EVALUATION OF WETTING FRONT DETECTOR TO DETERMINE WATER DEMAND, WATER AND CROP PRODUCTIVITY OF SELECTED FODDER VARITIES UNDER SUPPLIMENTAL IRRIGATION

(CASE STUDIES IN LEMO AND ANGEACHA AREAS OF SNNP REGION)

M.Sc. THESIS

DESALEGN TEGEGNE MENGISTU

OCTOBER, 2015

ARBA MINCH, ETHIOPIA

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DESALEGN TEGEGNE MENGISTU

A THESIS SUBMITTED TO THE DEPARTMENT OF WATER RESOURCE AND IRRIGATION ENGINEERING, INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES, ARBA MINCH UNIVERSTYIN, PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER SCIENCE IN IRRIGATION AND DRAINAGE ENGINEERING

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OCTOBER, 2015

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DECLARATION

I hereby declare that this M.Sc specialty is my own original work and has not been and will not be presented for a degree in any other university, all sources of material used for this thesis have been duty acknowledged

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APPROVAL PAGE

This thesis entitled **"Evaluation of Wetting Front Detector to Determine Water Demand, Water and Crop Productivity of Selected Fodder Varieties Under Supplemental Irrigation (Case Studies in Lemo and Angeacha Areas of SNNP Region)"** has been approved by the following advisor, Examiners, Department head, Coordinator and Director of Graduate studies in partial fulfillment of the requirement for the degree of Master of Science in Irrigation and Drainage Engineering at Arba Minch University.

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DEDICATION

To

My

Mother, Father

And

My Brother, Woretaw

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LIST OF ABBREVIATIONS

ΔS	Change in moisture storage
BYHC	Biomass yield harvested of the Crop
Control O&V	Control treatment (local irrigation practice) oats & vetch
Control D	Control treatment (local irrigation practice) Desho grass
D	Deep percolation
DAP	Dates after plantation (mid-day for 2 measurement)
E	Evaporation
ERF	Effective Rainfall
ET	Evapotranspiration
ETC	Evapotranspiration of the crop
ETo	Reference evapotranspiration
FAO	Food and Agricultural Organization
FARMIS	Farm Managed Irrigation System
H	Plant Height
I	Irrigation
IWMI	International Water Management Institute
Kc	Crop coefficient
LA	Leaf Area
LSD	Least of Significant Difference
MOA	Ministry of Agriculture
MOFED	Ministry of Finance and Economic Development
MoWR	Ministry of Water Resource
N	Number of days between the two measurements
P	Precipitation
PET	Potential Evapotranspiration
R	Runoff
SNNP	Southern Nation Nationalities of the people
T	Transpiration
TC^0	Temperature in Degree centigrade

TDR	Time Domain Reflector-meter
U	Upward movement of water
VISW	Volume of irrigation water supplied
WFD	Wetting Front Detector
WFD O &V	Wetting Front Detector treatments Oats and Vetch
WFD D	Wetting Front Detector treatments Desho grass
WP	Water Productivity
WUE	Water Use Efficiency

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ABSTRACT

Crop water estimation is relevant to address issues such as proper utilization of water, prediction of crop productivity to design irrigation systems, farm irrigation scheduling and environmental assessment. An experiment was conducted during April to July 2015 at Jawe and Kerekicho Kebeles in SNNP. The aim was to measure ETc, K_c of Desho grass, oats and vetch fodder crops; with objectives of evaluating the WFD in terms of biomass yield and water productivity. The study contained two treatments with three replicated plots at each of the study areas. To determine ETc of the fodder crops, water balance method was used. K_c of desho grass and oats & vetch fodder crops were computed from measured ETc and ETo which was calculated from weather data. Seasonal ETc of desho grass and oats and vetch was 206 and 186 mm, respectively. K_c values of desho grass at early, vegetative, mid and late stages were 0.4, 0.71, 0.89, and 0.72 respectively whereas for oats & vetch was 0.29, 0.89, 1.01, and 0.71, respectively. Evaluation of WFD was tested by one way ANOVA software at a significant level of ($p<=0.05$). At the mid and late stages of Desho grass, plant height under WFD treatment was higher than the local practices by 28% and 23% respectively whereas plant height of oats and vetch under WFD treatment was higher than the local practices at the mid and late season by 23% and 9% respectively. The biomass of desho grass and oats and vetch at WFD treatment was higher than the local practices by 19% and 21% respectively. The irrigation water use efficiency difference of desho grass and oats and vetch under WFD treatment was higher than the local practices by 15 % and 19% respectively. In conclusion, WFD was better to save time, to have better yield, and to use the water resource effectively and efficiently.

Key Words: *WFD, ETc, Kc*

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Irrigation is critical in overcoming the rainfall shortage and alleviating agricultural production especially in arid and semi-arid areas (FAO, 1995). In developing countries, 85% of the available water is used for agriculture According to the same source 2.4 billion people depend directly on irrigated agriculture to food and employment. For Developing countries irrigation plays an essential role in meeting the basic needs of billions of people (FAO, 1996). The objective of agricultural development in Ethiopia comprises assurance of staple food supplies for the rapidly growing population and spread of foreign exchange earnings for accelerated growth of the overall economy. Commonly Ethiopia is considered as a water abundant country. However, water availability for crop production is highly irregular both in space and time. Where in some areas there is a significant rainfall and surface runoff during some months of the year while in the other there are high dry spell periods (Awulachew et al. 2007).

Rainfalls erratic and unevenly distributed between seasons and agro ecological regions led to low productivity, food insecurity poor yields, and poverty within the farming population, thus emphasizing the need for irrigation in the region (Kinfe, 2012). Irrigation has option to improve and sustain rural livelihoods by increasing livestock and crop production. The need of developing irrigation for crop production is acquiring more and in Ethiopia in response to the growing demand for agricultural produce. Small-scale irrigation has been chosen by the majority of the cooperating sponsors as a strategic intervention to address food security in Ethiopia. Small scale irrigation farming has been known as an important avenue for improving the wellbeing of poor people living in arid and marginal areas of the world. The contribution of small scale irrigation can be seen in its ability to provide food security as well as contribute to the income of farmers (Amosah et al, 2014.). Small-scale irrigation can be well-defined as irrigation, usually on small plots, in which small numbers of farmers have controlling influence, using a level of technology which they can operate and maintain effectively. Smallholder irrigation involves the diversion of water from one area into a relatively small area for the purpose of supplementing available water for crops (FAO, 2001). Hosaenna and the surrounding area, which is characterized by arid and semiarid climatic conditions and a rapidly growing population, from southern nation nationalities of the people (SNNP). In this area there is small-scale irrigation under small holder farming practice operated by individual farmers and their experience varies significantly between areas. In Angacha particularly in Kerekicho kebele which is near to Hosaena, farmers have a long experience with small scale irrigation practices. Water lifting technologies such as rope and washer, introduced over the past years, and are well adopted. In Hosaenna (Jawe), a simple rope and washer and bucket is used by the farmers for irrigation and their overall experience is less compared to Angacha (Kerekicho). Under the project "Innovation laboratory for Small Scale irrigation", this study was monitored the experienced farmers in Kerekicho and compare the findings with the less experienced farmers, who were given rope and washer in Lemo. In both areas there was a fodder shortage for livestock during the dry season. Hence, the main objective of the study was to assess the water requirement of the selected forage crops and to evaluate the new introduced technology (WFD) whether devices are suitable for the irrigation of fodder during the dry season or not. The assessment will include the water demand of the cropped fodder and its yield related with the water consumed and the land utilized by the user groups in order to evaluate the potential of the scheduling tool (WFD) by comparing with the local irrigation practice.

1.2. Statement of Problem

The use of shallow groundwater for irrigation is restricted due to lack of low cost irrigation technologies like water lifting technologies, although irrigation using river diversion is widely practiced in Ethiopia, A range of technologies, practices and techniques have been introduced over the last few years to support smallholder farmers but it is not widely practiced. Most of small scale irrigations are traditional and practical for crop production only to increase the income of farmer's in Ethiopia. In such a system, the livestock is greatly constrained by feed shortage, in terms of quantity and, quality as land is primarily used for agricultural lands (Macdonald and Simon, 2011).

Now a day the income which is found in livestock is more attractive and it needs more attention. However, with increasing variability of climate, water and land scarcity, fodder becomes a limiting factor for livestock production. Although irrigation has a potential of enhancing fodder production, such practice is not common in Ethiopia. Therefore, there is a need to integrate fodder production with crop production to improve the livelihoods of the rural poor. In Jewe and Kerekicho potential irrigable land is underutilized due to scarcity of water but there is a potential of shallow groundwater that can be selected to grow crops and fodder during dry season by introducing low cost water lifting technologies such as: Rope and Washer, pulley pump etc. However, irrigation scheduling for such practices, sustainability and feasibility of the adoption of these technologies by small holder farmers is not assessed. In Jewe and Kerekicho there is a problem of having fodder during the dry season (February – June) to feed cattle especially at the time of plowing. After the IWMI staff members discussed with farmers, this research was initiated to use simple and less water consumptive forage crops with the scheduling tool (WFD) for future intervention.

1.3. Objective of the Study

The main objective of the study is to assess the water demand, water and crop productivity of two fodder varieties (desho-grass and oat & vetch) under small holder irrigated farms using wetting front detector in Lemo and Angacha areas of SNNP Region.

The specific objectives are:

- To estimate the crop water demand of Desho-grass and mixed oats and vetch under Angacha and Lemo conditions
- To determine crop coefficient (K_c) for the two fodder verities
- To test Wetting Front Detector (WFD) as a tool for irrigation scheduling
- To measure and compare crop and water productivity of the two fodder varieties under local irrigation practices and WFD as irrigation scheduling tool

1.4. Research Question

The main research questions are:

- What is the crop water requirement for Desho grass and oats & vetch?
- What is the crop coefficient (K_c) of Desho-grass and oats & vetch?
- Is the WFD appropriate for irrigation under Angacha and Lemo condition?
- Can WFD be used to help farmers to improve irrigation scheduling and water productivity of irrigated fodder?
- Is the WFD enhance efficient irrigation and hence productivity?

1.5. Significance of the Study

Irrigation can provide increase the well-being of farmers with sustainable livelihoods. The goal of this research is to assess ways to expand the irrigable area in a sustained fashion using optimum irrigation techniques with a suitable scheduling tool. These techniques needs to be technically feasible, specific agro ecology and landscape, suitable to and desired by the farmers, which will increase the living standard of smallholder farmers. The goal of this research is also to evaluate the economic impact of fodder through small-scale irrigation on income at household level. Fodder grasses appear to be a good opportunity for their utilization as feed through cut and carry system. Livestock remains main safety resource, a living bank during periods of crop failure, and represent more than half the average wealth of rural households (WISP, 2008). The use and sustainability of irrigation pumps for fodder production during the dry season is not well developed; hence, interventions involving irrigated fodder in the dry season linked to improved feeding of dairy animals and marketing of milk will improve livelihood benefits from dairy production.

1.6. Scope of the Study

The main focus of the research was on evaluating the suitability of wetting front detectors when performing supplementary irrigation. The hypothesis is that wetting front detector (the scheduling tool) will improve farmers' irrigation practices and therefore increase water productivity and the irrigation water use efficiency compared to the traditional way of irrigation. The crop water determination was done for less water consumptive forage crops. But it was not for other staple food crops. Finally the level of difference between the traditional way of irrigation and the technology intervention was high and recommendation was given to the farmers and in the project as per the result obtained.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Irrigation

Irrigation is an artificial application of water to agricultural crops, designed to allow farming in arid regions and to offset the effect of drought in semi-arid regions. Even in areas where total seasonal rainfall is enough to average, variable from year to year it may be poorly distributed during the year and. Where traditional rain-fed farming is a high-risk enterprise and irrigation can help to ensure stable agricultural production (FAO, 1997). Irrigation is a process that uses more than two-thirds of the Earth's renewable water resources and supply to one-third of the Earth's population (FAO, 1996). According to the same source 2.4 billion people be contingent directly on irrigated agriculture for food. Irrigated agriculture plays an important role in meeting the basic needs of billions of people in developing countries although water resources are still plenty on regions (Hall, 1999).

2.1.1. Overview of irrigation in Ethiopia

The need of developing irrigation for crop production is obtaining more and more attention in Ethiopia in response to the growing demand for agricultural produce. But the distribution of rain varies from region to region. Ethiopia receives an annual rainfall apparently enough for food crop and pasture production much of the eastern part of the country receives less rain while the western areas receive adequate rainfall. Production of sustainable and reliable food supply is almost intolerable due to the temporal and spatial difference in the distribution of rainfall and the consequential non- availability of water at the required period. Sometimes, even the western highlands of the country suffer from food shortage owing to the discrepancies in the rainfall distribution (MoWR, 2002).

2.1.2. Small scale irrigation

Small-scale irrigation will be highly cost effective when locally adapted and simple technique are used and quick returns can be estimated as planning and design are implemented at local level with farmers directly contributing towards the construction. And this also plays important role in poverty alleviation and improving the nutritional conditions of the rural poor who often do not get the common benefits of economic growth (FAO,1998). Irrigation can increase those farmers' incomes with access to irrigated land. The benefit is by reducing production risk and farm output diversification, thereby encouraging farmers to gain the benefits of greater specialization and commercialization and at the same time enabling farmers to adapt timing of production to take into account market demand (Hasnip et al., 2001). Since irrigation enables farmers to avoid adverse weather conditions and reducing production risk, it reduces the need to borrow to smoothen consumption, avoiding costs of credit access, higher-values allowing benefits from specialization, facilitate development of multiple farm enterprise around livestock and crop (Smith, 1998).

2.1.3. Supplementary irrigation (SI)

Supplemental irrigation may be defined as 'the addition of small amounts of water to fundamentally rained crops during times when rainfall fails to provide sufficient moisture for normal plant growth to improve and stabilize yields. By this definition, since rainfall is the major water supply source for crop growth and production, the amount of water added by Supplementary Irrigation cannot by itself support economical crop production. Shortage of soil moisture in the dry rained areas often happens during the most sensitive growth stages (grain filling and flowering) of the crops. As a result, rain fed crop growth is yield is consequently low and poor. Supplemental irrigation, using a limited amount of water, if applied during the critical crop growth stages, can result in substantial improvement in water productivity and yield. Increase in crop production per unit of land or per unit of water does not necessarily increase farm profit, just because of the nonlinearity of crop yield with production inputs, particularly with water and its interaction with other input factors. Therefore, a water management strategy that maximizes yield or water productivity is not necessarily the most desirable one, especially in water-scarce areas. Often such a strategy is not the most economical in terms of net return. Therefore, Supplementary Irrigation (SI) is an effective response to ease the adverse impact of soil moisture stress during dry spells on the yield of rained crops. In addition to yield increases, SI also stabilizes rain fed crop production (Oweis and Hachum, 2003).

2.1.4. Food security situation in Ethiopia

Population growth, frequent land distribution and deforestation have affected agricultural production in Ethiopia. This is reflected in a decrease in household production, a decrease in grazing land and scarcity of manure. That is why in most instances, food insecurity quickly turns into famine when there are some climatic variations (Seleshi et al, 2005). Thus, it has become a common occurrence to appeal for emergency food assistance for food insecure people in Ethiopia. Now, about 15 million people are facing food insecurity that is either chronic or transitory in nature. There are people who do not have the capacity to produce or buy enough to meet their annual food needs even under usual weather and market conditions. The remaining 10 million are vulnerable, with a weak resilience to any shock (FAO, 2006).

2.1.5. Livestock fodder production using small scale irrigation

Smallholder dairy farmers in developing countries face many feed limitations such as scarce feed quantity, quality and, poor storage facilities for feed conservation as well as insufficient water. However, feeding of livestock continues to stop many problems due to the lack of information on composition and utilization of locally available feed resources. These problems are worse by high cost of feed inputs and lack of access to. Fodder or animal feed is any feedstock used specifically to supply domesticated livestock such as cattle, goats, sheep, horses, chickens and pigs. "Fodder" refers particularly to food given to the animals, rather than that which they forage for themselves in pasture and grazing land. It includes straw hay, silage, and pelleted feeds, oils and mixed rations, and also sprouted grains and legumes. With many regions of in the world experiencing record droughts and water shortages becoming more of a concern for many businesses and individuals who own and raise livestock, seeking options and solutions to maintain the health and growth of their animals can be a challenge. Developing fodder on site can be a dependable and nutritional supplementation, creating a local, on demand feed source that can build great resiliency and independence for homesteaders and those in agricultural industries. When looking at starting a homestead or beginning to raise animals for personal consumption, the nutritional needs of the livestock being raised will become a key factor in the load and expense of a setup. Feed readiness, quality and price are all continuous concerns. The availability of fodder is one of the limiting factors in animal husbandry. As is the case with humans, there is a direct link between the food and the health of the animals (Ouda, 2001).

2.2. Determining Evapotranspiration

2.2.1. Soil water balance

Crop evapotranspiration under standard conditions is denoted as ETc which is evapotranspiration from disease-free, grown in large fields, optimum soil water conditions, well-fertilized crops, and achieving full production under the given climatic conditions. Specific instruments and accurate measurements of various physical parameters or the soil water balance in lysimeters are needed to determine evapotranspiration. The methods are often demanding in terms of accuracy of measurement and fully exploited by well-trained research personnel. Although the methods are inappropriate for tedious measurements, they remain significant for the evaluation of evapotranspiration estimates obtained by more indirect methods. Estimation of crop evapotranspiration is important for computing the soil-water balance and irrigation scheduling Crop water estimation is relevant to address issues such as proper utilization of water prediction of crop productivity to design irrigation systems, resources, farm irrigation scheduling and environmental assessment. The term water consumption of the crops refers to the water transpired by the plant (i.e. the evaporation of water passing through the plant interior and suffering some physiological control), the water evaporated from the soil and the water may be consumed for metabolic purpose processes. Since transpiration by the plant (T) and evaporation from the soil (E) occur concurrently in nature. Furthermore, since the water consumed for the plant metabolism is substantially negligible as compared to E and T. The evapotranspiration processes involves a phase change of water from liquid to gaseous state, with latent heat requirement of about 2.47 MJ per Kg of water evaporated, and is one of the major constituents of hydrological cycle. Climatic conditions can dictate the amount and timing of precipitation and it has a direct influence on hence crop evapotranspiration (ETc), and through evaporative demand. The rate of ETc increases with an increase in net radiation and a decrease in relative humidity delivered the soil water status can provide for water lost due to E and T, and if precipitation occurs in quantities greater than the soil water holding capacity, drainage will occur (Allen et al, 1998).

If the rate of water infiltration into the soil is low, some of the water will be lost as run-off. Es is primarily depended upon soil water status and atmospheric conditions. If the soil is wet, Es will be dependent on the climatic situation, and will be in the constant rate stage and will be at the potential soil evaporation rate (Ep), (Chriswell, 2003). Transpiration (T) is more complicated to measure than Es. This is because it involves physical as biological well as processes. Practical models for determining T include E, thus ET rather T alone can to some extent be easily computed with equations like the Penman-Monteith equation. This equation requires weather data to estimate ET. Precipitation (rainfall) on the other hand, occurs uncontrollably, so irrigation planning has to adjust to it. Historical climatic data gives information as to what it was in the past, so there is a need to adjust to what can be happen. If the amount of run-off and drainage is known, The amount of rain that can be stored by soil can only be effectively determined Drainage, Dr, is probably the most unclear water balance component because it is so difficult to measure what is happening in soil at the bottom of the root zone. Flow is very slow and may be highly variable and soil properties also may be highly difficult. Use of models is probably the best approach to estimate D_r based on water balance concerns. Surface run off, R, is also difficult to estimate in many examples. There are few measurements made of R in irrigation, it is difficult to estimate R, so additional uncertainty is introduced. However, there are many conditions where R is zero and can be predicted as such. R is usually zero if the field were irrigation is applied is in a confinement and or plots separated hydraulically, like in this experiment or in pot experiments. However, if R is not zero the amount is uncertain. Technologies and know how happen for determining soil water depletion. Such tools involve the use of devices like the neutron probe for measuring soil water status at the beginning and end of a certain time period (Hanks and Campbell, 1993).

$$\mathrm{P} + \mathrm{I} = E_s + \mathrm{T} + \mathrm{R} + \mathrm{D} \pm \Delta S \qquad 1$$

Where P and I (usually the inputs) are precipitation and irrigation, respectively while E, T, R and D (usually the outputs) are evaporation from the soil, transpiration, runoff and deep percolation respectively and ΔS is change in soil water shortage. All the terms in Eq. (1) are expressed in rates (amount over a given time).

As it can be explained in the above, it is evident that depth of irrigation required for optimum plant growth depends on several factors. Soil water loss due to direct evaporation from the soil surface, drainage and surface run-off are not important to dry matter production, but are components of the field water balance. Under water scarce conditions, the best management strategy would be one that aims at maximizing water loss through T, by minimizing the wasteful losses that do not contribute to yield, by irrigating to match the shortfall in precipitation with the losses due to evapotranspiration.

2.2.2. Effective precipitation

Effective rainfall (ERF) is the amount of precipitation that is directly added and stored in the soil. The effective precipitation and total precipitations are both given on farm west. During drier periods less than 5mm of daily rainfall would not be considered effective, as this amount of precipitation would likely evaporate from the surface before saturated into the ground. Effective precipitation enters the soil and becomes available to the plant. The moisture deficit is calculated by subtracting the effective precipitation from the calculated evapotranspiration. Several methods to calculate the effective rainfall are: Fixed percentage of rainfall dependable rainfall, Empirical formula USDA Soil Conservation Service Method. In this study, the effective rainfall is a fixed percentage of actual rainfall, to account for the losses due to runoff and deep percolation (FAO, 1998).

2.2.3. Reference evapotranspiration

Reference crop evapotranspiration (ETo) is defined as hypothetical grass evapotranspiration rate from a reference surface, not shortage of water and the initial surface is reference crop with particular characteristics. To study the atmospheric evaporative demand independently of the crop development, crop type, and management practices, reference evapotranspiration concept was introduced. soil factors do not affect E, As water is abundantly available at the reference surface evapotranspiration, Linking ET to a specific surface provides the reference to which ET from other surfaces can be related and used The reference surface is a hypothetical grass reference in which crop with an expected crop height of 0.12 m, an even surface resistance of 70 s m^{-1} and an albedo of 0.23. The reference surface closely resembles well-watered grass of uniform height, an extensive surface of green, actively growing and completely shading the ground. The fixed surface resistance of 70 s m^{-1} suggests a moderately dry soil surface causing from about a weekly irrigation frequency (Allen et al, 1998). There are various ways to estimate reference evapotranspiration like Penman Montieth equation by using different climate data (Minimum and maximum temperature, solar radiation, relative humidity, and wind speed); Hargreaves method by using only maximum and minimum temperature; and Error estimation method. In this study Penman Monteith equation used to determine reference evapotranspiration by using climate data. The FAO Penman-Monteith method is selected as the method by which the evapotranspiration of the reference surface (ETO) can be unambiguously determined, and as the method which provides consistent ETo values in all regions and climates (Allen et al, 1998).

2.3. Crop Coefficient (Kc)

The single crop coefficient (Kc) method is used to define transpiration and soil evaporation lumped over a number of periods (days or weeks). The single time-averaged Kc curve incorporates averaged soil wetting effects and transpiration into a single Kc factor. As per FAO-56 publication crop growth stages divided into four phonological stages. Initial stage is from planting to 10% cover of ground; Development stage is from 10% groundcover to maximum cover; Midseason stage is from the beginning of covering full to the start of senescence and the late season stage is from the start of senescence until full senescence or harvest. The Kc begins to increase during the crop development stage and ranges a maximum value Kc_{mid} which is relatively constant for most cultural conditions and growing. Kc_{ini} is supposed to be constant and relatively small (<0.4). As leaves begin to age and senesce, late season period the Kc begins to decrease until it reaches a lower value at the end of the growing period equal to Kc end. The Kc during the development is estimated using linear interpolation between Kc_{mid} and Kc_{ini}. Similarly, Kc during the late season stage is determined using linear interpolation between Kc_{end} and Kc_{mid}. The value of Kc_{ini} and Kc_{end} can vary considerably on a daily basis, depending on the frequency of wetting by rainfall and irrigation. The single crop coefficient method can be used for irrigation planning and design. It is also used for catchment level hydrological water balance studies (Allen et al., 1998).

2.4. Irrigation Scheduling

In agricultural production irrigation represents a major resource investment every wise farmer that irrigates to enhance productivity considers the resource trade-offs: How much water will be needed and how much will it cost? How much water is available? Where will the benefits be? When will irrigation be required and who will do the work? (Hanks and Campbell, 1993). The primary aim of irrigation scheduling is to enable the farmers to minimize crop water stress and maximize yields schedule the water rotation among the various fields; to lower fertilizer costs by holding surface runoff and deep percolation losses (leaching) to a minimum ;to increase crop yields and crop quality; to minimize water logging problems by reducing the drainage requirements; to assist by controlling the root zone salinity problems through controlled leaching; to minimize wasteful losses of water (percolation beyond what is necessary for salt leaching evaporation and runoff) and to increases transpiration by the crop; and crops otherwise would not be irrigated during water short periods (Borner, 2015). Therefore scheduling brings a fundamental role in crop productivity and water productivity determination which are performance indicators used to describe the relationship between water applied and agricultural product outputs. Ideally, at the beginning of the growing season, the amount of water given per irrigation application, is called the irrigation depth, is small and given frequently. This is due to their shallow root depth and the low evapotranspiration of the young plants. During the mid-season, the irrigation depth should be larger and given less frequently due to high evapotranspiration and maximum root depth. The introduction of computer programs, however, has made it becomes easier and it is possible to schedule the irrigation water supply exactly according to the water needs of the crops. Methods to determine the irrigation schedule are: plant observation method, and simple calculation method. The plant observation method is the method which is normally used by farmers in the field to estimate "when" to irrigate. The changes can often only be detected by looking at the crop as a whole rather than at the individual plants. The method is based on observing changes in plant characteristics, such as changes in color of the plants, curling of the leaves and ultimately plant wilting. To use the plant observation method successfully, experience is required as well as a good knowledge of the local circumstances. During the early stages, when the plants are small, the crop water is less than during the mid-season stage. Therefore it may be possible to irrigate during early stages of the crop growth, with the same frequency as during the mid-season, but with smaller irrigation application .it is risky to give the same irrigation application as during the mid-season, but less frequency; the young plant may suffer from water shortage as their roots are not able to take up water from the lower layer of the root zone. Dry harvested crops or crops which are allowed to die before harvest needs less water during the late season stage than during the mid-season stage. During the late season stage the roots of the crop are fully developed during the mid-season stage. During the late season stage, the roots are fully developed and therefore the amount of water can be stored in the root zone as during the mid-season stage less frequently but with the same irrigation depth as during the peak period. The Critical thing to any irrigation management approach is an accurate estimate of the amount of water applied to a field properly. Too often, growers apply water to make the fields and rows look good. When growers do not take their system's efficiency into account, they may too much water apply or too little. Too little water causes unnecessary water stress and can result in yield reductions whereas too much water can cause water leaching, logging, and may also result in loss of yield. Estimating the amount of water applied to a set is fairly easy for surface systems or a field (Brouwer et al., 1989). The Irrigator's Equation, Q x t = d x A, can be used to estimate the depth of water applied. In the equation:

$$Qt = dA \qquad 2.2$$

Q is the flow rate, in cubic feet per second (cfs); t is the set time or total time of irrigation (hours); d is the depth of water applied (inches) and A is the area irrigated (acres) (Edward, 2000).

2.5. Wetting Front Detector

2.5.1. Introduction to wetting front detector

Wetting front detector (WFD) is a simple user friendly device designed to help farmer's better managing irrigation and it is a funnel shaped device that is buried open end up in the soil. The Wetting Front Detector is buried in the root zone and gives a signal to the farmer when water reaches field capacity at a specific depth in the soil. Farmers can use the detector to know whether they are applying too little or too much water (Stirzaker et al., 2000). The WFD comprises a specially shaped funnel, and a mechanical float mechanism the funnel is buried in the soil within the root zone of the plants or crop. When rain falls or the soil is irrigated, water moves downwards through the root zone. The soil at the base becomes so wet that water seeps out of it and the infiltrating water converges inside the funnel, passes through a filter and is collected in a reservoir (Stirzaker, 2005). More water is needed before the detector will respond. The wetting front detector can be used to schedule irrigation because the time it proceeds for water to reach an appropriate depth be determined by on the initial water content of the particular soil. The wetting front will move faster through the soil if the soil is quite wet before irrigation. This is because the soil pores are already mostly filled with water so there is little space for additional water to be stored. Thus a short irrigation will cause the detector to respond. After the wetting front dissipates water is withdrawn from the funnel by capillary action Free water produced at the base of the funnel by convergence activates the float in the detector. If the soil is dry before irrigation the wetting front moves slightly because the water must fill the soil- pores on its way down. (Stirzaker, 2003).

2.5.2. How the wetting front detector works

The wetting front detector was developed and patented by CSIRO Land and Water, Australia, in 1997. Irrigation water or rain moving downwards through the soil is concentrated when the water molecules enter the wide end of the funnel. The detector works on the principle of flow line convergence The soil in the funnel becomes wetter as the funnel narrows and the funnel shape has been intended so that the soil at its base reaches saturation when the wetting front outside is at a similar depth. Once saturation has occurred free water flows through a filter in to a small reservoir and activates a float (Stirzaker. 2003). Water in the soil moves as a front, except for cases of preferential flow and this front is a resultant difference in wetness between the wetted upper zone and the drier soil below the wet zone. The area between the wet and dry soil is characterized by rapid change in wetness is called the wetting front. This is because the hydraulic conductivity of the as yet not wetted soil is so low that water can only penetrate it when the gradient is very steep. At the wetting front, the moisture gradient is so steep that there appears to be a sharp boundary between the moistened soil above and the initially dry soil beneath. The free water would escape through the filter into the chamber to activate the switch, in the case of the electronic WFD or into the bottom section of the PVC pipe in the case of the mechanical version to activate a polystyrene float (Strizaker et al., 2003).The wetting front detector can be used to schedule irrigation, because the time it takes for water to reach a certain depth depends on the initial water content of the particular soil (Stirzaker**,** 2004). If the soil is dry before irrigation, the wetting front moves slowly because the water must fill the soil pores on its way down. Therefore a lot of water is needed before the detector will respond. This is because the soil pores are already mostly filled with water so there is little space for additional water to be stored. Thus a short irrigation will cause the detector to respond. The float in the detector is activated when free water is shaped at the base of the funnel. Depending on the version used, capillary action can be used to reset the detector automatically, or water can be detached via a syringe. The water sample can be used for routine salt and fertilizer monitoring Water is withdrawn from the funnel by capillary action after the wetting front dissipates (Stirzaker**,** 2004).

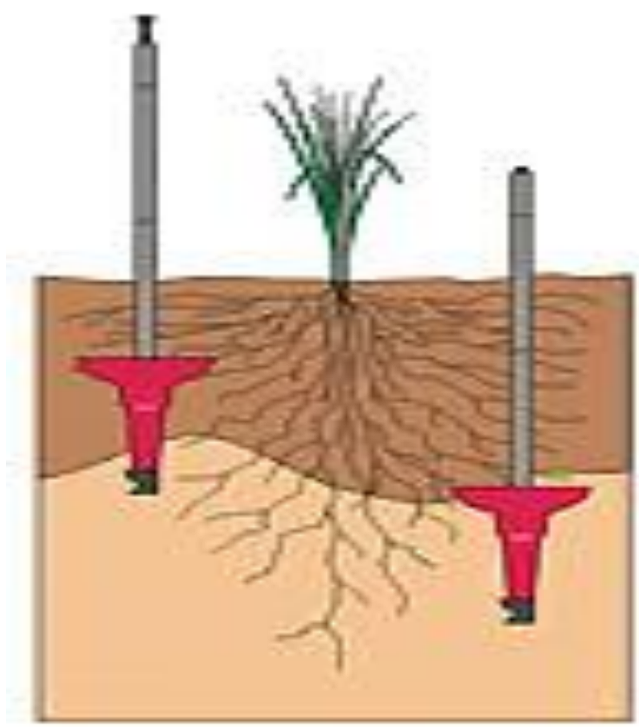


Figure 2.1: Wetting Front Detector (Stirzaker, 2004)

2.5.3. Time domain reflectometry (TDR) measurement principles

Time domain reflectometry (TDR) is a relatively new method for measurement of soil water content and electrical conductivity. Each of these attributes has substantial utility in studying a variety of hydrologic processes. The main advantages of TDR over other soil water content measurement methods are: (i) superior accuracy to within 1 or 2% volumetric water content; (ii) calibration requirements are minimal—in many cases soil-specific calibration is not needed; (iii) lack of radiation hazard associated with neutron probe or gamma-attenuation techniques; (iv) TDR has excellent spatial and temporal resolution; and (v) measurements are simple to obtain, and the method is capable of providing continuous measurements through automation and multiplexing. A variety of TDR systems are available for water content determination in soil and other porous media. Many, but not all commercially available systems may also be used to measure soil electrical conductivity. Thus potential users should consider present and future measurement requirements before purchasing (Scott et al., 2001).

2.6. Water Productivity

Water productivity in its definition, it reflects the objectives of having more food, income, and being profitable at less social and environmental cost per unit of water consumed, where water use means either water delivered to a use or depleted by a use. When assessing the feasibility of growing crops in any region Crop water productivity (CWP) and water requirement (consumptive use) of crops are two important factors that should be careful. By and large, the term water productivity refers to the benefit resulting magnitude of output from the input quantum of water as applied (irrigation and rainfall) on a unit base. the term water use efficiency is a manifestation of integrated physical or economic water productivity and land as the numerator is the equivalent income or yield and the denominator is the depth of water consumed per unit land area used (tons per hectare per cm of water, for instance). When lonely as water productivity it converts a partial productivity of one factor viz., water, irrespective of the land unit but in reference to the scale of production in the range of a single plant's effective root zone to a basin or system of irrigation command. As more and more water losses are incurred when the scale of reference expands, the apparent or relative water productivity is bound to decrease (Palanisami et al, 2006). For agricultural systems, WP is a measure of output of a given system in relation to the water it consumes. Productivity is a measure of system performance expressed as a ratio of output to input. Assessment maybe mandatory for the whole system or parts of it, defined in time and space. This distinction is increasingly important as we move upscale from field to farm to basin, because the water that is taken into a system, but not consumed, is available downstream and hence is excluded from calculation in its broadest sense; water productivity (WP) is the net return for a unit of water used. Improvement of water productivity aims at producing more income, food, better ecosystem services and livelihoods with less water. Practices used to achieve this include water harvesting, deficit irrigation supplemental irrigation, precision irrigation techniques and soil–water conservation practices. Practices not directly related to water management impact water productivity because of interactive effects such as those derived from improvements in pest and disease control, soil fertility, access to better crop selection or markets (Molden et al, 2010). Hence it is logical to assess the productivity of irrigation and rainfall in terms of this scarce resource; Water is an increasingly scarce resource within many irrigated areas. The most common are; the productivity in terms of actual evapotranspiration and in terms of an actual evapotranspiration and in terms of the volume of complete irrigation water (Molden et al., 1998). The water productivity then is defined as

$$WP = \frac{Yield}{I + P} \qquad 2.3$$

Where

WP = Water productivity (Kg/m3)

Y = yield of harvested crop (Kg)

I = Irrigation

P = Precipitation

The yield of the harvested crop equals the unit yield (kg/ha) times the considered area (ha) if viewed from the farmers perspective. Because of the values of ET_c and the volume of (needed) irrigation water are heavily influenced by local climate, the use of the above two indicators (yield harvested and water applied) is restricted to on project evaluation (Molden et al., 1998).

2.7. Water Use Efficiency

Irrigation water productivity is becoming one of the key issues facing water managers and irrigation farmers. To maintain access to water, there will be more pressure on farmers to demonstrate that they are using water efficiently and effectively. With increasing demand on water resources, it is becoming more important to manage those resources effectively. There are many benefits to improve efficiency, including both economic and environmental.

$$\mathrm{WUE} = \frac{\mathrm{Y}}{\mathrm{ETc}} \qquad 2.\mathbf{4}$$

Where

WUE = Water Use Efficiency (kg/m^3), ETc=Crop Evapotranspiration (m^3), Y = harvested yield (biomass) (kg),

CHAPTER THREE

3. MATERIALS AND METHODOLOGY

3.1. Description of the Study Area

3.1.1. Location

Lemo Gilgel Gibe sub basin is one of the sub basins of the Omo Gibe basin, one of the twelve basins of Ethiopia, and is located completely in the southern nation’s nationalities people region. The research was conducted near Hosaenna from the two selectd kebeles watershed (Kerekicho and Jewe) in SNNPS.

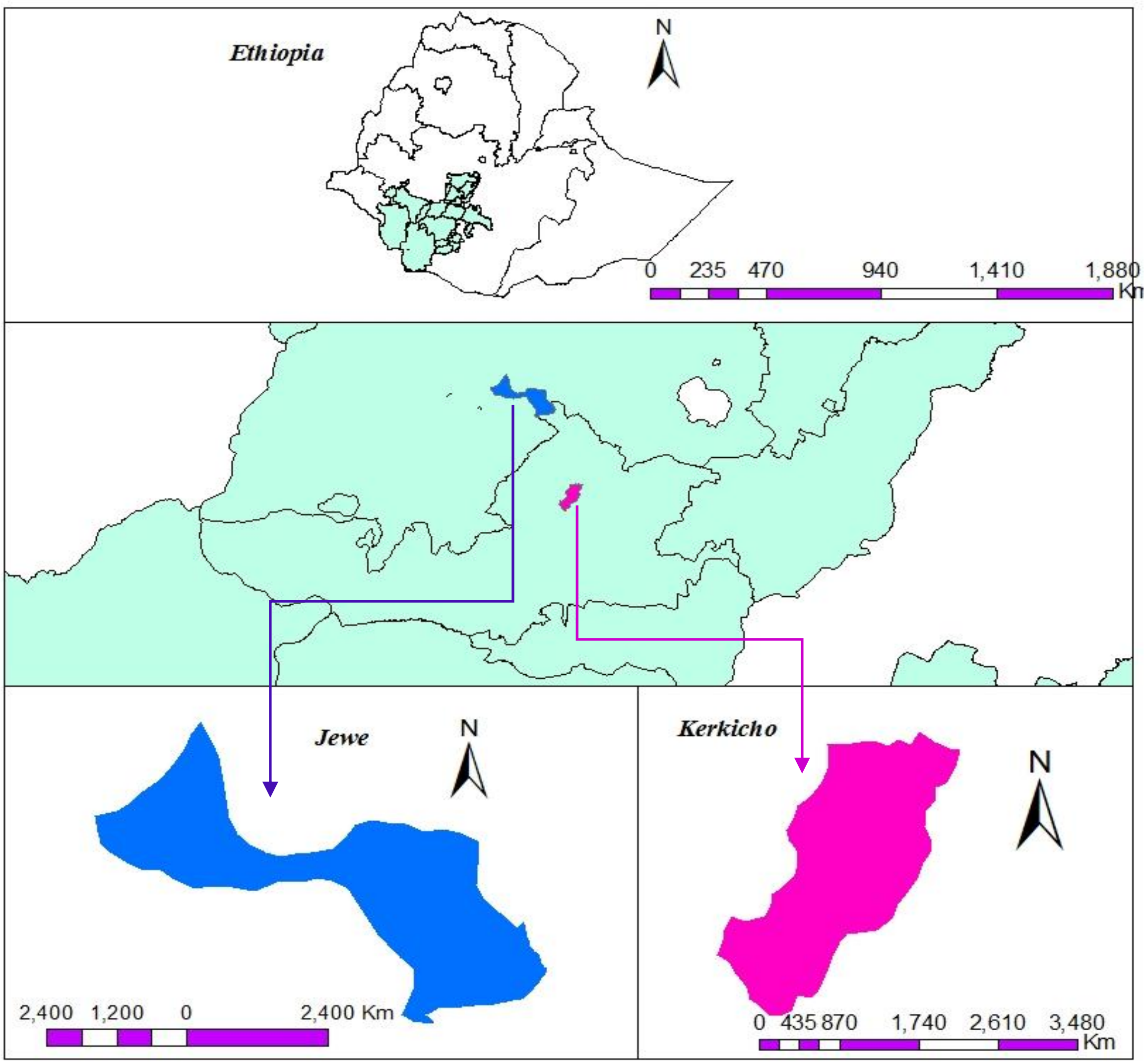


Figure 3.1: Map of the study area

Hosaenna is situated at about 232 km south of Addis Abeba and it is found within this sub basin. Jawe micro watershed is the one micro watershed from 26 micro watersheds found in Lemo Gilgel Gibe sub basin. This micro watershed is the specific area where the study has been undertaken. Jewe micro watershed is located between 7° 30' 54" and 7° 25' 55" latitude and 37° 45' 29" and 37° 49' 12" longitudes and it is found 5 km away from Hossaenna. It has an area of about 1313 ha and its land mass lies between 1900 – 2700 m above sea level altitude. The major river that drains this Jawe micro watershed is Ajo. Angacha and Durame towns are situated to the South East of this Jewe watershed. Jawe micro watershed is one of these 24 micro watersheds where interventions have been undertaking on irrigated fodder. The study was conducted on the farmers plot in these respective kebeles near to Hossenna and the location map is shown in figure 3.1.

The other site where the research intervention has been undertaken is kerekicho kebele at angecha woreda and it is found between Angacha town and Hosaena. Angacha district is one of the six woredas in Kambata Tambaro Zone, Southern Nations, Nationalities and Peoples' Region (SNNPR). It is located about 260 km south west of Addis Ababa. Agriculture, mainly composed of crop production and animal husbandry, is the main livelihood of the population in the woreda. The agricultural practice employed in the area is traditional oxen-plough and horticulture practices. Kerekicho kebele is one of the 28 kebeles in Angacha Woreda. It is found in 5 km away from Angacha and 23 Km away from Hosaenna and It is located at 07^{o} 21` 47`` East and $38^{o}$ 51 `00`` North. The area has an average elevation of 2280 masl. The main production system in the kebele is mixed crop livestock production system where Enset (Ensete ventricosum) is the major food for humans and feed for livestock (especially during the period of feed shortage in the dry season). It is estimated that close to 900 household heads are residing in the kebele. The location map is shown in Figure 3.1 in the right side.

3.1.2. Temperature

From the analysis of ten years (2005-2014) data the mean daily maximum temperature ranges from 20.1 C^{o} (August) to 25.3 C^{o} (March) and the mean daily minimum temperature ranges from 8.5C^{o} (December) to 12 C^{o} (April). The mean maximum and minimum monthly temperature for Hosanna is indicated in Figure 3. 2.

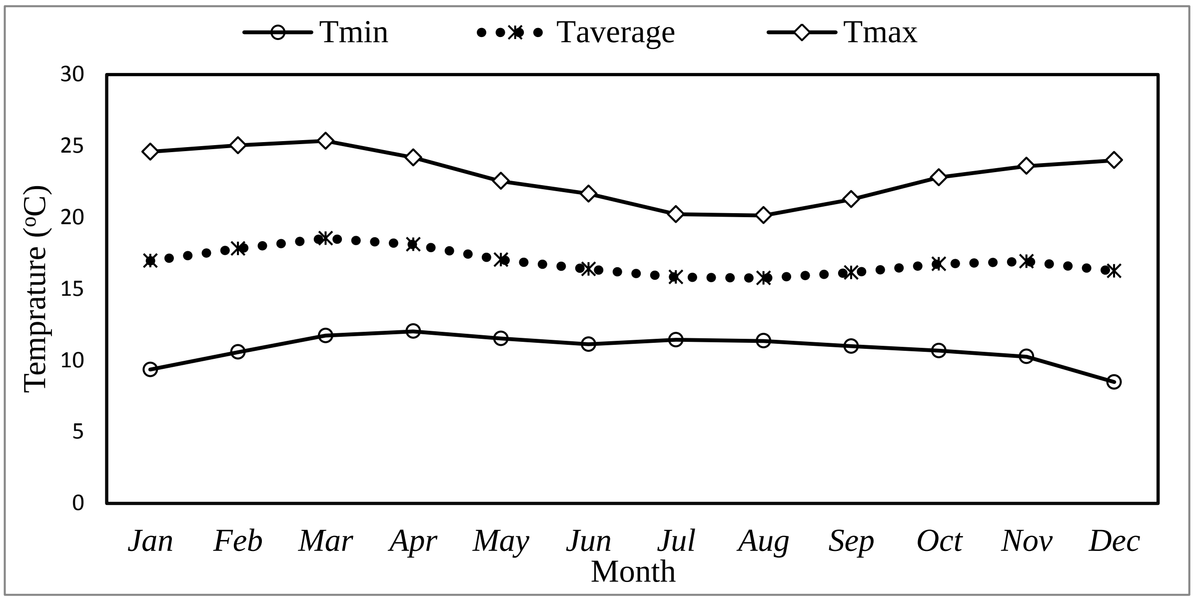


Figure 3.2: Mean monthly temperature (2005-2014) of station at Hosanna.

3.1.3. Rainfall

Ten year (2005 – 2014) rainfall data at Hosanna indicated that the mean annual rainfall in the area is about 1161.1 mm. the maximum mean monthly rainfall occurs at July (180.2 mm). The mean monthly of rainfall is shown in figure 3.3.

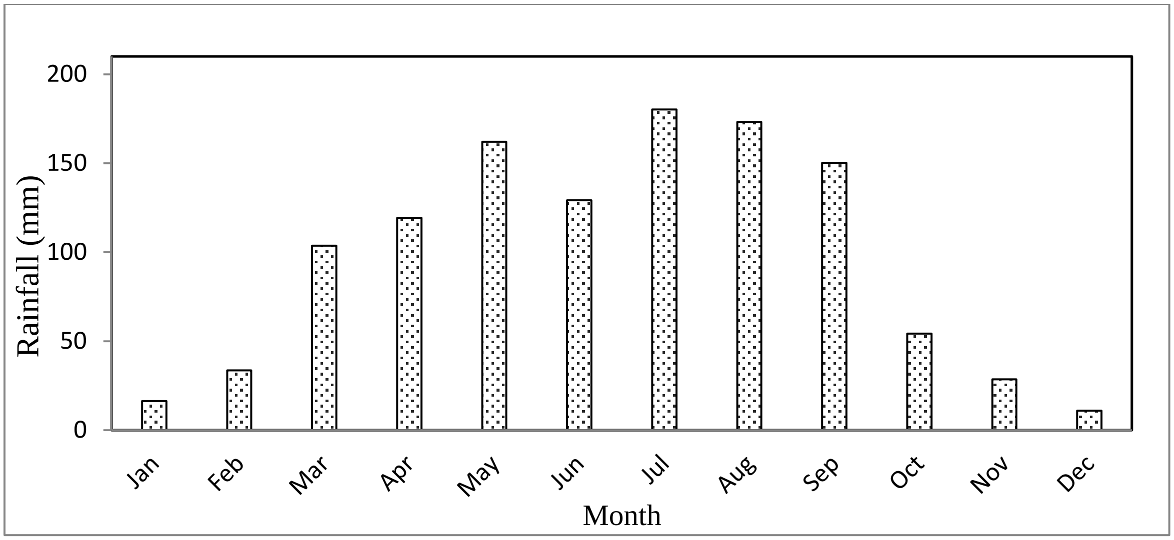


Figure 3.3: Mean monthly rainfall (2005-2014) for station Hosanna

3.1.4. Soil

According to Omo Gibe master plan study (cited in Zenebe (2014) the soil of Jawe micro watershed is Pellic Vertisol as is extracted from the Omo Gibe master plan study. This soil is black in color and has a relatively high water storage capacity in the root zone because of its high clay content and depth

According to Abay et al. (2012), the physico-chemical characteristics of the soil in Angacha has good soil fertility status but organic carbon (OC) content was medium (1.56%). The soil type was identified to be Alf sols. Organic carbon (OC), total N, and K contents of the soil, ranging between 0.5 and 1.56%, 0.06 and 0.25%, and 0.19 and 0.37 cmol (+) kg^{-1}, respectively, and decrease with depth, whereas the available P content is the same (40 ppm) throughout the horizons. Therefore, it is concluded that soil fertility management practices focus on maintaining and increasing OC and N content of the soil and monitoring for balances among nutrients. Even if the study was done at Angacha it can describe Kerekicho since Kerekicho is found 5 Km away from Angacha.

3.2. Materials

For proper implementation of the proposed study, some of the materials and software were used for data collection, processing and evaluation. Some of the materials used for this study include:

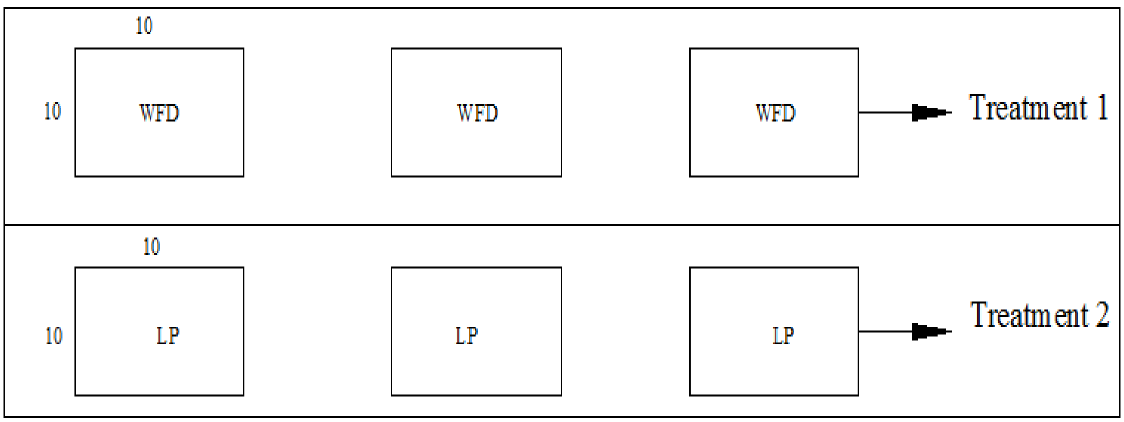
- Time Domain Reflector-meter (TDR): used to measure the top soil moisture content (0-20 cm) of the soil.
- Soil moisture profiler was used to measure the soil moisture content of the soil (0- 100 cm) and to monitor deep percolation below the root zone of the fodder varieties.
- Watering can : was used to irrigate the plots through overhead application method
- Wetting Front Detector: used to irrigate the plot and to schedule the irrigation for when to apply and how much to irrigate.
- Rope and washer water pumps : used to discharge water from the ground well
- Sensitive balance: used to measure the biomass yield which was harvested.
- Pen, pencil, paper bag, meter etc. were used

3.3. Methodology

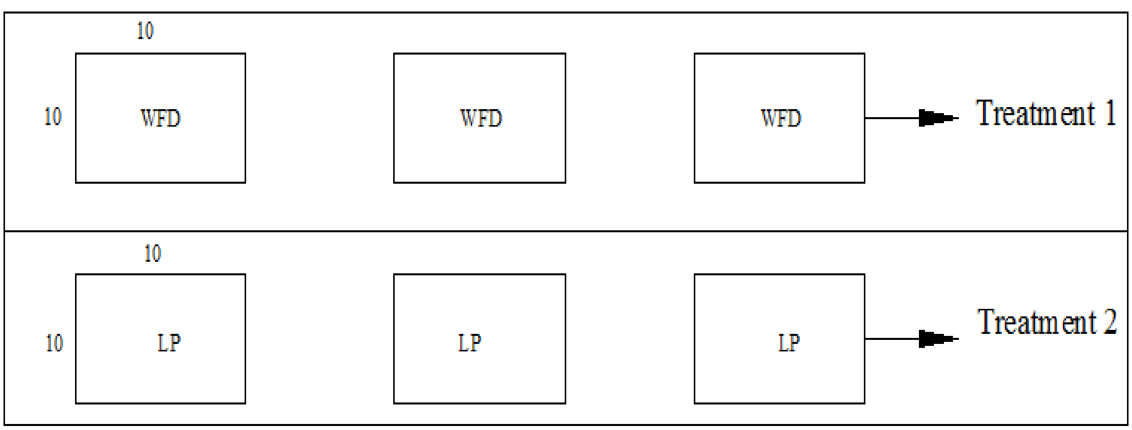
This research was done with the support of "Innovation Laboratory for Small Scale Irrigation (ILSSI)" and Africa RISING projects, managed by International Water Management Institute (IWMI). Rope and washer pumps were made available to farmers via a micro credit management of the Omo-Micro Finance under Africa RISING. The method followed in this research involves; pre - field work, during field experimentation and post Field work activities. This includes a careful inventory of all available and necessary data related to the study area. Searching and reviewing of relevant literature to justify the studies which are rationales, collecting necessary working materials from relevant Bureau in the region /zone. All the activities are discussed in this section in the following manner: The study was conducted at Jewe and Kerekicho Kebeles for two selected fodder varieties (i.e. Desho grass at Kerekicho and Oats & Vetch at Jawe) and the data collection has been carried out throughout the growing season of these fodder crops starting from reconnaissance survey till the harvesting time. Research was done from April 2015 to July 2015. During the reconnaissance survey, agricultural offices, sponsor organizations (IWMI professional staffs) , DAs and some farmers were consulted about the general conditions of small-scale irrigations and the water resource potential of the area. Based on the survey made and the information gathered; two irrigation sites were selected to evaluate the scheduling tool (WFD) with different types of fodder varieties (desho grass at Kerekicho and mixed Oats & vetch at Jawe). The criteria for selection were water availability (i.e. ground water potential from the well); nearness to weather station, and willingness of farmers to accept the intervention. Data collected included primary data sources; at field level in the sites.

3.3.1. Experimental design Kerekicho for Desho Grass and Jawe for Oats and Vetch

Desho Grass



Oats and Vetch



LP = Local Practice plot, WFD= Wetting Front Detector plot
Figure 3. 4: Experimental design of Kerekicho and Jewe

Six farmer fields were selected at each study sites (i.e. six farmer field at Jawe for mixed oats and vetch and six farmer fields at Kerekicho for the fodder Desho grass). Plots were relatively close to each other. The reason to make the selection in close was to minimise soil variations from each other. Oats & vetch was planted at Jawe and Desho grass was transplanted at Kerekicho. The study was among two treatment plots with three replications at each study sites:

- Treatment 1 (WFD plots); which had wetting front detector (WFD) and the irrigation scheduling was done based on the Wetting Front Detector
- Treatment 2 (Local Practice plots): the irrigation was done according local irrigation practice (without WFD).

3.3.2. Land preparation and planting of fodder

The plot size prepared for each treatment was 10 m X 10 m. Each treatment contains three randomly arranged replicated plots therefore there were six plots (two treatments) at Kerekicho and six plots (two treatments) at Jawe for the fodder varieties of Desho-grass and Oats and vetch respectively. Five subplots were delineated with in each plot for the irrigation water, biomass yield, and agronomic performance parameter measurements. Dsho grass was transplanted were as for oats and vetch a mixture of 75% oats and 25% vetch seed was used.

3.3.3. Wetting front detector (WFD) installation

After land preparation, wetting front detector installation was done for both sites (Jawe for oats and vetch and Kerekicho for Desho grass) for the farmers in the scheduled treatment. Since one treatment had three replicates, three pairs of wetting front detectors were installed and this was done for both sites (three WFD at Jawe and three WFD at Kerekicho). The installation of Wetting Front Detector was done after the training was taken from Addis Ababa by International Water Management institute (IWMI) staff members. Depth of installation was different as per the fodder crops root depth; for desho grass the installation of yellow and red WFD indicators were installed at 30cm and 45cm and for mixed oats and vetch the yellow and red indicators were installed at 25cm and 40cm depth respectively. Installation steps which were done in the plots were discussed below with the help of pictures.

Installation steps

1. Digging the hole: Local digging instruments were used to dig the hole.
2. Filter sand was added in to the funnel and inserted in to the hole. empty the supplied filter sand in to the funnel until it was covered the locking ring by 1 cm. holding the extended tube vertically upright in the hole, filled the funnel with removed from the layer at the same depth and formed down lightly.
3. Buried the full stop detector
4. The floating was activated :Water the site over the detector was done and tested after installation to check the proper functioning of the WFD.

Figure 3.5: Wetting Front Detector Installation

3.3.4. Determination of the amount of water applied

Before the beginning of the actual irrigation practices for each treatment at both sites of the study area, water was lifted from the well to the given bucket by using rope and washer water pump. Then by taking water from the well to the plots irrigation water application was done. This process was the same for all plots. For WFD treatment plots the irrigation interval and amount of water applied was guided by the scheduling tool. Irrigation was applied when the WFD shallow indicator (scheduling tool) popped down; and the irrigation stopped when the shallow indicator reacted (i.e. yellow indicator pop up). Whereas the local practice treatment plots depth of water application was done by the farmer's experience (by their way of supplementary irrigation) without any technology (scheduling tool) intervention. This was done to evaluate the suitability of the tool and whether the use of the tool would reduce water consumption, improve yield and water productivity. In this study primary data and secondary data were collected with respect to their source.

Figure 3. 6**:** Soil moisture profiler installation

3.3.1. Soil moisture profiler instalation

The soil moisture profiler tube instalation was done for all treatment plots at each study area. The instalation was done by using auger to dig the hole and the soil moisture tube instalation with auger can be seen in figure 3.5. The instalation was done after land preparation, and plantation of the fodder seed was done. The soil moisture profiler was installed up to 1m below the earth's surface. The purpose of this instrument was to monitor the deep percolation if there is moisture change below the profiler, understand the functioning of the WFD, and the changes of the soil moisture content. The profiler reading was taken before irrigation and after irrigation. The application of irrigation which is before and after irrigation was determined by the help of the wetting front detector at each study sites, whereas in the control plots before and after irrigation was determined by the farmer's traditional ways of irrigation (local irrigation practice) what they applied. The profiler readings were at 10cm, 20cm, 30cm, 40cm, 60cm, and 100cm depth below the surface.

3.4. Primary Data Collection

Primary data are data which are found directly from the field measurements. Among these data the following were measured during this study: change in the soil moisture content of the soil, deep percolation, plant height, leaf length, leaf width, irrigation water depth and finally biomass yield data were taken from the field.

3.4.1. Soil moisture content measurement

Measurement of soil moisture content was done by using Time domain Reflector-metre (TDR) and soil moisture profiler for each replicated plots in both treatments was taken before every irrigation. Time Domain Reflector-meter was used to measure the soil moisture content at the top 20 cm. For a proper calibration of TDR and soil moisture profiler, volumetric moisture content determination was done. The soil moisture profiler was installed for all treatment plots (3 for control (local irrigation practice users) + 3 for scheduled plots) at each study area (Total 12 profiler tubes were installed at both sites) to determine potential deep percolation. The reading from the surface up to the effective root zone of the given fodder crop was taken as soil moisture reading. The depth of root zone for desho grass was taken 0.5

m and the depth of oats and vetch was taken 0.6 m. For one time measurement ten TDR readings and 3 Profiler readings were taken. From ten readings of the TDR, five readings were in one diagonal of the plot and five in the other diagonals of the plot. The ten times readings were latter on averaged. Similarly, three readings were taken of the entire 1m profil by rotating the soil moisture profiler at 45 degree inside of the profiler tube. The three readings were latter on averaged. Additional measurements were taken to determine at which moisture content the WFD yellow indicator popped up and down.

3.4.2. Agronomic data measurements

Agronomic parameters such as plant height, leaf length, leave width and total biomass yield of all treatment plots were measured and recorded, five 1 m^2 subplots were selected in each of the 12 plots. From each subplot 3-plants were randomly selected and monitored throughout the various growing stages (. The average value of each replicated plots is shown Appendix 4 and 5 for desho grass and for oats & vetch respectively). Plant height and leaf area measurements are the two important parameters indicating potential crop growth performance and yield. The biomass was measured by harvesting each subplot and the average of the subplots were used to evaluate the productivity. Desho grass was harvested when it reached at the height of 70 cm as it becomes difficult to feed the cattle if it passes this height whereas for oats and vetch harvest was performed at a height around 1 m after it logged.

Finally the collected data from the agronomic measurement is summarised and presented in Appendix – 4 and 5 for both fodder crops for Desho grass and for oats and vetch. Leaf length (cm) and leaf width (cm) of plants from each treatment was me[asured using tape meter at each growth stages. The total leaf area a (cm^2) for each fodder crops were obtained with the relationship (Yemane et al 2014, Kang et al., 2003):

$$A = 0.759 \sum L X W \qquad 3.1$$

3.5. Secondary Data Collection

Secondary data are data which are found indirectly from secondary sources such as metrological stations, national meteorological agencies were collected during this study.

3.5.1. Weather data

Daily weather data (rainfall, minimum and maximum temperature, solar radiation, relative humidity, and wind speed) were collected from the meteorological station of the Hosanna meteorological station adjacent to the experimental Jawe site. For Kerekicho the Angacha rainfall station was used which was 5 km away from the study area whereas for Jawe, rainfall was taken from Hosanna metrological station 5 km away from the study area which was done by Africa RISING project. Historical ten years weather data (rainfall, minimum and maximum temperature, solar radiation, relative humidity, and wind speed) were also obtained from national meteorological agency. Generally the weather data are summarized in appendix – 1.

3.5.2. Rainfall data analysis

To determine the crop water requirement of the crop of oat and vetch at Jewe and Desho grass at kerekicho daily rainfall data of Hosanna metrological station and Angach rainfall station were used respectively.

Effective rainfall (ER) determination

All the depth of rainfall which reaches to the earth's surface may not be stored in the root zone. As a result of this there was a need to determine the effective rainfall. Effective rainfall is a part of rainfall that enters in the soil and stored in the root zone of the crop and it might be used for evaporation purpose. Unless the effective rainfall is determined the crop water determination may be incorrect because the entire rainfall would be lost through runoff, deep percolation or variation of rainfall from place to place. During the dry season when desho grass and mixed oats & vetch were planted, effective rainfall and total rainfall which reaches to the earth's surface was almost similar. Therefore the amount of rainfall received was used as effective rainfall from April to July. But in the rain season the soil in the root zone becomes almost saturated as a result of this effective rainfall decreased (effective rainfall was different from the total rainfall received in depth). As it can be seen in appendix 10 there was rain during the study at both stations (from Angacha and Hosanna meteorological station) for Kerekicho to Desho grass and Jewe to Oats and vetch respectively. Effective rainfall was calculated by using fixed percentage method for the two station readings to consider losses.

And variation of rainfall from the metrological station to the study plots, it was decided ninety percent of the total rainfall was effective for the plots in the two study sites.

3.6. Determination of Fodder Crop Coefficients

3.6.1. Actual crop evapotranspiration

The actual crop evapotranspiation was derived through the application of the soil water balance in the wetting front detector plots. The reason to use the WFD treatment for ETc determination was the assumption that through the use of the irrigation tool no water stress occurred for both oats and vetch and desho grass in the WFD plots Influencing Etch. As such, the WFD treatments with three replicated plots were used; whereas ETc of control treatment plots were not discussed in the result and discussion part but calculated and shown in appendices 3 and 4. Rain or irrigation reaching a unit area of soil surface, might result in surface runoff, or may infiltrate into the soil. The infiltrated water may (a) evaporate directly from the soil surface, (b) taken up by plants for growth or transpiration, (c) drain downward beyond the root zone as deep percolation, or (d) accumulate within the root zone. The water balance method is based on the conservation of mass which states that change in soil water content ΔS of a root zone of a crop is equal to the difference between the amount of water added to the root zone, Qi, and the amount of water withdrawn from it, Qo (Hillel, 1998) in a given time interval expressed as in Eq. (3.2).

$$\Delta S = S_I - S_o \qquad 3.2$$

$Where\ SI = Before\ irrigation$ (mm); So = Before the next irrigation (mm)

Eq. (3.2) can be used to determine evapotranspiration of a given crop as follows

The last simplified equation, changed in to the following form can be used for direct estimate of ET if other terms are known.

$$\mathrm{ET} = (\mathrm{P} + \mathrm{I}) - \mathrm{D} - \mathrm{R} \pm \Delta S \qquad 3.3$$

Where ΔS = change in root zone soil moisture storage (mm), P = Precipitation (mm), I = Irrigation (mm), R = Runoff (mm), D = Deep percolation (mm), ET = evapotranspiration (mm). All quantities are expressed as volume of water per unit land area (depth units). In order to use eq 3.3 to determine evapotranspiration (ET), other parameters must be measured or estimated. It is relatively easy to measure the amount of water added to the field by rain and irrigation. In overhead irrigation application, since overhead irrigation was applied the amount of runoff is generally small so is often considered negligible. When the groundwater table is deep, capillary rise U is negligible.The final equation from this is ;

$$\mathrm{ET} = (\mathrm{P} + \mathrm{I}) - \mathrm{D} \pm \Delta\mathrm{S}$$

3.6.2. Reference evapotranspairation

FAO Penman Montheith approach was used as a standard method to caalculate reference evapotranspiration (ETo) using weather data as given in Eq. (3.4).

$$ET_o = \frac{0.408\Delta(Rn + G) + r\frac{900}{T+273}u_{2(es-ea)}}{\Delta + r(1 + 0.34u_2)} \qquad 3.4$$

where ETo= reference evapotranspiration (mm/day); Rn = net radiation at the crop surface (MJ/m² day); G = soil heat flux density (MG/m² day); T = air temperature at 2 m height (°C); u2= wind speed at 2 m height (m/s); es= saturation vapor pressure (kPa); ea = actual vapor pressure (kPa); es-ea= saturation vapor pressure deficit (kPa); slope vapor pressure curve (kPa/°C); psychometric constant (kPa/°C).

3.6.3. Determination of Crop Coefficient

In the crop coefficient method, crop evapotranspiration ETc is estimated from a single crop coefficient (Kc) and reference evapotranspiration's ETo from equ.3.4. After ETc becomes calculated with water balance equation local calibrated Kc will be calculated based on the following formula

$$K_C = \frac{ET_C}{ET_O} \qquad 3.5$$

Where

Kc= Crop coefficient

ETo = Reference evapotranspiration

ETc = Crop evapotranspiration

The crop coefficient (Kc) method is used to compute soil evaporation and transpiration lumped over a number of days or weeks. Kc depends throughout the cropping season due to the crop characteristics as such Kc values have to be determined for each crop stage. In this study the Kc value was calculated at a weekly time step and averaged for each of the various cropping stages.

3.7. Water Productivity

Crop water productivity (WP) is a key term in evaluating both water management practices: the scheduling tool (WFD) and local farmers practice (LP) in this field experiment. Water productivity of each treatment was determined after wet fodder crops harvested. From planting to harvesting the total water applied (irrigation and rainfall) (m^3) was recorded for both treatments for desho grass and the fodder crops of oats & vetch respectively. The water productivity with dimensions of kg/m^3 is defined as the ratio of the total wet biomass of the fodder crops (kg/ha) to the total volume of water applied (effective rainfall + supplementary irrigation).

$$\mathrm{WP} = \frac{\mathrm{Y}}{\mathrm{I} + \mathrm{R}} \qquad 3.6$$

I : Irrigation , R : Rainfall (irrigation and rainfall) (m^3). Since there is no easy way of separating between evaporation and transpiration in the field experiments, they are generally combined under the term of evapotranspiration (ET) (Allen et al., 1998).

3.8. Water Use Efficiency

Water use efficiency is another method to evaluate the effect of different irrigation method on crop performance. It was done using the fresh wet biomss yield of the two fodder crop harvested and the estimated ETc from the soil moisture balance for each treatment (i.e.WFD and farmers practice). Water use efficacy (WUE) was calculated for all treatments using the net seasonal irrigation during the growing period nd the wet total biomass obtained .

$$\mathrm{WUE} = \frac{\mathrm{Y}}{\mathrm{ETc}} \qquad 3.7$$

Where WUE is the water use efficency (kg/ha), Y is the wet total biomass Yield (kg ha^{-1}), ETc is the total seasonal water consumed (m^3).

3.9. Data Analysis and Interpretation

Crop water requirement of desho grass and oats and vetch was computed by using water balance method from Kerekicho and Jawe respectively. Reference evapotranspiration was determined from daily climatological data by using Penman monteith equation. After the determination of water requirement (ETc) and reference evapotranspiration (ETo), Crop coefficient (Kc) of both crops were determined at each growth stages.

Treatments which had Wetting Front Detector (scheduling tool) and control plots (local irrigation practice) were compared, and evaluation of the scheduling tool was done. The comparison was done in terms of the yield (total biomass of the treatments), water productivity (WP), water use efficiency (WUE) and agronomic performance indicators like plant height, leaf area (LA) at each growth stages. For this comparison, one way ANOVA software was employed to compare the WFD (scheduling tool) treatments and the local irrigation practices (control treatments) Differences of productivity at ($P <= 0.05$; Least Significant difference, LSD).

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. Determination of crop evapotranspiration

4.1.1. Determination if Supplemented Irrigation water

Supplementary irrigation was done for each replicates. For desho-grass at Kerekicho the total seasonal supplemented water in WFD and Local practice treatments were 72.9 mm and 69.8 mm respectively. These values were the average of each replicates from each treatment. Total seasonal supplementary irrigation water of WFD and Control treatments (local irrigation practice) was the average of WFD plot 1, WFD plot 2, WFD plot 3 and Local practice plot 1, Local practice plot 2, and Local practice plot 3 respectively, this is the same for both fodder types at Kerekicho and Jawe. And the total seasonal irrigation water for oats and vetch in WFD and Control treatments was 60 mm and 60.3 mm respectively. This average of irrigation water at each treatment plots used to calculate the crop water demand of two fodder varieties.

4.1.2. Determination of desho grass evapotranspiration

To determine the crop water requirement of desho grass; change in moisture storage of the soil, effective rainfall, and supplementary irrigation water applied were monitored as it can be seen in Table 4.1. From April 23 - May 11 (until 20 days after plantation at the initial stage of the crop) the irrigation depth was higher than the rainfall depth because rains were scarce and supplementary irrigation was needed to fulfill the crop water requirement. During the other growing stages rainfall depth was larger than the irrigation depth. The computed crop evapotranspiration was the average of the WFD replicated plots as it is presented for each replicated plots in appendix-2 (average of WFD plot 1, WFD plot 2, WFD plot 3). As it can be seen in Table 4.2, from the total amount of water applied (irrigation and rainfall), 206.4 mm depth of water was used by the crop throughout the growing season of desho grass.

Table 4. 1: Duration and Length of growing days for Desho grass at Kerekicho

	Initial stage	Development stage	Middle stage	Late stage
Duration	April 23-May 11	May 12-May 23	May 24-July 2	July 3- July 8
DAP	0-20	21-28	29- 71	72-76
Length of growing days	20	8	42	4

The desho grass water requirement from the table below was determined by using water balance equation at the different days of measurement.

Table 4. 2: Values of water balance components for Desho grass at Kerekicho

DAP	ER (mm)	I (mm)	ΔS (mm)	D (mm)	Total ETC (mm)	N (days)	ETC (mm/day)
20	7	36.1	9.1	0.0	34.0	20	1.7
28	15.7	7.8	3.4	0.0	20.0	8	2.5
29	0.0	3.8	-0.5	1.4	2.9	1	2.9
33	10.8	2.9	-1.9	1.7	13.9	4	3.5
39	20.7	3.0	1.6	2.2	20.0	6	3.3
46	17.1	3.6	-2.9	1.1	22.4	7	3.2
51	12.4	3.7	-2.1	2	16.3	5	3.3
55	10.0	3.4	-2.2	1.9	13.7	4	3.4
63	20.8	3.3	-4.6	0.5	28.2	8	3.5
71	36.1	2.9	9.5	4.8	24.7	8	3.1
76	13.6	3.5	0.5	6.2	10.4	5	2.1
sum	164.1	72.9	8.9	21.8	206.4	76	

DAP =Dates after planting (the middle date between two measurements), ER = depth of Effective Rainfall, I = depth supplemented Irrigation, ΔS, D = change in soil water content, Total ETc = the total crop evapotranspiration at each dates of interval, ETc (mm/day) = daily evapotranspiration of the crop and deep percolation monitoring, N = Number of days between the two readings.

The daily ETc values ranged from 1.7 to 3.5 mm per day. Higher ETc values were calculated at the middle stage (May 21 to July 2) compared to the values at beginning of the crop stage. The evapotranspiration of the crop varied across the growing stages and the crop evapotranspiration increased from initial to development to middle stage at the plant growth. The Calculated ETc values were 1.7, 2.5, 3.3 and 2.1 mm per day during the initial, development, mid-season and late season stages, respectively. The highest water requirement was recorded at the mid-season stage followed by the development stage while the lowest was observed at the initial growth stage. Like the initial stage, the difference could be mainly due to the effect of crop characteristics, because ETc is affected by the nature of the crop (leaf arrangement, stomata and plant height) and crop growth stage. This means when the crop grows from time to time, the water demand increases parallel until the crop reaches to leaf scene sense (harvesting stage). The lowest crop water requirement at the initial stage is mainly due to the low crop leaf area development with a low transpiration capacity.

4.1.3. Determination of evapotranspiration for oats and vetch

Like desho grass, crop evapotranspiration of oats and vetch at Jewe was determined by using water balance method for the various cropping stages as it is presented in the Table 4.3 and 4.4).

Table 4. 3: Duration and Length of growing days for Oats and Vetch at Kerekicho

	Initial stage	Development stage	Middle stage	Late stage
Duration	April 25-May 10	May 11-May 19	May 20-June 18	June 19-June 22
DAP	1-16	17-25	26 - 54	56-59
Length of growing days	16	9	28	4

As it can be seen in Table 4.2, the total change in soil moisture content which was measured by using Time Domain Reflect meter and the soil moisture profiler probe reading (the reading which was taken before every irrigation) are presented here table 4.4.

Table 4. 4: Values of water balance components oats and vetch fodder type

DAP	ER (mm)	I (mm)	ΔS (mm)	D (mm)	ETC (mm)	N (days)	ETC (mm/Day)
16	3.3	30.6	12.67	0.0	21.2	16	1.25
23	21.6	2.90	0.3	0.0	24.1	7	3.44
32	32.5	3.90	-2.0	1.3	37.2	9	4.14
34	0.0	3.00	-6.4	5.3	4.1	1	4.10
40	28.5	2.70	4.9	1.4	24.8	6	4.14
46	20.0	7.90	2.8	0.6	24.5	6	4.10
51	16.0	3.20	-2.2	0.7	20.6	5	4.13
56	20	3.10	-2.1	4.8	20.4	5	4.09
59	14.9	2.80	2.7	5.3	9.6	3	3.22
Sum	156.8	60.0	10.7	19.2	186.6	59	

DAP =Dates after planting (the middle date between two measurements), ER = depth of Effective Rainfall, I = depth supplemented Irrigation, ΔS, D = change in soil water content, and deep percolation monitoring, N = Number of days between the two readings.

The total crop water requirement of oats and vetch was 186.6 mm throughout the course of the growing season. The measured ETc values were 1.25, 3.44, and 4.11; and 3.22 mm per day during the initial, development, mid-season and late season stages respectively. The highest crop water requirement was recorded at the mid-season stage followed by the development stage while the lowest was observed at the initial growth stage. The highest crop water requirement was recorded from 28 –53 days after plantation as compared to the values in the initial stage and at the beginning of the late season stage. The variation of ETc from one stage to the other was expected because of changes crop characteristics and weather parameters such as radiation, humidity, wind speed and temperature. Crop evapotranspiration increases with increasing air temperature and solar radiation, the two primary drivers of ET (Irmak, 2009).

4.1.4. Relations of reference evapotranspiration and crop evapotranspiration

Reference evapotranspiration attained its maximum during the initial growth stage which could be attributed to the high evaporative demand of the atmosphere as it can be seen in Figure 4.2. This is because the beginning of the crop period fell within the dry season and the latter part of the cropping season fell within the rainy season was there was less solar radiation. ETo decreased from initial to the end of the mid-season stage with fluctuation trend which was subjected to the variability of climatological factors during the growing season of oats and vetch at Jewe as it can be seen in Figure 4.1. The value of ETc at Jewe for exceed ETo from 28 – 48 days after planting and which coincides at the beginning of the mid- season stage of the crop demand for high water use due to flowering. Whereas the crop evapotranspiration of Desho grass and reference evapotranspiration is observed in Figure 4.2 ETo was higher than ETc during initial and development stage whereas ETc and ETo were almost the same during the mid and at the beginning of late season stage of the desho grass. The calculated ETo was done at each calculation interval of ETc and it is different for both fodder crops. The crop water use declined from the mid-season to the late season stage which is attributed to the cessation of leaf growth and a corresponding decrease in water demand (Allen et al., 1998).

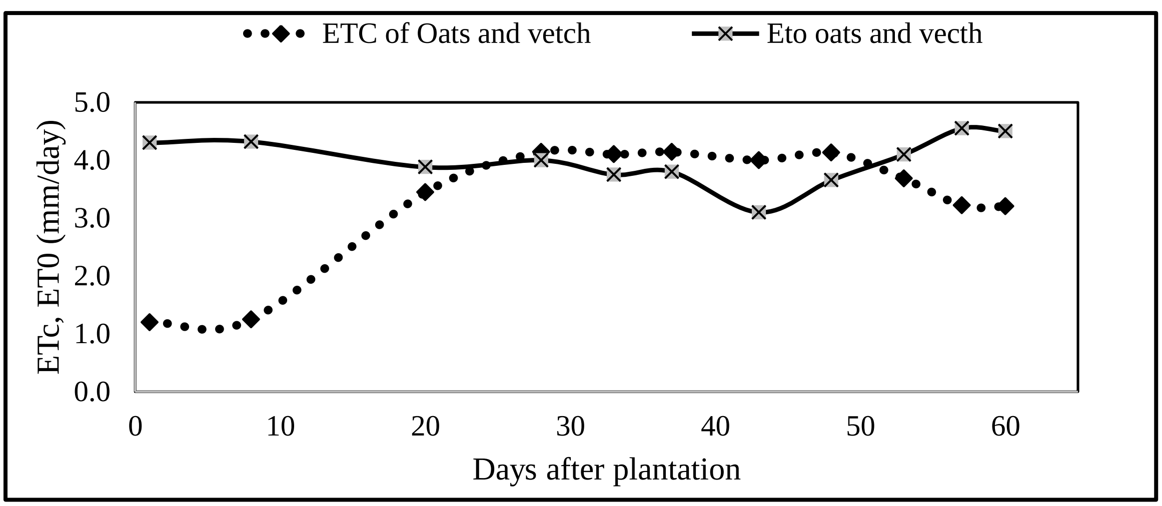


Figure 4. 1: ETc of Oats & vetch and ETo over crop growing season at Jawe

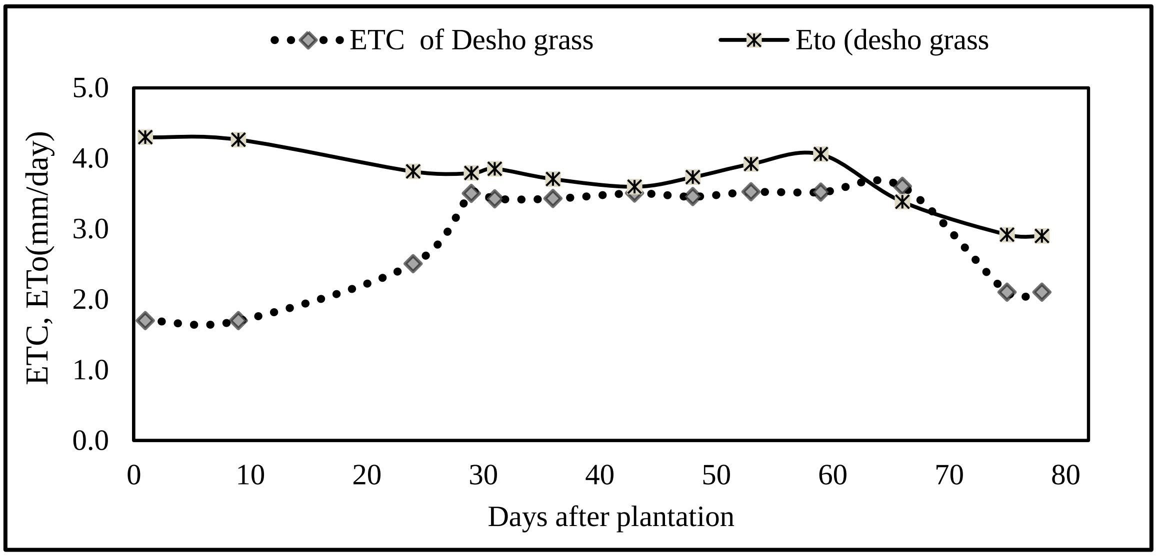


Figure 4. 2: ETc of Desho-grass and ETo over growing season at Kerekicho

4.2. Crop Coefficient (Kc)

4.2.1. Crop coefficient (Kc) of desho-grass

Crop coefficient values of Desho grass were obtained by dividing crop evapotranspiration measured by water balance method with reference evapotranspiration, as it can be seen in Table 4.5. There is a general trend of K_c increment from initial stage to the end of the development stage and in the mid-season sage the curve shows almost approaches to constant value. As the results of water balance analysis showed no stress periods, the scatter of points can be assumed to be normal for experimental data.

Table 4.5: Determination of average crop coefficient for Desho grass

DAP	N	ETc (mm/Day)	ETo (mm/Day)	Kc
20	20	1.7	4.3	0.40
28	8	2.5	3.8	0.66
29	1	2.9	3.8	0.77
33	4	3.5	3.9	0.90
39	6	3.3	3.7	0.89
46	7	3.2	3.6	0.89
51	5	3.3	3.7	0.87
55	4	3.4	3.9	0.87
63	8	3.5	4.1	0.87
71	8	3.1	3.4	0.91
76	5	2.1	2.9	0.71

The curve presented in Figure 4.3, represents the changes in the Kc over the length of the growing season. The shape of the curve represents the changes in the vegetation and ground cover during plant development and maturation that affects the ratio of ETc to ETo. The value of Kc increased from the initial to development stages while reached its maximum and relatively remained constant at the mid-season(table 4.6). The Kc declined during the late season stage. Higher Kc values were recorded from May 22 – July 2 after planting as compared to the values in the beginning and end of the crop life cycle. The increase in Kc value from initial stage up to mid-season stage is due to increase in ground cover of the crop, which influences evapotranspiration. During initial stage, leaf area is small and evapotranspiration is mainly in the form of soil evaporation. This stage is terminated when 10% of the ground is covered (Allen et al., 1998). It can be observed that there is a slight variation in Kc values during the crop development, mid-season and late season stages. The computed overall average Kc values during initial, crop development; mid-season and late-season stages were 0.4, 0.71, 0.89 and 0.72, respectively. The Kc values for other fodder crops which have similarity with desho grass were given by FAO 56 publications in Table 12 and the average values ranges at initial, mid- season and end season stage were 0.35 – 0.8, 0.5 – 0.95, 0.5 – 0.9 respectively. The desho grass Kc values obtained in this experiment was in between the values listed by FAO for other fodder varieties which are more or less similar with desho grass. Kc value at the end of the growing season (harvest) was found to be 0.68. Crop coefficient value at late season stage reflects water and crop management practices hence the crop at this stage does not require frequent irrigation as evaporation becomes restricted (Samson et al., 2006).

Table 4.6: Stage wise crop coefficient (Kc) values of Desho grass

	Initial-stage	Devt.-stage	Mid-stage	Late- season
Duration	April 23-May 11	May 12-May 23	May 24-July 2	July 3-July 8
ETC (mm/day)	1.7	5.4	3.33	2.1
ETo (mm/day)	4.3	7.6	3.75	2.9
Kc	0.4	0.7	0.9	0.7

4.2.2. Crop coefficient (Kc) of oats and vetch

Since oats and vetch fodder types were mixed during plantation, the calculated Kc was Kc of integration for oats and vetch and the evolution of Kc values reflected the effects of both crop development and physiology on ETc. The value of crop coefficient was calculated for each growth stage of oats &vetch at Jewe as it can be seen in the Table 4.5.

Table 4. 7: Determination of average crop coefficient for oats and vetch

DAP	N (days)	ETc (mm/day)	ETo (mm/day)	Kc
16	16	1.25	4.32	0.29
23	7	3.44	3.88	0.89
32	9	4.14	4.00	1.04
34	1	4.10	3.75	1.09
40	6	4.14	3.80	1.09
46	6	4.08	3.6	1.1
51	5	4.13	3.65	1.13
56	5	4.09	4.10	1.0
59	3	3.22	4.55	0.71

Accordingly, the Kc values increased from initial stage to mid- season stage and decreased during the late season stage. Since oats and vetch was harvested at the beginning of the late season stage, the Kc at the late season stage from the graph was at the beginning of the late season stage. The computed overall Kc of oats and vetch values during initial, development; mid-season and late season stages of the fodder were 0.29, 0.89, 1.07 and 0.71 respectively. Higher Kc values were recorded from dates of intervals of reading 28-53 days after planting as compared to the values in the beginning and end of the crop life cycle. The maximum Kc value was 1.1 at the mid- season stage and the minimum Kc value was 0.3 at initial stage of the growing season for the reason that low evaporative demand of the atmosphere (ETo) and rainfall that increases ETc. Kc value of Oats and Vetch at the end of the growing season (harvest) was found to be 0.75.

Table 4. 8: Stage wise crop coefficient (Kc) of oats and vetch values

	Initial-stage	Deve-stage	Mid-stage	Late- season
Duration	April 25-May10	May 11- May 19	May 20-June 18	June 19-June22
ETc (mm/Day	1.25	3.44	4.1	3.22
ETo(mm/day)	4.32	3.88	3.8	4.55
Kc	0.29	0.89	1.08	0.71

4.3. Evaluation of Wetting Front Detector (Irrigation Scheduling Tool)

4.3.1. Depth of water consumption

Irrigation of the WFD treatment water application was done by following the sign of the WFD (scheduling tool) for oats & vetch at Jewe and for desho grass at Kerekicho. As it can be seen in Figure 4.7 and Figure 4.8, the daily water depth applications between the two treatments were different for oats and vetch at Jewe and for desho grass at Kerekicho respectively. The water depth applied in the control treatments during the mid- season stage of the crops was lower than for the WFD plots. This different ways of water application brought different amount of water depth computation among treatments. Since crops are sensitive to water shortage at its mid stage, shortage of water at the mid- season resulted in lower crop height compared to the plots which had WFD. At Jewe for the oats and vetch the same explanation as for Desho grass at Kerekicho can be given, the depth of water applied between the WFD plots and Control plots (local irrigation practice) were different. This difference brought significant variation between the crop height and the biomass among the two treatments. The WFD treatment curve shows similar characteristics with the normal crop water demand curve whereas the control group treatments shows some variations compared with the normal crop water demand curve. For both fodder crops, the control treatments curve was done from the calculated daily water depth which is the average of Control Plot 1, control plot 2, control plot 3, for desho grass and for oats& vetch respectively.

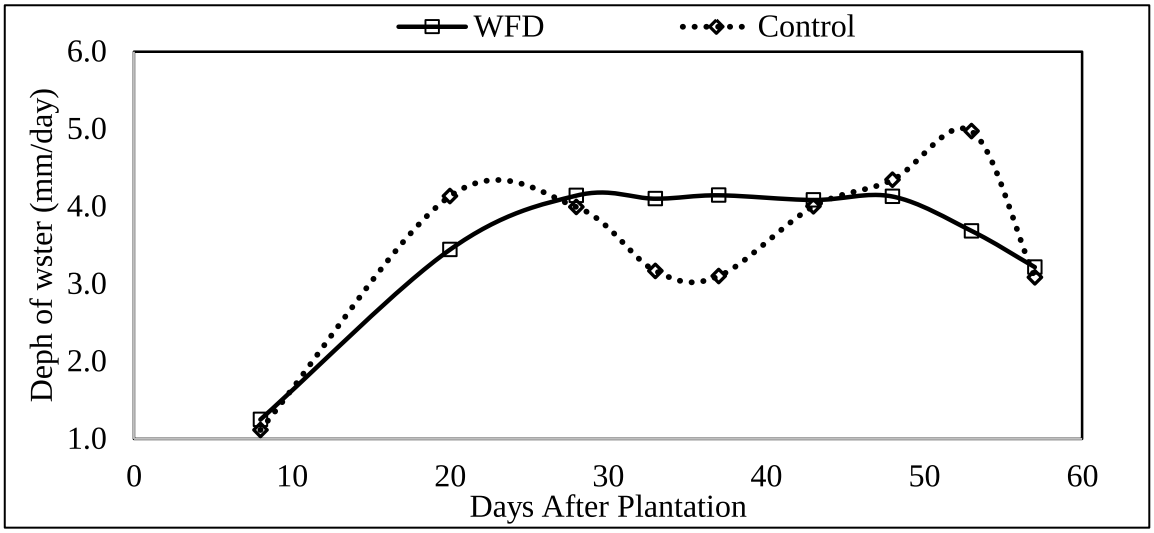


Figure 4. 3 Depth of water applied growing season of Oats and Vetch

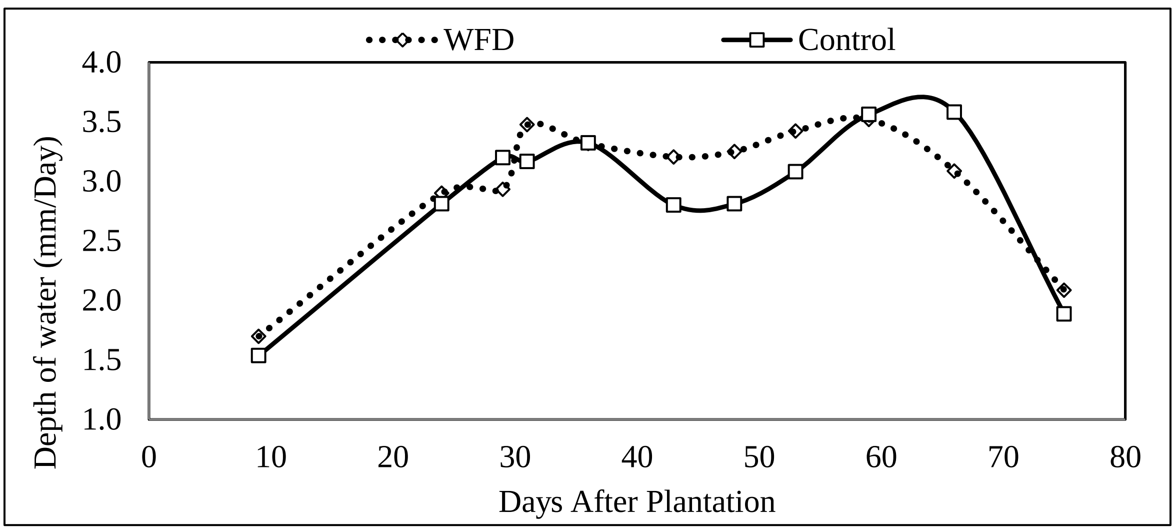


Figure 4. 4: depth of water in the growing season of desho grass

4.3.2. Agronomic Performances of fodder under different irrigation treatments

The measured plant height in each treatment plots and the leaf area parameters are shown in the following way; and the analyzed ANOVA results are found in Appendix 8.

4.3.2.1. Plant height

Table 4.9, shows the plant height which was measured at each growth stages of desho grass and oats and vetch. It can be observed that both fodder crops plant height increased as the crop passes through the different growth stages and reached maximum at the beginning of the mid-season stage. Plants were harvested at the beginning of the maturity stage when oats and vetch lodged and desho grass reached at the height of 70 cm. The result indicates that the plant height did not differ significantly between both irrigation treatments at the initial and development stage for fodder crops. However; there was significant variation at the middle and late season stages ($p<=0.05$) with the crop in the WFD treatment being higher compared to the control (local irrigation practice). The plant height difference among the WFD and Control treatments for desho grass in the mid-season and late-season stages, was 28.3% and 23% respectively. Whereas for oats and vetch as it can be seen in Figure 4.7, the height difference was 23.4% and 9% at the mid and late stage respectively. The height of desho grass from the WFD plots increased from initial-development, development-mid, mid-late-season stages by 21.5, 15, and 18.5 cm respectively. Whereas control plots also increased by 20, 3 and 17 cm from initial-development, development-mid, mid-late-season stages respectively.

Table 4.9:The average Plant height (cm) of Desho grass and oat & vetch at each growth stage

No	Treatments	Area	Plant height (cm) over the growth stages			
			initial	development	Mid	Late
1	WFD	Kerekicho	23.8[a]	45.3[a]	60.3[a]	78.8[a]
2	(Local practice)		23[a]	43.0[a]	47.0[b]	64.0[b]
LSD	P<=0.05	Cv (%)	5.1	4.6	5.4	2.2
3	WFD	Jewe	13.7[a]	23.0[a]	63.3[a]	98.0[a]
4	Local practice		12.2[a]	21.2[a]	51.3[b]	84.0[b]
LSD	P<=0.05	Cv (%)	10.5	9.9	14.1	10.4

Whereas the height of oats for WFD plots increased from initial-development, development-mid, mid-late season stage by 9.3, 40.3, and 19.7 cm whereas for control treatment (with local irrigation practice) increased by 9, 21.4, and 23.7cm respectively. As it is shown from Figure 4.9, the increment from development to mid –season stage was significantly different and WFD plots were higher than the control group plots.

4.3.2.2.Leaf area measurement of desho grass and oats

Leaf area of Desho grass and oats was computed after leaf length and leaf width measurements were taken to compare the two treatments. The measurement was done at each growth stages as the time as for the plant height measurement. The value of leaf area is presented in Table 4.10.

Table 4.10: Leaf area (cm^2) of desho grass and oat at each growth stage

No	Treatment	Study site	Crop Growth Stages			
			Initial	devt.	Mid.	Late
1	WFD	Kerekicho	6.5[a]	14.4[a]	25.2[a]	26.0[a]
2	Control		5.1[a]	14.0[a]	25.6[a]	26.5[a]
	LSD: P<=0.05	Cv (%):	18.0	11.8	10.4	13.3
3	WFD	Jewe	2.7[a]	8.6[a]	24.0[a]	26[a]
4	Control		2.4[a]	6.5[a]	23.0 [a]	23[b]
	LSD: P<=0.05	Cv (%):	17.8	20.0	12.0	5.5

One way ANOVA analysis was conducted for the analysis of leaf area variation among treatments for both fodder verities. The leaf area of Desho grass at initial, development, middle and late season stages were not significantly different among treatments. Whereas the leaf area of oats at initial, development, and middle stages were not significantly different but there was a significant variation at the end stage of the oats at a significant level of (P<=0.05). The leaf areas of the fodder were increased continuously at each treatment. Therefore the intervention of the scheduling tool didn't have any significant variation at the leaf area of the fodder verities.

4.3.2.3.Biomass Yield of Desho Grass and Oats and Vetch

The total biomass yield was significantly affected by water application depth and /or irrigation requirement level. The biomass yield of desho grass and mixed oats and vetch significantly differed between treatments with WFD having 79.5 t/ha, (P < = 0.05) by the wetting Front Detector. The highest biomass yield for both desho grass and oats and vetch was, in WFD treatment 79.5 tone/ha and 79.7 t/ha were harvested for desho grass and oats and vetch respectively; were as in the control plots harvest of 66.9t/ha and 65.9t/ha were obtained.

Table 4.11: The average biomass yield (t/ha) of Desho grass and Oats and vetch

No	Treatment	Location	Fodder type	Biomass (t / ha)
1	WFD	Kerekicho	Desho grass	79.5[a]
2	Control (local practice)		Desho grass	66.7[b]
LSD; P<=0.05		Cv (%)		4.2
3	WFD	Jewe	Oats & vetch	79.7[a]
4	Control (local practice)		Oats & vetch	65.9[b]
LSD; P<=0.05		Cv (%)		6

As it can be seen from Table 4.11, the biomass yield of desho grass at Kerekicho among the two treatment plots was significantly different and the analyzed results are presented in Appendix 6 (i.e detailed information for each plot). The biomass for desho grass monitored using WFD was found higher than the control treatment plots by 19% whereas the biomass difference for oats and vetch among the WFD treatment plots and control treatment plots was 21%. As it was observed in the field, the biomass yield was not only affected by adding too much or too less water but also frequency of water application based on the water demands of the fodder crops at each growth stage may affect. The use of WFD helps to know, the depth of water needed to be applied and the time when to apply. Therefore the applied water through the guidance of WFD was considered proper application compared with that of the control (local irrigation practice plots) treatments. At the initial growth stage the depth of water needed to be applied was less but frequent. Whereas at the development stage water depth applied was more than the initial stage and in development stage there was enough rain and the contributed irrigation was less when compared with initial and mid stage. At the mid-stage water supplied was higher than the development stage. In WFD, the depth of water application at initial stage was more frequent but in small amount whereas at development stage of the fodder crops the depth of water applied was less frequent than at the initial stage. At the middle stage of fodder crop the water application was not frequent but the depth of one time application was more when it was compared with that of initial and development. at the mid stage water application in the WFD plots was more frequent and higher compared to late season stage. Therefore the result obtained indicates supplying enough water during the middle, late or maturity stage of the fodder growing season has resulted in higher biomass yield under WFD treatments than the control treatment plots.

4.3.2. Water Productivity

Crop water productivity was estimated for the two fodder crops by dividing the fresh biomass yield production by the amount of total water applied (rainfall + supplementary irrigation) throughout the growing seasons. The water productivity was computed by using water productivity equation 3.6, as it was mentioned in chapter three from the methodology part. As it can be seen in Table 4.10, water productivity differed significantly at (P< = 0.05) between the two treatments for desho grass and for oats & vetch. For the WFD plots the water productivity increased by 18% and 21% for desho grass, oats & vetch, respectively. The average moisture content at harvest was 73% for oats and vetch and 80% for desho grass (dataobtained from the International Livestock Research institute) resulting in average water productivity of 9.1kg/m^3 (WFD) and 7.7 kg/m^3 (control) for desho and 9.9 kg/m^3(WFD) and 8.2kg/m^3(control) for oats and vetch.

Table 4.12: Average water productivity of Desho grass and mixed oat and vetch based on fresh biomass production and water productivity using dry matter biomass estimation at moisture content of 73%

N	Treatment	Location	Fodder type	Biomass (t/ha)	Water(m^3)	WP(kg/m^3)
1	WFD	Kerekicho	Desho grass	79.5^a	2370^a	33.6^a
2	Control	Kerekicho		66.7^b	2339^a	28.5^b
	LSD; P<=0.05		Cv(%)	4.2		3.2
3	WFD	Jewe	Oats & vetch	79.7^a	2168^a	36.8^a
4	Control	Jewe		65.9^b	2170.8^a	30.3^b
	LSD; P<=0.05		Cv(%)	6		3.8

Although the average water depth applied throughout the season did not show a significant difference beteween two treatments a large variation of applied depth was found between the replications with in control plot. The depth of water applied throughout the season did not show a significant difference between the two treatments a large variation of wtr applied was found between the replications with in the control plots the deph of water application under WFD treatment plots were consistent meaning that each field had more or less the same water application wereas in the control treatments (local irrigation practice) each plots had different irrigation depths. Sometimes in the control plots water depth was applied beyond the crop demand whereas in other control treatment plots received very small irrigation depths below the crop water demand compared to the plots using the Wetting Front Detector (consistent application of water). The reason why the control plots applied different amount of water with different frequency is that these farmers had no access to irrigation information and hence used their irrigation knowledge obtained from horticultural crops to irrigate fodder as they didn't have experience in irrigating fodder. The farmers in the WFD plots on the other hand were guided by the yellow detector and followed the signaling during irrigation. Hence the risk of under irrigation is less common as the flag responds when field capacity is reached. As it can be observed during the study and from farmers discussion; the WFD was better to save human power, it was simple to be used by farmers and it provided good guidance on when and how much to apply throughout the growth stages of the fodder crop. Therefore supplementary irrigation with the scheduling tool (Wetting Front Detector) was better and provide useful information to farmers in guiding how much water to apply when irrigating new crops.

4.3.3. Water Use Efficency (WUE)

As it can be seen from Table 4.13, there was a significant variation in water use efficiency (WUE) at a significant level of ($p<=0.05$) among the two treatments for each fodder variety. For desho grass at Kerekicho, the WFD treatment plots had better result (38.5 kg/m^3) than control treatment (32.7 kg/m^3) (detailed information for each plot is given in appendix 6). Similar results were obtained for oat & vetch at Jewe where WFD treatment plots had better result (42.7 kg/m^3) than the control treatment plots (34.7 kg/m^3). Water use efficiency of oats and vetch was slightly higher than desho grass producing slightly higher yields by unit volume of water even though the location is different.

Table 4.13: Water use efficiency at fresh biomass and dry matter biomass estimation at a moisture content of 73%

N	Treatments	Location	Fodder type	Biomass(t/h)	ETc (m^3)	WUE (kg/m^3)	WUE (kg/m^3)
1	WFD	Kerekicho	Desho grass	79.5^a	2064^a	38.5^a	7.7^a
2	Control		Desho Grass	66.7^b	2036^a	32.7^b	6.5^b
	LSD; P<=0.05		Cv (%)	4.2		3.8	3.8
3	WFD	Jewe	Jewe	79.7^a	1866^a	42.7^a	11.5^a
4	Control		Jewe	65.9^b	1897^a	34.7^b	9.4^b
	LSD; P<=0.05		Cv (%)	6		4.3	1.3

The biomass yield of both fodder varieties can be significantly improved by monitoring irrigation water application using WFD at both study sites. Although the crop evapotranspiration did not differ significant between both treatments for any of the fodder crops the results show that water application at the exact time of water shortage in the soil according to the crop water demand does improve fodder production and therefore water use efficiency. As it can be seen from Table 4.13, water use efficiency difference between treatment plots for desho grass and oats & vetch at Kerekicho and Jewe was 15% and 19% respectively. The results are in line with the water productivity results found for both fodder crops and confirms the earlier observation that irrigation information on when and how much to apply reduces water stress during critical crop stages. By using WFD, farmers who are new in irrigated fodder production can improve their irrigation knowledge and decide how much water to apply throughout the various cropping stages.

CHAPTER FIVE

5. CONCLUIONS AND RECOMMENDATIONS

5.1. Conclusions

- Water balance approach of estimating crop evapotranspiration was demonstrated using two fodder varieties, namely desho grass and oats and vetch grown in the environment of Angacha (Kerekicho) and Lemo (Jewe) respectively. The components of the root zone water balance, except evapotranspiration, were measured. Evapotranspiration was calculated as an independent parameter in the soil water balance equation. Finally, the ETc and Kc of desho grass and oats and vetch fodder crops were evaluated for each growth stages at Kerekicho and Jewe condition respectively. Since ETc and Kc are a function of crop characteristics, irrigation water management, climate conditions, local and agricultural practices, it should be localized and this result can be used for appropriate irrigation planning, improve irrigation scheduling. This emphasizes the strong need for local calibration of Kc for each crop variety. The Kc value was estimated using the ratio of crop evapotranspiration and reference evapotranspiration, and Kc values of desho-grass at early, vegetative , middle and late-season crop stages were 0.4, 0.71, 0.89, and 0.72 respectively whereas for oats and vetch was 0.29, 0.89, 1.01, and 0.71 respectively. Kc value of desho grass and oats & vetch at the end of their growing season was 0.68 and 0.78 respectively.
- Results obtained from this experiment revealed that great potential of using cheap and simple WFD to manage irrigation. WFD and control treatments (local irrigation practices) produced different biomass yields with varying amounts of irrigation water depth.
- The variation of supplementary irrigation brought variation of biomass yield between the two irrigation treatments. More detailed evaluation between the WFD scheduled plots and farmers practice was done in terms of plant height, leaf area, the biomass yield, water productivity and water use efficiency. The results revealed that the plant height (at the mid-season and late season only for each fodder crops); leaf area (at the late season; for oat only); biomass yield obtained from each treatments; water productivity and water use efficiency were significantly affected by the WFD (scheduling tool) ($p<=0.05$). In depth

evaluation showed that the guidance of irrigation by using the WFD helped farmers who were new to irrigated fodder scheduling their supplementary irrigation water both in frequency and amount whilst saving labor and time. Overall oats and vetch had a higher water productivity in both treatments compared to desho grass showing that in case of water scarcity preference could be given to oats and vetch. However, this recommendation does not include the difference in nutritional value of both fodder species.

5.2. Recommendations

- ✓ In Jewe and kerekicho Livestock's are greatly constrained by feed shortage in terms of quality and quantity during the dry season especially from February to the beginning of June. The reason for this shortage of feed occurrence was the problem of adopting small scale irrigation for fodder production (it is not common to irrigate fodder). To boost small holder's income, there should be well integrated agricultural systems, integrating crop as well as livestock production. In Jewe and Kerekicho potential irrigable land is underutilized due to scarcity of water but there is a potential of using shallow groundwater that can be tapped to grow crops (i.e. vegetables) and fodder during dry season by introducing low cost water lifting technologies such as: Rope and Washer, pulley pump etc.
- ✓ The values of ETc and Kc obtained at both study areas can be used for further studies related to water management. Since the actual crop evapotranspiration of desho grass and mixed oats and vetch was determined, farmers can store water to grow these fodder crops during the dry season.
- ✓ In this study, evaluation of Wetting Front Detector was done through supplementary irrigation and the result was more attractive. By having this result, concerned organizations, woreda agricultural offices, DAs, and other stakeholders should participate to scale up the technology intervention. During the study, there was open group discussion with farmers and their interest was to use the scheduling tool not only for fodder crops but also for other crops like vegetables, fruits etc. therefore it is better to distribute this scheduling tool for farmers to use it based on farmers preference.

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Appendix 1: Meteorological Data

Table – 1.1: monthly rainfall (mm) for Hosaena station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	32	19	178	162	197	65	160	99	163	38	68	0
2006	29	54	136	160	76	170	184	222	88	50	6	27
2007	6	0	119	152	121	163	180	127	210	19	0	0
2008	0	1	43	64	239	145	193	136	139	126	117	1
2009	43	5	73	86	120	123	189	181	157	169	5	24
2010	12	110	140	111	183	94	116	145	139	19	19	34
2011	16	11	102	116	233	124	159	183	119	0	49	0
2012	0	0	67	138	68	150	233	156	164	1	2	1
2013	1	17	101	68	132	182	201	211	173	46	0	0
2014	25	118	77	135	252	76	188	271	150	73	20	24
AVERAGE	**16.3**	**33.5**	**103.6**	**119.2**	**162.1**	**129.1**	**180.2**	**173.1**	**150.2**	**54.2**	**28.6**	**10.9**

Table 1.2: monthly Minimum temperature (C^o) for Hosanna

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	9.5	11.0	12.4	12.8	11.9	11.4	11.5	11.8	11.6	10.6	10.1	8.0
2006	9.8	11.3	11.5	12.0	11.1	11.1	12.0	11.8	11.3	11.9	11.1	10.1
2007	10.2	11.5	12.5	12.1	11.9	11.9	11.6	11.4	11.5	10.2	10.9	8.1
2008	9.1	8.7	10.7	11.6	11.0	10.6	11.4	11.3	11.3	11.7	9.6	7.8
2009	9.1	10.5	12.0	12.2	10.9	10.5	10.9	11.2	10.9	10.5	9.7	8.9
2010	9.2	11.5	11.4	12.2	12.3	11.5	11.4	11.4	11.1	10.5	10.5	8.4
2011	9.4	10.4	12.0	12.1	12.3	11.0	11.3	11.5	10.9	10.8	10.6	9.0
2012	9.2	9.8	11.4	11.9	11.2	11.1	11.5	10.9	10.7	10.3	10.1	8.9
2013	8.9	10.4	11.7	11.8	11.3	11.3	11.1	10.9	10.0	9.7	10.0	7.0
2014	8.9	10.6	11.7	11.5	11.4	10.9	11.5	11.4	10.7	10.6	10.0	8.6
Average	**9.3**	**10.6**	**11.7**	**12.0**	**11.5**	**11.1**	**11.4**	**11.4**	**11.0**	**10.7**	**10.3**	**8.5**

Table 1.3: monthly Maximum temperature (C^o) for Hosanna

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	24.0	26.5	24.6	24.0	22.2	21.4	19.8	20.8	21.2	22.5	23.1	24.0
2006	24.6	25.5	24.0	22.9	23.3	21.7	21.0	19.6	20.9	23.0	23.8	23.6
2007	24.4	24.5	25.9	24.0	23.5	20.9	20.3	20.2	21.1	22.7	23.7	24.2
2008	25.5	24.7	26.9	24.9	22.7	21.0	19.2	19.9	20.9	22.4	22.3	23.8
2009	23.9	25.1	26.7	24.7	25.0	23.3	20.9	20.8	22.2	22.5	23.5	23.8
2010	24.2	23.3	23.8	23.8	14.3	21.2	19.6	19.7	21.3	22.5	23.5	23.8
2011	24.2	24.9	25.3	26.0	23.3	21.2	21.2	20.3	21.1	23.8	23.9	24.2
2012	25.7	25.8	26.7	23.0	24.6	22.1	20.0	20.3	21.1	23.4	24.6	24.9
2013	24.9	25.9	24.8	24.3	23.4	21.3	19.9	19.6	21.6	22.8	24.2	24.0
2014	24.5	24.4	24.7	24.4	23.1	22.5	20.3	20.3	21.3	22.5	23.5	23.8
Average	24.6	25.0	25.3	24.2	22.5	21.7	20.2	20.1	21.3	22.8	23.6	24.0

Appendix 2: All the parameters water balance for each plot (replications) at Kerekicho

Table 2.1: WFD plot 1; Calculated value of ETC,ETo& KC (Desho grass, Kerekicho)

DAP	ΔS	RF (mm)	I (mm)	D (mm)	ETC (mm)	N	ETC(mm/Day)	Eto(mm/Day)	KC
9	-10.40	6.96	36.8	0.00	33.36	20	1.67	4.26	0.39
24	-5.00	15.66	8.4	0.00	19.06	8	2.38	3.81	0.62
29	3.10	0	3.6	-3.90	2.80	1	2.80	3.79	0.74
31	2.80	10.8	2.6	-2.00	12.40	4	3.10	3.85	0.80
36	0.80	20.7	3	-4.00	20.30	6	3.38	3.71	0.91
43	3.10	17.1	3.6	-1.00	23.00	7	3.29	3.60	0.91
48	-0.40	12.42	3.8	-0.50	15.12	5	3.02	3.73	0.81
53	4.20	9.99	3.2	-4.10	14.29	4	3.57	3.92	0.91
59	2.00	20.79	3.1	1.60	24.69	8	3.09	4.06	0.76
66	-7.30	36.09	2.8	-6.00	24.29	8	3.04	3.39	0.90
75	-0.30	13.59	2.5	-5.00	11.49	5	2.30	2.92	0.79

Table 2.2: WFD plot 2; Calculated value of ETC, ETo & KC (Desho grass), Kerekicho

DAP	**Δ**S (mm)	RF(mm)	I (mm)	D (mm)	ETC (mm/Day)	N	ETC (mm/Day)	Eto (mm/Day)	KC
9	-8.00	6.96	36.2	0.00	35.16	20	1.76	4.26	0.41
24	-2.60	15.66	9.1	0.00	22.16	8	2.77	3.81	0.73
29	-0.30	0	3.9	-0.60	2.70	1	2.70	3.79	0.71
31	1.90	10.8	3.2	-2.20	13.70	4	3.43	3.85	0.89
36	-3.70	20.7	3.1	-1.00	18.10	6	3.02	3.71	0.81
43	3.40	17.1	3.5	-2.50	23.50	7	3.36	3.60	0.93
48	3.00	12.42	3.6	-2.60	14.22	5	2.84	3.73	0.76
53	3.90	9.99	3.5	-3.80	13.69	4	3.42	3.92	0.87
59	6.70	20.79	3	-3.20	26.99	8	3.37	4.06	0.83
66	-11.80	36.09	3	-2.10	24.59	8	3.07	3.39	0.91
75	4.10	13.59	2.4	-9.00	11.99	5	2.40	2.92	0.82

Table 2.3: WFD plot 3; Calculated value of ETC,ETo& KC (Desho grass ,Kerekicho)

DAP	ΔS	RF (mm)	I (mm)	D (mm)	ETC (mm/Day)	N	ETC (mm/Day)	Eto (mm/Day)	KC
9	-9.00	6.96	35.4	0.00	33.36	20	1.67	4.26	0.39
24	-2.60	15.66	5.8	0.00	18.86	8	2.36	3.81	0.62
29	-1.40	0	4	0.40	1.40	1	1.40	3.79	0.37
31	1.00	10.8	2.8	-0.80	14.60	4	3.65	3.85	0.95
36	-1.80	20.7	2.8	-1.60	21.10	6	3.52	3.71	0.95
43	2.20	17.1	3.6	0.10	21.20	7	3.03	3.60	0.84
48	3.80	12.42	3.6	-2.80	19.82	5	3.96	3.73	1.06
53	-1.40	9.99	3.5	2.10	11.99	4	3.00	3.92	0.76
59	5.00	20.79	3.8	0.10	29.49	8	3.69	4.06	0.91
66	-9.40	36.09	2.9	-6.30	22.89	8	2.86	3.39	0.85
75	-2.20	13.59	2.6	-4.60	9.19	5	1.84	2.92	0.63

Table 2.4: Control plot 1 (local irrigation practice); Calculated value of ETC, ETo& KC (Desho grass ,Kerekicho)

DAP	ΔS (mm)	(mm)	I (mm)	D (mm)	ETC (mm/Day)	N	ETC(mm/Day)	Eto(mm/Day)	KC
9	-9.00	6.96	31.8	0.00	29.76	20	1.49	4.26	0.35
24	0.00	15.66	5.2	0.00	20.86	8	2.61	3.81	0.68
29	1.80	0	2.6	-0.80	4.00	1	4.00	3.79	1.06
31	4.20	10.8	2	-2.40	14.20	4	3.55	3.85	0.92
36	-2.40	20.7	3	-1.20	20.30	6	3.38	3.71	0.91
43	5.40	17.1	2.8	-6.40	18.70	7	2.67	3.60	0.74
48	-2.00	12.42	3	0.20	12.62	5	2.52	3.73	0.68
53	4.00	9.99	4.6	-6.30	12.29	4	3.07	3.92	0.78
59	4.80	20.79	4.5	-1.10	27.79	8	3.47	4.06	0.86
66	-10.80	36.09	6.8	-5.70	27.59	8	3.45	3.39	1.02
75	-4.10	13.59	4.5	-3.40	9.49	5	1.90	2.92	0.65

Table 2.5: Control plot 2; Calculated value of ETC, ETo & KC (Desho grass ,Kerekicho)

DAP	ΔS(mm)	RF (mm)	I (mm)	D(mm)	ETc(mm/Day)	N	ETC (mm/Day)	Eto(mm/Day)	KC
9	-12.00	6.96	31	0.00	25.96	20	1.30	4.26	0.30
24	-2.00	15.66	7.4	0.00	21.06	8	2.63	3.81	0.69
29	0.10	0	2.8	-0.10	2.90	1	2.90	3.79	0.77
31	13.60	10.8	0	-13.2	14.20	4	3.55	3.85	0.92
36	1.60	20.7	1.8	-4.30	21.00	6	3.50	3.71	0.94
43	0.90	17.1	2.4	-0.30	20.00	7	2.86	3.60	0.79
48	1.00	12.42	2.6	-2.00	14.02	5	2.80	3.73	0.75
53	-1.10	9.99	2.1	1.10	10.99	4	2.75	3.92	0.70
59	6.90	20.79	0	1.00	27.59	8	3.45	4.06	0.85
66	-3.80	36.09	4.2	-7.10	32.59	8	4.07	3.39	1.20
75	-8.00	13.59	4.6	-1.20	6.99	5	1.40	2.92	0.48

Table 2.6: Control plot 3; Calculated value of ETC, ETo & K_C (Desho grass ,Kerekicho)

DAP	ΔS(mm)	Rf (mm)	I (mm)	D (mm)	ETC (mm/Day)	N	ETC (mm/Day)	Eto (mm/Day)	KC
9	-7.00	6.96	36.4	0.00	36.36	20	1.82	4.26	0.43
24	4.00	15.66	5.9	0.00	25.56	8	3.20	3.81	0.84
29	9.20	0	3.6	-9.60	3.40	1	3.40	3.79	0.90
31	2.60	10.8	0	-1.20	10.20	4	2.55	3.85	0.66
36	0.40	20.7	3.6	-4.80	20.90	6	3.48	3.71	0.94
43	-1.10	17.1	7.2	-3.40	20.00	7	2.86	3.60	0.79
48	4.90	12.42	0	-2.80	14.12	5	2.82	3.73	0.76
53	2.60	9.99	3.4	-3.40	13.19	4	3.30	3.92	0.84
59	3.60	20.79	7	-3.60	27.39	8	3.42	4.06	0.84
66	-12.20	36.09	7.2	-0.90	29.99	8	3.75	3.39	1.11
75	-7.80	13.59	5.4	-2.50	8.89	5	1.78	2.92	0.61

Appendix 3: All the water balance components for each plot (replications) at Jew

Table 3.1: WFD plot 1; Calculated value of ETC, ETo & KC (Jawe ; oats and vetch)

DAP	RF(mm)	I(mm)	ΔS (mm)	D (mm)	ETC (mm)	N	ETC (mm/Day)	ETo (mm/Day)	KC
8	3.26	27.8	-12.00	0.00	19.06	17	1.12	4.32	0.26
20	21.6	2.8	-3.00	0.00	21.40	7	3.06	3.88	0.79
28	33.6	2.9	1.50	0.00	38.06	9	4.23	3.75	1.13
33	0	2.9	5.10	-3.80	4.20	1	4.20	3.75	1.12
37	28.53	2.8	-2.30	-3.60	25.43	6	4.24	3.80	1.12
43	20.02	7.9	0.50	-4.20	24.22	6	4.04	3.60	1.12
48	16.02	2.9	1.00	0.60	20.52	5	4.10	3.65	1.12
53	13.9	9.1	10.90	-8.00	25.90	5	5.18	4.10	1.26
57	14.85	2.8	-0.90	-8.00	8.75	3	2.92	4.55	0.64

Table 3.2: WFD plot 2; Calculated value of ETC,ETo& KC (Jawe ; oats and vetch)

DAP	ΣR (mm)	ΣI (mm)	SMC ΔS	D (mm)	ΣETC (mm/Day)	N	ETC (mm/Day)	Eto (mm/Day)	KC
8	3.26	34.8	-16.00	0.00	22.06	17	1.30	4.32	0.30
20	21.6	2.9	0.00	0.00	24.50	7	3.50	3.88	0.90
28	33.6	2.9	3.60	-4.40	35.76	9	3.97	3.75	1.06
33	0	3.1	9.40	-8.60	3.90	1	3.90	3.75	1.04
37	28.53	2.9	-8.30	0.80	23.93	6	3.99	3.80	1.05
43	20.02	7.8	-4.00	0.00	23.82	6	3.97	3.60	1.10
48	16.02	3.2	4.10	-2.80	20.52	5	4.10	3.65	1.12
53	13.9	9.3	1.20	-3.20	21.20	5	4.24	4.10	1.03
57	14.85	2.8	-4.00	-2.00	11.65	3	3.88	4.55	0.85

Table 3.3: WFD plot 3; Calculated value of ETC,ETo& KC (Jawe ; oats and vetch)

DAP	ΣR (mm)	ΣI (mm)	SMC ΔS	D (mm)	ΣETC (mm/Day)	N	ETC (mm/Day)	Eto (mm/Day)	KC
8	3.26	29.3	-10.00	0.00	22.56	17	1.33	4.32	0.31
20	21.6	2.8	2.00	0.00	26.40	7	3.77	3.88	0.97
28	33.6	2.9	1.00	0.40	37.96	9	4.22	3.75	1.13
33	0	3	4.60	-3.40	4.20	1	4.20	3.75	1.12
37	28.53	2.2	-4.10	-1.40	25.23	6	4.21	3.80	1.11
43	20.02	7.9	-4.86	2.40	25.46	6	4.24	3.60	1.18
48	16.02	3.3	1.56	0.00	20.88	5	4.18	3.65	1.14
53	13.9	6.2	-5.70	-3.20	14.20	5	2.84	4.10	0.69
57	14.85	2.8	-3.30	-5.80	8.55	3	2.85	4.55	0.63

Table 3.4: Control plot 1; Calculated value of ETC,ETo& KC (Jawe ; oats and vetch)

DAP	ΣR (mm)	ΣI (mm)	SMC ΔS	D (mm)	ΣETC (mm/Day)	N	ETC (mm/Day)	Eto (mm/Day)	KC
8	3.26	27.7	-11.00	0.00	19.96	17	1.17	4.32	0.27
20	21.6	3.7	2.00	0.00	27.30	7	3.90	3.88	1.01
28	33.6	10	0.70	-7.20	37.16	9	4.13	3.75	1.10
33	0	2.4	4.60	-3.80	3.20	1	3.20	3.75	0.85
37	28.53	2.3	-4.30	-2.80	23.73	6	3.96	3.80	1.04
43	20.02	10	0.60	-3.20	27.42	6	4.57	3.60	1.27
48	16.02	6.2	-3.60	3.00	21.62	5	4.32	3.65	1.18
53	13.9	3.2	8.00	-5.00	26.20	5	5.24	4.10	1.28
57	14.85	2.4	-2.20	-6.00	9.05	3	3.02	4.55	0.66

Table 3.5: WFD plot 2; Calculated value of ETC,ETo& KC (Jawe ; oats and vetch)

DAP	ΣR (mm)	ΣI (mm)	SMC ΔS	D (mm)	ΣETC(mm/Day)	N	ETC(mm/Day)	Eto (mm/Day)	KC
8	3.26	15.5	-6.80	0.00	11.96	17	0.70	4.32	0.16
20	21.6	3.7	2.80	0.00	28.10	7	4.01	3.88	1.03
28	33.6	6.7	-3.80	-3.20	33.36	9	3.71	3.75	0.99
33	0	2.4	0.60	0.00	3.00	1	3.00	3.75	0.80
37	28.53	1.8	-6.90	-4.00	19.43	6	3.24	3.80	0.85
43	20.02	9.3	-3.10	0.00	26.22	6	4.37	3.60	1.21
48	16.02	4.1	4.10	-4.00	20.22	5	4.04	3.65	1.11
53	13.9	10.7	-4.00	-1.00	19.60	5	3.92	4.10	0.96
57	14.85	2.4	-1.10	-5.00	11.15	3	3.72	4.55	0.82

Table 3.6: WFD plot 3; Calculated value of ETC, ETo & KC (Jawe ; oats and vetch)

DAP	ΣR (mm)	ΣI (mm)	SMC ΔS	D (mm)	ΣETC (mm/Day)	N	ETC(mm/Day)	Eto (mm/Day)	KC
8	3.26	27.6	-8.00	0.00	22.86	17	1.34	4.32	0.31
20	21.6	1.8	8.00	0.00	31.40	7	4.49	3.88	1.16
28	33.6	7.8	1.00	-5.20	37.26	9	4.14	3.75	1.11
33	0	1.8	3.70	-2.20	3.30	1	3.30	3.75	0.88
37	28.53	1.5	-5.00	-5.00	20.03	6	3.34	3.80	0.88
43	20.02	8	0.90	-2.80	26.12	6	4.35	3.60	1.21
48	16.02	3.8	3.50	0.00	23.32	5	4.66	3.65	1.28
53	13.9	11.3	2.50	1.10	28.80	5	5.76	4.10	1.41
57	14.85	1.8	1.00	-10.10	7.55	3	2.52	4.55	0.55

Appendix 4: Average of the 3 replicated Agronomic data's at each stages (Kerekicho)

Table 4.1: WFD Plot 1; at initial stage of Desho grass (Kerekicho)

	Plant 1 (cm)				Plant 2(cm)				Plant 3(cm)			
Plot Id	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)
Sub-Plot 1	29.3	10	6	6	32.7	24.7	20.7	16.0	31.0	24.3	15.7	23.0
Sub-Plot 2	31.3	12	14	11	37.0	23.7	18.0	15.0	34.0	23.7	15.7	22.0
Sub-Plot 3	30.0	11	14	12	33.3	22.7	14.7	16.0	32.0	23.7	17.3	16.0
Sub-Plot 4	30.3	12	14	11	30.3	22.0	15.3	16.0	25.3	17.7	17.0	16.7
Sub-Plot 5	31.3	8	14	12	26.3	19.7	13.0	14.7	27.7	16.7	16.7	15.0

Table 4.2: WFD Plot 1; at Development stage of Desho grass (Kerekicho)

	Plant 1 (cm)				Plant 2(cm)				Plant 3(cm)			
Plot ID	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)
Sub-Plot 1	48.3	31.0	19.3	21.0	47.0	32.0	17.7	20.0	55.0	37.3	21.7	20.7
Sub-Plot 2	56.3	34.0	22.3	22.0	41.0	33.0	26.7	19.3	47.7	29.3	19.0	20.3
Sub-Plot 3	50.0	36.7	20.3	21.0	42.7	31.7	20.3	20.0	42.0	28.0	20.0	19.3
Sub-Plot 4	42.3	30.3	20.7	21.3	39.7	31.3	20.7	20.0	52.3	37.0	21.3	19.7
Sub-Plot 5	43.0	33.7	20.3	16.3	44.0	30.0	16.3	19.0	45.0	32.3	17.0	16.7

Table 4.3: WFD Plot 1; at Middle stage of Desho grass (Kerekicho)

	Plant 1 (cm)				Plant 2(cm)				Plant 3(cm)			
Plot ID	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)
Sub-Plot 1	62.5	31	18	21	65	38.5	21	21	56	41.5	21	22.5
Sub-Plot 2	64.5	34.5	22	22.5	47.5	29	20.5	21	54.5	34.5	22.5	21.5
Sub-Plot 3	67	34.5	19.5	19.5	29.5	41	21	22	49	29	23	21.5
Sub-Plot 4	49.5	30	19.5	19	54	33	20	21	55.5	35	19.5	19
Sub-Plot 5	49.5	35.5	20	20	53.5	34	21	20.5	45.5	29	21	20

Table 4.4: WFD Plot 1; at Late season stage of Desho grass (Kerekicho)

	Plant 1 (cm)				Plant 2 (cm)				Plant 3 (cm)			
Plot	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)
Sub-Plot 1	75.3	36.0	23.7	22.7	81.7	47.7	43.0	30.0	193.3	39.0	24.0	24.3
Sub-Plot 2	79.0	41.7	25.0	23.7	70.7	41.0	47.7	30.3	217.7	33.3	24.0	23.3
Sub-Plot 3	80.7	40.0	21.7	22.3	77.0	38.3	40.3	31.3	95.7	30.3	22.0	22.0
Sub-Plot 4	80.0	43.0	22.0	22.7	79.7	42.3	44.7	29.7	197.7	36.0	22.7	22.3
Sub-Plot 5	53.7	37.0	21.3	21.7	56.3	35.0	32.0	28.0	167.3	32.3	23.0	22.0

Table 4.5: Control Plot; at initial stage of Desho grass (Kerekicho)

	Plant 1 (cm)				Plant 2(cm)				Plant 3(cm)			
Plot	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)
Sub-Plot 1	31.3	24.3	14.3	15.7	29.0	24.7	19.3	18.0	31.7	23.7	15.3	18.3
Sub-Plot 2	30.0	21.0	16.3	14.3	32.0	25.7	16.7	16.7	33.7	25.3	14.3	16.0
Sub-Plot 3	27.3	17.3	15.0	14.0	26.0	21.0	16.7	15.7	27.0	22.7	14.0	13.0
Sub-Plot 4	28.3	18.7	14.3	13.0	27.3	20.3	19.0	16.0	27.7	20.7	14.3	14.7
Sub-Plot 5	31.0	20.0	13.7	13.7	27.3	22.0	14.0	14.7	27.3	19.3	12.7	14.0

Table 4.6: Control Plot; At Development stage of Desho grass (Kerekicho)

	Plant 1 (cm)				Plant 2(cm)				Plant 3(cm)			
Plot	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)
Sub-Plot 1	44.3	32.7	17.3	19.7	45.0	29.7	17.7	19.7	40.3	29.0	17.7	19.0
Sub-Plot 2	40.3	34.3	21.3	18.7	35.0	29.0	19.3	15.7	45.7	29.0	19.0	16.7
Sub-Plot 3	47.3	27.7	18.0	18.0	32.7	27.3	16.3	17.7	38.3	26.0	19.3	20.3
Sub-Plot 4	50.0	29.3	17.3	21.0	46.7	30.7	21.0	22.0	47.7	38.0	19.3	19.0
Sub-Plot 5	36.7	28.0	22.0	15.3	39.7	22.0	15.7	18.0	40.3	30.0	18.0	16.7

Table 4.7: Control Plot; at mid-season stage of Desho grass (Kerekicho)

	Plant 1 (cm)				Plant 2(cm)				Plant 3(cm)			
Plot	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)	H	L	W1(mm)	W2(mm)
Sub-Plot 1	60.5	35.5	23.5	23	52	34	20.5	20.5	45.5	34	21	21.5
Sub-Plot 2	55	30.5	20	19	36.5	26	17.5	18.5	44.5	31	20.5	20.5
Sub-Plot 3	34.5	21	19.5	19	33.5	21.5	19	18.5	34.5	23	20	22
Sub-Plot 4	47.5	27	20	20	51.5	33.5	20.5	19.5	47	31.5	20	19.5
Sub-Plot 5	36.5	25.5	17.5	17.5	47.5	28	19	19	53.5	28	19.5	20

Table 4.8: Control Plot; at Late-season stage of Desho grass (Kerekicho)

	Plant 1				Plant 2				Plant 3			
Plot ID	H(cm)	L(cm)	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)
Sub-Plot 1	77	39.3	25.3	23.0	71.0	42.7	43.3	30.3	184.0	34.7	23.7	23.3
Sub-Plot 2	77.7	42.7	24.0	24.3	66.7	37.7	46.0	29.7	216.7	32.7	23.3	23.0
Sub-Plot 3	62.7	38.3	20.7	21.0	69.3	39.0	42.7	32.0	83.0	25.7	19.7	17.7
Sub-Plot 4	75.3	38.0	22.0	22.0	75.0	39.3	45.3	29.3	183.3	30.0	22.0	21.0
Sub-Plot 5	56.3	34.0	19.7	20.0	61.3	33.7	32.7	28.7	169.7	29.0	23.3	22.0

Appendix 5: Average of the 3 replicated Agronomic at each stages of oats and vetch

Table 5.1: WFD Plot 1; at initial stage of Oats and Vetch (Jewe)

Plot ID	H(cm)	L(cm)	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)
Sub-Plot 1	14.3	6.3	4.3	4.7	15.3	7.7	4.3	5.3	16.3	8.7	3.3	4.0
Sub-Plot 2	14.7	6.7	4.7	4.3	14.7	6.7	4.3	5.3	16.3	7.7	3.7	3.7
Sub-Plot 3	14.0	7.3	4.3	4.3	14.3	6.7	5.0	4.3	14.7	7.7	4.0	4.0
Sub-Plot 4	13.3	6.7	4.3	3.7	16.0	6.7	5.3	5.0	15.0	7.3	5.0	4.3
Sub-Plot 5	13.3	7.3	4.7	4.3	14.0	6.7	5.3	3.7	13.7	6.7	4.3	4.3

Table 5.2: WFD Plot; at development stage of Oats and Vetch (Jewe)

Plot ID	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)
Sub-Plot 1	26	20.0	6.0	7.7	23.3	21.0	5.3	6.0	26.7	23.0	6.0	5.7
Sub-Plot 2	26.7	21.3	6.3	5.7	28.3	25.7	7.3	5.0	26.7	22.0	7.0	6.7
Sub-Plot 3	25.0	21.0	7.0	5.3	21.7	18.0	7.7	4.7	23.0	20.0	6.7	5.3
Sub-Plot 4	23.7	21.3	6.3	5.7	26.7	19.3	6.3	5.7	24.7	20.3	5.7	4.3
Sub-Plot 5	23.7	20.0	7.0	4.7	24.7	20.7	7.0	4.3	27.0	22.0	4.3	5.0

Table 5.3: WFD Plot F; at mid-stage season stage of Oats and Vetch (Jewe)

	Plant				Plant2					Plant 3		
Plot ID	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)
Sub-Plot 1	70.3	47.3	12.3	12.0	60.0	44.0	11.0	12.0	76.7	56.3	10.7	49.7
Sub-Plot 2	63.0	45.3	12.0	13.7	67.0	50.0	12.3	11.0	69.3	52.0	11.0	13.3
Sub-Plot 3	77.0	51.7	11.3	11.3	65.3	49.7	14.0	12.3	71.3	56.0	13.3	12.3
Sub-Plot 4	69.0	53.7	13.7	11.3	68.0	50.0	14.3	14.3	69.0	49.0	14.3	13.0
Sub-Plot 5	296.7	56.0	12.3	13.3	65.7	50.3	13.3	11.3	70.7	49.7	12.7	14.0

Table 5.4: WFD Plot; at mid-stage season stage of Oats and Vetch (Jewe)

	Plant	1			Plant 2				Plant 3			
Plot ID	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)
Sub-Plot 1	100	71.3	16.0	15.0	96.0	73.3	15.7	14.3	96.7	77.0	14.3	13.0
Sub-Plot 2	95.3	75.7	16.7	13.7	94.7	69.7	16.0	15.7	108	72.3	14.3	14.7
Sub-Plot 3	110	76.0	15.0	15.7	102	70.3	15.0	16.3	93.7	75.0	15.3	16.3
Sub-Plot 4	94.7	69.7	17.0	16.7	97.7	73.3	15.3	15.7	96.0	73.0	16.3	14.7
Sub-Plot 5	96	74.0	16.3	16.3	110	76.7	16.3	16.3	99.7	81.7	15.7	17.0

Table 5.5: Control Plot 1; at initial stage of Oats and Vetch (Jewe)

	Plant				Plant 2				Plant 3			
Plot ID	H(cm)	L(cm	W(mm)	W(mm)	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W(mm)	W(mm)
Sub-Plot 1	12.3	11.0	3.7	4.0	12.0	7.0	3.0	3.7	13.7	7.3	3.7	3.3
Sub-Plot 2	11.3	11.0	4.0	3.7	12.3	7.0	3.7	3.3	13.7	6.7	3.3	2.7
Sub-Plot 3	13.0	9.7	5.7	4.3	13.3	7.3	3.3	3.3	11.7	6.0	3.0	3.0
Sub-Plot 4	11.7	8.3	5.0	4.7	13.0	7.7	3.0	3.3	11.3	5.7	3.7	3.0
Sub-Plot 5	13.0	10.3	4.3	3.0	10.7	6.3	3.3	3.7	11.0	6.7	3.0	2.7

Table 5.6: Control Plot; at development stage of Oats and Vetch (Jewe)

Plot ID	H(cm)	L(cm	W(mm)	W(mm)	H(cm)	L(cm	W(mm)	W (mm)	H(cm)	L(cm	W(mm)	W(mm)
Sub-Plot 1	19.7	16.3	5.7	5.7	21.0	19.0	4.3	6.0	18.0	15.3	5.0	5.3
Sub-Plot 2	24.3	21.0	6.0	5.7	23.0	20.0	5.3	5.3	22.0	18.7	4.3	5.7
Sub-Plot 3	28.7	22.3	7.7	6.7	17.0	14.7	4.3	7.0	20.7	17.3	5.3	5.3
Sub-Plot 4	19.7	17.0	5.0	4.7	17.7	13.3	5.3	6.0	24.0	20.3	5.0	5.0
Sub-Plot 5	20.3	18.3	6.0	5.0	15.0	12.7	7.3	5.3	16.0	17.0	7.7	5.3

Table 5.7: Control Plot; at mid-stage season stage of Oats and Vetch (Jewe)

	Plant				Plant 2				Plant 3			
Plot ID	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)
Sub-Plot 1	43.7	33.3	10.0	11.3	50.7	38.3	10.0	10.0	49.0	38.3	11.0	10
Sub-Plot 2	47.0	32.3	10.7	10.3	53.0	41.7	12.3	10.0	61.0	43.3	10.3	9.7
Sub-Plot 3	41.7	31.3	11.7	12.3	52.0	42.7	9.0	11.7	58.3	41.7	12.3	11.3
Sub-Plot 4	46.0	33.0	10.0	9.3	53.3	42.3	11.7	10.0	61.0	45.7	10.7	11.0
Sub-Plot 5	48.7	40.0	11.0	13.3	53.7	40.0	10.0	11.3	55.3	43.3	11.3	11.0

Table 5.8: Control Plot; at Late stage season stage of Oats and Vetch (Jewe)

	Plant				Plant 2				Plant 3			
Plot ID	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)	H(cm)	L(cm	W (mm)	W (mm)
Sub-Plot 1	79.7	57.0	13.3	12.7	76.7	51.3	13.3	13.3	78.0	57.3	13.3	13.7
Sub-Plot 2	76.3	52.7	14.0	13.0	82.7	51.3	13.3	12.3	75.0	50.0	14.3	15.0
Sub-Plot 3	75.3	51.7	13.3	14.7	80.0	54.0	14.7	12.3	74.3	58.7	15.0	13.7
Sub-Plot 4	81.7	53.3	14.0	13.0	74.0	51.0	14.7	13.7	77.7	51.3	13.3	12.7
Sub-Plot 5	79.3	51.0	13.7	15.0	72.7	43.7	13.7	14.0	78.7	51.0	13.7	13.3

Appendix 6: yield of each plot and from each sub plots at Kerekicho for Desho grass

Table 6.1: Biomass of Angacha at each sub plots

WFD treatment replication sub plots				Control treatment replication sub plots			
Plot Id	Quadrant No	Quadrant Biomass(Kg/m^2)	Average Biomass (Kg/m^2)	Quadrant No	Quadrant Yield	Quadrant Biomass(Kg/m^2)	Average Biomass (Kg/m^2)
1	1	8	**7.8**	1	1	5.9	**6.8**
	2	8.1			2	6.9	
	3	7.2			3	7	
	4	7.8			4	6.5	
	5	7.9			5	7.7	
2	1	8.2	**8.06**	2	1	7.1	**6.2**
	2	8			2	7.3	
	3	7.8			3	6.5	
	4	7.8			4	6.6	
	5	8.5			5	8	
3	1	8	**8**	3	1	5.9	**7**
	2	8.6			2	6.9	
	3	7.6			3	6.5	
	4	8.2			4	6.5	
	5	7.6			5	7.2	

Table 6.2: Jewe total biomass of each sub plots

WFD treatment replication sub plots				Control treatment replication sub plots			
Plot Id	Quadrant No	Quadrant Biomass(Kg/m2)	Average Biomass (Kg/m2)	Quadrant No	Quadrant Yield	Quadrant Biomass(Kg/m2)	Average Biomass (Kg/m2)
1	1	7.8	**7.72**	**1**	1	6.9	**7.08**
	2	8.1			2	7	
	3	7.2			3	7.1	
	4	8			4	7.5	
	5	7.5			5	6.9	
2	1	7.8	**8.5**	**2**	1	6	**6.28**
	2	8			2	6.3	
	3	8.5			3	6.6	
	4	8			4	6.5	
	5	7.7			5	6	
3	1	8.5	**7.7**	**3**	1	7.6	**6.8**
	2	7.5			2	7.3	
	3	7.5			3	7	
	4	7			4	7.1	
	5	8			5	5	

Appendix 7: Water Productivity and Irrigation Productivity of each treatment replications

Table 7.1: Angacha Water Productivity and water use efficency

Replication	Treatment	Yield	WP	IWP
1	WFD	78000	3.284	9.03
1	WFD	80600	3.378	9.21
1	WFD	80000	3.406	9.55
2	Control	68000	2.895	8.11
2	Control	62000	2.780	8.62
2	Control	70000	2.871	7.55

Table 7.2: Jewe Water Productivity and Irrigation water Productivity

Replication	Treatment	Yield	WP	WUE
1	WFD	77200	3.613	11.73
1	WFD	85000	3.837	11.55
1	WFD	77000	3.578	11.44
2	Control	70800	3.135	9.09
2	Control	62800	3.013	10.38
2	Control	64000	2.949	9.24

Appendix 8: ANOVA results

8.1:Kerekicho ANOVA Results

ANOVA				
Parameters	sum of squares	df	R	F
$PH_{initial}$	0.88	1	0.133	0.62
$PH_{devel.}$	8.2	1	0.32	1.96
PH_{mid}	266.7	1	0.89	32.18
PH_{late}	334.5	1	0.97	133.5
$LA_{initial}$	9.5	1	0.4	2.39
$LA_{devel.}$	0.03	1	0.003	0.01
$LA_{mid.}$	10.6	1	0.55	3.38
LA_{late}	52.3	1	0.398	2.65
Yield	248326666	1	0.87	25.9
Water pro.	0.42	1	0.91	42.7
Irri.Water Pro.	5.68	1	0.85	23.55

8.1: Kerekicho ANOVA Results

ANOVA				
Parameters	sum of squers	df	R	F
PHinitial	3.47	1	0.31	1.87
PHdevel.	14	1	0.45	3.21
PHmid	214	1	0.45	3.25
PH late	56.8	1	0.17	0.82
LA initial	2.62	1	0.82	19.5
LA devel.	6.5	1	0.38	2.47
LA mid.	6.4	1	0.15	0.72
LA late	29.68	1	0.83	19
Yield	288426666.7	1	0.78	14.63
Water pro.	0.699	1	0.91	41.88
Irri.Water Pro.	21.68	1	0.93	51.82

Appendix 9: Daily climate data

9.1. Daily climate data of Jawe

Dates	T^0C		RH	Wind	sunshine	Dates	T^0C		RH	Wind	sunshine
	Max	Min					Max	Min			
4/25/2015	27	11.4	60	0.69	7.7	5/24/2015	22.8	11.5	73	0.7	4.1
4/26/2015	27.5	13	70	0.8	2.7	5/25/2015	20.5	13	86	0.5	4.7
4/27/2015	23.4	13.4	51	0.99	3.8	5/26/2015	22.6	11.5	71	0.71	1.2
4/28/2015	26.4	13.5	44	1.77	8.2	5/27/2015	23.2	12.6	80	0.56	8.4
4/29/2015	27.2	14.6	35	1.71	10.5	5/28/2015	22.4	13	81	0.46	9.5
4/30/2015	27	15.4	39	1.43	5.3	5/29/2015	21	12.6	91	0.56	5.5
5/1/2015	29	16	43	1.08	5.1	5/30/2015	23	13	62	0.60	5
5/2/2015	28.2	12.5	53	0.93	5.7	5/31/2015	23.4	12.4	66	0.57	8.5
5/3/2015	28.5	12.1	54	0.93	5.6	6/1/2015	23.2	13	66	0.56	8
5/4/2015	25	12.6	68	0.89	6.9	6/2/2015	22	11.6	74	0.51	6.4
5/5/2015	23.4	12	83	0.65	7	6/3/2015	24	11.8	57	1.06	10.4
5/6/2015	20.6	12.2	85	0.68	7.8	6/4/2015	25	12.5	57	0.88	7.5
5/7/2015	20.5	13	82	0.54	9.1	6/5/2015	25.2	11	72	0.66	8.1
5/8/2015	21	12.5	82	0.58	7.7	6/6/2015	24	10	75	0.63	5.5
5/9/2015	21.5	12	80	0.49	5.6	6/7/2015	23	11.5	75	0.53	7.8
5/10/2015	21.2	14	86	0.69	0.8	6/8/2015	23.2	11	71	0.63	1.5
5/11/2015	24.4	12.4	68	0.56	8	6/9/2015	22	11.6	79	0.52	0.5
5/12/2015	25.6	11	61	0.89	7.5	6/10/2015	22.4	12.5	76	0.79	5.7

5/13/2015	25	13.2	76	0.77	2.4	6/11/2015	20	11.6	83	0.6	3
5/14/2015	25.5	10	57	0.77	7.4	6/12/2015	21	13	83	1.09	4
5/15/2015	27	12.6	54	1.09	7.9	6/13/2015	23	14.4	77	1.13	4.8
5/16/2015	25	13	67	0.79	6.1	6/14/2015	22	13	75	1.02	6.8
5/17/2015	25.4	12	69	0.68	5.3	6/15/2015	22.2	13.5	75	1.09	4
5/18/2015	23	13.5	76	0.7	4.6	6/16/2015	23	14	73	0.96	4.4
5/19/2015	25.2	11.5	59	0.64	7.1	6/17/2015	22	13.4	74	0.83	5.5
5/20/2015	26	11	59	0.82	8	6/18/2015	22.2	14.5	82	0.96	7.5
5/21/2015	25.5	11.2	66	0.62	7.5	6/19/2015	21	11.5	81	0.55	2.8
5/22/2015	24	11	68	1.06	1	6/20/2015	22.2	12.5	78	0.84	3.3
5/23/2015	23	12.5	55	0.5	7.4	6/21/2015	22	13.5	78	0.75	0.7

9.2. Daily climate data of Angacha

Dates	T^0C		RH	Wind	sunshine	Dates	T^0C		RH	Wind	sunshine
	Max	Min					Max	Min			
4/23/2015	27	9.6	46	0.67	10	5/31/2015	23.4	12.4	66	0.57	8.5
4/24/2015	28	9.6	45	0.65	10	6/1/2015	23	12	66	0.56	8
4/25/2015	27	11.4	60	0.69	7.7	6/2/2015	22	11.6	74	0.51	6.4
4/26/2015	27.5	13	70	0.8	2.7	6/3/2015	24	11.8	57	1.06	10.4
4/27/2015	23.4	13.4	51	0.99	3.8	6/4/2015	25	12.5	57	0.88	7.5
4/28/2015	26.4	13.5	44	1.77	8.2	6/5/2015	25.2	11	72	0.66	8.1

4/29/2015	27.2	14.6	35	1.71	10.5	6/6/2015	24	10	75	0.63	5.5
4/30/2015	27	15.4	39	1.43	5.3	6/7/2015	23	11.5	75	0.53	7.8
5/1/2015	26	16	38	1.4	5	6/6/2015	22	11	75	0.53	7
5/2/2015	28.2	12.5	53	0.93	5.7	6/9/2015	22	11.6	79	0.52	0.5
5/3/2015	27	11.6	62	0.92	6.2	6/10/2015	22.4	12.5	76	0.79	5.7
5/4/2015	25	12.6	68	0.89	6.9	6/11/2015	20	11.6	83	0.6	3
5/5/2015	23.4	12	83	0.65	7	6/12/2015	21	13	83	1.09	4
5/6/2015	20.6	12.2	85	0.68	7.8	6/13/2015	23	14.4	77	1.13	4.8
5/7/2015	20.5	13	82	0.54	9.1	6/14/2015	22	13	75	1.02	6.8
5/8/2015	21	12.5	82	0.58	7.7	6/15/2015	22.2	13.5	75	1.09	4
5/9/2015	21.5	12	80	0.49	5.6	6/16/2015	23	14	73	0.96	4.4
5/10/2015	21.2	14	86	0.69	0.8	6/17/2015	22	13.4	74	0.83	5.5
5/11/2015	24.4	12.4	68	0.56	8	6/18/2015	22.2	14.5	82	0.96	7.5
5/12/2015	25.6	11	61	0.89	7.5	6/19/2015	21	11.5	81	0.55	2.8
5/13/2015	25	13.2	76	0.77	2.4	6/20/2015	22.2	12.5	78	0.84	3.3
5/14/2015	25.5	10	57	0.77	7.4	6/21/2015	22	13.5	78	0.75	0.7
5/15/2015	27	12.6	54	1.09	7.9	6/22/2015	21	12.5	82	0.75	1
5/16/2015	25	13	67	0.79	6.1	6/23/2015	20	13.5	89	0.42	1.2
5/17/2015	25.4	12	69	0.68	5.3	6/24/2015	20.2	11.6	86	0.55	1
5/18/2015	23	13.5	76	0.7	4.6	6/25/2015	20	12.6	81	0.77	1.1
5/19/2015	25.2	11.5	59	0.64	7.1	6/26/2015	20.5	14	83	0.48	1.1
5/20/2015	26	11	59	0.82	8	6/27/2015	21.5	11.6	78	0.66	4.4

5/21/2015	25.5	11.2	66	0.62	7.5	6/28/2015	20.6	13.5	84	0.72	3.8
5/22/2015	24	11	68	1.06	1	6/29/2015	19.5	13.4	89	1.06	5.2
5/23/2015	23	12.5	55	0.5	7.4	6/30/2015	21.5	12.5	80	0.49	7
5/24/2015	22	12	54	0.5	7	7/1/2015	21	12	81	0.50	8
5/25/2015	20.5	13	86	0.5	4.7	7/2/2015	20.5	12	75	0.44	5.9
5/26/2015	22.6	11.5	71	0.71	1.2	7/3/2015	22	11.2	77	0.48	4.3
5/27/2015	23.2	12.6	80	0.56	8.4	7/4/2015	23	11	74	0.52	3.2
5/28/2015	22.4	13	81	0.46	9.5	7/5/2015	21.4	10.4	72	0.43	2.5
5/29/2015	21	12.6	91	0.56	5.5	7/6/2015	22.5	8.5	71	0.52	1.3
5/30/2015	22.5	12	72	0.7	4.9	7/7/2015	23	10	73	0.55	1.3

Appendix 10: Daily rainfall Data

10.1: Daily rainfall data at Angacha rainfall station

DAP	Rain (mm)	Effective RF(mm)	DAP	Rain (mm)	Effective RF(mm)	DAP	Rain mm)	Effective RF(mm)
1	0	0	26	6	5.4	51	0	0
2	0	0	27	3.1	2.79	52	0	0
3	0	0	28	0	0	53	8.9	8.01
4	0	0	29	0	0	54	0	0
5	0	0	30	6.7	6.03	55	2.2	1.98
6	1.2	1.08	31	5.3	4.77	56	1.2	1.08
7	0	0	32	0	0	57	0	0
8	0	0	33	0	0	58	7.8	7.02
9	0.2	0.18	34	6.7	6.03	59	7.2	6.48
10	0.4	0.36	35	5	4.5	60	0	0
11	0	0	36	3.3	2.97	61	6.9	6.21
12	0.7	0.63	37	0	0	62	0	0
13	1.4	1.26	38	8	7.2	63	0	0
14	1.1	0.99	39	0	0	64	8	7.2
15	0	0	40	0	0	65	6	5.4
16	0	0	41	11.6	10.4	66	0	0
17	0.8	0.7	42	0	0	67	4.1	3.69
18	1	0.9	43	7.4	6.6	68	10	9
19	1	0.9	44	0	0	69	10	9
20	0	0	45	0	0	70	2	1.8
21	0	0	46	0	0	71	0	0
22	0	0	47	0	0	72	0	0
23	0	0	48	2.7	2.4	73	4.6	4.1
24	8.3	7.4	49	11.1	9.9	74	4.2	3.7
25	0	0	50	0	0	75	6.3	5.6

Appendix 10.2: daily rainfall data of Jewe

DAP	Rain (mm)	Effective RF(mm)	DAP	Rain (mm)	Effective RF(mm)	DAP	Rain (mm)	Effective RF(mm)
1	0	0	21	4	3.6	41	0	0
2	0	0	22	10	9	42	0	0
3	0	0	23	10	9	43	0	0
4	0	0	24	0	0	44	6.1	5.4
5	0.9	0.8	25	0	0	45	8	7.2
6	0	0	26	4	3.6	46	8.2	7.3
7	1.7	1.53	27	8	7.2	47	0	0
8	0	0	28	2	1.8	48	0	0
9	0	0	29	1.3	1.1	49	7.8	7.0
10	1	0.9	30	1	0.9	50	10	9
11	0	0	31	10	9	51	0	0
12	0	0	32	11	9.9	52	0	0
13	0	0	33	0	0	53	0	0
14	0	0	34	0	0	54	0	0
15	0	0	35	0	0	55	12.2	10.98
16	0	0	36	0	0	56	10.2	9.18
17	0	0	37	16	14.4	57	0	0
18	0	0	38	13.4	12.06	58	6	5.4
19	0	0	39	0	0	59	10.5	9.45
20	0	0	40	0	0			

Images whchi were taken during the activity of the research