayana, 2011). Recently, however, there is almost no natural forest in the watershed except its remnants of very few scattered trees occasionally seen in the crop lands and around steep slops. Contrary to this, eucalyptus tree plantations have been increasing in the watershed (Birhanu Ayana, 2011). Fodder trees and shrub species were also common in the area. According to Seyoum and Zinash (1998), these fodder trees and shrub species were mainly concentrated around homestead for better management and protection to be used as a supplemental animal feed in the highlands of Galessa-Jeldu areas. Regarding the water resources of the area, it was reported that there was about 16 springs (14 were seasonal and two were perennial), 88 streams (55 were seasonal and 33 were perennial) and only one permanent river in the watershed (Birhanu Ayana, 2011).

3.1.7 Socioeconomic Conditions

According to the National Population Census of 2007, the total population of the district was about 202,655 of which 49% and 51% are males and females, respectively. Rural population alone constitutes 94% (JDOA, 2009, Unpublished Annual Report) which indicated that the district is primarily agricultural. The agricultural population density of the district was 315p/km^2. It was estimated that about 4,769 households were living in the study watershed of which 16% were females (JDOA, 2002, unpublished Kebeles' profile report). The average family size for the district was 6 and the average land holding per household was 2 ha (ILRI, 2010, Unpublished Survey Report). Farmers obtain income mainly from selling of barley, wheat, potato, green maize, vegetables, and eucalyptus and livestock products (Birhanu Ayana, 2011 and Personal Communication).

3.2 Study Design

3.2.1 Sources of Data and Data Collection Method

Both primary and secondary data were required for the study. The primary data were collected from the beginning of July 2011 to the end of February, 2012 through preliminary household survey, field observation, field measurement, key informant interview, personal communication and focus group discussion using semi-structured questionnaires. Secondary data were collected from the district offices of agriculture and office trade and industry.

3.2.2 Reconnaissance Survey

The collection of secondary data from the district offices was the first task that was made during the first week of July, 2011 in order to get base line information about agricultural activities and related aspects of the district in general. Following this, a reconnaissance survey was conducted within the same week in order to understand the site conditions and to identify sampling sites. The study was basically conducted to identify major crops (covering more than 70% of total arable land) cultivated by small holder farmers in different landscape positions of *Meja* watershed under varying agronomic and management practices.

3.2.2 Household Survey

Preliminary household survey was made using semi-structured questionnaire to understand the farming systems, crops management and agronomic practices implemented by the smallholder farmers in the area during the second and third weeks of July, 2011. A total of 45 households (15 from each local landscape positions) were randomly selected for this purpose and interviewed in person. Group discussion was also arranged with randomly selected individuals of 10 – 15 model farmers, who best implemented improved crop management practices and obtained better yield, during their time of meeting with development agents.

3.2.3 Sampling Representative Crop Fields

It was pre-determined by the project (NBDC) that crops covering more than 70% of the study area are taken as major crops. Based on preliminary household survey result, field observation and secondary data from the district's office of Agriculture, major crops covering more than 70% of the total cultivated lands in each local agro-ecological zone of the district were identified (Table 3). Depending on altitude and its suitability for crop types, the district has three local agro-ecological zones (personal communication). Accordingly, the majority of the study watershed falls in highland and the remaining is categorized in mid altitude zone. Hence, stratified random sampling method was employed to select representative major crop fields from each zone. Sample crop fields were also taken from third agro-ecological zone which is out of the study watershed, but in the district.

Table 3: Area coverage of major crops in the local agro-ecology of Jeldu District.

Landscape Position	Altitudinal Range (m)	Common Crops	Area (ha)	%
Highland	2700 - 3200	Barley, potato, wheat, faba bean, field pea, flax and enset	25,410	91
Mid Altitude	2300 - 2700	Wheat, teff, sorghum, maize and niger seeds	12,227	82
Low Land	1800 - 2300	Teff, sorghum, maize and niger Seed	12,442	91

Source: Jeldu District Office of Agriculture, Annual Reports (2006 to 2010); ILRI Baseline Survey Report, 2010 and own calculation.

Three crops each from highland (barley, potato and wheat), mid altitude (wheat, teff and sorghum) and low land (teff, sorghum and maize) were identified as major crops covering more than 70% of the total cultivated lands in each zone. Each crop field was selected by walking along a simple cross-sectional transects. Three transects in the upper zone, two in

each of the mid altitude and lower zone were made to select a total of 45 crop fields with five replication of each crop.

3.2.4 Monitoring the Crop Fields and Data Recording

The sampled crop fields were continuously monitored in 10 - 20 days intervals and detailed data on crop management and agronomic practices including tillage frequency, planting dates, seeding rates, types and rates of fertilizer applied, methods of sowing, method of weeding, canopy cover estimates, date to flowering, date of maturity and harvesting date were recorded.

3.2.5 Estimating Aboveground Biomass and Grain Yield

Above ground biomass and grain yield were estimated using quadrate sampling technique at the time of harvesting. The average of three quadrates was taken from each crop fields so as to minimize sampling errors. For large grain cereals like maize and sorghum, 3 x 4 x 5 (right angle triangle) using measuring tape was applied instead of a metallic one meter square quadrate. During the time of harvesting, above ground biomass within the quadrate was harvested, total fresh weight was measured using a spring balance before threshing. After threshing, the weight of the grain yield obtained from each quadrate was measured. The average weight of grain and straw yields (fresh biomass) from the three quadrates was taken as a representative sample for the entire field. In addition to this, the average plant population density of large cereal crops (maize and sorghum) and potato was estimated by counting the number of plants in the a quadrate while that of small cereals (wheat, barley and teff) was estimated by counting the number of plants in a quarter of a quadrate (*i. e.*, 50 cm by 50 cm) during the time of harvesting. For the former crops it was easy to count the plant population within the quadrate due to its big size and small numbers, for the later crops (small cereals) however, it was very difficult to count the number of plants within a quadrate due to its dense population, time taking, and tediousness.

3.2.5.1 Determination of Crop Dry Matter

Representative samples of grain and straw collected from the field were brought to laboratory and forced to dry in the oven at $65^{o}C$ for 24 hours. It was primarily intended to adjust the moisture content of the grain yield to 12% moisture (agronomic standard for grain storage). However, it also helps to know whether the crop was harvested wet or dried and to determine HI by dividing dry grain to dry biomass yields.

3.2.5.2 Local Price Estimation of Straw and Stover yields

In order to determine above ground BMWP of each crop, it was necessary to estimate the local market price of straw and stover. To attain this objective, an informal local market survey was conducted during the time of harvesting. Personal discussion with beneficiaries (buyers) in the open market, measuring weight of straw by using sacks and taking price estimate was made for teff straw. Based on the result of teff, the price of wheat and barley was made. In case of sorghum and maize, personal discussion was made with sampled HHs and price estimate was made. According to the idea of the local farmers, market price of straw and stover in the study area were governed by environmental benefit (its use to maintain soil fertility) and economical benefit (building house, household energy source, animal feed) and value gained by the sellers in the study area.

3.2.6 Determination of Soil Water Characteristics

Surface soil samples (0 – 15 cm) were collected from the study watershed by IWMI. The samples were collected from the study watershed across three cross-sectional transects beginning from around the outlet and upward to the highland areas (Annex- 3) for the purpose of its chemical analysis. The analysis was done in National soil laboratory, Addis Ababa. Soil texture obtained from this data set was used for this study. Based on their geographic coordinate points, the nearest point or average of the nearest points to the sampled crop fields were considered to determine soil water characteristics using a

pedotransfer function (Saxton, 2006) with the soil-water characteristics calculator software (Figure 4).

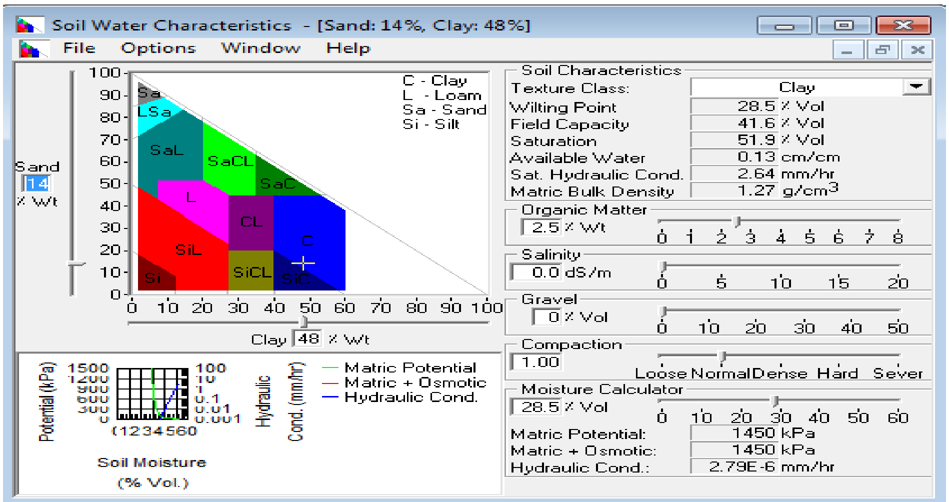


Figure 4: Soil water characteristics calculator software (USDA soil texture triangle) version 6.02.74, revised in 2012.

From the results, total available moisture (mm/m), maximum rain infiltration rate (mm/day) and initial soil moisture depletion (%) were used as input to the CROPWAT model (Annex - 2) to simulate crop water requirement.

3.2.7 Simulating Crop Water Requirements and Water Use

In order to compute the crop water requirement for each crop, CROPWAT model version 8.0 (2009) was used. It is a computer program developed for Water Resources Development and Management Services of FAO based on the previous versions of 1992 and 1999 (FAO, 2009). It was mainly designed to calculate crop water requirements and irrigation schedules based on climate data. The users can directly enter data into the CROPWAT model or import from other sources like New_LocClim (Figure 6) model (ibid). The required input parameters for the CROPWAT model include: ET_O/climate, total rainfall, crops and soil characteristics of the study area (Figure 5).

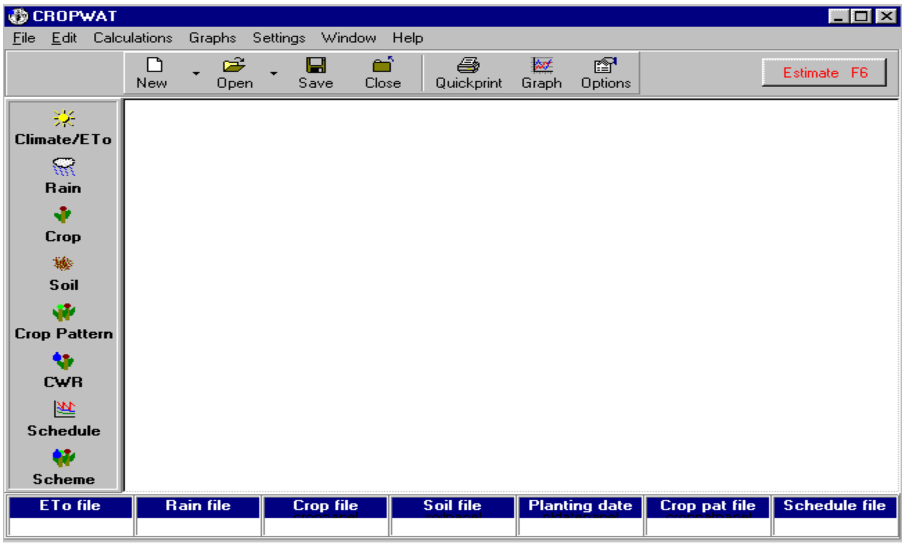


Figure 5: The FAO CROPWAT model Version 8.0, 2009.

The CROPWAT model allows the user to enter measured ET_0 or input data including temperature, rainfall, wind speed, sunshine duration hours and relative humidity which allows the model to calculate ET_0 using Penman-Monteith formulae. For this particular study, however, due to the absence of weather stations in the area, local climate data were estimated using the New_LocClim model version 1.10, 2006 from 10 nearby stations within 100kms interval (the minimum radius for the model to access stations to use their data for simulation).

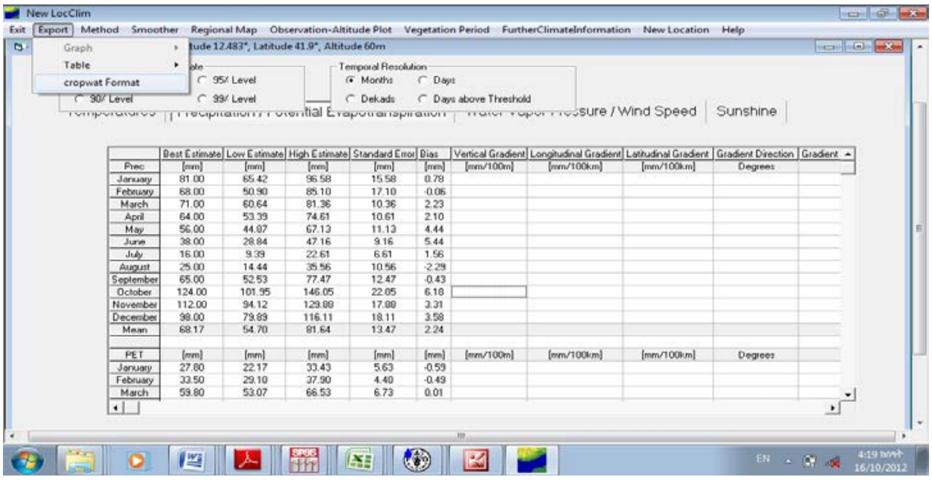


Figure 6: The New_LocClim (local climate estimator) mode versions 1.10, 2006.

By providing a single geographical coordinate point (single point mode) of the sampled crop field into the model, it has given us the average climate data for that particular crop

field in the form of tables or graph. Finally, the data in the form of tables were exported to the CROPWAT model. By using these input data, the model calculated ET_0 and effective rainfall. Crop characteristics like planting dates, LGP and crop name were provided to the model from primary field data collected. Soil water characteristics were also determined by using Soil water characteristics calculator model and the resulting values were entered into the model manually. Finally, the CROPWAT model can provide us with the final Crop water requirement data (ET_C, Effective rain and IR). From this, consumptive crop water use (m^3) was calculated by subtracting IR from ET_C. According to FAO (2009), the amount of water transpired is equal to the amount of water consumed to compensate it.

3.2.8 Mapping Land Use and Crop Types

In order to produce cropping pattern map of the study watershed, track points of boundaries of each crop types and other land use types were recorded using a hand held GPS. Beside this digital photographs were taken with digital camera and rough sketch map had been prepared by hand to minimize errors. The collected track points were transferred to ArcMap directly from GPS using DNR Garmin software and changed to shape file (polygon). Finally, the map of the study watershed was produced using different GIS techniques. In order to identify the boundaries of each crop fields clearly, the field data collection was completed before the end of harvesting. Area coverage of each crop and other land use types were also calculated by using ArcGIS software.

3.2 Determination of Different Parameters

3.3.1 Crop Productivity

After adjusting the moisture content of the gain yield in to 12%, the average productivity of each sampled crop types were determined in kg/ha from the sampled crop using excel. These values were used as a numerator in crop water productivity assessment.

3.3.2 Actual Crop Water Use/ Consumptive Water Use

Rainfed crops use infiltrated rainfall that forms soil moisture in the root zone. This accounts for most of the crop water consumption in agriculture (Singh *et al.* 2011). Hence, consumptive crop water use by each crop was determined using the following formula:

- ♣ $CW = ET_C - IR$, where CW refers to the amount of water consumed by the crop, ET_C represents potential crop evapotranspiration (m^3) and IR represents irrigation requirement (m^3).

Both IR and ET_C were determined by the CROPWAT model. The model determined ET_C as a product of k_C and ET_0.

3.3.3 Determination of Crop Water Productivity

In the study, both physical and economic water productivity with respect to consumptive crop water use were determined for further analysis. The procedures employed for each of them were described below.

3.3.3.1 Physical Crop Water Productivity

Physical crop water productivity is the ratio of the mass of agricultural output (in kg ha^{-1} or ton ha^{-1}) to the amount of water used in m^3 (Steduto *et al*. 2007). The following formula was used to calculate physical crop water productivity:

- ♣ WP of GY or TY = Grain Yield or Tuber Yield (kg/ha) $\div[ET_C - IR\ (m^3)]$ = GY or TY (kg/ha) $\div$ CW (m^3).
- ♣ WP of SY = Straw Yield (kg/ha) $\div\ [ET_C - IR(m^3)]$=SY(kg/ha)$\div$CW (m^3)

Where WP, GY, TY, SY refer to Water productivity, grain yield, tuber yield and straw yield, respectively.

3.3.3.2 Economic Crop Water Productivity

Economic crop water productivity refers to the economic value derived per unit of water used (economic return or nutrition, any other economic and social benefits). In agronomic context it refers to the economic return in Ethiopian Birr (ETB)/m^3 or USD/m^3 (Steduto *et al*. 2007). Similarly, the economic WP of each sampled crop was analyzed by using the following formula:

- ♣ EWP of Grain (ETB/m^3) = GY (ETB) ÷ CW (m^3) . . . . (a)
- ♣ EWP of Straw (ETB/m^3) = SY (ETB) ÷ CW (m^3) . . . . (b)
- ♣ TEWP of above ground biomass (ETB/m^3) = a + b . . . . (c)

Where EWP denotes economic water productivity and TEWP represents total economic water productivity.

3.3.4 Data Analysis

i. Comparison of Means:

In order to test whether there is significant difference between mean biomass water productivity (BMWP) of the major crops among the three agro-ecological zones, comparison of means was employed. The null hypotheses for such a test would be: H_O: $x_1 = x_2 = x_3 = \ldots = x_k$ where x_1 to x_k represent sample means of the 1 to k groups (Storck., *et al.,* 1991), and the most appropriate statistical technique to test such hypothesis is the analysis of variance (Norusis, 1987). Analysis of variance is used to examine the degree of variability in the mean biomass water productivity results. Based on the variability, some conclusions about the means were drawn. Again, the one_way analysis of variance (multiple comparisons) was also used to justify the differences among mean biomass water productivity magnitudes of the major crops with respect to each local agro-ecology. The F-statistics used is:

$$F = \frac{\text{Between}_{\text{groups}}\ \text{means square}}{\text{Within}_{\text{group}}\ \text{means square}}$$

$$F = \frac{\frac{\sum(\text{ni}\,(\text{Xj} - \text{X})2}{\text{k}-1}}{\sum\sum(\text{Xij} - \text{Xj})2/\,\text{N} - \text{k}}$$

ii. Pearson's Correlation:

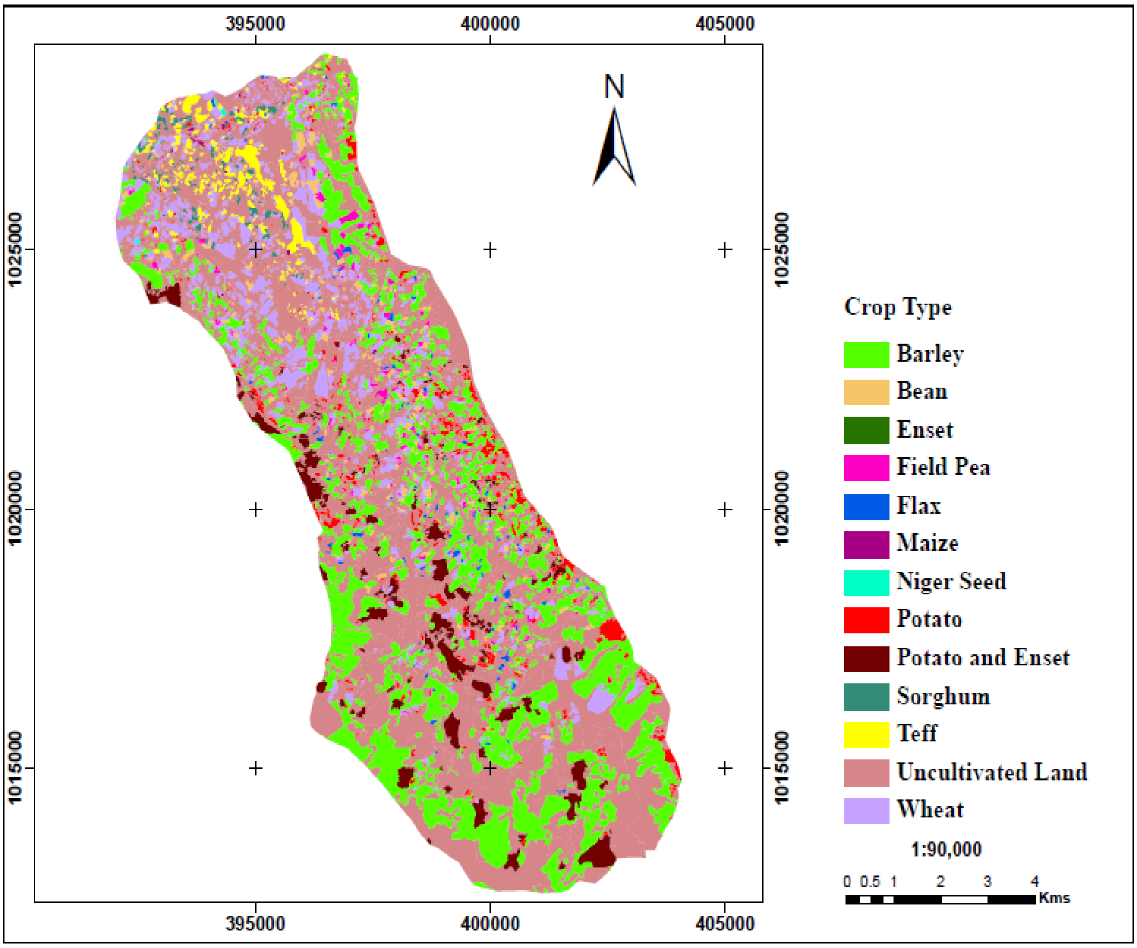
Among several factors that could affect crop water productivity in the study watershed, minor factors like UREA and DAP application rates, seeding rate and tillage frequency were considered to test their degree of association with biomass water productivity of the major crops. The Pearson's correlation analysis was employed to verify the existence of relationships between the selected four crops management practices and biomass water productivity of the major crops across the three local agro-ecological zones by using SAS software version 9.2 (2008). From the values of the calculated correlation coefficients and level of significance, the possible effects of the four management practices on BMWP of each crops was presumed.

4. RESULTS AND DISCUSSION

4.1 Field Observations, Household Survey and Monitoring Results

4.1.1 The Major Crop Types and Cropping Systems

Agricultural intensity in *Meja* watershed is extremely high. The multi temporal image analysis results of the study watershed revealed that more than 70% of the total drainage area was cultivated in 2010 (Birhanu Ayana, 2011). However, the map layers of land use and crop types of the watershed for the current year (2011) indicated that 49% of the total area (8536.21 ha) was covered with various crops (Figure 9). This disparity in percentage of cultivated lands between the two years was because of the fact that fallowed land in the later year that should be categorized under cultivated land were excluded and categorized under grazing lands.



Source: Field Survey Using Hand Held GPS, 2011

Figure 7: Map layers of land use and crop types of *Meja* watershed

As can be seen from the figure, the dominant crop cultivated in the study watershed was barley (2110 ha) which covered over 50% of the total cropped area (4201.21 ha) in 2011, followed by wheat (803ha) covering above 19%. Others include horticultural crops such as potato and enset (false banana) together (692.21 ha) constituted more than 16% and minor crops (596 ha) like teff, sorghum, maize, faba bean, field pea, flax and niger seed constituted over 14% of the total cropped area. Uncultivated land constituted 51% (4335 ha) of the total area of the study watershed which comprises of fallowed lands, permanent pasture land, natural and plantation forests, bush and grasslands, settlement area and others (Annex 4).

Crop rotation was a common cropping system in the study area followed by fallowing in the upper zone. The HHS result indicated that 72% of the HHs in the upper and 100% in both the middle and lower zones used crop rotation while the remaining 28 % in the upper zone used fallowing. Crop rotation has a long history in the study area. The farmers and elders reported that they traditionally inherited this practice from their ancestors and have been using as a best mechanism to maintain soil fertility. Fallowing land was most widely practiced in the upper zone of the watershed. Recently, however, it has declined due to increasing human population and declining in the size of landholding (personal communication). Relay and mixed copping systems were not commonly practiced.

Small scale traditional irrigation farming is common in the middle and lower zones, particularly along the left and right side of *Melka (Meja)* and *Lege Jeba* Rivers in the middle zone and *Gora* River in the lower zone. In the middle zone, maize, potato, cabbage, green pepper, onion and garlic are grown under irrigation using diversions from the two rivers. Maize was mainly cultivated through irrigation along the right and left side of the major river and right side of *Legejeba* River in Kolu Gelan KA primarily for consumption at the stage locally called '*Asheeta*' (green maize). In addition, farmers also obtain income from the sale of green maize, potato, vegetables and spices. In this area, potato is cultivated three times a year (one with small scale irrigation from December to April, second with short spring rain from March to June and third with main rainy season from May to October). Cultivating potato in the upper zone during the short spring rainy season assist

the farmers to overcome the problem of food shortage during the main cropping season (life savior), when they used almost all of their stocks for seeds.

Traditional diversion for irrigation is common also in *Gora Lalisa* KA along Gora River. Maize, onion, garlic, cabbage, green pepper and tomato are the major crops grown in the schemes. Maize is usually cultivated twice a year. In the year 2011, large area of land was covered by irrigated maize.

There were two teff cropping systems in this area. One was the cultivation of teff within the normal planting period in July. The second was cultivation of teff immediately after harvesting maize in August. This type of teff cropping system involves planting after only one tillage operation on a farm land with moist and soften soils. Because of the late plating, it requires supplemental irrigation in the rainfed system. Normally, after mid-September shortage of rainfall is expected. Hence, farmers started applying the river water to irrigate this teff crop land in September till it reached its physiological maturity. Apart from this, when the fertility level of the soil is poor, the local farmers cultivated chick pea after harvesting maize instead of teff. They also applied irrigation water to moist the soil before cultivating chick pea so as to assist its germination. Small scale sugarcane plantation through irrigation was also observed in the area.

4.1.2 The Crop Management and Agronomic Practices

4.1.2.1 Crop Rotation

An important aspect of studying the crop rotation pattern was to determine which crop is changed to the other on a given plot of land at a certain time interval(s). This helps us forecast the impact of precursor crop(s) on soil quality and the productivity of the current crop. Crop rotation practice is essential in sustainable agriculture (Crookston, 1984). The properly implemented rotation system will have several benefits for crop production. Crop rotation was practiced mainly for the purpose of disease control, improve soil tilth, reduce soil erosion and control serious weeds (Santos *et al*. 1993; Ball, 1992; Derksen *et al*. 1993; Blackshw *et al*. 1994). Length of the rotation pattern depends on the fertility level of the

soil (personal communication). That means, the more fertile the soil is the longer the rotation pattern and vice versa. The crop rotation cycle varies across agro-ecology which determines the type of crops to be cultivated. According to Hailu and Van Luer (1996), barley mainly grows from 1,950 m to 3,000m asl in Ethiopia. Potato is best suited above 1800m. Similarly, wheat grows from 1,800 to 2,900 m asl in East Africa (FAO, 1986).

4.1.2.1.1 Crop Rotation Pattern in the Upper Zone

In the upper zone of the study watershed barley, potato and wheat were the dominant crops that covered 68%, 17% and 8%, respectively of the total cultivated land of the sampled HHs in the year 2011(Table 4). A field observation by the investigator in 2011 confirmed that the major part of the cropped land in the upper zone was covered by barley but, seems to be followed by wheat than potato. According to the average of the five consecutive years' report of the district's office of Agriculture, the area covered with wheat was almost comparable to barley, but recently started declining in area coverage due to frequent frost damage. Recent study in the watershed (Birhanu Ayana, 2011) and experience of the local farmers indicated that barley-wheat rotation was a common cropping system in the upper zone of the watershed and all the highland areas of the district in general mixed with bean, peas, potato and flax in between the system. However, HHS result revealed that the rotation pattern is changing. In the year 2010, the major portion of cultivated land of the sampled HHs was fallowed (28%) followed by potato (27%) and barley (26%). However, in 2011, barley alone coved 68% of the total cultivated land. Similarly, in the coming year (2012) 46.76% of those cultivated land was expected to be fallowed. The same pattern repeats itself a year after next year (2013) and so on. From this, it can be concluded that Barley=>Fallow=>Barley is the dominant cropping system in the upper zone. Thus, farmers used rotation of legumes with cereal crops randomly. However, when cereal crops rotated with legumes, it maintains soil fertility with the addition of nitrogen in to the soil and could significantly increase yield (Santos *et al*. 1993; Hesternman *et al*. 1987; Baldock *et al*. 1981). Therefore, crop rotation system used by the local farmers here was not appropriate and needs to be changed.

4.1.2.1.2 Crop Rotation Pattern in the Middle Zone

Wheat, teff and sorghum were the dominant crops which together covered 86% of the total cultivated land of the sampled HHs in the year 2011. In 2011, wheat covered 39% of the cultivated land of the sampled HHs. In 2010, teff covered 48% of those cultivated land. In the year 2012, wheat is expected to cover 54% of the crop lands. From this, it can be concluded that in the middle zone of the watershed, wheat is rotated with teff every year and most probably the total area that was covered with wheat in the year 2012 will be changed to teff in the year 2013 and vice versa. Thus, the pattern could be Wheat => Teff => Wheat which needs change.

4.1.2.1.3 Crop Rotation Pattern in the Lower Zone

According to the local classification system, *Gora Lalisa* KA is categorized under the lower agro-ecological zone of the district with its altitude ranging from about 1950 to 2300m asl. Teff, sorghum and maize were major crops which together constituted 95% of the total cultivated land of the sampled HHs in the year 2011. Tef is the dominant crop covering 61% of the total cultivated land of the sampled HHs. In the next year (2012) 58% of the same crop lands are expected to be covered with sorghum. Similarly, in the year 2010, 58.16% of these lands were under sorghum. From this, it can be concluded that Teff => Sorghum/Maize rotation every year was a common cropping system using legumes in the system. Unpublished survey report made by ILRI in 2010 also agreed with this result. However, farmers and development agents reported a frequent failure of sorghum in recent years due to unreliability of spring rainfall, which was the case during the year 2011 as all the farmers interviewed gave reported. Usually, teff or legumes like check pea and grass pea rotated in between maize and sorghum. Because of the above problem, most farmers were forced to grow tef instead of sorghum during the main cropping season. Consequently, it was estimated that teff covered more than 70% of the cultivated land in year 2011. This led to repetitive cultivation of teff on the same plot each year. Farmers fear that such trend may lead to prevalence of diseases, nutrient depletion, wide spread weed infestation and declining yield.

4.1.2.2 Tillage, Fertilizer and Seeding Rates

Proper tillage practices increase infiltration, reduce soil evaporation, enhanced root penetration and extraction of water and nutrients from the soil profile leading to increased productivity and high water use efficiency (Singh *et al*. 2011). However, more aggressive and frequent tillage also damages the soil texture, macro porosity and reduces rainwater infiltration in to the soil through the effect on hydraulic conductivity (Hatfield *et al*. 2001). The frequency of tillage in the study area was high which depend on the type of the previous land use and crop types to be cultivated. For example, when the land to be cultivated was fallowed for one or more years, it requires more frequent tillage. Farmers often till the fallow land once before the end of the rainy season and keep it fallow to repeat the tillage next season when the rain starts. When the precursor crop was potato, less frequent tillage would be done regardless of the crop type to be grown because the farmers applied deep tillage to harvest potato tubers and the field remains tilled up to the onset of next rainy season (Figure 14). Table 4 shows tillage frequency, fertilizers rate and seeding rate applied on major crop fields monitored in the upper zone.

Table 4: Tillage frequency, fertilizer and seeding rates in the upper zone.

Management Practice	Crop Types		
	Barley	Wheat	Potato
Tillage Frequency	3.80	3.60	3.80
Fertilizers rate:			
DAP (kg/ha)	84	85	321
UREA (kg/ha)	0	15	177
Seeding Rates (kg/ha)	218	162	2645

Source: HHS and Field observation, 2011.

Most of barley, wheat and potato fields monitored were cultivated 3 to 4 times before planting. Barley and wheat were sown by hand broadcast method approximately at average rate 218kg/ha and 162 kg/ha, respectively. Fertilizers were applied to the crops field at an average rate of DAP 84kg/ha in case of barley; DAP 85kg/ha, UREA 15kg/ha and DAP 92kg/ha, UREA 59kg/ha (Table 5) for wheat both in the upper and middle zones,

respectively. This rate is lower than the research recommended dose of 100kg DAP and 50kg UREA (Eyasu, 2002). On the sampled fields, potato tubers were planted by hand at an average rate of approximately 2,647kg/ha. It was planted with rows at estimated spacing between plants ranging from 25cm to 30cm. The width of a furrow was varying from 20cm to 25cm. The breadth of the ridges was also measured and ranges from 30cm to 35cm. Fertilizers were applied to potato fields by mixing them together at an average rate of UREA177kg/ha and DAP 321 kg/ha during the time of planting. Similar procedures followed in the middle and lower zones as shown in Table 5 & 6 below.

Table 5: Tillage frequency, fertilizer and seeding rates in the middle zone.

Management Practice	Crop Types		
	Wheat	Teff	Sorghum
Tillage Frequency	3.40	3.40	1.60
Fertilizers rate: DAP (kg/ha)	92	67	10
UREA (kg/ha)	59	49	10
Seeding Rates (kg/ha)	216	68	23

Source: HHS and Field observation, 2011.

As can be understood from Table 5, most of teff and sorghum fields monitored were cultivated 3 times and 1 to 2 times, respectively. Both, teff and sorghum were sown traditionally by hand broadcasting at an average rate of 68 kg/ha and 23 kg/ha respectively. Most of the time farmers in the study area do not apply fertilizers to sorghum. From the monitored crop fields both in the middle and lower zones, only one farmer from the middle zone applied fertilizers at an average rate of DAP10kg/ha UREA 10kg/ha. Farmers also applied fertilizers to teff crop fields at an average rate of DAP 59kg/ha and UREA 49kg/ha.

Table 6: Tillage frequency, fertilizer and seeding rates in the lower zone.

Management Practice	Crop Types		
	Teff	Sorghum	Maize
Tillage Frequency	2.80	1.80	2.40
Fertilizers rate:			
DAP(kg/ha)	0.00	0.00	28.00
UREA(kg/ha)	0.00	0.00	6.40
Seeding Rates (kg/ha)	51.00	19.00	24.00

Source: HHS and Field observation, 2011.

As can be understood from Table 6, most of teff and maize crop fields monitored were cultivated 2 to 3 times while that of sorghum was cultivated 1 to 2 times respectively. Both, teff and sorghum were sown traditionally with hand broadcasting method at an average rate of 51 kg/ha and 19 kg/ha, respectively. Farmers in this zone did not apply fertilizers to both teff and sorghum crop fields monitored. Recently, farmers started to make use of fertilizers for maize based on the recommendation of development agents.

4.1.2.3 Application of Compost

Very few farmers applied organic fertilizers. Applications of organic fertilizers (compost/manure) mainly depend on the number of livestock owned by the farmer and the proximity of farm lands to their homestead. Farmers mostly applied compost or manure to crop fields around homesteads and sometimes to the land nearest to residential areas. Most farmers directly applied animal dung to their crop fields during summer season by mixing with rainwater and disposing on crop fields before and after planting. Table 7 shows the proportion of practice of using compost by the farmers on the monitored crop fields across agro-ecology.

Table 7: Proportion of compost application per crop fields (%) for different agro-ecology

Agro-ecology	Application of compost per crop types (%)					
	Barley	wheat	potato	teff	sorghum	maize
Upper	-	20%	40%	-	-	-
Middle	-	20%	-	0%	0%	-
Lower	-	-	-	0%	0%	40%

Source: HHS, 2011.

The Table demonstrated that the practice of using compost was very low in the study area. Farmers applied on 20% of wheat crop fields monitored both in the upper and middle zones where as on 40% of sampled potato and maize crops fields in the upper and lower zones, respectively. Generally, only on 13% of the total sampled crop fields that compost was applied by the farmers. Some of the possible reasons include the use of animal dung for household energy (Figure 8) and distant location of farm lands from residential area and lack of awareness (Berhanu Ayana, 2011).

Figure 8: The uses of animal dung for household energy sources, in Chilanko KA.

4.1.2.4 Major Crop Types, Cultivar and Variety

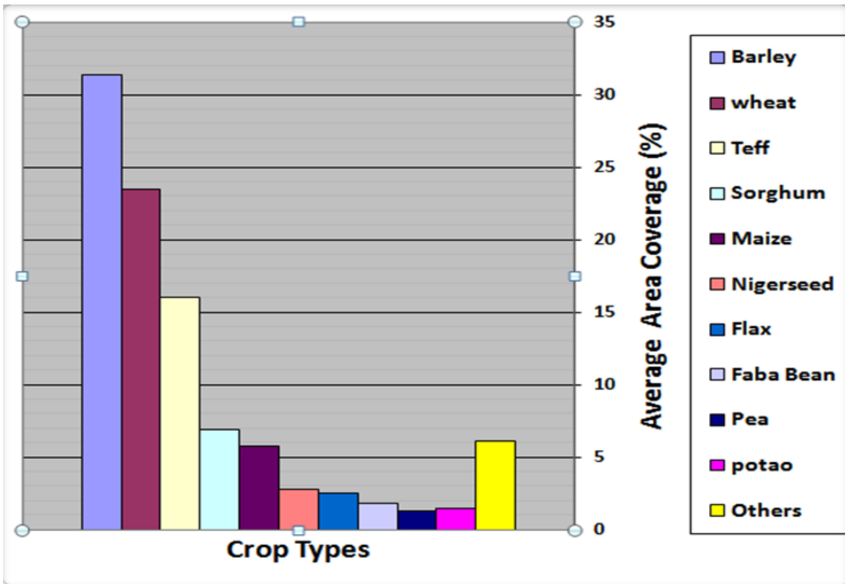
Barley was the leading crop cultivated by most farmers in the district (Figure 10) and on the upper zone of the study watershed (Table 2) approximately above an altitude of 2700m. Three cultivars were commonly cultivated in the area. These were namely malt barley single and double, locally called '*garbuu biiraa naxalaa and dirribii*', black barley single and double locally called *ballami naxalaa and dirribii* and '*senef kolo*'. Malt barley and

ballami are improved varieties while senef kollo is a local variety. All of them required almost comparable management systems. Malt barley was the most widely cultivated cultivar in the district in general and in study watershed in particular (Figure 9).

Figure 9: Malt barley sampled from the upper zone, Chilanko KA

Farmers prefer malt barley because it is more productive, has higher market demand and suitable to make '*Enjera*'.

Wheat was the second cereal crop cultivated by the local farmers next to barley in the upper and lower zones of the study district (Figure 10) above an altitude of about 2300m. It was a dominant crop cultivated followed by teff in the middle zone of the watershed. Here, about 39% of the sampled HHs' land was allocated to wheat in the year 2011. The past five consecutive year's reports by the district office of agriculture indicated that wheat remained the second cultivated in the district in terms of area coverage (Figure 10).



Source: Jeldu District Office of Agriculture Annual Reports, Unpublished, 2006 – 10.

Figure 10: Five years' average crops area coverage (%) of the district (2006-10).

Recently however, cultivation of wheat is diminishing in the upper part of the district due to the frequent frost damage. Both improved and local varieties were cultivated by the local farmers mostly in the middle zone of the watershed. The most widely cultivated wheat cultivars in the study watershed include *galema, digalu, dashen, roma/selato,* and *dejameta.* Among these, *galema* and *dashen* were the most common in the watershed. *Roma/selato* was cultivated mostly in the middle zone of the watershed. Only few model farmers are trying *digalu* which was newly introduced to the area. During the time of this particular research work, it was observed that potato was the second major crop covering extensive area of land in the upper zone of the study watershed next to barley. It was best cultivated above an altitude of 2500masl. There were more than three improved potato varieties in the study area (*Gudane, Jalane*, *Menagesha*). *Gudane* was the most widely cultivated one for its high productivity, disease resistance and good taste (Figure 11). The farmers could get high quantity (50 to 60 ton/ha) of tuber from small plot of land. *Chilanko* KA was a well known and leading producer of potato in the study area. Others include *Edensa Gelan, Kolu Gelan, Tullu Bultuma* and *Tullu Gurra* KAs which were also known for their high potato production.

Figure 11: A commercially improved Potato variety locally called "Gudane" sampled from Chilanko KA.

Teff was the third most widely cultivated crop next to wheat in the district (Figure 12). It was cultivated both in the lower and middle zone of the area up to an altitude of about 2800 m a.s.l. Teff was the second major crop next to wheat in the middle zone and the leading crop in the lower zone in terms of area coverage.

Figure 12: Area coverage of Teff in the lower zone (Gora Lalisa FA), October, 2011.

Three cultivars were commonly cultivated in the area, namely white, red and short growing cultivar locally called '*bunise*'. About 90% of the sample HHs use local varieties. White improved variety locally called '*filetama*' was cultivated by very few farmers in the middle zone.

Sorghum (Figure 13b) was cultivated both in the middle and lower zone. However, it was most widely cultivated in the lower zone than in the middle zone. It has the longest growing period than all other crops in the study area (Table 11). Four local cultivars were determined to be cultivated in the study district, which were known by their local names as *'cate', 'achiere-adi', 'turketa' and 'bobe'*.

(a) *(b)*

Figure 13: Sampled teff crop in the lower zone (a) and sorghum in the middle zone (b)

Maize (*Zea mays*) was most widely cultivated in the lower zone of the study area with irrigation than rainfed. One improved variety (BH-660) was identified to be cultivated in the lower zone by the sampled HHs.

4.1.2.5 Rainwater Management Practices

The field observation and HHS revealed that very limited types of RWM practices exist in the cultivated lands of the sampled HHs in the study watershed. RWM practices implemented by the local farmers in the study watershed were mainly determined by the location of the crop field in the various landscape positions and the existing soil type. That means, the type of RWM practice applied in highland, mid altitudes and low land areas are different. The most common RWM practice used by the local farmers in the monitored crop fields was surface drainage (100%). Others include cut-off drainage (6.6%), deep furrows (11%), deep tillage (22%) and use of improved varieties (53%). This finding

agreed with Birhanu Ayana, 2011. Improved agronomic and RWM practices significantly increased crop yield and thereby enhance water productivity (Palanisami *et al*. 2006).

4.1.2.6 Weed Control

The farmers tried to control weeds using frequent tillage and crop rotation practices. It was observed that most farmers removed weeds by hand from potato, teff, maize and sorghum fields. However, herbicides were mostly applied to barley and wheat 30 to 40 days after planting and the farmers would come back to the field for harvesting. It was basically because of lack of labor. However, Hailu and Van Luer (1996) reported that weed competition is a major cause for barley yield reduction up to 17%. The sampled local farmers used weeds removed from maize and sorghum as livestock feed.

4.1.2.7 Lengths of Crop Growing Period (LGP)

A total of six major crops (three in each local agro-ecological zone) were selected and monitored. Their planting and harvesting dates were recorded from which the four plant development stages, that is initial, development, mid stage and late stages (Allen *et al*. 1998) in number of days was determined to be used as input to the CROPWAT model to simulate CWR (Annex 8).Table 8 shows the average total length of growing period of the sampled major crops. There was a little bit difference in sowing dates between barley and wheat in the upper zone. Wheat was sown earlier than barley both in the upper and middle zones. There was difference in sowing dates of the same crops across different agro-ecology. Both teff and sorghum were sown earlier in the middle than in the lower zone.

Table 8: Average LGP (days from planting to maturity) in the three local agro-ecological zones.

Crop Type	The Average LGP in each local agro-ecology			
	Upper Zone	Middle Zone	Lower Zone	**Average**
Barley	159	-	-	**159**
Wheat	165	155	-	**160**
Teff	-	152	133	**143**
Sorghum	-	271	242	**257**
Maize	-	-	173	**173**
Potato	163	-	-	**163**
Average	**162**	**193**	**183**	**176**

Source: Field Measurement, 2011

As can be seen from the above table, the average LGP (number of days from planting to maturity) for wheat in the upper zone was 165 days and 155 days in the middle zone. For barley, it was 159 days. Similarly, it was 152 days and 271 days for teff and sorghum in the middle zone, respectively. The LGP in the lower zone was 133, 242 and 173 days for teff, sorghum and maize, respectively. As we move down across the local agro-ecology, crops mature faster than moving to the upper due to moisture stress in the lower zone. For instance, wheat matures earlier in the middle zone than in the upper zone. Similarly, teff and sorghum were also matured earlier in the lower zone than in the middle zone.

4.1.2.8 Methods of Harvesting

All sampled crops were harvested traditionally by hand mostly using family labor and social cooperation system locally called *'Dabo'*. In the upper zone, farmers mostly used hired labor for potato harvesting in addition to family labor (Figure 14).

(A) (B)

Figure 14: Farmers harvesting potato with oxen plough and collecting with hand using family labor (A); and both family and hired labor (B), in 'Edensa Gelan' KA, October, 2011

Harvesting potato that was planted in short growing period usually began in the month of June and continues to the end of September. October was the usual harvesting time for potato that was grown during the main growing period. However, few farmers living in extreme highland areas of *Seriti* and *Gelessa* KAs left the tubers to stay longer (even up to January) in the soil without being harvested. This type of potato was mostly used for seeds. Method of harvesting barley, teff and wheat were similar (Figure 15).

(I), November, 2011 (II), December, 2011

Figure 15: Traditional harvesting method of teff (I) in 'Goral Lalisa' and barley (II) locally known as *'ballami'* in '*Seriti*' KAs.

4.1.3 Crop Productivity Status

Agricultural productivity of major crops sampled from each local agro-ecology was estimated as shown in the subsequent Tables (9 – 12). It is the crop productivity in terms of

either grain or tuber or total biomass which was used as a numerator in CWP determination.

Table 9: Average crop productivity (kg/ha) status in the upper zone

Crop Type	Biomass Productivity (kg/ha)			
	Grain	Straw	Total Biomass	Tuber
Barley	3487	5937	9424	-
Wheat	3629	10544	14173	-
Potato	-	1360	54600	53240

Source: Field Measurement, 2011.

Table 9 shows that the average grain yields of barley and wheat were comparable while they showed variation in their mean biomass and straw yield. The tuber yield of potato was 53200 kg/ha while barley and wheat grain was about 3500 kg/ha and 3600 kg/ha, respectively. As a result of this, the average biomass and grain or tuber productivity was greater in the upper zone compared to the other two local agro-ecological zones (Table 10 and 12).

Barley and wheat grain yield varies from less than 1000 to 3000 kg/ha in water limited rainfed condition. The world average productivity of barley was estimated to be 2800 kg/ha while that wheat was 3000 kg/ha (FAO, 2011). Thus, the average barley and wheat grain yield in the study area falls within the range but above the world average. The minimum average potato tuber yield under rainfed ranges from 5000 to 25000 kg/ha in subtropics and cool tropics (FAO, 2011). Thus, the potato tuber yield in the area was much better than the FAO estimate.

Table 10: Average crop productivity (kg/ha) in the middle zone

Crop Type	Biomass Productivity (kg/ha)		
	Grain	Straw	Total Biomass
Wheat	3569	7167	10735
Teff	1093	3336	4429
Sorghum	3050	17435	20485

Source: Field Measurement, 2011.

Wheat was cultivated both in the upper and middle zones. Its average marketable yield (both straw and grain) do not show significant variation which was almost equal (3600 kg/ha). Grain yield of sorghum was a little bit lower than wheat. Productivity of teff was the lowest in this zone and compared to all other crops in the three agro - ecological zones. According to ketema (1993) yield reduction in teff is a common problem due to frequent lodging which results in possible yield reduction up to 17%. He also confirmed that lodging was the result of over application of Nitrogen fertilizer and use of higher seeding rate. Wastage in teff grain was also another possible factor for yield reduction. It was observed that in the study area there was high wastage of teff grain during the time of harvesting and threshing. Thus, yield reduction in teff was most probably associated with these two problems. Similarly, this yield reduction could significantly reduce its WP. The national average teff yield under rainfed condition in Ethiopia was 1000 kg/ha and potentially a yield more than 2000 kg/ha may be attained if good agronomic practice is made (FAO, 2011). As compared to this, the average teff grain yield (1400 kg/ha) in Jeldu wereda was above the national average but below the achievable yield. In the lower zone (Table 11), maize was the best productive as compared to the other two crops followed with sorghum. Even though it is better than that of in the middle zone, teff still is the lowest in both grain and straw yield.

Table 11: Average crop productivity (kg/ha) status in the lower zone.

Crop Type	Biomass Productivity (kg/ha)		
	Grain	Straw	Total Biomass
Teff	1631	3799	5430
Sorghum	3802	20799	24601
Maize	5986	22129	28115

Source: Field Measurement, 2011.

Table 12 shows the average productivity in terms of grain and tuber yield in 100 kg/ha of each crop across the three agro-ecological zones. In the upper zone, the average productivity of barley, wheat and potato (tubers) were 3500, 3600 and 53200 kg/ha, respectively. In the middle zone, wheat, teff and sorghum grain yield was 3600, 1100, and 3100 kg/ha, respectively. Similarly, the average productivity of teff, sorghum and maize was 1600, 3800 and 6000 kg/ha in that order. From this result one can conclude that both

barley and wheat had given almost comparable grain yield in upper and lower zones. Productivity of teff and sorghum were better in the lower zone than in the middle zone.

Table 12: Average grain and tuber yield (100 kg/ha) across agro-ecology.

Crop Type	Productivity in terms of Grain and tuber yield (100kg/ha)			
	Upper Zone	Middle Zone	Lower Zone	**Average**
Barley	35.00	-	-	**35.00**
Wheat	36.00	36.00	-	**36.00**
Teff	-	11.00	16.00	**14.00**
Sorghum	-	31.00	38.00	**35.00**
Maize	-	-	60.00	**60.00**
Potato	532.00	-	-	**532.00**
Average	**201.00**	**26.00**	**38.00**	**119.00**

Source: Field Survey, 2011

4.2 Crop Water Requirement

According to Seleshi Bekele *et al.* (2009) when the amount of water that can be stored in the root zone and gradually be used by a crop every day is 1mm in 1m^2 areas, the amount of water required by the plants every day in one ha of land is equal to 10m^3. This was used as a conversion factor for CWR value from mm to m^3 and utilized in determination of both physical and economic crop water productivity in the subsequent sections of this particular study.

4.2.1 Magnitude of Water Consumed: The Denominator

Rainfed crops used infiltrated rainfall that forms soil moisture in the root zone. This accounts for most of the crop water consumption in agriculture (Singh *et al.* 2009). Table 13 shows the average amount of water consumed by each crop in the three local agro-ecological zones simulated by the CROPWAT model.

Table 13: Average amount of water consumed (m3) by each crop across agro-ecology

Agro-ecology	Crop type						Average
	Barley	Wheat	Potato	Teff	Sorghum	Maize	
Upper zone	2677	2618	3733	-	-	-	3009
Middle zone	-	2556	-	2516	3679	-	2917
Lower zone	-	-	-	2018	3378	4224	3207
Average	2677	2587	3733	2267	3529	4224	3044

Source: Simulated by CROPWAT model, New_LocClim model and own calculation.

As indicated in Table 13, the amount of water consumed varies between crops. An ANOVA calculated by SPSS software revealed that its mean variation among the three agro-ecological zone is not significant ($p = 0.568$). Among the sampled crops maize was the highest water consumer followed by potato and sorghum whereas teff consumed the least. This variation comes from the difference in nature of each crop. According to Seleshi Bekele *et al.* (2009) except wheat and barley, WR among cereal crops is not similar irrespective of their location in different landscape positions.

4.3 Crop Water Productivity Status

4.3.1 Physical Crop Water Productivity

Physical crop water productivity refers to the ratio of the mass of crop yield (kg/ha or ton/ha) to the amount of water used in m^3 (Steduto *et al*. 2007); Singh *et al.* 2011). In other words, it denotes the proportion of marketable yield produced per unit of water taken up by plants.

As indicated in Table 14, the average rainwater productivity of barley grain was 1.32 kg/m^3. WP of wheat in the upper and middle zone was almost comparable whereas WP of teff in the lower zone was almost twice that of the middle zone. The WP of sorghum was also better by 33% than that of the middle zone while WP of maize was 1.42 kg/m^3 in the lower zone and that of potato was 14.25 kg/m^3 in the upper zone. According to Droogers *et al*. (2001) the value of the WP index ranged from 0.50 to 1.50 kg/m^3 for cereals, depending

on variety, soil, climate and management. The world average WP of barley ranges from 1.20 to 1.40 kg/m^3 while that of wheat was ranging from 1 to 1.20 kg/ha (FAO, 2011). Average WP of sorghum at global level also ranges from 0.80 to1.30 kg/m^3 (Steiner, 1986) whereas that of fresh potato tubers ranges from 4 to 11 kg/m^3 (FAO, 2011). Thus, the average WP results of barley and sorghum were almost comparable the global average while that of potato and wheat showed a little bit above the world average. There is no well defined study on teff WP in Ethiopia except Araya *et al*. 2010 and Alemtsehay *et al*. 2011, who tried to estimate normalized WP of test to use in AquaCrop simulation. However, the result indicated that its WP seems lower in the study area.

Table 14: The average physical crops water productivity of each crop across agro ecology

Crop type	Grain or tuber WP (kg/m^3)			**Average**
	Upper Zone	Middle Zone	Lower Zone	
Barley	1.32	-	-	**1.32**
Wheat	1.41	1.42	-	**1.42**
Teff	-	0.44	0.86	**0.65**
Sorghum	-	0.84	1.12	**0.98**
Maize	-	-	1.42	**1.42**
Potato	14.25	-	-	**14.25**
Average	**5.66**	**0.90**	**1.13**	**3.34**

Source: Field Measurement, 2011.

Table 15 shows the state of average physical water productivity of biomass of the monitored crops across the three landscape positions of the study watershed. The average biomass WP of potato was very much higher than all other cereal crops due to its nature. Wheat has better average biomass water productivity than barley in the upper zone. In the middle zone, the average sorghum rainwater productivity is the highest followed by wheat whereas teff is the lowest. Similarly, the average sorghum rainwater productivity was better followed by maize. Even though teff grain and straw WP shows better performance than the middle zone, still it is the lowest in total biomass WP in the lower zone. From its very nature, sorghum and maize have high biomass as compared to other small cereal crops. Thus, shows a tendency to have highest biomass water productivity. According to FAO (2011) it was found that biomass WP of sorghum ranges from 2.30 to 6 kg/ha in India.

Table 15: The average physical crops water productivity of each crop across agro ecology

Crop Type	Biomass WP (kg/ha)			**Average**
	Upper zone	Middle zone	Lower zone	
Barley	3.57	-	-	**3.57**
Wheat	5.38	4.26	-	**4.82**
Teff	-	1.78	2.83	**2.31**
Sorghum	-	5.59	7.30	**6.45**
Maize	-	-	6.68	**6.68**
Potato	14.61	-	-	**14.61**
Average	**7.85**	**3.88**	**5.60**	**6.41**

Source: Field Measurement, 2011.

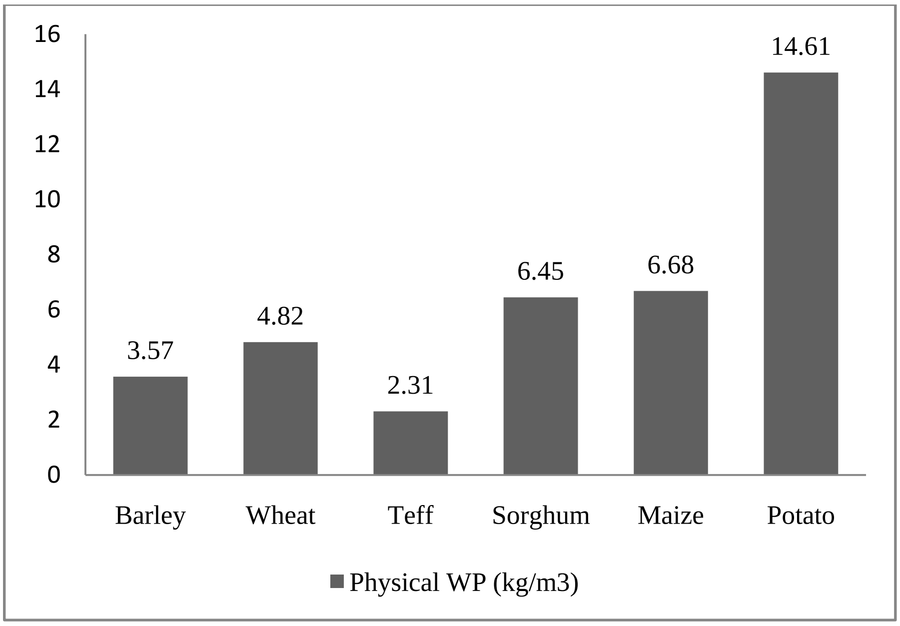


Figure 16: The total average biomass WP (kg/m^3) of the study area.

The figure indicated that potato was the highest in biomass WP (kg/m3) than all other crops followed by maize, sorghum and wheat while that of teff was the lowest in the study area. Here, the null hypothesis which states that there is no difference between mean total biomass water productivity across the three local agro-ecological zones was tested for significance using comparison of sample means (Annex 9).

The result indicated that there is significant difference in the mean total biomass CWP between the three agro-ecological zones (P = 0.014). This is not the end result to reach at the final conclusion because we do not know the existence of mean difference. Thus, a one – way ANOVA or multiple comparison tests was further employed (Annex 10) to test between which local agro – ecology do significant mean variability exists. The result indicated that the mean differences in total biomass WP between upper and lower; and between upper and middle were significant at p = 0.05. However, the difference between middle and lower zone is not significant. This is most probably because the average amount of consumed water (m^3) is almost similar, the major crops selected with their mean seeding rate and yields were comparable. This implied that the two local agro-ecologies (middle and lower zones) could be combined and treated as one agro-ecology. The greater variation in between the upper and the other two zones was due to the existence of extremely high tuber productivity of potato. This does not mean that CWP in the upper zone is better. From the very nature, fresh potato tuber has high water productivity. Ecologically, the upper zone was observed to be highly degraded and highly populated than in the other two zones. In addition, barley is a dominant crop in the district but, its total BM water productivity was found to be lowest next to teff. Therefore, technological interventions that could improve productivity are required mainly here. The nature protected the lower and middle from being extremely degraded. Most of the soil and soil nutrients washed away by erosion from the upper zone deposit in the middle and lower zones. This aspect was validated by the WP results of teff and sorghum. It tended to increase from middle to lower zones (Table 14 and 15).

4.3.2 Economic Crop Water Productivity

Economic crop water productivity means the value (Birr or USD) per unit of water used (Steduto *et al*. 2007). The local market price of grain and tuber yield during the time of harvesting is indicated in Annex 11. Teff had the highest average local market price (9.33 Birr/kg) followed by sorghum (6.03 Birr/kg) and barley (5.80 Birr/kg) respectively whereas potato tubers had the least price per unit weight (2.00 Birr/kg). From this one could easily understand that local market price will also have an effect on the total economic crop water productivity. The price of teff straw was estimated in the middle and

in the lower zones (outside the watershed) of the study district (Annex 11). The middle zone was located in proximity to Gojo town where there is a better market demand to use for building house from mud in addition to livestock feed. The price estimate of potato straw was the lowest because it was mostly left on the field and rarely used as animal feed. Sorghum and maize Stover was locally used for animal fed and source of household energy. The most part of wheat and barley straw was left on the field. The portion of its straw which was harvested with grain was stored to be used as animal feed after threshing. Based on this market value, the total economic water productivity of above ground biomass across the three local agro - ecological zones was estimated and the average results were presented in Table 16.

Table 16: Total average ECWP of BM (Birr/m^3) of major crops across agro-ecology

Crop type	Total average ECWP (Birr/m^3) across agro-ecology			
	Upper Zone	Middle Zone	Lower Zone	Average (between)
Barley	10.09	-	-	10.09
Wheat	11.44	10.23	-	10.84
Teff	-	6.20	10.69	8.45
Sorghum	-	6.84	9.26	8.05
Maize	-	-	10.18	10.18
Potato	28.82	-	-	28.82
Average (within)	16.78	7.76	10.04	12.74

Source: Field Measurement, 2011

Table 16 shows that the average total economic water productivity of potato was the highest while that of barley and wheat were almost comparable in the upper zone. In the middle zone, wheat had better economic productivity than both teff and sorghum while that of teff and sorghum were almost similar. As compared to the upper zone (16.78 Birr/m^3) the middle zone has lower in the mean economic water productivity (7.76 Birr/m^3). In the lower zone, teff and maize showed almost comparable economic water productivity followed by sorghum. When compared with the middle zone, the lower zone showed a little bit better. However, it remained lower as compared with the upper zone. The total average economic crop water productivity shows variation across the three local agro – ecological zones.

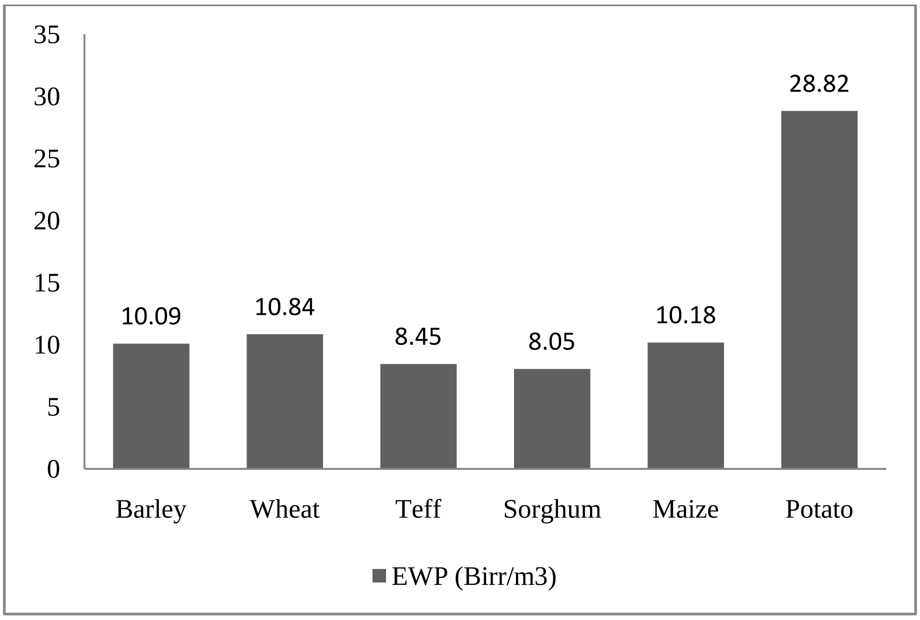


Figure 17: The total average biomass WP (Birr/m^3) of each crop in the study area.

The figure clearly shows that the total average economic water productivity of potato was the highest in the study area followed by wheat, maize and barley. Thus, potato is the most appropriate crop in economic water productivity than all others crops in the upper zone of the study watershed.

In order to test for the significance of variation in the mean ECWP among the three local agro-ecological zones, comparison of means was employed (Annex 13). The ANOVA test result indicated that the variation was significant (P = 0.001). Hence, there is significant mean difference in ECWP between the three local agro – ecological zones. Finally, one – way ANOVA test was employed to check in between which local agro – ecological zones that there exists significant variation (Annex 14).

4.4 Effects of Crop Management Practices on Water Productivity

Crop water productivity is a function of several factors from which crops management practices is one. Farmers applied either UREA or DAP or both to the monitored crop fields except on most sorghum crop fields in the middle and lower zones as well as teff in the lower zone. Wheat grow both in the upper and middle zones; both teff and sorghum also grow in the middle and lower zones of the study area with the limitation of potato and

barley mainly to the upper and maize to the lower zones, respectively. Here under, the relationships between the four management practices and BMWP of the major crops is treated.

4.4.1 Effects on Physical and Economical Crop Water Productivity

As mentioned earlier, the aspects like physical and economic crop water productivity in a system depend on many factors and the management practices prevailing in the watershed is one. The crop management practices differ with major crops like potato, barley, wheat, teff, sorghum and maize and these different practices contribute to the productivity parameters differently. We consider the four management practices like rate of UREA and DAP application, seeding rate and tillage frequency and investigated relationship with biomass WP. The Pearson's correlation coefficient calculated for the four crop management practices and corresponding WP of major crops showed no significant relationship (Annex 15). However, the rate of application of UREA and DAP as well as tillage frequency tended to positively correlate while seeding rate tended to negatively correlate with potato biomass water productivity (BMWP). The relationship of these management practices on wheat BMWP was different between the upper and middle zones of the study watershed. In the upper zone, the Pearson's correlation coefficient indicated that UREA application and seeding rates tended to negatively correlate whereas rate of application of DAP and tillage frequency tended to positively correlate with wheat BMWP. To the contrary, in the middle zone, UREA and DAP application rates tended to negatively correlate whereas seeding rate and tillage frequency tended to positively correlate with its BMWP. In case of barley, seeding rate tended to negatively correlate while rate of application of DAP and tillage frequency tended to positively correlate with its BMWP. For teff, rate of application of UREA and DAP as well as tillage frequency tended to negatively correlate whereas seeding rate tended to positively correlate with its BMWP in the middle zone. In the lower zone, the effect of only seeding rate and tillage frequency were tasted and the result indicated that seeding rate tended to positively correlate while tillage frequency tended to negatively correlate with its BMWP. Usually farmers didn't apply inorganic fertilizers to sorghum crop fields in the study area. Only on one former's crop field that both UREA and DAP were applied in the middle zone. Thus, in this zone,

rate of application of both UREA and DAP as well as tillage frequency tended to positively correlate while seeding rate tended to negatively correlate with its BMWP. In the lower zone, both seeding rate and tillage frequency tended to negatively correlate with sorghum BMWP. In case of maize, rates of application of UREA and DAP as well as tillage frequency tended to positively correlate while seeding rate tended to negatively correlate with its BMWP.

Generally, the absence of clear relationship of the four management practices on BMWP of major crops in the study watershed may be because, the management practices included here couldn't represent the actual variation in the management regime and BMWP. The other possible reason is that the management practices in this study couldn't be separately considered for statistical analysis. However, the results of several studies indicated that any management practices used to enhance crop yield significantly increased crop WP (Toung, 1999; Rockstrom *et al.* 2003; Mulugeta, 2006; Molden *et al*. 2003; Kijne *et al*. 2003; EIAR, 2004). Therefore, a more detailed further study concentrating on this aspect is highly required.

The effects of those management practices treated under physical crop water productivity were also treated with similar procedures for economic crop water productivity and obtained almost similar results (Annex 15). In other words, the Pearson's correlation coefficients calculated to define the relationship between the four management practices and economic BMWP showed a similar relationship trend with that of physical BMWP. Thus, the effect of the four management practices on physical and economic BMWP is similar and the concluding remark given under physical BMWP also works for economic BMWP.

5. CONCLUSIONS AND RECOMMEDDATIONS

5.1 Conclusions

The study revealed that crop rotation was a major cropping system in all agro-ecological zones. It was practiced on 91% of monitored crop fields (45). Barley => Fallow => Barley, Wheat => Teff => Wheat and Teff => Sorghum/Maize were the common rotation pattern in the upper, middle and lower zones, respectively which are not scientifically recommended. Relay cropping and intercropping systems were not commonly practiced in the area. Barley was the dominant crop in the watershed which covered over 50% of the cropped land in the year 2011 alone. Small scale irrigation farming downstream along the major river was also common. Farmers applied very limited types of rainwater management practices and surface drainage was the common rainwater management system (100%) in the area. But, very few farmers also used cut-off drainage (6.6%) in hilly areas, deep furrows (11%), deep tillage (22%) and improved varieties (53%). Compost was applied by only 13% of the sampled households in the study area. Rate of application of inorganic fertilizers (UREA and DAP), frequent tillage, seeding rate, crop diversification and others were common crop management practices implemented in the area. Traditional method of sowing (88%) and harvesting (100%) were mostly practiced. Farmers used to control weeds through frequent tillage, crop rotation, removing with hand and application of herbicides. Potato was the leading in average biomass yield in the upper zone followed with maize in the lower zone and sorghum in the middle zone. From cereal cops, maize was the first in average grain yield followed by wheat, barley and sorghum. Maize was the leading in the amount of water consumed followed by potato and sorghum. Potato has the highest average biomass water productivity in kg/m^3 followed by sorghum and maize. Teff grain was the leading in local market price followed by sorghum and barley correspondingly. There was no significant variation in economic crop water productivity among cereal crops. There was significant difference between the upper and middle as well as the upper and lower landscape positions in both total mean physical and economic water productivity. Potato was the most essential crop than all the other crops both in physical and economic water productivity in the upper zone. The effect of rate of UREA and DAP application, seeding rate and tillage frequency on biomass water productivity of major crops was tested for significance. Though they are very important scientifically to increase

crop water productivity, Pearson's correlation coefficient showed that there is no significant effect on both physical and economic biomass water productivity which may be because, the management practices included here couldn't represent the actual variation in the management regime and biomass water productivity as well as they couldn't be separately considered for statistical analysis. Thus, a more detailed further study concentrating on this aspect is highly required so as to design appropriate means of technological interventions in the rainfed crop production system that could enhance crop water productivity and improve livelihood of the rural community in the study watershed.

5.2 Recommendations

Based on the findings of the study the following recommendations were forwarded:

- ☞ Building the capacity of the local farmers through giving short term trainings in the area of implementing improved crop rotation system that could better maintain soil fertility and improve crop yield. Particularly, giving them direction to use legumes like faba bean, field pea, chickpea, niger seeds, *etc* in between rotation systems in their respective local agro-ecology.
- ☞ There is a need to give technical and material support to the farmers who are using the river water for small scale irrigation farming to sustainably and equitably use the water between upstream downstream regions without affecting the river ecosystem.
- ☞ Assisting the local farmers in providing them training and awareness creation to use diversified and appropriate rainwater management practice across the three landscape positions like soil bund, soil fertility enhancement, appropriate planting date, appropriate plant population, new crop varieties, surface drainage, terraces, stone bunds, and supplemental irrigation in the rainfed systems in the study area.
- ☞ Given the high current and potential productivity of potato in the upper part of the watershed and poor market linkage, all local and regional actors need to facilitate the development of value chain for this essential product.
- ☞ So as to make a proper intervention to enhance crop water productivity and improve livelihood of the rural community in the study watershed, a more detailed further study concentrating on the effect of crop management practice is required.

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APPENDICES

Annex 1: Table of crop water requirement simulated by the CROPWAT model.

This table shows crop water requirement simulated by the CROPWAT model for 45 major crops sampled from the three local Agro-ecological zones. All input climate data to the CROPWAT model were estimated by the New_LocClim model using a single point mode from 10 nearby meteorological stations within 100km radius. The consumptive water used by each crops (amount of water transpired) obtained by subtracting irrigation requirement from the crop evapotranspiration in m^3 was used as a denominator in determination of CWP.

No	Crop Type	Crop water Requirement (CWR)			ET_C - IR	
		ET_C (mm/dec)	Eff.Rain (mm/dec)	IR (mm/dec)	mm	m^3
1.	Pot_1	400.30	512.90	19.20	381.10	3811.00
2.	Pot_2	457.80	523.70	74.10	383.70	3837.00
3.	Pot_3	494.10	535.10	95.00	399.10	3991.00
4.	Pot_4	455.60	522.20	84.20	371.40	3714.00
5.	Pot_5	384.00	573.00	52.80	331.20	3312.00
6.	Wt_up_1	478.80	379.40	254.80	224.00	2240.00
7.	Wt_up_2	498.80	409.50	255.10	243.70	2437.00
8.	Wt_up_3	493.30	452.40	224.20	269.10	2691.00
9.	Wt_up_4	484.50	456.80	211.50	273.00	2730.00
10.	Wt_up_5	514.30	484.10	215.10	299.20	2992.00
11.	Bar_1	493.40	464.70	220.20	273.20	2732.00
12.	Bar_2	410.70	433.80	140.70	270.00	2700.00
13.	Bar_3	503.20	477.50	217.50	285.70	2857.00
14.	Bar_4	439.20	426.30	192.30	246.90	2469.00
15.	Bar_5	473.80	439.00	211.00	262.80	2628.00
16.	Wt_mid_1	459.00	365.90	223.40	235.60	2356.00
17.	Wt_mid_2	422.40	380.20	174.40	248.00	2480.00
18.	Wt_mid_3	464.30	345.80	252.10	212.200	2122.00
19.	Wt_mid_4	397.10	488.30	53.40	343.70	3437.00
20.	Wt_mid_5	592.60	393.30	354.10	238.50	2385.00
21.	Tef_mid_1	444.80	338.90	205.40	239.40	2394.00
22.	Tef_mid_2	418.10	409.10	149.50	268.60	2686.00
23.	Tef_mid_3	454.20	370.70	203.30	250.90	2509.002
24.	Tef_mid_4	482.80	366.00	236.40	245.60	2456.00
25.	Tef_mid_5	398.80	371.80	145.50	253.30	2533.00
26.	Sor_mid_1	686.90	597.80	289.50	397.40	3974.00
27	Sor_mid_2	756.40	590.90	393.50	362.90	3629.00
28	Sor_mid_3	678.90	590.50	291.90	387.00	3870.00
29	Sor_mid_4	741.70	596.10	366.40	375.30	3753.00
30	Sor_mid_5	715.90	564.00	399.10	316.80	3168.00

31	Maz_1	439.90	532.10	9.80	430.10	4301.00
32	Maz_2	441.90	513.60	31.60	410.30	4103.00
33	Maz_3	468.60	522.20	57.80	410.80	4108.00
34	Maz_4	491.00	549.30	35.30	455.70	4557.00
35	Maz_5	433.30	520.00	28.40	404.90	4049.00
36	Tef_low_1	388.20	283.60	161.20	227.00	2270.00
37	Tef_low_2	430.50	285.90	202.70	227.80	2278.00
38	Tef_low_3	444.80	279.30	231.80	213.00	2130.00
39	Tef_low_4	346.40	140.00	230.50	115.90	1159.00
40	Tef_low_5	448.40	286.40	223.00	225.40	2254.00
41	Sor_low_1	597.90	512.80	284.90	313.00	3130.00
42	Sor_low_2	633.80	545.60	285.90	347.90	3479.00
43	Sor_low_3	680.50	535.40	341.10	339.40	3394.00
44	Sor_low_4	667.20	565.70	313.60	353.60	3536.00
45	Sor_low_5	673.70	536.20	338.70	335.00	3350.00

Annex 2: Table of soil water characteristics of the 45 sampled crop fields simulated by soil-water characteristics calculator model.

It was simulated using National Laboratory analysis result of soil texture as input which was obtained from IWMI. The first three results of soil water characteristics were used as input to the CROPWAT model in determination of CWR.

Agro-Ecology	Crop Field	Soil Name	Soil-Water-Characteristics			
			TAM (mm/m)	MRIR (mm/day)	ISMD (%)	IASM (mm/m)
Upper Zone	Pot_1	Clay	130.00	63.00	29.00	92.30
	Pot_2	Clay	130.00	63.00	29.00	92.30
	Pot_3	Clay	120.00	49.00	30.00	84.00
	Pot_4	Clay	130.00	48.00	28.00	93.60
	Pot_5	Clay	110.00	72.00	33.00	73.70
	Wt_up_1	Clay	130.00	63.00	29.00	92.30
	Wt_up_2	Clay	130.00	63.00	29.00	92.30
	Wt_up_3	Clay	110.00	72.00	33.00	73.70
	Wt_up_4	Silty Clay	130.00	53.00	30.00	91.00
	Wt_up_5	Clay	130.00	60.00	28.00	93.60
	Bar_1	Clay	110.00	72.00	32.90	73.70
	Bar_2	Clay	130.00	48.00	28.00	93.60
	Bar_3	Clay	110.00	72.00	33.00	73.70
	Bar_4	Clay	130.00	63.00	29.00	92.30
	Bar_5	Clay	130.00	63.00	29.00	92.30
Middle Zone	Wt_mid_1	Caly	130.00	48.00	28.00	93.60
	Wt_mid_2	Silty Clay	130.00	71.00	30.00	91.00
	Wt_mid_3	Clay	130.00	67.00	30.00	91.00
	Wt_mid_4	Silty Caly	130.00	71.00	30.00	91.00
	Wt_mid_5	Caly	120.00	59.00	32.00	81.60
	Tef_mid_1	Silty Caly	130.00	53.00	30.00	91.00
	Tef_mid_2	Clay	120.00	59.00	32.00	81.60
	Tef_mid_3	Clay	120.00	59.00	32.00	81.60
	Tef_mid_4	Silty Caly	130.00	53.00	30.00	91.00
	Tef_mid_5	Silty Caly	130.00	71.00	30.00	91.00
	Sor-mid_1	Clay	120.00	49.00	30.00	84.00
	Sor-mid_2	Silty Clay	130.00	71.00	30.00	91.00
	Sor-mid_3	Silty Clay	130.00	53.00	30.00	91.00
	Sor-mid_4	Clay	120.00	59.00	32.00	81.60
	Sor-mid_5	Clay	130.00	48.00	28.00	93.60
Lower Zone	Maz_2	Clay Loam	140.00	109.00	21.00	110.60
	Maz_3	Clay Loam	140.00	109.00	21.00	110.60
	Maz_4	Clay Loam	140.00	109.00	21.00	110.60
	Maz_5	Clay Loam	140.00	109.00	21.00	110.60
	Tef_low_1	Clay Loam	140.00	109.00	21.00	110.60
	Tef_low_2	Clay Loam	140.00	109.00	21.00	110.60
	Tef_low_3	Clay Loam	140.00	109.00	21.00	110.60

	Tef_low_4	Clay Loam	140.00	109.00	21.00	110.60
	(Continued)					
	Tef_low_5	Clay Loam	140.00	109.00	21.00	110.60
	Sor_low_1	Clay Loam	140.00	109.00	21.00	110.60
	Sor_low_2	Clay Loam	140.00	109.00	21.00	110.60
	Sor_low_3	Clay Loam	140.00	109.00	21.00	110.60
	Sor_low_4	Clay	120.00	62.00	32.00	81.60
	Sor_low_5	Clay Loam	140.00	109.00	21.00	110.60

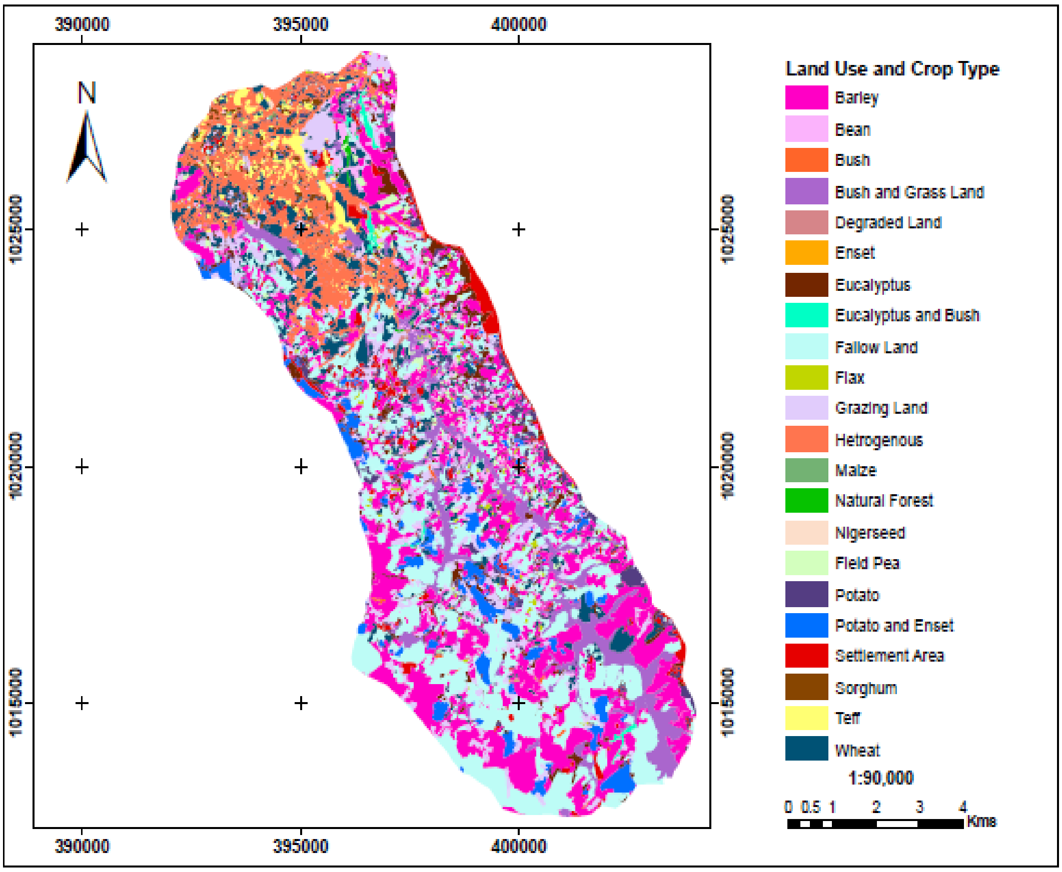
TAM = Total Available Moisture; MRIR = Maximum Rain Infiltration Rate; ISMD = Initial Soil Moisture Depletion; IASM = Initial Available Soil Moisture; Pot_1 to Pot_5 = the five sampled potato fields; Wt_up_1 to 5 = the five sampled wheat crop field taken from the upper zone of the watershed; Bar_1 to 5 = the five sampled barley crop fields; Wt_mid_1 to 5 = the five sampled wheat fields from the middle zone; Tef_mid_1 to 5 = five Sampled teff fields from the middle zone of the watershed; Sor_mid_1 to 5 = five sampled sorghum fields selected from the middle zone; Maz_1 to 5 = five sampled maize fields selected from outside of the watershed (lower zone); tef_low_1 to 5 = the five sampled teff crop fields from outside of the watershed and Sor_low_1 to 5 = the five sampled sorghum crop fields from outside of the watershed.

Annex 3: Table of soil water characteristics of the 45 sampled crop fields simulated by soil-water characteristics calculator model.

Sample ID	Definition	Coordinate Reading		Sand (%)	Silt (%)	Clay (%)
T1-001	Jeldu Transect 1…	N9 18.247	E38 03.412	9	36	55
T1-002		N9 18.178	E38 03.423	9	38	53
T1-003		N9 17.922	E38 02. 978	11	40	49
T1-004		N9 17.813	E38 03.098	25	40	35
T1-005		N9 17.781	E38 02.958	15	40	45
T1-006		N9 17.542	E38 02.822	21	32	47
T1-007		N9 17.307	E38 02.587	7	24	69
T2-001	Jeldu Transect 2…	N9 13.973	E38 05. 613	9	38	53
T2-002		N9 13.987	E38 05.485	11	42	47
T2-003		N9 13.975	E38 05.323	5	38	57
T2-004		N9 13.883	E38 05.176	5	38	57
T2-005		N9 13.763	E38 05.078	19	36	45
T2-006		N9 13.651	E38 05.033	25	44	31
T2-007		N9 13.447	E38 04.990	11	38	51
T2-008		N9 13.368	E38 04.859	13	42	45
T2-009		N9 13.256	E38 04. 757	13	42	45
T2-010		N9 13.004	E38 04.864	5	44	51
T3-001	Jeldu Transect 3…	N9 17.409	E38 01.748	9	40	51
T3-002		N9 17.25	E38 01.713	21	32	47
T3-003		N9 17.07	E38 01.692	15	34	51
T3-004		N9 16.765	E38 01.719	9	36	55

Source: IWMI, 2011.

Annex 4: Figure of land use land cover map of *Meja* watershed for the year 2011



Source: Field Survey, 2011.

Annex 5: Table of data codes used for SPSS entry.

Variable Name	Codes
Agro-Ecology	1= Upper Zone; 2= Middle zone; 3= Lower Zone.
Crop Types	1 = Barley; 2 = Potato; 3 = Wheat; 4 = Teff; 5 = Sorghum; 6 = Maize
Crop Variety	1 = Improved Variety (IV); 2 = Local Variety (LV)
Compost Applied	1 = Yes; 2 = No
Precursor Crop	1 = Fallow; 2 = Legume; 3 = None legume but same; 4 = None legume but different
Method of sowing	1 = Broadcast; 2 = Rows
Application of FYM	1 = Applied; 2 = Not applied

Annex 6: Table of crop area statistics of the study watershed.

Crop Type	Area coverage (ha)	% age share
Barley	2110	25
Wheat	803	9
Potato and Enset	692.21	8
Teff	205	2.4
Bean	154	2
Field Pea	83	0.97
Sorghum	81	0.95
Flax	57	0.67
Maize	12	0.14
Niger Seed	4	0.05
Uncultivated Land	4335	51
Total Area	**8536.21**	**100**

Annex 7: Table crop water productivity with respect to consumptive water use and effective precipitation.

Agroecology /code/	Crop Type (code)	Dry GY(kg/ha)	Dry SY (kg/ha)	CW (m3)	PE (m3)	WPGCW (kg/m3)	WPGPE (kg/m3)	WPSCW (kg/m3)	EWPG (ETB/m3)	EWPS (ETB/m3)	TEWP (ETB/m3)	Dry Biomass (kg/ha)	HI	WPSPE (kg/m3)	Total CWP (kg/m3)
1	2	72700.00	2100.00	3811	5129	19.08	14.17	0.55	38.15	0.11	38.26	74800.00	0.97	0.40	19.63
1	2	54500.00	1300.00	3837	5237	14.20	10.41	0.34	28.41	0.07	28.48	55800.00	0.98	0.24	14.54
1	2	45500.00	1400.00	3991	5351	11.40	8.50	0.35	22.80	0.70	22.87	46900.00	0.97	0.27	11.75
1	2	50700.00	1300.00	3714	5222	13.65	9.71	0.35	27.30	0.70	27.37	52000.00	0.98	0.23	14.00
1	2	42800.00	700.00	3312	5730	12.92	7.47	0.21	25.85	0.04	25.89	43500.00	0.98	0.18	13.13
1	3	4055.00	7750.00	2240	3794	1.81	1.07	3.46	9.09	3.81	12.86	11805.00	0.34	1.89	5.27
1	3	3500.00	4750.00	2437	4095	1.44	0.85	1.95	7.18	2.14	9.32	8250.00	0.42	1.05	3.39
1	3	3136.00	16273.00	2691	4524	1.17	0.69	6.05	5.83	6.65	12.48	19409.00	0.16	3.56	7.21
1	3	4855.00	12127.00	2730	4568	1.78	1.06	4.44	8.89	4.89	13.78	16982.00	0.29	2.51	6.22
1	3	2600.00	11818.00	2992	4841	0.87	0.54	3.95	4.34	4.34	8.69	14418.00	0.18	2.54	4.82
1	1	3136.00	6333.00	2732	4647	1.15	0.67	2.32	6.66	2.55	9.21	9469.00	0.33	1.46	3.47
1	1	3700.00	5236.00	2700	4338	1.37	0.85	1.94	7.95	2.13	10.08	8936.00	0.41	1.10	3.31
1	1	2000.00	3568.00	2857	4775	0.70	0.42	1.25	4.06	1.37	5.43	5568.00	0.36	0.86	1.95
1	1	3301.00	7875.00	2469	4163	1.34	0.79	3.19	7.75	3.51	11.26	11176.00	0.30	1.79	4.53
1	1	5300.00	6671.00	2628	4390	2.02	1.21	2.54	11.70	2.79	14.49	11971.00	0.44	1.82	4.56
2	3	1500.00	4533.00	2356	3659	0.64	0.41	1.92	3.18	2.12	5.30	6033.00	0.25	1.19	2.56
2	3	7600.00	11498.00	2480	3802	3.06	2.00	4.64	15.32	5.10	20.42	19098.00	0.40	3.33	7.70
2	3	2091.00	4286.00	2122	3458	0.99	0.60	2.02	4.93	2.22	7.15	6377.00	0.33	0.88	3.01
2	3	2867.00	6933.00	3437	4883	0.83	0.59	2.02	4.17	2.22	6.39	9800.00	0.29	1.76	2.85
2	3	3786.00	8583.00	2385	3933	1.59	0.96	3.60	7.94	3.96	11.90	12369.00	0.31	2.53	5.19
2	4	1291.00	3960.00	2394	3389	0.54	0.38	1.65	5.12	2.65	7.77	5251.00	0.25	0.97	2.19
2	4	968.00	1929.00	2686	4091	0.36	0.24	0.72	3.60	1.15	4.75	2897.00	0.33	0.52	1.08

2	4	1761.00	4960.00	2509	3707	0.70	0.48	1.98	6.67	3.16	9.83	6721.00	0.26	1.36	2.68
2	4	728.00	2700.00	2456	3660	0.30	0.20	1.10	2.52	1.76	4.28	3428.00	0.21	0.73	1.40
2	4	717.00	3133.00	2533	3718	0.28	0.19	1.24	2.41	1.98	4.39	3850.00	0.19	0.52	1.52
2	5	2775.00	20327.00	3974	5978	0.70	0.46	5.11	3.91	2.30	6.21	23102.00	0.12	3.44	5.81
2	5	2880.00	19620.00	3629	5909	0.79	0.49	5.41	4.44	2.43	6.88	22500.00	0.13	3.32	6.20
2	5	4266.00	13407.00	3870	5905	1.10	0.72	3.46	6.17	1.56	7.73	17673.00	0.24	2.25	4.57
2	5	1568.00	18307.00	3753	5961	0.42	0.26	4.88	2.34	2.20	4.53	19875.00	0.08	3.25	5.30
2	5	3763.00	15514.00	3168	5640	1.19	0.67	4.90	6.65	2.20	8.86	19277.00	0.20	2.92	6.08
3	6	6272.00	23893.00	4301	5321	1.46	1.18	5.56	8.02	2.50	10.52	30165.00	0.21	4.65	7.01
3	6	7146.00	27109.00	4103	5136	1.74	1.39	6.61	9.58	2.97	12.55	34255.00	0.21	5.19	8.35
3	6	5286.00	19800.00	4108	5222	1.29	1.01	4.82	7.08	2.17	9.25	25086.00	0.21	3.60	6.11
3	6	5864.00	18938.00	4557	5493	1.29	1.07	4.16	7.08	1.87	8.95	24802.00	0.24	3.64	5.44
3	6	5362.00	20907.00	4049	5200	1.32	1.03	5.16	7.28	2.32	9.61	26269.00	0.20	7.37	6.49
3	4	1905.00	3593.00	2270	2836	0.84	0.67	1.58	7.13	2.37	9.51	5498.00	0.35	1.26	2.42
3	4	1523.00	4480.00	2278	2859	0.67	0.53	1.97	6.35	2.95	9.30	6003.00	0.25	1.60	2.64
3	4	1088.00	3418.00	2130	2793	0.51	0.39	1.60	4.85	2.41	7.26	4506.00	0.24	2.44	2.12
3	4	1593.00	3285.00	1159	1400	1.37	1.14	2.83	11.68	4.25	15.93	4878.00	0.33	1.15	4.21
3	4	2045.00	4219.00	2254	2864	0.91	0.71	1.87	8.62	2.81	11.43	6264.00	0.33	0.82	2.78
3	5	2464.00	22425.00	3130	5128	0.79	0.48	7.16	5.51	3.22	8.73	24889.00	0.10	4.11	7.95
3	5	3696.00	22691.00	3479	5456	1.06	0.68	6.52	5.95	2.94	8.88	26387.00	0.14	4.24	7.58
3	5	5224.00	25020.00	3394	5354	1.54	0.98	7.37	8.62	3.32	11.94	30244.00	0.17	4.42	8.91
3	5	4967.00	16191.00	3536	5657	1.40	0.88	4.58	7.87	2.06	9.93	21158.00	0.23	3.02	5.98
3	5	2658.00	17670.00	3350	5362	0.79	0.50	5.27	4.44	2.37	6.82	20328.00	0.13	3.30	6.07

Annex 8: Table of crop characteristics used as in put for CROPWAT model in the determination of CWR with respect to crop type and agro - ecology.

Agro-ecology	Crop Type	Planting Date	Length of Growing Period (LGP)					K_C Values			Max. Rooting Depth (cm)	Simulated Harvesting Date
			Initial stage	Development stage	Mid Stage	Late stage	Total LGP	K_{Cinit}	K_{Cmid}	K_{Clate}		
1	2	10/05/2011	30	49	57	38	174	0.50	1.15	0.75	60	30/10/2011
1	2	21/05/2011	25	42	56	37	160	0.50	1.15	0.75	60	27/10/2011
1	2	10/05/2011	31	53	48	42	174	0.50	1.15	0.75	60	30/10/2011
1	2	23/05/2011	30	40	47	45	162	0.50	1.15	0.75	60	31/10/2011
1	2	03/06/2011	28	38	46	35	147	0.50	1.15	0.75	60	26/10/2011
1	3	18/07/2011	16	31	68	42	157	0.30	1.15	0.30	120	21/12/2011
1	3	12/07/2011	16	33	71	44	164	0.30	1.15	0.30	120	22/12/2011
1	3	03/07/2011	17	33	72	44	165	0.30	1.15	0.30	120	15/12/2011
1	3	02/07/2011	16	33	71	44	164	0.30	1.15	0.30	120	12/12/2011
1	3	22/06/2011	18	35	76	47	175	0.30	1.15	0.30	120	14/12/2011
1	1	02/07/2011	17	34	73	45	168	0.30	1.15	0.25	110	17/12/2011
1	1	04/07/2011	14	29	62	38	143	0.30	1.15	0.25	110	23/11/2011
1	1	27/06/2011	17	35	75	46	173	0.30	1.15	0.25	110	16/12/2011
1	1	11/07/2011	15	30	65	40	150	0.30	1.15	0.25	110	07/12/2011
1	1	06/07/2011	16	32	70	43	161	0.30	1.15	0.25	110	13/12/2011
2	3	15/07/2011	15	30	64	40	149	0.30	1.15	0.30	120	10/12/2011
2	3	12/07/2011	14	28	61	37	140	0.30	1.15	0.30	120	28/11/2011
2	3	23/07/2011	15	30	65	40	150	0.30	1.15	0.30	120	19/12/2011
2	3	05/06/2011	15	30	64	40	149	0.30	1.15	0.30	120	31/10/2011
2	3	15/07/2011	18	38	82	50	188	0.30	1.15	0.30	120	18/01/2011
2	4	22/07/2011	21	29	57	43	150	0.80	0.95	0.40	120	18/12/2011
2	4	07/07/2011	21	28	57	43	149	0.80	0.95	0.40	120	02/12/2011
2	4	17/07/2011	20	39	59	45	156	0.80	0.95	0.40	120	19/12/2011
2	4	18/07/2011	23	31	63	47	164	0.80	0.95	0.40	120	28/12/2011
2	4	13/07/2011	20	27	53	40	139	0.80	0.95	0.40	120	29/12/2011
2	5	21/04/2011	41	71	92	61	265	0.30	1.00	0.55	140	10/01/2012

2	5	05/05/2011	44	76	98	65	283	0.30	1.00	0.55	140	11/02/2011
2	5	26/04/2011	40	71	91	61	262	0.30	1.00	0.55	140	13/02/2011
2	5	03/05/2011	43	76	97	65	281	0.30	1.00	0.55	140	07/02/2011
3	5	23/05/2011	41	71	92	61	265	0.30	1.00	0.55	140	11/02/2011
3	6	18/04/2011	28	47	56	37	168	0.30	1.20	0.35	100	02/10/2011
3	6	03/05/2011	28	47	56	37	168	0.30	1.20	0.35	100	17/10/2011
3	6	02/05/2011	30	49	59	39	177	0.30	1.20	0.35	100	25/10/2011
3	6	18/04/2011	31	51	62	41	185	0.30	1.20	0.35	100	19/10/2011
3	6	06/04/2011	28	46	56	37	167	0.30	1.20	0.35	100	19/10/2011
3	4	25/07/2011	18	24	49	37	128	0.80	0.95	0.40	120	29/11/2011
3	4	25/07/2011	20	27	53	40	139	0.80	0.95	0.40	120	11/12/2011
3	4	28/07/2011	20	27	55	41	143	0.80	0.95	0.40	120	17/12/2011
3	4	30/08/2011	15	21	41	31	108	0.80	0.95	0.40	120	15/12/2011
3	4	27/07/2011	21	28	55	41	145	0.80	0.95	0.40	120	18/12/2011
3	5	23/05/2011	34	60	77	50	222	0.30	1.00	0.55	140	29/12/2011
3	5	08/05/2011	37	64	82	55	237	0.30	1.00	0.55	140	31/12/2011
3	5	12/05/2011	38	67	86	58	249	0.30	1.00	0.55	140	15/01/2012
3	5	05/05/2011	40	69	89	59	257	0.30	1.00	0.55	140	16/01/2012
3	5	13/05/2011	38	66	85	56	244	0.30	1.00	0.55	140	14/01/2012

Annex 9: Table of ANOVA of mean biomass WP with respect to local agro-ecology

	Sum of Square	df	Mean Square	F	P-value
Between Groups	119.240	2	59.620	4.706	0.014
Within Groups	532.109	42	12.669		
Total	651.349	44			

Annex 10: Table of one-way ANOVA to test significance of mean biomass WP difference

(I) Agro-ecology	(J) Agro-Ecology	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Upper zone	Middle Zone	3.976*	1.29971	.004	1.3531	6.5989
	Lower Zone	2.248	1.29971	.091	-.3749	4.8709
Middle Zone	Upper Zone	-3.976*	1.29971	.004	-6.5989	-1.3531
	Lower Zone	-1.728	1.29971	.191	-4.3509	.8949
Lower Zone	Upper Zone	-2.248	1.29971	.091	-4.8709	.3749
	Middle Zone	1.728	1.29971	.191	-.8949	4.3509

* The mean difference is significant at the 0.05 level.

Annex 11: Table of local market values of grain yield in 2011/12.

Crop Type	Market Price (ETB/100kg)
Barley	580.00
Wheat	500.00
Potato	200.00
Sorghum:	
'Achire adii'	700.00
Others	560.00
Maize	550.00
Teff:	
White IV	1000.00
White LV	950.00
Red LV	850.00

Source: Jeldu district office of trade and industry, personal interview, 2011.

Annex 12: Table of price estimate of straw and Stover yield (Birr/kg).

Crop Type	Local estimate (Birr/kg)	Price Estimated in Oromia (Birr/kg)**
Teff	1.55	0.65 – 2.00
Potato	0.20	-
Sorghum/Maize	0.45	0.5 – 0.70
Barley/Wheat	1.10	0.25 – 0.28

Source: Informal Survey, 2011 and **Berhanu Gebremedhin, *et al*., 2009

Annex 13: Table of ANOVA of mean economic CWP (Birr/m3) across agro-ecologies

	Sum of Square	df	Mean square	F	P - value
Between Groups	647.122	2	323.561	8.660	0.001
Within Groups	1569.206	42	37.362		
Total	2216.326	44			

Annex 14: Table of one – way ANOVA to test significance of mean difference.

(I) Agro-ecology	(J) Agro-ecology	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Upper Zone	Middle Zone	8.93867*	2.23195	0.000	4.4344	13.4429
	Lower Zone	6.65733*	2.23195	0.005	2.1531	11.1616
Middle Zone	Upper Zone	-8.93867*	2.23195	0.000	-13.4429	-4.4344
	Lower Zone	-2.28133	2.23195	0.313	-6.7856	2.2229
Lower Zone	Upper Zone	-6.65733*	2.23195	0.005	-11.1616	-2.1531
	Middle Zone	2.28133	2.23195	0.313	-2.2229	6.7856

* The mean difference is significant at the 0.05 level.

Annex 15: Table of Pearson's correlation coefficient indicating the relationship between four management practices and CWP across the three zones.

Upper Zone				Middle Zone			
Crop	Variables	Pearson's corr. coef. (P value)		Crop	Variables	Pearson's corr. coef. (P value)	
		BMWP	ECWP			BMWP	ECWP
Potato	UREA	0.32675 (0.5915)	0.33988 (0.5757)	Wheat	UREA	-0.56245 (0.3237)	-0.34253 (0.5726)
	DAP	0.56839 (0.3174)	0.58630 (0.2988)		DAP	-0.22660 (0.7140)	-0.54024 (0.3472)
	SR	-0.30039 (0.6234)	-0.29892 (0.6251)		SR	0.68159 (0.2051)	0.71637 (0.1734)
	TF	0.20072 (0.7462)	0.19513 (0.7531)		TF	-0.75029 (0.14400)	0.76295 (0.1335)
Barley	UREA	-	-	Teff	UREA	-0.24417 (0.6922)	-0.42402 (0.4768)
	DAP	0.21174 (0.73240	0.32757 (0.5905)		DAP	-0.52974 (0.3585)	-0.56841 (0.3173)
	SR	-0.86756 (0.0567)	-0.74812 (0.1459)		SR	0.60191 (0.2828)	0.41648 (0.4855)
	TF	0.84103 (0.0742)	0.79319 (0.1093)		TF	-0.66769 (0.2181)	-0.60018 (0.2846)
Wheat	UREA	-0.49038 (0.4016)	-0.08366 (0.8936)	Sorghum	UREA	0.50878 (0.3813)	0.01304 (0.9834)
	DAP	0.14650 (0.8141)	0.41710 (0.4848)		DAP	0.50878 (0.3813)	0.01304 (0.9834)
	SR	-0.29410 (0.6310)	-0.42467 (0.4760)		SR	-0.18407 (0.7670)	-0.38311 (0.5244)
	TF	0.21305 (0.7308)	0.26168 (0.6707)		TF	0.08117 (0.8968)	0.16546 (0.7903)
Lower Zone				Lower Zone			
Teff	UREA	- -	- -	Maize	UREA	0.85254 (0.0665)	0.90945 (0.0906)
	DAP	- -	- -		DAP	0.39411 (0.5115)	0.32737 (0.6726)
	SR	0.81289 (0.0944)	0.67910 (0.2074)		SR	-0.63302 (0.2517)	-0.55707 (0.4429)
	TF	-0.83151 (0.0809)	-0.82559 (0.0851)		TF	0.45851 (0.4374)	0.41100 (0.5890)
Sorghum	UREA	- -	- -	-	-	-	-
	DAP	- -	- -	-	-	-	-
	SR	-0.84961 (0.0684)	-0.23630 (0.7020)	-	-	-	-
	TF	-0.71531 (0.1744)	-0.80051 (0.1037)	-	-	-	-

Annex 16: Data Collection Formats

I. Data to be Collected from the District Offices

A. Land use/Land cover

“Agro-ecology”	Altitude Range (masl)	Area (ha)	Major Livelihood Strategy	Remark
Highland				
Mid Altitude				
Low Land				

B. Area Coverage of the Major Crops Grown in Different Agro-ecologies.

Crop type								
Agro-ecology	Area (ha)	%						
Highland								
Mid Altitude								
Low Land								

II. Checklist for Assessing Crop Management Practices (HHS).

Name of Watershed---

Position in the Landscape (upper, middle, lower)

Location------------- (Lat----------------Long-----------------Alt---------------)

Household’s Name---

i. Major Crops Grown

Crop	Soil type	Area allocation (ha)	Variety Name*	Planting Date	Seeding Rate (kg/ha)	Planting Method	Fertilizer Used (yes/no)	Harvesting Date

*Name of Commercially improved varieties or local

ii. Input Used for the Major Crops

Crop	Type and Quality of fertilizer Applied (kg/ha)						Major Constraints Perceived	Biomass (kg/ha)	Grain (kg/ha)
	UREA		DAP		Compost/ manure				
	Rate	Date	Rate	Date	Rate	Date			
…etc									

iii. Common Cropping Systems

a. Crop Rotation Practiced (yes/no). If 'yes' show patterns.

Pattern 1					
Pattern 2					
Pattern 3					
Pattern 4					
Pattern 5					

b. Relay Cropping Practiced (yes/no). If 'yes' show Sequence.

Options	Crop 1	Crop 2	Crop 3	Crop 4
1				
2				
3				
4				
5				

c. Mixed Cropping

Major Crop	Secondary Crops		
	1	3	3
…etc			

iv. Water Management

a. Identify water related constraints with respect to the major crop fields and suggested solutions.

Crop	Major Constraints	Suggested Solutions
…etc		

b. Opinion about some suggested rainwater management alternatives.

Rainwater Mgt. Practices	**Pros**	**Cons**
RWH ponds		
Terraces		
Soil bund		
Stone bund		
Surface drainage		
Grass strip		
Soil fertility enhancement		
New crop species		
New Crop varieties		
Appropriate planting date		
Appropriate plant population		
Land use change		
Supplemental irrigation in the rainfed system		

III. Data Record Sheet for the Focused Crop Monitoring

Monitor 5 to 10 plots each of the top 3 or 4 crops that cover at least 70% of the area.

Name of household head____

Landscape position (upper, middle, lower)

Crop Type	Variety	Planting Date	Seeding Rate	Plant Population Count	Land Cover* Estimate (%)		Date to flowering	Date to maturity
					Seedling Stage	Max. canopy cover		
…etc								

… Continued from above

Crop	Type and quantity of fertilizer applied (kg/ha)						RWM practices used	Biomass (kg/ha)	Grain (kg/ha)
	UREA		DAP		Compost/manure				
	Rate	Date	Rate	Date	Rate	Date			

i. *Land cover estimate (%) taking within 10 to 20 days intervals.

	Date	Land Cover (%)
Seedling Stage		
↓		
Maximum canopy cover		

ii. Criterion for planting:

____

____

____

____

____

iii. Tillage frequency:

____

____

iv. Types of RWM practices applied:

____

____

____

v. Total Area of the monitored crop field (ha) ________________________

vi. Geographical Location of the field (lat______long________alt_________)

vii. Name of agrochemicals used:

____

____

____

a. Rate of Herbidcide:

1st round ________________ 2nd round _______________

b. Rate of insecticide applied:

   1st round___________________ 2nd round__________________

   3rd round____________________

viii. Cost of production:

a. Labor power (in number of persons) involved from land preparation to thrashing:

   1st round tillage_______________ 2nd round tillage ________________

   3rd round tillage_______________ 4th round tillage ________________

   Planting_________________ Weeding ____________________

   Chemical Application________________ Harvesting _______________

   Thrashing___________________ Others ___________________

b. Labor cost (birr/person/day)____________________________________

c. Fertilizer cost (birr/100kg): UREA_________________ DAP________

d. Seed cost (birr/kg)______________________________

IV. Checklists Used for Group Discussion

i. Which crop did you mainly cultivate on you farmland? (Put them in their order of importance).

ii. What types of farm inputs you mainly used? (UREA/DAP/Compost/FYM/Agrochemicals/improved seeds?)

iii. What type(s) of constraint(s) you mainly face in crop production? (poor soil fertility/shortage of farm inputs/water scarcity/insecure land ownership/others)

iv. Could you get enough supply of improved crop varieties? Commercial fertilizers?

v. What types of cropping systems you commonly practiced? (Crop rotation/mixed cropping/relay cropping)

vi. Have you faced a water related constraints in relation to cultivation of major crops?

vii. If your answer for Q #5 is ‘yes’, what do you suggest as a solution?