

**PERFORMANCE EVALUATION OF IRRIGATION MANAGEMENT
PRACTICE AT AMBOMESK IRRIGATION UNIT IN *KOGA* IRRIGATION
SCHEME, ETHIOPIA**

MSc THESIS

BERHANIE ENDRIE

**FEBRUARY 2017
HARAMAYA UNIVERSITY, HARAMAYA**

**Performance Evaluation of Irrigation Management Practice at Ambomesk
Irrigation Unit in *Koga* Irrigation Scheme, Ethiopia**

**A Thesis Submitted to the Postgraduate Program Directorate through
The School of Water Resource and Environmental Engineering,
HARAMAYA UNIVERSITY**

**In Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE IN IRRIGATION ENGINEERING**

Berhanie Endrie

**February 2017
Haramaya University, Ethiopia**

HARAMAYA UNIVERSITY
POSTGRADUATE PROGRAM DIRECTORATE

I hereby certify that I have read and evaluated this thesis entitled **Performance Evaluation of Irrigation Management Practice at Ambomesk Irrigation Unit in Koga Irrigation Scheme, Ethiopia** prepared under my guidance by Miss Berhanie Endrie Hussien. We recommend that it be submitted as fulfilling the thesis requirement.

Prof. Shoeb Quraishi (PhD)

Thesis Major Advisor

Signature

Date

Petra Schmitter (PhD)

Thesis Co-Advisor

Signature

Date

As member of the Board of Examiners of the M.Sc. Open Defense Examination, I certify that we have read, evaluated the thesis prepared by Berhanie Endrie Hussien and examined the candidate. I recommended the thesis be accepted as fulfilling the Thesis requirement for the degree of Master of Science in Irrigation Engineering.

Chairperson

Signature

Date

Internal Examiner

Signature

Date

External Examiner

Signature

Date

DEDICATION

This thesis is especially dedicated to my co advisor **Dr. Petra Schmitter**, and to all my families for their love and dedicated partnership in the success of my life.

STATEMENT OF THE AUTHOR

This is to certify that this thesis is my own work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at Haramaya University and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that this thesis has not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

Brief quotations from this thesis are allowed without special permission provided that accurate acknowledgement of source is made. Requests for permission for extended quotation or reproduction of this manuscript in whole or in part may be granted by the Head of the School of Water Resource And Environmental Engineering or Directorate of Postgraduate Program when in his or her judgment the proposed use of the material is in the interest of scholars. In all other instances, however, permissions must be obtained from the author.

Name: Berhanie Endrie Hussien

Signature: _____

Place: Haramaya University, Haramaya

Date of submission: February 2017

BIOGRAPHICAL SKETCH

The author was born in March 1973 at Dessie Town south wollo zone. She attends her elementary and secondary education at Dessie Etege Menen elementary School and Hote Junior and Senior Secondary School respectively. She completed her high school education in 1990.

She joined Agarfa Technical Educational Vocational Collage and graduated Diploma in Natural Resource in 2004. In 2010 graduated with B.Sc. degree in Soil and Water Engineering and Management from Haramaya University.

She was working in office of Agriculture, South wollo zone, Dessie Town as soil and water conservation expert. In July 2014, she was enrolled to the Postgraduate Program Directorate of Haramaya University to pursue her M.Sc. study under Soil and Water Engineering program, (Irrigation Engineering stream).

ACKNOWLEDGMENTS

First of all I would like to thank Almighty God who made possible for me to begin and finish this work successfully. My deepest gratitude and appreciation goes to my advisors, Professor Shoeb Quraishi and Dr. Petra Schmitter, for their enthusiastic effort, invaluable and stimulating guidance, moral support, and unbounded constructive comment, from the inception of the study up to the preparation of the manuscript. Without their encouragement, insight, guidance and professional expertise the completion of this work would have been impossible.

I would like to thank the Livestock and Irrigation Value Chain for Ethiopian Smallholder Project (LIVES) led by - the International Livestock Research Institute (ILRI) and the International Water Management Institute (IWMI) for financing this project. I am thankful to the Dessie Town Agricultural office also.

My deepest gratitude and appreciation is extended to Dr. Amare Hailelassie, Dr. Yigzaw Desalene, Melaku Tesma and Banteamlak Mengstie for their kind collaboration, encouragement and support starting from site selection to the implementation of the research activities and providing materials and also for their genuine and constant advice. I would also like to appreciate Dr. Fentaw Abegaz, James Ray, Assum Tesfaw, Amblu Tebanel and Kassahun Alebachew for their technical support.

Great appreciation and special thanks is given to Mecha Agriculture Office, Agronomy expert Guadenew zerehun, data collector Ewnetu Kende, Mandefro Agumas and Ambomesk farmers who helped me during my field work and worked with me constantly in the field without any payment.

I am highly indebted to my beloved husband Guangul Tegene for their great moral. Acknowledgment is expressed to Dessie Town Agriculture Office staff member friends. Finally I would like to express my acknowledgment for the generous support and contribution of all my colleagues, friends, families and relatives.

ABBREVIATIONS AND ACRONYMS

AFI	Alternate Furrow Irrigation
ANOVA	Analysis of Variance
AW	Available Water
BEC	Bulk Electrical Conductivity
CFI	Conventional Furrow Irrigation
CV	Coefficient of Variance
DAP	Di Ammonia Phosphate
ET	Crop Evapotranspiration
ET _o	Reference Evapotranspiration
ET _c	Crop Water Requirement
FAO	Food and Agriculture Organization
FC	Filed Capacity
FDR	Frequency Domain Reflectometry
FF	Farmers Fertilizer
FIP	Farmer Irrigation Practice
FSWD	Full Stop Wetting Detector
GMS	Granular Metric Sensor
GPS	Geographic Information System
ILRI	International Livestock Research Institute
IWMI	International Water Management Institution
K _c	Crop Coefficient
LSD	Lest Significant Difference
m.a.s.l.	Meter above Sea Level
MoWR	Ministry of Ware Recourse
NMM	Neutron Moisture Meter
pH	Power of hydrogen
PVC	polyvinylchloride
PWP	Permanent Wilting Point
RCBD	Randomized Complete Block Design

RF	Recommended Fertilizer
RH	Relative Humidity
Rn	Net Radiation
SAS	Statistical Analysis
SE	Standard Error
SOM	Soil Organic Matter
SWP	Soil Water Potential
TDR	Time domain Reflectometry
VSWC	Volumetric Soil Water Content
WFD	Wetting Front Detector
WUE	Water Use Efficiency
WP	Water Productivity
USDA	United State Department of Agriculture

TABLE OF CONTENTS

STATEMENT OF THE AUTHOR	v
BIOGRAPHICAL SKETCH	vi
ACKNOWLEDGMENTS	vii
ABBREVIATIONS AND ACRONYMS	viii
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
LIST OF TABLES IN THE APPENDIX	xv
LIST OF FIGURES IN THE APPENDIX	xvi
1. INTRODUCTION	1
2. LITERATURE REVIEW	5
2.1. Irrigation	5
2.2. Irrigation Development in Ethiopia	5
2.3. Crop Water Requirement	6
2.4. Irrigation Scheduling	7
2.5. Monitoring Soil Water in Irrigation Scheduling	8
2.5.1. Wetting Front Detector	9
2.5.2. Tensiometers	12
2.5.3. Gypsum Block	13
2.5.4. Granular Metric Sensor (GMS)	14
2.5.5. Frequency Domain (FD): Capacitance and FDR	15
2.5.6. Time Domain Reflectometry (TDR)	16
2.5.7. Capacitance Sensors for Use in Access Tubes	17
2.5.8. Neutron probe	18
2.6. Irrigation Performance Indicator	19
2.6.1. Application efficiency	19
2.6.2. Distrubution uniformity	20
Continues	

2.6.3. Storage efficiency	21
2.6.4. Deep percolation losses	22
2.6.5. Runoff loss	22
2.7. Water Productivity	23
2.8. Agronomy and Management of Potato (<i>Solanum tuberosum</i> L.)	24
3. MATERIALS AND METHODS	26
3.1. Description of the Study Area	26
3.1.1. Location of the study area	26
3.1.2. Climate	27
3.1.3. Soils	28
3.1.4. Vegetation	28
3.1.5. Cropping practices and crop production	28
3.2. Experimental Design and Treatment	29
3.2.1. Experimental design	29
3.2.2. Land and seed bed preparation	31
3.2.3. Materials used	31
3.2.4. Installation of full stops wetting detector	31
3.3. Data Collection and Laboratory Analysis	32
3.3.1. Soil moisture content determination	32
3.3.2. Soil nutrient availability	33
3.4. Water Application Duration	33
3.5. Measurement of Water Flow in Partial Flume	34
3.6. Irrigation Scheduling by WFD	34
3.6.1. Amount of irrigation water applied	34
3.6.2. Irrigation interval	35
3.7. Water productivity	36
3.8. Statistical Analysis	37
4. RESULTS AND DISCUSSION	38

Continues

4.1. Soil Physical Characteristics	38
4.3. Irrigation Water saved	39
4.4. Moisture Content	41
4.5. Agronomic Performance of Potato	42
4.5.1. Plant height	42
4.7. The Status of Fertilizer	45
4.8. Water, Fertilizer and Yield Interaction	47
4.9. Water Productivity	49
5. SUMMARY, CONCLUSION AND RECOMMENDATIONS	50
5.1. Summary and Conclusion	50
5.2. Recommendations	51
6. REFERENCE	52
7. APPENDICES	60
7.1. Appendix Table	60
7.2. Appendix Figure	71

LIST OF TABLES

Tables	Page
1. Physical characteristics of the soil	38
2. Discharge interaction between irrigation time and applied water in total crop season	39
3. Irrigation water applied on WFD and FIP	40
4. Using TDR volumetric moisture content before irrigation & applied water	41
5. Gravimetric moisture content after 24 hr of irrigation	42
6. Mean value of potato plant height at 50 and 100 days	43
7. Marketable and non-marketable yield	45
8. Status of fertilizer in the soil before planting and after harvesting	47
9. Mean value of water, fertilizer and yield of potato	48
10. Mean value of crop water productivity	49

LIST OF FIGURES

Figures	Page
1. Position of WFD after irrigation and management	10
2. Location map of Koga watershed in Mecha Worda	27
3. Location and layout of experiment in farmer`s field	30
4. Water amounts at different growth stages of potato crop	41

LIST OF TABLES IN THE APPENDIX

Appendix Tables	Page
1. Physical and chemical properties of soil	60
2. Irrigation based on WFD and FIP single experimental data sheet	61
3. Irrigation applied water amount each irrigation with wetting front detector	62
4. Irrigation applied water amount each irrigation with farmer irrigation practice	63
5. Each irrigation applied water irrigation depth in WFD and FIR	63
6. Discharge, time, fertilizer, water, yield and water productivity	64
7. Applied water in four development stage of potato	65
8. Soil moisture measurement by TDR at three stages	66
9. Irrigation interval the study area determined by WFD for next season	67
10. Monthly Reference evapotranspiration of the crop	68
11. Potato crop parameters used for CROPWAT model	68
12. ANOVA plant height at 50 day	69
13. ANOVA plant height at 100 day	69
14. ANOVA applied water	69
15. ANOVA Marketable Yield	69
16. ANOVA Total Yield	70
17. ANOVA Non makeable Yield	70
18. ANOVA Potato crop water productivity	70

LIST OF FIGURES IN THE APPENDIX

Appendix Figures	Page
1. Installation of WFD	71
2. Discharge measurement by Parshall flume	71
3. Flowering to maturity stage of the potato crop	72
4. Potato crop yield at plant label	73

**PERFORMANCE EVALUATION OF IRRIGATION MANAGEMENT
PRACTICE AT AMBOMESK IRRIGATION UNIT IN KOGA
IRRIGATION SCHEME, ETHIOPIA**

ABSTRACT

*This research was conducted to introduce the concept of evaluating water saving, yield and water productivity of potato (*solanum tuberosum l.*) by using wetting front detector and different levels of fertilizer application at Koga irrigation scheme Ambomesk farmer's farm Mecha, woreda during 2016 irrigation season. The necessary data to calculate with nine replication were collected which were measurements of discharge, irrigation time, moisture content, plant height and yields. This was done by two factorial water management systems and fertilizer application that was irrigation with wetting front Detector and farmer irrigation practice combined with recommended fertilizer and farmer's fertilizer. The result of the analysis shows that the yield and water productivity contributing characters in the wetting front detector treatments irrigation were significantly higher compared to those in the farmer's irrigation practice treatments. Additionally, the yield and water productivity on the recommended fertilizer treatments were significantly higher compared to those in the farmer's fertilizer practice treatments. The highest yield for irrigation wetting front detector (34.06 t/ha) for recommended fertilizer and (32.86 t/ha) for farmers fertilizer and lowest yield for farmer irrigation practice (31.15 t/ha) for recommended fertilizer and (30.78 t/ha) for farmers fertilize were obtained. The highest water productivity of 3.42 kg/m³ was obtained with irrigation wetting front detector with recommended fertilizer and the least 2.52 kg/m³ was obtained with farmer's irrigation practice with farmer's fertilizer. The overall findings of these experiments are that Wetting front detector irrigation water management system can save 18.5 % water and labor that is (18.3 %) time save more over (7.5 %) yield increment with respect to farmer irrigation usual practice. Under the same water management method and different fertilizer, wetting front detector with recommended fertilizer (3.5 %) yield increment compared to farmer's fertilizer. The study is that wetting front detector with recommended fertilizer has explicit role in increasing the yield and water productivity of potato.*

1. INTRODUCTION

For a country like Ethiopia that follows Agricultural Development Lead Industrialization, there is no readily identifiable yield increasing technology other than improved seed irrigation, fertilizer approach. Irrigation will, therefore, play an increasingly important role now and in the future both to increase the yield from already cultivated land and to permit the cultivation of what is today called marginal or unusable land due to moisture deficiency (FAO, 2002). In addition, production intensification without irrigation in the face of vagaries of weather cannot be imagined.

Irrigation is an essential component of agricultural management where greater production of food and fiber is required despite severe constraints of water resources. Effective use of irrigation water is a key issue for agricultural development in regions where water is limiting factor for crop production. The amount of water and land available for agriculture is limited in many developing countries. Although efforts to increase crop production have been focused on the field of irrigation, the world is continually challenged to increase production using an ever decreasing amount of water. Therefore, the world wide decline in water resources requires further development of water saving irrigation strategies in order to improve irrigation water base and crop water use efficiency. Thus, increasing water use efficiency has been an urgent issue in such a region where water demand has been an increasing concern. One of the possible approaches is to increase the efficiency and productivity of the existing irrigation systems to optimize water use i.e. less volume of applied water with greater production (Kassaw, 2011).

The appropriate application of water that, assures adequate soil moisture, is available for crop consumptive use without excessive run off, deep percolation or conveyance losses must be the goal of all irrigators. There are many methods available for farmers to schedule irrigation applications. They range from the simple feel and appearance method to sophisticated irrigation scheduling techniques using microcomputers.

The science of irrigation scheduling has a long and illustrious pedigree. Field monitoring of soil suction began in the 1930's with the development of the tensiometer (Richards and Neal 1936), followed by water content measurement using neutron scattering (Gardner and Kirkham 1952).

More recently the development of a range of capacitance or reflectometry probes that measure the dielectric property of soil (Topp and Davis 1985, White and Zegelin 1995), has reinvigorated interest in soil water monitoring. Other methods for improving irrigation have proceeded in parallel with soil water monitoring. The simplest is the pan evaporation crop factor method, which has been greatly enhanced by availability of automated weather data acquisition and crop simulation models (Allen *et al.* 1998, Annandale *et al.* 1999). Lastly there are several methods to monitor the water status of the plant itself, the simplest field-based method being canopy temperature (Jackson *et al.* 1977) as cited in Stirzaker *et al.*, (2004).

The wetting front detector (WFD) was conceived and developed against the background of poor adoption of commonly available technologies. Essentially the WFD reframed the age old irrigation scheduling question from ‘when to turn the water on’ to ‘when to turn it off’ (Stirzaker, 2003). The focus of soil based monitoring had been on specifying refill points, i.e. how dry the soil could be allowed to get without affecting production of the crop.

Farmers in poor areas have suffered from chronic poverty and severe food insecurity being vulnerable to climatic changes and dependant on variable rainfall. This is mainly attributed to a low level of agricultural productivity. Such low productivity areas are characterized by persistent rural poverty, and increasing population pressure has often resulted in a vicious circle of poverty and environmental degradation (Von Braun *et al.*, 2008). As many of the low productivity areas have untapped water resources, irrigation development is being suggested as a key strategy to enhance agricultural productivity and to stimulate economic development (Bhattarai *et al.*, 2002). In the contemporary literature, irrigated farming is recognized as central in increasing land productivity, enhancing food security, earning higher and more stable incomes and increasing prospects for multiple cropping and crop diversification (Hussain *et al.*, 2001; Smith, 2004). In some places, cereal production more than doubled between 1995 and 2001 due to the combined effect of expansion of irrigation and the use of high yielding varieties and fertilizers (Hussain and Hanjra, 2004).

The study area Mecha is one of great food insecurity, which is a problem for the majority of the rural population (Tesfaye and Fasile, 2011). During the feasibility study, the command area of the Koga irrigation scheme was designed to irrigate 7000 ha, but in reality it is not covering this area. The reason for this is over irrigation, which is the result of a lack of knowledge regarding

adequate water application amounts and poor irrigation scheduling. Most farmers think that more water used to irrigate a crop, the higher the crop productivity. This over irrigation washes away necessary plant nutrients and leads to deep percolation beyond the root zone, resulting in land fertility loss and productivity decreases. Now irrigation water utilization is a serious problem in the study area. The poor adoption of irrigation scheduling by farmers leads to irrigation water scarcity for agricultural production in the Koga scheme. The shortage of irrigation water has become the source of conflict between irrigators and Water User Association. The problem of low water use efficiency has contributed to the under development of scientifically informed irrigation in the locality as well as low crop production and productivity. Currently, a considerable numbers of farmers/irrigators have been out of production in the irrigation season rather than producing high value and short duration seasonal horticultural crops.

In most irrigable lands, horticultural crops play an important role in contributing to the household food security. This irrigation area, irrigation is typically applied on a routine basis without scheduling and inadequate management of irrigation water has been an important limiting factor to potato production. The farmers generally lack knowledge on aspects of soil water plant relationship and they apply water to the crop regardless of the plant needs. Therefore, irrigation scheduling based on deficit irrigation requires careful evaluation to ensure enhanced efficient use of increasingly scarce irrigation water in this area. The knowledge of proper irrigation scheduling, when to irrigate and how much water to apply, is essential to optimize crop production per unit water and for sustaining irrigated agriculture on permanent footing (Anac *et al.*, 1999).

Irrigation without soil moisture monitoring can be costly, wasteful guesswork. (Stirzaker *et al.*, 2000, Stirzaker 2003). A much simpler tool for soil moisture measurement has been developed for practical use in the field. The Full Stop Wetting Front Detector (FSWD) is simple, accurate, and affordable for small scale growers. It does not require wires, batteries, computer and loggers unlike most other soil moisture sensors. The FSWD shows how deep the water has penetrated into the soil after irrigation. It also stores a sample of water from the soil so that fertilizer and salt levels can be monitored. It can be used to find out if irrigation water is too little or too much, assist in management of fertilizer and salts, and detection of water logging (Palada *et al.*, 2011). Generally soil moisture readings are useful to determine how much water is available for the

crop, when to start irrigating, and how much water to apply. Soil moisture monitoring can help conserve water and energy, minimize pollution of surface and ground water, and produce optimum crop yields. Efficient scheduling of irrigation water applications gives the highest return for the least amount of water (Werner, 2002).

The study was useful in determining the irrigation crop water demand and irrigation interval in the irrigation scheme command area regarding the usage of wetting front detectors as a tool to identify the actual crop water requirement, so that water productivity and water savings could be ascertained. An additional benefit is that fertility is not lost by over irrigation and productivity increased. The sensor is an easy tool for farmers, involving no complicated calculations or reading numbers, tasks involved when using electronic sensors. Wetting front detectors help inform the farmer that the wetting front of irrigated water has reached a certain root depth, indicating to the irrigator that an adequate amount of water has been applied during one irrigation, which helps prevent excess water usage and deep percolation in addition to overflow runoff losses. This efficient water use helps solve conflicts between irrigators and increases agricultural production the irrigation command area increases and maintains its fertility.

The general objective of this study is to ascertain the amount of potential water savings and evaluate the crop and water productivity by using Wetting Front Detector, with different levels of fertilizers applied.

- To quantify the amount of water saving by using wetting front detectors compared to farmers practice,
- To evaluate irrigation scheduling techniques for potato crops at the scheme area
- To evaluate yield and water productivity of potato with different levels of fertilizer application and irrigation practices (i.e. WFD and farmer practice).

2. LITERATURE REVIEW

2.1. Irrigation

A technique that involves artificially providing water to crops enables them to grow. This technique is used in farming to enable plants to grow when there is not enough rain, particularly in arid areas. It is also used in less arid regions to provide plants with the water they need when seed setting. When using irrigation due to insufficiency of rainfall to allow crop to grow, irrigation is said to be supplementary; which is the process of distribution of additional water to the crop with the objective of stabilizing and increasing yield, in environments where the given crop is usually grown under rainfed agriculture. In arid and semi arid areas, irrigation is used for production during the dry season in the absence of rain; in that case irrigation is said full. Related to full irrigation, one can use sometime deficit irrigation to save water (Water Report 22: Deficit Irrigation Practices, FAO).

2.2. Irrigation Development in Ethiopia

Modern water development schemes are a relatively new phenomenon in the country. The Imperial government took the first initiatives in water resource development in the second half of the 1950s. Large scale water projects for agricultural purposes and power generation were constructed from the end of the 1950s, and were concentrated in the Awash valley as part of the agro-industrial enterprises that were expanding in the area at that time. They subsequently spread to the Rift valley and the Wabe Shebelli basin. Essentially, the government's interest at that time centered almost entirely on large-scale and high technology water projects: hydro-power dams, irrigation schemes and water supply projects for Addis Ababa and a few major towns.

From 1974 to 1991, no large scale private capital investment was committed as a result of the prohibition of private land ownership or rental of land on commercial scale by the land reform proclamation of 1975 as per the then socialist policy adopted by the Government. During this period public capital expenditure concentrated on the development of state farms and producer cooperatives which contributed for less than 10 percent of the total production during that period (Fekadu *et al.*, 2000).

The Military Government nationalized the rural lands and commercial farms, and changed the existing commercial farms together with newly established farms (mainly rain fed farms), into state owned enterprises. It was considered as a way out to address the problem of food self-insufficiency and to earn foreign currency. Consequently, commercial farm development during this regime was practically nonexistent. On the other hand, development of small scale irrigation was encouraged to be effected by the local farmers to cope with recurrent droughts (Fekadu *et al.*, 2000).

The attempt by the government to enhance the participation of individual peasants in small scale irrigation development had been considered earlier throughout the 1970s and 1980s; but the results were below expectations. Though the Government has been providing irrigation infrastructure free of charge and the infrastructure development progressed well, but putting the schemes into production at optimum level was very disappointing, and in some instances only 10% of the developed areas were put into production (Fekadu *et al.*, 2000).

2.3. Crop Water Requirement

Crop water requirements and crop irrigation requirements can be carried out from basic information from the crops selected and should include, average planting date and average harvesting date (FAO, 1996). Standard information on crop coefficient, rooting depth, depletion level and yield response factors, and length of individual growth stages are also needed.

The water requirements are different from one crop to another. Although growing crops are continuously using water, the rate of water use depends on (1) the kind of crop, (2) the degree of maturity and (3) atmospheric condition, such as radiation, temperature, wind, and humidity. The rate of growth at different soil water contents varies with different soils and crops. During early stages of growth the water needs are generally low, but they increase rapidly during the maximum growing period to the fruiting stage. During the later stages of maturity, water use decreases as the crops ripen (Schwab *et al.*, 1995).

CROPWAT model is a computer program for irrigation planning and management, developed based on the FAO Penman-Moneith method (Smith, 1992). Calculation of water requirements utilizes inputs of climatic, crop and soil data, as well as irrigation and rainfall data. Its basic

function includes the calculation of reference evapotranspiration, crop water requirement and crop and scheme requirement. Reference evapotranspiration can be calculated from the actual maximum and minimum temperatures, relative humidity, sunshine/radiation and wind speed data, According to Penman-Monteith method (Allen *et al.*, 1998), the equation can be written as:

$$ET_o = \frac{0.408\Delta(R_n - G) + y \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + Y(1 + 0.34U_2)} \quad (2.1)$$

where: ET_o is reference evapotranspiration in mm/day, R_n net radiation at the top surface MJm^2/day , G is soil heat flux density MJm^2/day , T mean daily air temperature at 2 m height ($^{\circ}C$), U_2 is wind speed at 2 m height (m/s), $e_s - e_a$ is saturation vapor pressure deficit (Kpa), Δ is the slope vapor pressure curve ($Kpa/^{\circ}C$), Y is psychrometric constant ($Kpa/^{\circ}C$).

Crop water requirements (ET_c) over the growing seasons are determined from ET_o and estimates of crop evaporation rates, expressed as crop coefficient (K_c), are based on well-established procedures. The updated values of crop coefficients are determined from Allen *et al.*, (1998).

$$ET_c = K_c \times ET_o \quad (2.2)$$

where: ET_c is crop evapotranspiration, K_c is crop coefficient, and ET_o is reference evapotranspiration in mm/day.

2.4. Irrigation Scheduling

Irrigation scheduling is the process of determining when to irrigate and how much water to apply per irrigation. Proper scheduling is essential for the efficient use of water, energy and other production inputs, such as fertilizer. It allows irrigations to be coordinated with other farming activities including cultivation and chemical applications. Among the benefits of proper irrigation scheduling is improved crop yield and/or quality, water and energy conservation, and lower production costs (James, 1988).

FAO (1989) explained that when surface irrigation methods are used, it is not very practical to vary the irrigation depth and frequency too much. In surface irrigation, variations in irrigation depth are only possible within limits. It is also very confusing for the farmers to change the

schedule all the time. Therefore, it is often important to estimate the irrigation schedule and to fix the most suitable depth and interval to keep the irrigation depth and the interval constant over the growing season.

Irrigation scheduling should be based on avoiding water deficit during the period of stolonization and tuber initiation and yield formation. Supply of water can be restricted during the early vegetative and ripening periods. Savings can also be attained by allowing higher soil water depletion toward the ripening period so that all available stored water in the root zone is used by the crop. This practice may also hasten maturity. Correct timing of irrigation may save irrigation applications including the last irrigation prior to harvest.

2.5. Monitoring Soil Water in Irrigation Scheduling

Measurement of soil water can be used to indicate when to irrigate, thus avoiding over and under irrigation. Soil water sensor measures either soil water potential (SWP) or volumetric soil water content (VSWC). Device for measuring potential include the tensiometer, gypsum block and granular matrix sensor (Shock *et al.*, 2005). A variety of frequency domain reflectometry (FDR) (Stizaker *et al.*, 2005), time domain reflectometry (TDR) (Chares worth, 2005) and capacitance probes (Fares and Alva, 2000) are available for measuring volumetric soil water content.

Measuring soil moisture detects if there is a water shortage that can reduce yields or if there is excessive water application that can result in water logging or leaching of nitrates below the root zone. Measuring soil moisture also can build an awareness and knowledge of each irrigated field that is invaluable for planning and management (Werner, 2002).

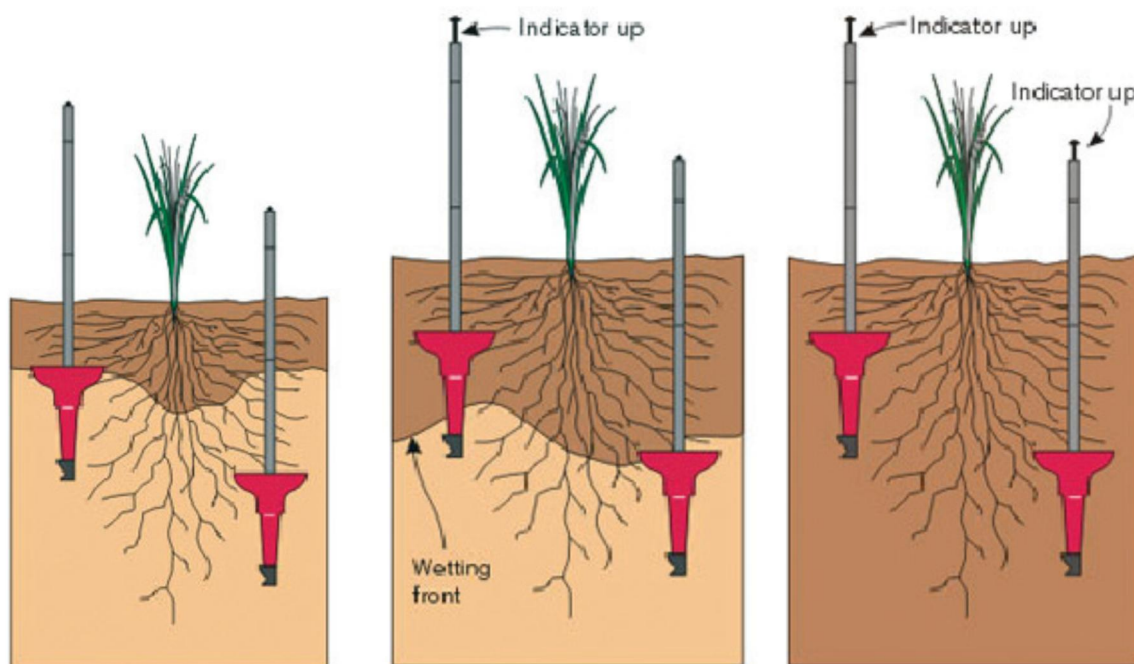
Monitoring soil moisture levels is required for effective irrigation water management. Many tried and proven methods of estimating or measuring soil moisture are available. The method selected depends on a variety of factors such as accuracy, cost, and ease of use (Werner, 2002).

2.5.1. Wetting Front Detector

Type of sensor (not SMP or VSWC) is the wetting front detector such as the “Full Stop sensor” which is a useful, simple and cheap sensor that indicates when sufficient irrigation has been applied by indicating the arrival of the wetting front at a given depth by the mechanical movement of a signal (Charlesworth, 2005; Stirzaker *et al.*, 2009).

Wetting front detectors are simple devices that are buried at points of interest and provide information to growers as to when water has reached that point in the soil profile. When soil moisture increases above a set point the detector switches on, or is activated, indicating that water has reached a given depth. When the soil moisture dries to below a set point the detector switches off. Wetting front detectors are often placed near the bottom of the root zone so that they can be used to warn against over irrigation (Jenny *et al.*, 2008).

WFDs are based around the tipping bucket analogy, where soil layers are viewed as a sequence of buckets that store water. As the upper bucket is filled by irrigation, it tips and spills excess water into the bucket below and so on down the profile. The WFD was designed to show when water moved from one layer to the next. It is comprised of a specially shaped funnel, a filter, and a float plus indicator mechanism. The funnel shape was designed so that the soil at its base reaches saturation when matric potential of the soil outside the funnel is around 2 kPa to 3 kPa (Stirzaker, 2008), which corresponds to a relatively ‘strong’ wetting front. Once saturation occurs at the base of the funnel, free water flows through a filter into a small reservoir and activates a float. The float trips a magnetically latched indicator, visible to the irrigator. These detectors are often installed at different depths and used in a similar way to that for tensiometry, namely a shallow detector indicating water entering the root zone and a deeper detector possibly warning of over irrigation (Stirzaker and Hutchinson, 2005).



A. Too little water

B. About right

C. Too much water

Figure 1. Position of WFD after irrigation and management

Full stop Wetting Front Detector showing soil moisture status:

- A. If indicator of the shallow detector rarely pops up, and then water is not moving deep enough to fill most of the root zone. More water should be applied.
- B. The indicator of the shallow detector should pop up regularly after irrigation. The deeper detector should respond during periods of high demand for water.
- C. If the indicators of both the shallow and deep detectors regularly pop up then water could be wasted. Apply less water or lengthen the period between irrigations.

In a project which is nearing completion in 2003, participatory action research was undertaken which involves application of the tool, training of farmers and field evaluation of findings (Stirzaker, 2003). Through the project the following has been achieved: Introduce farmers to the wetting front detector method and install detectors on selected farms. Develop appropriate guidelines for the use of wetting front detectors for different crops. Evaluate factors affecting the perceived acceptability of this irrigation scheduling technology by small scale subsistence

farmers. Determine from users their perception of whether the wetting front detectors saved water and/or increased yield.

The project has demonstrated acceptance of the wetting front detector by small scale subsistence farmers for practical irrigation scheduling under varying farming conditions. Several hundred prototype detectors have been distributed to farmers in South Africa and Australia, operating at both small and commercial scales. In almost all cases the farmers were very keen to try them out, regardless of their level of education or scale of operation. The Wetting Front Detector was designed to be cheap and “farmer friendly”. However, it also needs to be sufficiently accurate so that it can identify over and under irrigation. The detectors will be available commercially from a South African company by the end of 2003.

Melaku Tesma, (2015) result shows the reason of water saving is the installation of the Wetting Front Detector at 20 cm compared to the full root zone calculations in the TDR group. In the WFD group the devices is triggered when the moisture is reached at 20 cm of the root depth and the other portion of the root zone is slowly wetted and wetted without water loss by percolation, while for the TDR group the calculations are based on the assumed root zone of 40 cm. The measured field capacity of the top soil (0-20 cm) was 31.7 % and 33.67 % for the WFD and TDR treatment, respectively while the permanent wilting point was 20.6 % for both treatments. Melaku *et al.*, (2016) conference report indicates that the irrigation water applied was on average 372 mm for the WFD and 462 mm in the TDR plots. There is a non-significant 24% reduction of irrigation water application in WFD plots. The average irrigation reduction obtained is a lower compared to those reported in Schmitter *et al.*, (2015) for the furrow irrigation of potato (34 %) and wheat (39 %). In the latter study, experiments were conducted in Koga irrigation scheme where WFD plots were compared to farmers practice instead of soil moisture based irrigation scheduling. Melaku *et al.*, (2016) result shows the Crop Evapotranspiration (ET) for each field was calculated. On average 612 mm was used by the onion in the WFD plot which is 10 % less compared to the 677 mm in the TDR plot. The highest onion yield of 7087 kg ha⁻¹ was obtained in the TDR treatment and lower than the highest yield of 5800 kg/ha WFD treatment. The difference in lowest yield (286 kg/ha) obtained in both treatments was much smaller compared to the highest yield. The variation of onion yield between the farmers differed strongly within each of the irrigation treatment resulting in rather similar average yields of 3430 kg/ha (TDR) and

3758 kg/ha (WFD). Although the average yield in the WFD plot was slightly (10 %) higher, yields did not differ significantly ($p>0.05$). The average water productivity in the onion plots under the WFD treatment (0.60 kg/m^3) did not differ significantly from the (0.47 kg/m^3) obtained in the TDR treatment ($p>0.05$). Similar values were found for water user efficiency given that soil moisture changes before and after the season were minimal.

2.5.2. Tensiometers

Tensiometric methods estimate the soil water matric potential that includes both adsorption and capillary effects of the soil. The matric potential is one of the components of the total soil water potential that also includes gravitational (position with respect to a reference elevation plane), osmotic (salts in soil solution), gas pressure or pneumatic (from entrapped air), and overburden components. The sum of matric and gravitational potentials is the main driving force for water movement in soils and other soil like porous media.

All available tensiometric instruments have a porous material in contact with the soil, through which water can move. Thereby, water is drawn out of the porous medium in a dry soil and from the soil into the medium in a wet soil. It is worth noticing, that in general, they do not need a soil specific calibration, however, in most cases they have to be permanently installed in the field, or a sufficiently long time must be allowed for equilibration between the device and the soil before making a reading.

Working principle: When a sealed water-filled tube is placed in contact with the soil through a permeable and saturated porous material, water (inside the tube) comes into equilibrium with the soil solution (i.e., it is at the same pressure potential as the water held in the soil matrix). Hence, the soil water matric potential is equivalent to the vacuum or suction created inside the tube (Rafael, 2015).

Description: The tensiometer consists of a sealed water filled plastic tube with a ceramic cup at one end and a negative pressure gauge (vacuometer) at the other. The shape and size of the ceramic cup can be variable and the accuracy depends on the gauge or transducer used (about 0.01 bars). Typically the measurement range is 0–0.80 bar, although there are low-tension versions (0–0.40 bar) designed for coarse soils (Rafael, 2015).

The most familiar tool to irrigators is the tensiometer, which measures matric potential (suction) at the wet end of the plant-available water spectrum, making it valuable for horticultural crops. Streutker (1978) used tensiometers to keep the top (0 cm to 45 cm) soil layer at a high water potential and the subsoil water at a low water potential, achieved through medium frequency irrigation. This early research demonstrated how objective scheduling could result in significant water savings with no loss of yield. Promoted the use of tensiometers in the Loskop Irrigation District during the 1980s, and was very successful at improving irrigation management by, amongst other interventions, highlighting the contribution of shallow water tables to crop water use. They developed water yield functions for several crops enabling farmers to benchmark their water productivities and gauge whether or not they had room to improve. Generally, soil water tension increases with decreased soil water content; this means high readings for dry soils and low for wet soils. Most soil types, readings less than 10 cbars indicate a wet soil; above 50 cbars indicate a dry soil. The tensiometers are available in various lengths, allowing the monitoring of soil moisture tension at various depths.

The main limitation limited soil suction ranges less than 1 bar. Relatively slow response time. Especially in swelling or coarse soils, the ceramic cup can lose contact with soil, thus requiring reinstallation (Rafael, 2015).

2.5.3. Gypsum Block

Electrical resistance or gypsum blocks work in a similar manner to tension meters. They measure soil moisture tension. They do this by using a block of material (often gypsum) that absorbs water from the soil. Electrical probes in the block measure how much water the block contains. Again, the readings are reported in centi bars with the higher the reading the dryer the soil.

Description: A gypsum block sensor constitutes an electro chemical cell with a saturated solution of calcium sulphate as electrolyte. The resistance between the block embedded electrodes is determined by applying a small AC voltage (to prevent block polarization) using a Wheatstone bridge. Since changes to the soil electrical conductivity would affect readings, gypsum is used as a buffer against soil salinity changes (up to a certain level). The inherent problem is that the block dissolves and degrades over time (especially in saline soils) losing its calibration properties. It is recommended that the block pore size distribution match the soil texture being

used. The readings are temperature dependent (up to 3% change/°C) and field measured resistance should be corrected for differences between calibration and field temperatures. Some reading devices contain manual or self-compensating features for temperature or the manufacture provides correction charts or equations. Measurement range is 0.3–2.0 bar (Rafael, 2015).

The main limitation is low resolution, limited use in research. Block cannot be used for measurements around saturation (0–0.3 bar). Block properties change with time, because of clay deposition and gypsum dissolution. Degradation speed depends on soil type, amount of rainfall and irrigation, and also the type of gypsum block used (Rafael, 2015).

2.5.4. Granular Metric Sensor (GMS)

The granular matrix sensor is similar to the gypsum block, although apparently more durable. It operates on the principle that resistivity of the block depends on its moisture content, which in turn depends on soil water potential. Like the gypsum block, the granular matrix sensor has been reported to have slow response times in some circumstances and each sensor needs calibration (Shock *et al.*, 1998). However, both sensors are inexpensive Granular matrix sensor operate in the range 0.02 Mpa, and therefore have a wide range of application that the tensiometer. In a comparison of instruments, Munoz Capena *et al.* (2005) found that granular matrix sensors (and thensiometers) were the most and suitable for automatic drip irrigation. There appear to have been advances in design and performance over time, and Shock *et al.* (2004) concluded that it was a very effective irrigation scheduling aid for drip irrigated mint and onions on silt loam soils.

Description: The sensor consists of electrodes embedded in a granular quartz material, surrounded by a synthetic membrane and a protective stainless steel mesh. Inside the gypsum is used to buffer against salinity effects. This kind of porous medium allows for measuring in wetter soil conditions and lasts longer than the gypsum blocks. However, even with good sensor soil contact, GMS have rewetting problems after they have been dried to very dry levels. This is because of the reduced ability of water films to reenter the coarse medium of the GMS from a fine soil. The GMS material allows for measurements closer to saturation. Measurement range is 0.10–2.0 bar (Rafael, 2015).

The main limitation is slow reaction time. It does not work well in sandy soils, where water drains more quickly than the instrument can equilibrate. Not suitable for swelling soils. If the soil becomes too dry, the sensor must be pulled out, re-saturated and installed again. Temperature dependence. If connected to a logging system, another variable and sensor for temperature must be added to the system.

2.5.5. Frequency Domain (FD): Capacitance and FDR

Working principle: The electrical capacitance of a capacitor that uses the soil as a dielectric depends on the soil water content. When connecting this capacitor (made of metal plates or rods imbedded in the soil) together with an oscillator to form an electrical circuit, changes in soil moisture can be detected by changes in the circuit operating frequency. This is the basis of the Frequency Domain (FD) technique used in Capacitance and Frequency Domain Reflectometry (FDR) sensors. In Capacitance sensors the dielectric permittivity of a medium is determined by measuring the charge time of a capacitor made with that medium. In FDR the oscillator frequency is swept under control within a certain frequency range to find the resonant frequency (at which the amplitude is greatest), which is a measure of water content in the soil (Rafael, 2015).

Description: Probes usually consist of two or more electrodes (i.e., plates, rods, or metal rings around a cylinder) that are inserted into the soil. On the ring configuration the probe is introduced into an access tube installed in the field. Thus, when an electrical field is applied, the soil around the electrodes (or around the tube) forms the dielectric of the capacitor that completes the oscillating circuit. The use of an access tube allows for multiple sensors to take measurements at different depths (Rafael, 2015).

A soil-specific calibration is recommended because the operating frequency of these devices is generally below 100 MHz. At these low frequencies the bulk permittivity of soil minerals may change and the estimation is more affected by temperature, salinity, bulk density and clay content.

The main limitation sensing sphere of influence is relatively small (about 1.6 in.). For reliable measurements, it is extremely critical to have good contact between the sensor (tube) and soil.

Careful installation is necessary to avoid air gaps. Tends to have larger sensitivity to temperature, bulk density, clay content and air gaps than TDR. Needs soil specific calibration

2.5.6. Time Domain Reflectometry (TDR)

Time domain reflectometry is a precise and relatively newer technology based on sensing the dielectric constant of the soil which is dependent on the soil moisture. The equipment consists of an electronic meter connected to two rods placed into the ground. The instrument sends an electrical signal through the soil and the rods serve as the transmitter and receiver (Werner, 2002). To assess volumetric soil water content is the Time Domain Reflectometer. TDR voltage readings can be converted into volumetric soil water content (VSWC) which is a popular method to report the soil water status (Take *et al.*, 2007).

Working principle: The soil bulk dielectric constant (K_{ab}) is determined by measuring the time it takes for an electromagnetic pulse (wave) to propagate along a transmission line (TL) that is surrounded by the soil. Since the propagation velocity (v) is a function of K_{ab} , the latter is therefore proportional to the square of the transit time (t , in seconds) down and back along the (Rafael, 2015) TL:

$$K_{ab} = (c/v)^2 = ((c \cdot t)/(2 \cdot L))^2 \quad (2)$$

Where c is the velocity of electromagnetic waves in a vacuum ($3 \cdot 10^8$ m/s or 186,282 mile/s) and L is the length of the TL embedded in the soil (in m or ft).

Description: A TDR instrument requires a device capable of producing a series of precisely timed electrical pulses with a wide range of high frequencies used by different devices (e.g., 0.02–3 GHz), which travel along a TL that is built with a coaxial cable and a probe. This high frequency provides a response less dependent on soil specific properties like texture, salinity or temperature. The TDR probe usually consists of 2–3 parallel metal rods that are inserted into the soil acting as waveguides in a similar way as an antenna used for television reception. At the same time, the TDR instrument uses a device for measuring and digitizing the energy (voltage) level of the TL at intervals down to around 100 picoseconds. When the electromagnetic pulse traveling along the TL finds a discontinuity (i.e., probe-waveguides surrounded by soil) part of

the pulse is reflected. This produces a change in the energy level of the TL. Thereby the travel time (t) is determined by analyzing the digitized energy levels (Rafael, 2015)

Soil salinity or highly conductive heavy clay contents may affect TDR, since it contributes to attenuation of the reflected pulses. In other words, TDR is relatively insensitive to salinity as long as a useful pulse is reflected (i.e., as long as it can be analyzed). In soils with highly saline conditions, using epoxy-coated probe rods should solve the problem. However, this implies loss of sensitivity and change in calibration. It is interesting to notice that in addition to time of travel another characteristic of the pulse traveling through the soil (i.e., change in size or attenuation of the pulse) can be related to the soil electrical conductivity. Based on this some commercial devices incorporate the possibility of measuring water content and soil salinity simultaneously.

The main limitation is relatively expensive equipment due to complex electronics. Soil specific calibration required for soils having large amounts of bound water (i.e., those with high organic matter content, volcanic soils, etc.). Relatively small sensing volume (about 1.2 inch radius around length of waveguides) (Rafael, 2015)

2.5.7. Capacitance Sensors for Use in Access Tubes

The EnviroSCAN and Diviner 2000 from Sentek are two frequency domain measurement systems based on similar electronics but having very different uses. The Diviner 2000 employs a single capacitance type sensor housed in a cylindrical plastic probe, which is inserted into a plastic access tube and withdrawn in order to obtain 16 readings at depths from 10 to 160 cm in 10 cm increments. The instrument is intended only for manual use. Readings are stored in a data logger and can later be transferred to a personal computer. The EnviroSCAN uses capacitance sensors of similar design, which are fixed by the user to a plastic 'backbone' at predetermined intervals of 10 cm or at intervals that are multiples of 10 cm. The backbone with affixed sensors is sealed inside a plastic access tube and connected to a data logger for unattended, long term measurements. The EnviroSCAN is not intended for manual measurements. Both sensors use the same rigid polyvinylchloride (PVC) plastic access tubes (Rafael, 2015).

The Delta-T PR1/4 and PR1/6 are constructed as a cylindrical plastic shaft into which are embedded the capacitor electrodes at pre-fixed intervals. These systems are intended for manual data acquisition. In use, the shaft is connected by a cable to a display unit. The shaft is inserted

fully into the access tube and readings are taken with a single key press at all of the fixed depths. The PR1/4 has sensors centered at depths of 10, 20, 30 and 40 cm. The PR1/6 has sensors centered at 10, 20, 30, 40, 60 and 100 cm. As of 2005, these instruments were replaced by the PR2/4 and PR2/6, which did not perform appreciably better. The Troxler Sentry 200AP is most similar to the neutron moisture meter (NMM) in its mode of employ. It consists of a single capacitance sensor connected by a cable to a readout display. The sensor is allowed to descend down a plastic access tube to any depth determined by the user, where a reading is then taken. Readings may thus be taken for the entire profile. Several other capacitance type sensors exist, including the probe and the Gopher, both of which are for use in plastic access tubes. Due to the authors' lack of experience with them, they will not be discussed here except to say that they use similar technology as those discussed, and share their limitations (Rafael, 2015).

2.5.8. Neutron probe

Working principle: Fast neutrons are emitted from a decaying radioactive source ($^{241}\text{Am}/^9\text{Be}$) and when they collide with particles having the same mass as a neutron (i.e., protons, H^+), they slow down dramatically, building a "cloud" of "thermalized" (slowed-down) neutrons. Since water is the main source of hydrogen in most soils, the density of slowed-down neutrons formed around the probe is nearly proportional to the volume fraction of water present in the soil.

Description: The probe configuration is in the form of a long and narrow cylinder, containing a source and detector. Measurements are made by introducing the probe into an access tube (previously installed into the soil). It is possible to determine soil moisture at different depths by hanging the probe in the tube at different depths. The soil moisture is obtained from the device based on a linear calibration between the count rate of slowed-down neutrons at the field (read from the probe), and the soil moisture content obtained from nearby field samples (Rafael, 2015).

The neutron probe has long been the standard instrument for measuring soil-water content. It has been used with great success in practical irrigation management, especially in orchards and vineyards (Mkhize *et al.*, 1996; Nel, 1995b). On a large commercial citrus estate near Marble Hall, Mkhize *et al.* (1996) were able to demonstrate 24% water saving, while increasing yield and fruit quality through neutron-probe scheduling following a PAWC approach, thereby facilitating a significant saving in irrigation costs. The neutron probe is, however, being

superseded by a range of logged capacitance type sensors, such as DFM capacitance probes (Haarhoff, 2011). Although potentially not as representative as neutron probes because of their smaller volume of measurement, automated capacitance sensors are usually far easier to deploy in farmers' fields.

The main limitation is safety hazard, since it implies working with radiation. Even at 16 in. depth, radiation losses through soil surface have been detected. Heavy, cumbersome instrument takes relative long time for each reading. Readings close to the soil surface are difficult and not accurate. Manual readings; cannot be automated due to hazard and expensive to buy.

2.6. Irrigation Performance Indicator

To evaluate the performance of irrigation systems a set of recognized and accepted parameters are required. According to FAO (1989), among the factors used to judge the performance of an irrigation system or its management, the most common are application efficiency and distribution uniformity. This parameter can be subdivided and defined in a multitude of ways, as well as named in different manners. There is not a single parameter, which is sufficient for defining irrigation performance. Conceptually, the adequacy of irrigation depends on how much water is stored within the crop root zone, losses percolating below the root zone, losses occurring as surface runoff or flow as tail water, the uniformity of the applied water, and the remaining deficit or under irrigation within the soil profile following irrigation.

2.6.1. Application efficiency

Application efficiency, is defined as the amount of water beneficially used by the crop divided by the total amount of water applied (FAO, 1989). Hansen *et al.* (1980) noted that the concept of water application efficiency can be applied to a farm, can vary from extremely low to values approaching 100%. The depth of water applied is a dominant factor influencing efficiency of application. Even if water spread uniformly over the land surface, excessive depths of application would result in low efficiencies. Many variable factors such as land uniformity, irrigation method, size of irrigation stream, length of run, soil texture, permeability, and time the irrigator keeps water running on his farm and hence the depth he applies can influence the application efficiency.

According to Kenneth (1988), application efficiency is an irrigation concept that is very important both in system selection and design and in irrigation management. The ability of an irrigation system to apply water uniformly and efficiently to the irrigated area is a major factor influencing the agronomic and economic viability of farming enterprise. Application efficiency is also an index, which is a measure of how effective an irrigation event is in minimizing unavoidable losses.

According to Solomon (1988), attainable water application efficiencies vary greatly with irrigation system type and management, and the attainable water application efficiency of furrow irrigation system ranges from 60 to 75% that might be achieved with reasonable design management. According to Morris and Vicki (2006), the attainable water application efficiency of furrow irrigation system ranges from 60 to 80 % and efficiency of surge flow irrigation system ranges from 65 up to 80 %. According to Kassa (2001), evaluation of the performance of surface irrigation methods at MelkaWerer, Middle Awash Valley, indicated that the maximum possible application efficiency for furrow irrigation computed was 64.5% for inlet flow rate 2.5 l/s and 0.8 m furrow spacing. Whereas the total irrigation water losses (due to deep percolation and runoff) was 56 - 62%. Other reported range of application efficiency is from 50 to 70% (Rogers *et al* 1997).

2.6.2. Distribution uniformity

When a field is with uniform slope, soil and crop density receives steady flow at its upper end the waterfront will advance at a monotonically decreasing rate until it reaches the end of the field (FAO, 1989). Roger *et al.* (1997) explained that water lost to percolation below the root zone due to non-uniform application or over application water runoff from the field, all reduces irrigation efficiencies. To express the efficiency of an irrigation system, the uniformity of the water applied should be determined.

Yonts *et al.* (1995) reported that surge flow irrigation helps to obtain a uniform wetting of the root zone, with minor differences in the infiltration depth at the beginning and end of a furrow. Thus, the difference in intake opportunity time between the upper and lower ends of the furrow was less and resulted in a uniform distribution of water intake over the length of the furrow.

Besides, Ismail (2006) in his research carried out in Egypt indicated that in continuous flow, the water is allowed to run long enough to fill the root zone area. Therefore, the water stayed longer on the soil at the beginning than at the end; as a result, more water infiltrates at the beginning and less infiltrates at the end of furrows, and this leads to low distribution uniformity along the furrows. According to Mahmood (2004), under the water application during surge irrigation, the computed distribution uniformity at different experimental site ranges from 63.5 to 92.5% but for continuous irrigation, it ranges from 59.5 to 83.5%.

2.6.3. Storage efficiency

The storage efficiency is the ratio of the stored water depth to the required depth. The storage efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone. The value of storage efficiency is important either when the irrigations tend to leave major portions of the field under-irrigated or where under-irrigation purposely practiced to use precipitation as it occurs. This parameter is the most directly related to the crop yield since it will reflect the degree of soil moisture stress. Usually, under-irrigation in high probability rainfall area is a good practice to conserve water but the degree of under-irrigation is a difficult question to answer at the farm level (FAO, 1989).

Jurreins *et al* (2001) expresses adequacy of irrigation turn in terms of storage efficiency and the purpose of an irrigation turn is to meet at least the required water depth over the entire length of the field. Conceptually, the storage efficiency depends on how much water is stored within the crop root zone, losses percolating below the root zone, losses occurring as surface runoff or tail water, the uniformity of applied water and the remaining under irrigation. The water storage efficiency refers to how completely the water needed prior to irrigation has been stored in the root zone during irrigation.

Derbew (2007) was evaluating storage efficiency in his experiment for the AFI, CFI systems. The result shows that there were no significant differences among irrigation systems in terms of their storage efficiency. The result obtained was 78.73% and 75.83% for AFI and CFI respectively.

2.6.4. Deep percolation losses

High deep percolation losses aggravate water logging and salinity problems, and leach valuable crop nutrients from the root zone. Depending on the chemical nature of the groundwater basin, deep percolation can cause a major water quality problem of a regional nature. These losses can return to receiving streams heavily loaded with salts and other toxic elements and thereby degrade the quality of water (FAO, 1989).

According to Mulubrihan (2007), cycle ratio affects the deep percolation significantly. In his study, the highest deep percolation losses were observed for the cycle ratio of continuous (C) flow with the mean value of 35.42% and the least deep percolation losses were for the small cycle ratio 1/3 (CR2) with average value of 28.8%. Based on his research work, the average deep percolation losses for continuous flow treatments ranged from 34.50% to 36.33%. Here, there was no significant difference between continuous flow treatments, whereas for surge flow, it ranged from 27.62% to 32.53% and the treatments were significantly different. Kanber *et al.* (2001) also concluded that surge flow treatments reduce deep percolation losses by 19-70% over the continuous flow treatments for Harran clay soils. In Horst *et al.* (2007) reported that deep percolation was very high for continuous flow treatment but small for surge flow irrigations.

2.6.5. Runoff loss

Runoff losses cause additional pressure to irrigation systems and regional water resources. Erosion of the top soil on a field is generally the major problem associated with runoff. The sediments can then obstruct conveyance and control structures downstream, including dams and regulation structures (FAO, 1989).

Mulubrihan (2007) reported that the highest runoff losses were observed for continuous flow cycle ratio 1(C) with the mean value of 17.4% and the least runoff losses were recorded for the large cycle ratio ½ (CR2) with the mean value of 13.25%. In his experiment, the runoff losses in continuous flow treatments were higher than that of all surge flow treatments, which had the same discharge with the continuous flows. The results reveals that the highest tail water loss was measured for treatments of continuous flow with the mean value of 19.37% and 15.43%, and the least tail water was observed for surge flow treatments with the mean value 12.67%. Kanber *et*

al. (2001), Minwiyelet (2004), Abebaw (2009) also reported that surge flow was found to be promising in minimizing the tail water runoff loss. Besides, Horst *et al* (2007) states that surge flow has the ability to reduce tail water runoff.

2.7. Water Productivity

To increase crop yield per unit of water requires both better cultivars and better agronomy. The challenge is to manage the crop or improve its genetic makeup. After analyzing a large dataset Passioura (2006) found that in the field, the upper limit of water productivity of well managed water-limited cereal crops is typically 20 kg ha⁻¹ mm⁻¹. If the productivity is markedly less than this (e.g. rain-fed water use efficiency in China is 2.3 kg ha⁻¹ mm⁻¹, far less than the potential; Deng *et al.*, 2006), it is likely that major stresses other than water appear, such as poor nutrition and diseases. Unfortunately, there are no genetic transformations that are likely to improve water productivity greatly. Small and timely irrigation, along with management of soil nutrients is the focal issue which is shown to increase water use efficiency by 10-25%. Often, soil fertility is the limiting factor to increase yields in rain fed agriculture. Soil degradation, through nutrient depletion and loss of organic matter, causes serious yield decline closely related to water determinants, as it affects water availability for crops, due to poor rainfall infiltration, and plant water uptake, due to weak roots. Studies have even shown that within certain limits, nitrogen and water supply have substituted for each other in increasing crop yields (Gajri *et al.*, 1993).

The low water use efficiency in farmer's fields compared with well-managed experimental sites indicates that more efforts are needed to transfer water saving technologies to the farmers. Under such scenarios, water-saving agriculture and water saving irrigation technologies, including deficit irrigation, low pressure irrigation, subsurface drips, drip irrigation under plastic covers, furrow irrigation, rainfall harvesting and conservation agriculture shall be quite helpful. Water saving agriculture includes farming practices that are able to take full advantage of the natural rainfall and irrigation facilities. Where water is more limiting than land, it is better to maximize yield per unit of water and not yield per unit of land (Drechsel *et al.*, 2015).

Irrigation along with fertilizers and improved seeds has been essential components of a global strategy for increasing agricultural productivity. During the past decades emphasis on improved

agricultural water management has been on increasing irrigation water use efficiency, but more recently enhanced emphasis is placed on producing more with relatively less water increasing water productivity. There is a need to find new ways to increase water productivity by improving biological, economic and environmental output per unit of water used in both irrigated and rain fed agricultural systems. Physical productivity improvements can be made by obtaining more productive transpiration from rain and irrigation withdrawals, producing more and higher-value crops per unit of transpiration, reducing evaporation, and managing agricultural water deliveries and drainage better. Such opportunities are very diverse and occur at biological, environmental and management levels (Drechsel *et al*, 2015)

2.8. Agronomy and Management of Potato (*Solanum tuberosum* L.)

Potato (*solanum tuberosum* L.) originates in the Andes from the tropical areas of high altitude. The crop is grown throughout the world but is of particular importance in the temperate climates. Present world production is some 308 million tons fresh tuber from 19 million ha (FAO, 2002). In general potatoes are best adapted to the cool temperate zones of the high altitudes (2000-3000 m above sea level) and at appropriate altitudes in intermediate latitudes (Hawkes, 1992). The frost resistant species are grown from about 3000 – 4000 m above sea level.

Potato performs well on a well-drained, sandy loam, loamy sand, or sandy clay loam with p^H 6.0-7.8 (Frank, 2003). Fertilizer requirements are relatively high and for an irrigated crop they are 80 to 120 kg/ha N, 50 to 80 kg/ha P and 125 to 160 kg/ha K. The crop is grown on ridge or on flat soil. For rainfed production in dry condition, flat planting tends to give higher yields to soil water conservation. Under irrigation, the crop is mainly grown on ridges. The sowing depth is generally 5 to 10 cm, while plant spacing is generally 0.75 × 0.30 m under irrigation and 1 × 0.5 m under rainfed conditions. Potato root system development is relatively shallow, 45 – 60 cm, with the majority of the roots in the surface 30 cm (Bradley, 1997).

For high yields, the crop water requirements (ET_C) for a 120 to 150 day crop are 500 to 700 mm, depending on climate. The relationship between maximum evapotranspiration (ET) and reference evapotranspiration (ET_o) is given by the crop coefficient (k_c) which is: during the initial stage 0.4 - 0.5 (20 to 30 days), the development stage 0.7 - 0.8 (30 to 40 days), the mid-

season stage 1.05 - 1.2 (30 to 60 days), the late season stage 0.85 - 0.95 (20 to 35 days), and at maturity 0.7 - 0.75 (FAO, 2002).

Potato is relatively sensitive to soil water deficits. To optimize yields the total available soil water should not be depleted by more than 30 to 50 percent. Depletion of the total available soil water during the growing period of more than 50 percent results in lower yields. Water deficit during the period of stolonization and tuber initiation and yield formation have the greatest adverse effect on yield, whereas ripening and the early vegetative periods are less sensitive. In general, water deficits in the middle to late part of the growing period thus tend to reduce yield more than in the early part (FAO, 2002).

The amount of seed needed for planting depends on Variety, distance between rows, the spacing within rows and the size of the seed pieces. Seed pieces cut from smaller tubers are more uniform in size, give better plant stands and are usually more tubers per hill.

Maximum productivity for potato occurs when the soil is kept consistently moist and with nitrogen available during periods of high demand. Good yields under irrigation of a crop about 120 days in the temperate and subtropical climates are 25 to 35 ton/ha fresh tubers and in tropical climates yield are 15 to 25 ton/ha (FAO, 2002).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location of the study area

The study was conducted in the Koga Irrigation scheme Watershed Management Project area which is situated adjacent to the town of Merawi in the Mecha Woreda, West Gojam Zone in Amhara Regional State as shown in Figure 2 (Eguavoen and Tesfai, 2011). Merawi lies in the middle of the Woreda and is situated 35 km south of Bahir Dar, the capital city of the Amhara Region. The main purpose of the project is to irrigate 7,000 ha, and to improve the formerly used rainfed agriculture by allowing two crop seasons which will increase the yield. The Koga basin is one of 14 sub basins. Together, they make up what is called the Abbay basin. (Simon Eriksson, 2012).

The Koga watershed lies in the Blue Nile basin above the confluence with the Gilgel Abay (Little Nile). The project area covers a total size of about 10,000 ha. The Koga River and its tributaries effectively drain 27,850 ha of the watershed area that lies to the north of the Wezem Mountains. The Koga River flows south to northwest with a total length of over 50 km. The River terminates at its confluence with the Gilgel Abay just to the west of the town of Wettet Abay (Tesfaye and Fasile, 2011). The storage capacity of the reservoir is 83.1 Mm³ with an altitude of 1998 masl. The catchment is situated between 11^o10' to 11^o32'N and 37^o04' to 37^o17'E. The catchment area to the dam is 170.9 km² and extends to an altitude of 3,200 masl (Mott Macdonald, 2004).

The command area has a total population of 57,155 and is divided into twelve irrigation units corresponding to the secondary canals. The experimental site is Ambomeske one of the block with a total farm land area of 1,729 hectares. Out of this, the irrigated land covers an area of 812 hectare and is associated with 1,386 households, totaling 6,842 farmers.

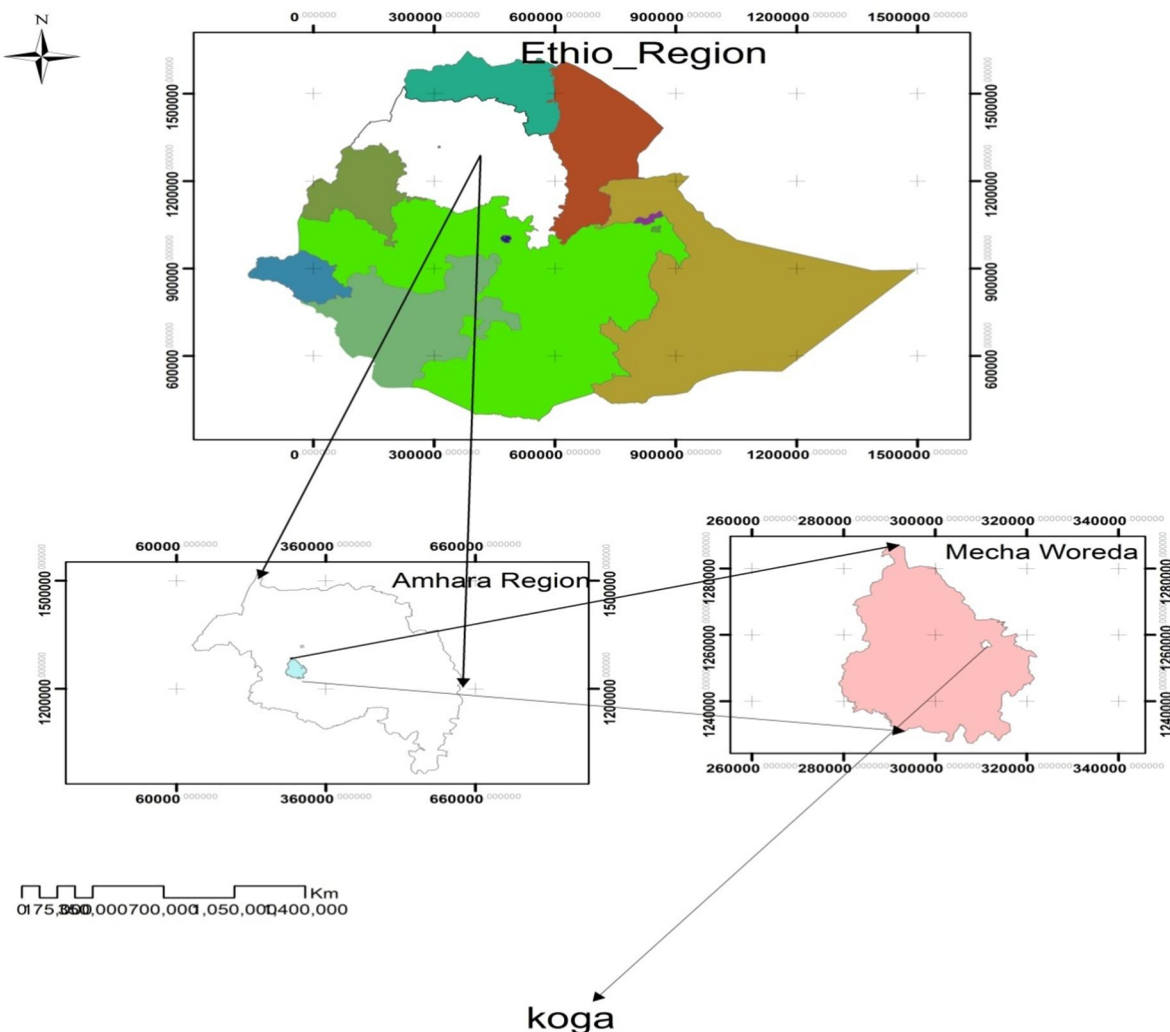


Figure 2. Location map of Koga watershed in Mecha Woreda

3.1.2. Climate

Rainfall distribution over the area is unimodal. The rains usually begin in May and increase gradually in frequency to reach a maximum in July or August. (MoWR, 1998) The annual precipitation ranges from 800 to 2200 mm, with a mean of 1,420 mm (Ministry of Water Resources, 1998). The average day time temperature of the study area is found to be 24°C. Mean maximum temperature varies from 30.1°C in April to 24.3°C in July and August; mean minimum temperature varies from 8.9°C in January to 15.5°C in May. The highest mean temperatures are always between March and May. The mean monthly relative humidity (RH) is 58.4%; RH values

are highest during the humid rainy season (75%) from July to August and lowest during March (42.9%). The variability of RH was also lowest during the wet season. Mean monthly sunshine hour varies from a low value of 4.4 h/d during the month of August (rainy season) to as high as 9.9 h/d during the month of December. The average monthly sunshine hour during the year is 7.2 h/d and its highest variability occurred during the wet season probably because of the frequent sky overcast (Tesfaye and Fasile, 2011).

3.1.3. Soils

The reddish brown soils in the irrigation area are relatively homogeneous and show the same physical and chemical characteristics. As much as 87% of the area is believed to consist of silt clay soils suitable for irrigation (Ministry of Water Resources, 2008). These are generally, well drained soils formed in the upland positions mainly in the downstream of the dam site and on both sides of the Koga River. The slopes range from 0 to 8% but are dominantly at 0 to 2%. These soils are intensively cultivated in the study area and possess good drainage and workability (Tesfaye and Fasile, 2011). Overall, the soils are well suited for irrigation, with some exceptions. The lack of nutrients (mainly phosphorous), local abundance of sodium, low pH and a base saturation below 50% are some of the drawbacks.

3.1.4. Vegetation

The plant species that dominate the watershed are Eucalyptus Spp, Gravelia Robusta, Coardinal Africana and Syniesse Mollie. The irrigated command area is dominated by Eucalyptus Spp for fuel wood, charcoal production and construction purposes. Based on field observations and discussions made with the local community and district experts, the natural vegetation in the lower watershed and command area is almost completely destroyed due to increased demand in the last decades for fuel wood, construction, timber and agricultural land.

3.1.5. Cropping practices and crop production

There are two types of agriculture in the study area: rainfed agriculture and irrigated agriculture. During the year there is a production of improved seeds on the site to satisfy the growing need of farmer's crop production. The major field crops generally grown are wheat, maize, *teff* and

barley. Horticulture crop include onion, potato, cabbage and pepper. Crop yield are used for home consumption and market. Some of the crops that are produced for household consumption include maize, wheat, *teff*, potato and pepper. The cash crops produced in the study area include wheat, potato, onion, cabbage, maize and barley. Most farmers in the study area rely on rainfed agriculture and the crops that are most produced in the rainy season includes maize, *teff*, potato, paper, barley and wheat. Irrigated agriculture in the area includes potato, onion, cabbage, pepper; wheat and maize. Out of these crops potato, onion, cabbage, maize, and wheat are produced for cash crop / marketable commodity/.

3.2. Experimental Design and Treatment

3.2.1. Experimental design

The experimental design was a two factor experiment arranged in Randomized Complete Block Design (RCBD) as shown in Figure 3. Nine potato farmer plots within the irrigation scheme were involved with four experiments within each plot and nine replications. Each experiment was 100 m² and the four treatments require a total of 400 m² within one farmer's plot. Each treatment was replicated in nine selected farmer's plot of 400 m² (20×20 m) each. Two treatments were in 200 m² with WFD and the remaining two treatments in 200 m² without WFD and instead managed by the farmer's common water application practice. Treatment with WFD was divided into two additional treatments with DAP and Urea fertilizer as the recommendation and the farmer's common fertilizer application as the other treatment. The experimental block under the farmer's common irrigation practice was also divided into the treatments with DAP and Urea fertilizer as the recommendation and the farmer's common fertilizer application as the other treatment.

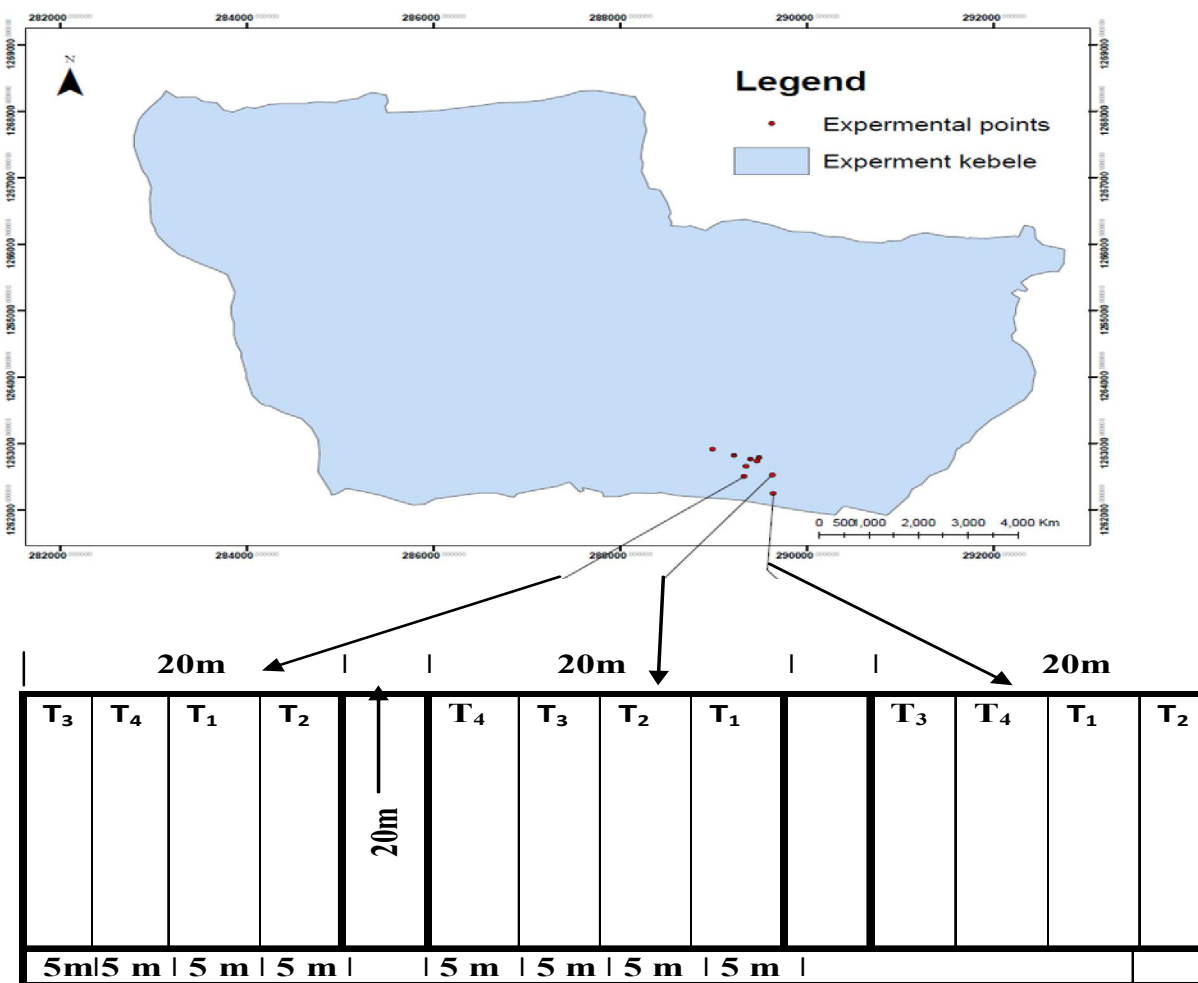


Figure 3. Location and layout of experiment in farmer's field

The numbers of treatments organized into each plot was as follows.

T1: Irrigation with WFD and applied recommended fertilizer rate(200 kg/ha DAP and 300 kg/ha Urea).

T2: Irrigation with WFD and applied farmer common practice fertilizer rate (300 Kg/ha DAP and 300 Kg/ha Urea).

T3: Irrigation without WFD (i.e. farmer common practiced irrigation water application) and applied recommended fertilizer rate(200 kg/ha DAP and 300 kg/ha Urea).

T4: Irrigation without WFD (i.e. farmer common practiced irrigation water application) and applied farmer common practice fertilizer rate (300 Kg/ha DAP and 300 Kg/ha Urea).

3.2.2. Land and seed bed preparation

Farmers in the experimental field plowed each plot with traditional means; oxen by Marsha plow for proper seed germination, farm operation; irrigation furrow lay out, pest control, easy fertilization application and soil organic matter (SOM) decomposing. Furrow irrigation was used in potato production. Water was supplied from a quaternary channel by way of supply field channels into the cultivation furrows ridge and tie at the end.

One experiment of potato crops was planted within 20 meter furrow length and 5 meter width. The row to row average distance was 70 cm and plant to plant 30 cm. There were 7 beds and 8 furrows within a plot of one treatment. The Julienne cultivar of potato was used in the experiment.

3.2.3. Materials used

The materials used to conduct the experiment include shovel, trowel, measuring tape, wetting front detector, fertilizer, potato tuber for seed, partial flume, GPS, TDR, Soil Moisture Profile Probe and siphon.

3.2.4. Installation of full stops wetting detector

During the technology installation, wetting front detector instrument use and installation training was given to all 9 farmers and data collectors were trained to assist in data collection. Nine WFDs were installed in pairs with the first at one third root depths, and the second at two thirds depth. The depth for the shallow detector was 20 cm and for the deep detector was 40 cm (from the base of the furrow). Detectors were positioned half under the furrow and half under the bed with the extension tube rising through the shoulder of the bed. The procedure for installing the WFDs was as follows:

- ✓ Make a hole with the shovel and trowel that can accommodate the wide part of the funnel. When the hole is deep enough, to make a hole for the bottom of the Full Stop
- ✓ If the soil texture changes with depth, keep the different soil layers separate
- ✓ Add the filter sand (supplied with the WFD) to the detector until it covers the locking ring by at least 1 cm

- ✓ Place the detector in the hole and measure the distance to the rim of the funnel to check that it reaches the required depth
- ✓ Make sure the extension tubes are vertical
- ✓ Fill the funnel with soil from the same layer, and lightly pat it down

3.3. Data Collection and Laboratory Analysis

Data was collected regarding the GPS coordinates and altitudes of site locations, size of experimental areas, and soil samples were collected to test for soil moisture content, total nitrogen, available phosphorus, exchangeable potassium, P^H (H_2O), and electrical conductivity. The time taken for one irrigation, the amount of water used for a given irrigation event, number of days between consecutive irrigations and agronomic data concerning crop yield were collected as well.

Secondary data were collected which included last year's Koga soil study data e.g. soil texture, bulk density, field capacity, permanent wilting point. From Merawi Metrological Station, weather data such as mean daily values of maximum temperature, minimum temperature, precipitation, sunshine hours, relative humidity (RH) and wind speed were gathered.

3.3.1. Soil moisture content determination

Soil samples were collected during growing season (initial at development, middle at flowering and finally at maturity stage) to determine the moisture content of soil from irrigated fields at a depth of 20 cm. A time Domain Reflector meter was used at development, flowering and harvesting stages before irrigation and after irrigation events to obtain moisture readings for plots both with and without WFDs. The TDR has 20 cm rods that provide average soil moisture content in the first 20cm of the soil profile. Soil moisture readings were taken from six places in each plot and the average was calculated. For the harvesting stage of potato soil samples were taken from the effective root zone of 60 cm after one irrigation event and then weighed. The samples were dried in an oven for 24 hours at temperature of 105°C. After drying, the soil was again weighed and the mass of water determined on the basis of pre and post readings. The dry weight fraction of each sample was calculated using the equation (Jalota *et al.*, 1998).

$$\theta_w = \frac{W_w - W_d}{W_d} * 100 \quad (3.1)$$

where: θ_w = Soil water content on a dry mass basis [%]

W_w = Wet weight of the soil [gm]

W_d = Dry weight of the soil [gm]

Then the moisture contents of the soils collected from the selected fields at different depths was determined. To convert the dry weight soil moisture fraction into volumetric moisture content θ , the dry weight fraction (θ_w) was multiplied by its respective bulk density ($b\rho$) and divided by the specific weight of water (ρ_w) as follows;

$$\theta = \frac{b\rho \times \theta_w}{\rho_w} \quad (3.2)$$

3.3.2. Soil nutrient availability

The availability of soil nutrient in the soil before planting was evaluated for three farmers by taking random samples from three plots. Twelve samples were collected; four samples from each experimental plot taken one sample soil just after the harvest of the crop to know the availability of nutrient in the soil remained finally.

3.4. Water Application Duration

In the WFD experiments water application duration determined by yellow detector indicator whereas without WFD experiment water application duration determined by the farmer water application practice irrigated time. The gross irrigation water requirement was computed with the assumption of 70 % as average application efficiency for well managed surface irrigation system (Solomon, 1988; Morris and Vicki, 2006). The duration of water application to the plot was determined by the equation given below.

$$t = \frac{d \times W \times I}{360Q} \quad (3.3)$$

where ; t = water application time (hr),

d = gross depth of water applied (cm),

l = furrow length in (m),

w = furrow spacing in (m), and

Q = flow rate (discharge) (l/s)

3.5. Measurement of Water Flow in Partial Flume

The amount of water applied was measured by flume from the discharge of water from each experiment in the quaternary canal. The partial flume was installed at the entrance of each field of interest to measure the depth of water applied to the field. The partial flume was calibrated to specific dimensions. To estimate the discharge passing through partial flume the measured water depth was changed to its respective discharge by accounting for flume length, width and adjusting via calibration. The irrigation water equally distributed flow through three furrows after passing through the partial flume using siphon.

During the determination of the amount of water applied to the field, the average water depth of irrigation water passing through the flume and the respective time was recorded with the size of the fields being irrigated. The total volume of water applied to the field was obtained by multiplying the discharge rate with the inflow time. The depth of water applied to the field was obtained by dividing the total volume of water applied by the area irrigated.

3.6. Irrigation Scheduling by WFD

3.6.1. Amount of irrigation water applied

The method of scheduling by position of a wetting front was first proposed by Zur *et al.* (1994) and is based on the theory of Philip (1957) as modified by Rubin and Steinhardt (1963) cited in Stirzaker *et al.* (2005).

The velocity V of a wetting front is given by

$$V = \frac{IR - K_{\Theta_i}}{\Theta_{wf} - \Theta_i} \quad (3.4)$$

Where IR is the irrigation rate, K_{θ_i} is the unsaturated conductivity at the initial water content, Θ_{wf} is the water content behind the wetting front and θ_i the initial water content or water content ahead of the front. For values of θ_i less than the upper drained limit, K_{θ_i} is very low compared to the irrigation rate and can be omitted from equation 3.4. Time can be determined for a wetting front detector to reach a given depth d by the equation:

$$V = \frac{d}{t} \quad (3.5)$$

It can be redefined as:

$$t = \frac{d(\theta_{wf} - \theta_i)}{IR} \quad (3.6)$$

The amount of irrigation I in mm, is the product of the irrigation rate, IR, and t , so,

$$I = d(\Theta_{wf} - \Theta_i) \quad (3.7)$$

Assuming Θ_{wf} remains relatively constant for a given soil irrigation rate combination, and since d is fixed then

$$I(mm) \approx \theta_i \quad (3.8)$$

Thus the amount of irrigation applied on any day should be inversely proportional to the initial water content. Put simply, if the soil is dry before irrigation, then the front will travel slowly and a long irrigation will be permitted before the front reaches the detector. Conversely if the soil is wet before irrigation, the front will move quickly and irrigation would be of short duration.

3.6.2. Irrigation interval

A wetting front detector that turns irrigation off must be located above the depth we want water to infiltrate because there is an overhead, O , associated with each irrigation event given by:

$$O = d(\Theta_{wf} - \Theta_{udl}) \quad (3.9)$$

Where Θ_{udl} is the upper drained limit and d the depth to the detector (Zur *et al.*, 1994). This water above the upper drained limit moves down through the profile after irrigation ceases. The final depth of the wetting front depends on the ability of the soil below the detector to store the water or $(\Theta_{udl} - \Theta_i)$. It also depends on the transpiration rate during the redistribution period, since transpiration and redistribution occurs simultaneously.

The value of d depends on the rooting depth of the crop, and once d is chosen, conservative irrigation interval can be calculated. The interval, t , is calculated by estimating the total amount of water that can be added to the soil above the detector and dividing by the maximum expected transpiration rate for any period.

$$t = d (\Theta_{wf} - \Theta_{rf}) / Et \quad (3.10)$$

3.7. Water productivity

Within many irrigated areas, water is an increasingly scarce resource. Hence, it is logical to assess the productivity of irrigation in terms of this scarce resource (Kijne *et al.*, 2003). Such an assessment can be made from a variety of viewpoints. The most common are: the productivity in terms of actual evapotranspiration (Etc) and in terms of the volume of water applied during the cropping period. The water productivity then is expressed as (Molden *et al.*, 1997):

$$\text{Crop Water productivity} \left(\frac{kg}{mm} \right) = \frac{\text{Yield of harvested crop (kg)}}{ETc(mm)} \quad (3.11)$$

$$\text{Irrigation water productivity} \left(\frac{kg}{m^3} \right) = \frac{\text{Yield of harvested crop (kg)}}{\text{Total volume of water applied}(m^3)} \quad (3.12)$$

The yield of the harvested crop equals the unit yield (kg/ha) times the considered area (ha). If viewed from the farmer's perspective, the volume of supplied water is measured either at the farm inlet or at the head of the field, depending on his views. The values of ET actual and the volume of irrigation water are heavily influenced by local climate. Productivity of water can be also expressed in terms of monetary value per unit of water. Gross value of production is the yield multiplied by the price of output, while the net value includes costs. This is useful when an

irrigation system has multiple crops, especially grain and non-grain, like maize, potatoes and fruits. Increases in economic water productivity may indicate a shift towards higher valued crops or an increase in yields (Alterra-ILRI, 2005).

3.8. Statistical Analysis

For all data collected such as irrigation water amount, water productivity, potato plant height and yield measured response data variables of analysis of variance (ANOVA) was computed. Data has been analyzed for variability using the statistical package SAS version 9. Mean separation was done using the least significant difference (LSD) method at 1% and 5% level of probability.

4. RESULTS AND DISCUSSION

4.1. Soil Physical Characteristics

The average sand, silt and clay contents of the soil in the experimental area were 19 %, 55 % and 26 % respectively (Table 1). Thus according to the USDA soil textural classification, the soil was silt loam with pH ranges from 5.33 to 6.27, soil bulk density as 0.89 gm/cm³ and electrical conductivity as 0.08 dSm⁻¹. Frank (2003) and FAO (1996) states that potato performs well drained sandy loam, loamy sand, or sandy clay loam and porous soil with pH of 5 to 6. Hence, the physical characteristics of the soil in the proposed area are suitable for potato production. The average field capacity and permanent wilting point of the soil was found to be 34.0 % and 19.0 % on volume basis, respectively. According to Jensen *et al.*, (1990a) the values for FC and PWP of silt clay loam soil are 34 % and 19 % respectively and the values obtained are within the range reported.

Table 1. Physical characteristics of the soil

Particle size distribution			Textura l class	bulk density (gm/cm ³)	EC(dSm ⁻¹)	pH %	FC (% Vol.)	PWP (%Vol.)
sand %	silt %	clay %						
19	55	26	Silt loam	0.89	0.08	5.9	34	19

*FC= field capacity, PWP=permanent wilting point, pH = acidity, alkalinity, base and EC = Electrical conductivity

4.2. Relation with Irrigation Time and Water Volume

As indicated in Table 2, irrigation with wetting front detector (WFD) and farmer irrigation practice (FIP) had the same average of 0.42 m³/min discharge. With this average discharge, 100 m² field area of WFD treatment required 99.9 m³ of water to irrigate in 237 minutes where as FIP treatment required 122.66 m³ of water to irrigate in 291 minutes. Therefore irrigation WFD saved an average of 3.75 days/ha to irrigate and a saving average of 2,273 m³/ha of water with respect to FIP.

Table 2. Discharge interaction between irrigation time and applied water in total crop season

Replication	Discharge m ³ /min	WFD irrigation		FIP irrigation	
		time min/100 ²	water m ³ /100 m ²	time min/100m ²	water m ³ /100 m ²
1	0.35	258	89.96	322	112.3
2	0.43	222	95.32	272	116.7
3	0.41	255	104.48	308	126.2
4	0.44	243	106.53	300	131.4
5	0.45	213	95.69	259	116.5
6	0.43	225	95.86	280	119.5
7	0.45	213	95.67	266	119.6
8	0.44	264	115.01	317	138.2
9	0.42	240	100.87	294	123.5
Sum		2133	899.39	2618	1104.0
Average	0.42	237	99.93	291	122.66

Key WFD=Wetting Front Detector and FIP = Farmer Irrigation Practice

4.3. Irrigation Water saved

Table 3, indicated that an average of 9,993 m³/ha irrigation water was applied to the WFD experiment plots and 12,266 m³/ha in FIP treatment plots. The detailed observation of each WFD & FIP users is shown in (Appendix Tables 3 and 4). Therefore there had been (18.5 %) of water saved by WFD treatment than FIP treatment. According to Schmitter *et al.*, (2015) report in Koga irrigation scheme where WFD plots were compared to farmers practice instead of soil moisture based irrigation for the furrow irrigation of potato (34 %) and wheat (39 %). And also Melaku *et al.*, (2016) conference report the irrigation water applied was on average 372 mm for the WFD and 462 mm in the TDR plots. There is 24% reduction of irrigation water application in WFD plots.

Koga reservoir has a storage capacity of 83.1 million cubic meters (Mm³) of irrigation water .In this experiment average irrigation water required for 1 ha of potato planted area with farmer's irrigation practice was 12,666 m³, while the same size of land cultivated with same crop, potato, requires 9993 m³ of irrigation water with instruction of wetting front detector (WFD). This implies that the reservoir water 83.1Mm³ can irrigate 6,774.8 ha of potato field with farmers' irrigation practice while the same reservoir water can irrigate 8,315.8 ha of potato fields if it is

instructed with wetting front detector. This shows that using the instruction of wetting front detector was highly efficient than farmers' irrigation practice which can create an opportunity to irrigate an additional irrigation potato area of (1,541 ha) with WFD. This is a significant area of land with WFD technology for the farming community by arresting waste of irrigation due to deep percolation and evaporation

Table 3. Irrigation water applied on WFD and FIP

Replication	WFD (m ³ /ha)	FIP (m ³ /ha)	Reduction in water applied (%)
1	8996	11232	19.9
2	9532	11672	18.3
3	10448	12625	17.2
4	10653	13140	18.9
5	9569	11647	17.8
6	9586	11947	19.8
7	9567	11964	20
8	11501	13822	16.8
9	10087	12347	18.3
Average	9993	12266	18.5
Stdev	763	815	

Key: WFD=Wetting Front Detect FIP = Farmer Irrigation Practice.

According to (Appendix Table 7) the applied water at initial, development, mid-season and late season stages for WFD were 1,900 m³/ha, 2,186 m³/ha, 3,001m³/ha and 2,906 m³/ha respectively and for FIP 2370m³/ha, 2636m³/ha, 3620m³/ha and 3640 m³/ha respectively.(Figure 4) shows that applied water was high during the flowering stage of the crop development, when the crop needs more water and exhibits its peak physiological response. According to Pavlista (1995) Irrigation recommendations at key production periods are based on the S-shaped growth curves of roots, vines and tubers.

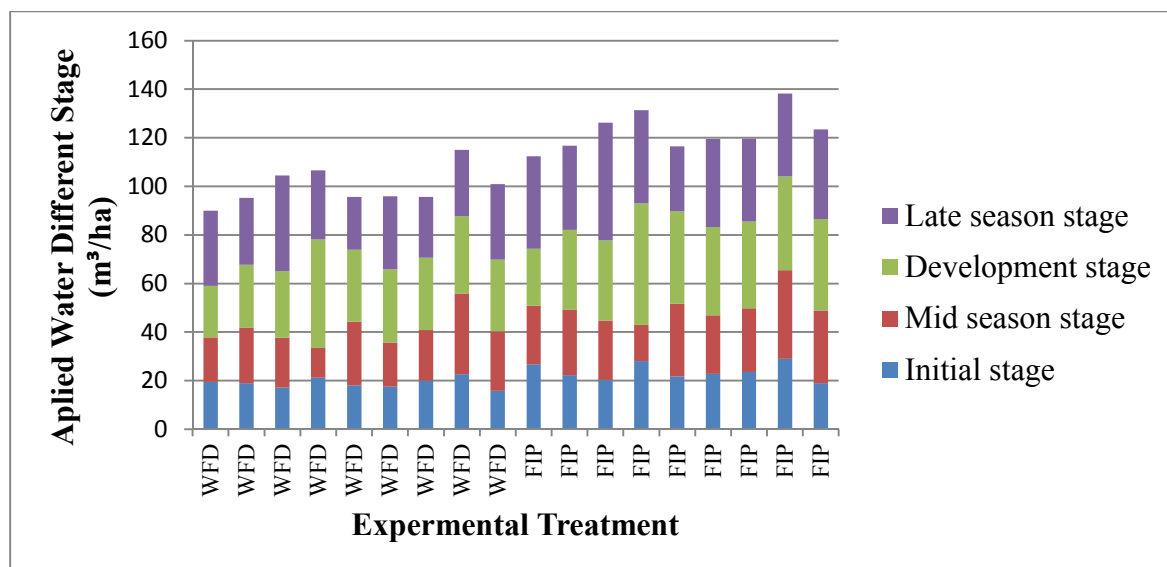


Figure 4. Water amounts at different growth stages of potato crop

4.4. Moisture Content

Using TDR, volumetric moisture contents before irrigation in WFD treatment plots and FIP treatment plots almost the same as indicated in Table 4. TDR measures volumetric moisture content of the water before and after irrigation (applied water). WFD shows a water savings in development, mid-season and late season stages (11.9 %, 12.1 % and 13.9 %) respectively compare to FIP. In the late season stage irrigation with WFD RF treatment shows a 15.5 % water savings than FIP FF treatment.

Table 4. Using TDR volumetric moisture content before irrigation & applied water

Water management	Development Stage		Mid-season stage		Late season stage	
	Moisture content %	Applied water %	moisture content %	Applied water %	moisture content %	Applied water %
WFD RF	24.1	18.7	24.1	18.0	23.7	16.9
WFD FF	23.8	18.9	24.0	18.1	23.6	17.1
FIP RF	24.4	21.3	24.4	20.6	23.9	19.5
FIP FF	24.2	21.4	24.3	20.4	23.8	20.0
WFD & FIR	Deference in %		Deference in %		Deference in %	
	11.9		12.1		13.9	

Key: Moisture content = TDR volumetric moisture content measurement before irrigation, Applied water = TDR volumetric moisture content after and before irrigation deference WFD RF = Irrigation wetting front detector with recommended fertilizer, WFD FF = Irrigation wetting front detector with farmers usual practice fertilizer, FIP RF = Farmer irrigation practice with recommended fertilizer, FIP FF = Farmer irrigation practice with farmers usual practice fertilizer and TDR = Time domain reflectometr.

For the late season stage of potato, a soil sample was taken at 60 cm depth 24 hrs after an irrigation event. the gravimetric moisture content of the laboratory results are indicated in Table 5. This shows that irrigation with FIP 38.2 % and for WFD 37.9 %, is reduced by (0.8 %), but time taken to irrigate in that day for FIP was 19.8 min/100m² and for WFD 16 min/100m² with reduction of time by (19.2 %), and amount of applied water for FIP as 8.5 m³/100m² and for WFD as 6.9 m³/100m² was reduce by (18.8 %). This shows that after 24 hrs there was (18.0 %) water was lost in FIP treatment.

Table 5. Gravimetric moisture content after 24 hr of irrigation

Replication	Moisture content %		Time min/100 m ²		Applied water m ³ /100 m ²	
	WFD	FIP	WFD	FIP	WFD	FIP
1	36.3	38.6	15	19	5.2	6.5
2	35.3	36.5	15	18	7.6	9.1
3	36.8	39.9	15	21	8.3	11.6
4	40.5	38.1	15	20	6.3	8.5
5	38.4	40.7	21	23	8.9	9.7
6	39.6	37.8	15	18	5.2	6.2
7	38.3	37.4	15	18	6.3	7.6
8	40.9	40.1	12	17	5.1	7.2
9	34.9	34.6	21	24	8.9	10.1
Average	37.9	38.2	16	19.8	6.9	8.5
Deference %	0.8		19.2		18.8	

WFD=Wetting Front Detector and FIP = Farmer Irrigation Practice.

4.5. Agronomic Performance of Potato

4.5.1. Plant height

There is no significant difference among experimental treatments in plant height at 50 days, between WFD RF and FIP RF and also WFD FF and FIP FF (Appendix Table 12 and Table 6). However, there is significance difference in Plant height among experimental treatment at 100 days at 5% level between WFD and FIP in both recommended fertilizer and farmer fertilizer conditions (Appendix Table 13 and Table 6). There is no significant difference between RF and FF in both WFD and FIP environments. This shows that no fertilizer effect on plant height at 100 days in both water management options According to (Admasuet *al.*, 2016) There is no

significant difference among 25% more on the recommended rate (244 kg DAP/ha + 206 kg urea/ha) and recommended fertilizer rate (195 kg DAP/ha + 165 kg urea/ha) but its significantly different from 25% less from the recommended rate (146 kg DAP/ha + 124 kg urea/ha) Fertilizer rates and irrigation treatments shows no significant interaction on the height of potato. DAP/ha + 124 kg urea/ha) Fertilizer rates and irrigation treatments shows no significant interaction on the height of potato.

At 50 days of planting, the higher height was recorded at WFD RF (46.89 cm) and the minimum height was at FIP RF (44.33 cm). On the case of 100 days the shortest plants (89.33 cm) were obtained from plots that were of FIP with RF. The taller plants were obtained from plots with WFD RF (92.89 cm). This shows that there is variability between farmers in using the same practice both for control as well as the wetting front detector. There is no difference between WFD RF and WFD FF and also between FIP RF and FIP FF at 100 days. At 50 days there is no difference between WFD FF and FIP FF. It has difference at 50 days between WFD RF and FIP RF. It has difference at 100 days between, WFD RF and FIP RF and also between WFD FF and FIP FF treatments.

Table 6. Mean value of potato plant height at 50 and 100 days

Water Management	50 days (cm)		100 days (cm)	
	RF	FF	RF	FF
WFD	46.89 ^a	44.56 ^{ba}	92.89 ^a	92.56 ^a
FIP	44.33 ^b	45.78 ^{ba}	89.33 ^b	89.67 ^b
CV	5.5		3.2	
LCD _(0.05)	2.4		2.8	

Key: same letter are not significantly different, WFD=Wetting Front Detector FIP = Farmer Irrigation Practice, RF = Recommended fertilizer, FF = Farmer fertilizer, CV= Coefficient of variance, LSD= list significant difference and SE = Standard error.

4.6. Crop Yield

There is highly significant difference in applied water, marketable yield and total yield at 5 % and 1% level between WFD RF and FIP RF and also WFD FF and FIP FF treatments. There is significant difference in marketable yield and total yield between different fertilizer rates, under WFD water management conditions. However, there is no significant difference in marketable yield and Total yield between different fertilizer rates under FIP water management conditions (Appendix Table 15, 16 and Table 7). There is significant difference in non-marketable yield at 5 % level between WFD RF and FIP RF treatments and also WFD FF and FIP FF treatments. However, there is no significant difference non marketable yield between different fertilizer rates under WFD and also FIP water management conditions (Appendix Table 17 and Table 7).

In recommended fertilizer there is a difference in marketable, total and unmarketable yield between different water management systems (WFD with FIP) and also the same for farmer fertilizer. In wetting front detector irrigation there is significance difference in marketable and total yield with (RF and FF). However, in farmer irrigation practice there is no significance difference in marketable and total yield in fertilizer application (RF and FF). There is no significant difference in non-marketable yield between different fertilizer rates under WFD and also FIP water management conditions. There is significant difference non marketable yield between different water management under RF conditions and also FF treatment.

The maximum marketable and total yield of potato observed at T1(wetting front detector with recommended fertilizer) and the minimum yield recorded at T4(Farmer irrigation practice with farmer fertilizer) Referring (Table 7). This increment is not only in quantity but also in quality, as observed in marketable yield in WFD RF (98 %) but FIP FF (97 %). The same irrigation level but different fertilizer application resulted in WFD RF by (1,194 kg/ha) higher yield than WFD FF with (98 %) marketable yield in both cases. FIP RF by (370 kg/ha) higher yield was obtained than FIP FF with (97 %) marketable yield in both cases. The marketable yield was higher in WFD than FIP. This shows that marketable yield was determined by irrigation level. Generally irrigation with WFD (7.5 %) total yield increment with respect to FIP. According to Melaku *et al.*, (2016) variation of onion yield between the farmers differed strongly within each of the

irrigation treatment resulting in rather similar average yields of 3430 kg/ha (TDR) and 3758 kg/ha (WFD). Although the average yield in the WFD plot was slightly (10 %) higher, yields.

Table 7. Marketable and non-marketable yield

Water management	Yield (kg/ha)					
	Marketable		Non marketable		Total	
	RF	FF	RF	FF	RF	FF
WFD	33402 ^a	32218 ^b	656 ^b	646 ^b	34058 ^a	32864 ^b
FIP	30380 ^c	30014 ^c	765 ^a	761 ^a	31145 ^c	30775 ^c
CV	2.3		12.7		2.4	
LCD _(0.05)	702		88		750	
SE	340		42		363	

WFD = Wetting front detector, FIP = Farmer irrigation practice, RF = Recommended fertilizer, FF = Farmers usual practice fertilizer, CV= Coefficient of Variance, LSD= List significant difference and SE = Standard error

4.7. The Status of Fertilizer

The recommended/applied fertilizer rate for the research during planting is 200 kg/ha DAP and 300 kg/ha Urea whereas farmers' common practice is use of 300 kg/ha DAP and 300 kg/ha Urea. The contents of nitrogen (N) and phosphorus (P) in DAP 18 % N, 46 % P while in Urea 46 % N, makes applied mineral elements of N 174 kg, P 92 kg in WFD fields and in farmers practice the amount of N is 192 kg and P is 138 kg. This implies that farmer's fertilizer application is higher than WFD rates by 9 % N and 33% P.

In Ethiopian market 1kg N costs 27 birr and 1kg P costs 24 birr. Therefore, recommended fertilizer rate cost of N and p was 6,906 birr and that of farmer's fertilizer was 8,496 birr. Hence in farmers fertilizer rate will incur 1, 590 birr additional cost for purchasing fertilizer compared to that of recommended fertilizer rate.

Laboratory results from the soil samples, Table 8, indicates that before planting exchangeable potassium was 0.85 Cmol(+)/kg, total nitrogen 0.21 % and available phosphorous 11.63 ppm which are the same amount for irrigation with wetting front detector and irrigation with farmer usual practice while post-harvest soils contained exchangeable potassium as 0.67 Cmol(+)/kg,

total nitrogen 0.21 % and available phosphorous 7.26 ppm. This shows that before planting nutrient contents of the soil was slightly higher compared to post harvest nutrient contents. The laboratory result indicates that additional fertilizer was used by plants from the soil and lowered the level of available nutrient contents of the soil.

Post-harvest nitrogen analysis shows that slightly high amount of N remained in the soil in case of FIP FF by (9.5 %) which is better than FIP RF but it is associated with high amount of fertilizer applied in FF which was higher than WFD by (9 %). WFD RF and WFD FF results were the same but the application amount by farmer's fertilizer application during cropping season was higher by (9%) which shows wastage of that amount of fertilizer. With different irrigation levels WFD RF (9.5 %) was better than FIP RF which indicates loss of fertilizer which may be a leaching effect due to over irrigation. Shock *et al.*, (2013) states over irrigation leads to erosion, disease susceptibility, water loss, and extra energy costs for pumping, nitrogen leaching, increased crop nitrogen needs, and tuber loss in storage.

In case of the same irrigation water level with different fertilizer application; available phosphorous after harvesting for WFD RF in comparison with WFD FF was higher by (12 %) which should be due to higher phosphorous (33%) application during planting season. This shows a loss of (21 %) phosphorous for farmer's fertilizer rate. FIP RF compared with FIP FF resulted in higher available phosphorus for FF by (15 %) which shows a loss of (18 %) phosphorous from farmer fertilizer application rate.

For different amount of irrigation water and with the same fertilizer application rate available phosphorous after harvesting on WFD RF was (37 %) higher than FIP RF and WFD FF was found (35%) higher than FIP FF. Both results show that after potato harvesting, the available phosphorus in the soil had been higher in WFD irrigation which could be the result of efficient use of irrigation water without leaching the available phosphorus and available for the next season crops.

Table 8. Status of fertilizer in the soil before planting and after harvesting

Water management and fertilizer	Before Planting			After Harvesting			deference		
	Ex.K	TN	Av.P	Ex.K	TN	Av.P	Ex.K	TN	Av.P
WFD RF	0.85	0.21	11.63	0.65	0.21	8.29	+(0.20)	(0.00)	+(3.34)
WFD FF	0.85	0.21	11.63	0.5	0.21	9.38	+(0.35)	(0.00)	+(2.25)
FIP RF	0.85	0.21	11.63	0.65	0.19	5.24	+(0.20)	+(0.02)	+(6.39)
FIP FF	0.85	0.21	11.63	0.89	0.21	6.13	-(0.04)	(0.00)	+(5.50)
Average	0.85	0.21	11.63	0.67	0.21	7.26	0.18	0.00	4.37

*WFD RF = Irrigation wetting front detector with recommended fertilizer rate, WDF FF = Irrigation wetting front detector with farmers usual practice fertilizer rate, FIP RF = Farmer irrigation practice with recommended fertilizer rate, FIP FF = Farmer irrigation practice with farmers usual practice fertilizer rate, Ex.K = Exchangeable potassium, TN = Total Nitrogen and Av.P = Available Phosphorous

4.8. Water, Fertilizer and Yield Interaction

As indicated in Table 9, irrigation with the use of WFD with RF and FF were applied with same volume of water, 9993 m³/ha, which were not significantly different. The same holds true for irrigation with FIP RF and FF with irrigation water volume 12266m³/ha. However, there is a highly significant difference of irrigation water between WFD and FIP. The plot which was applied with higher irrigation water was FIP and the lower irrigation water was applied on WFD plots. The figure shows that 18.5 % water was saved due to instruction of WFD than irrigating with FIP. This amount is not undermined amount per plot. This amount of water can enable to extend the command area when it is converted to the total water wastage in Koga irrigation scheme due to management practices which can in turn result in poor crop harvest and fertilizer leaching effects

In the above paragraph, the application of different amount of water results in yield deference. The same fertilizer application but different water level also results in yield difference. Crop productivity result showed that quantity of yield difference for WFD RF and FIP RF was (2,913 Kg/ha) which shows yield of WFD RF was higher than FIP RF while the yield difference between WFD FF and FIP FF was (2,098 kg/ha) which shows yield from WFD FF was higher than FIP FF. Both results show that the highest yield is obtained from WFD water application instruction.

Irrigation with different amount of fertilizer application also resulted in yield deference. The amount of yield difference for WFD RF and WFD FF was (1,194 kg/ha) while amount of yield difference for FIP RF and FIR FF was (370 kg/ha). For both irrigation methods, the recommended fertilizer application rate resulted in higher yield than farmer's fertilizer rate. This showed that use of required amount of water and nutrient absorption are highly linked i.e. a healthy soil-plant-water relationship is highly important for optimum yield gain. A plant with adequate nutrition can generally better withstand water stress (Gonzalez Dugo *et al.*, 2010; Waraich *et al.*, 2011). Plants which have adequately used fertilizers may also show higher drought tolerance (Lahiri, 1980; Wang *et al.*, 2011). Water use efficiency also increases with increases in water supply up to a certain point. Water supply has been observed to increase fertilizer use efficiency by increasing the availability of applied nutrients. In fact, water and nutrients have been shown to exhibit interactions in respect of yield (Prihar *et al.*, 1985; Aggarwal, 2000). In several studies, soil nitrogen level was positively related to water use efficiency (Paramweswaran *et al.*, 1981; Heiholdt, 1989). Phosphorus, in a balanced soil fertility program, increases water use efficiency and helps crops achieve optimal performance under limited moisture conditions (Payne *et al.*, 1992; Wang *et al.*, 2011).

Table 9. Mean value of water, fertilizer and yield of potato

Water management with fertilizer rate	Applied Water (m ³ /ha)	Applied Fertilizer rate (kg/ha)	Gained Yield (kg/ha)
WFD RF	9993	200	34058
WFD FF	9993	300	32864
FIP RF	12266	200	31145
FIPFF	12266	300	30775

*WFD RF = Irrigation wetting front detector with recommended fertilizer rate, WDF FF = Irrigation wetting front detector with farmers usual practice fertilizer rate, FIP RF = Farmer irrigation practice with recommended fertilizer rate and FIP FF = Farmer irrigation practice with farmers usual practice fertilizer rate.

4.9. Water Productivity

There is highly significant difference in applied water, water productivity at 5 % and 1% level between WFD RF and FIP RF and also WFD FF and FIP FF treatments. There is significant difference in water productivity between RF and FF, under WFD water management conditions. However, no difference was observed between the fertilizer treatments for the farmers who irrigated according to their own practice (Appendix Table 18 and Table 10). This shows that fertilizer effect on water productivity under WFD, but no effect FIP.

Under the same water management (WFD) are recorded better water productivity in recommended fertilizer application (3.42 kg/m³). The least water productivity (2.52 kg/m³) were observed for FIP FF. Water productivity is to get higher output to use minimum input that is to use less water, time, fertilizer and labor and needs to take in the full benefits of production. Referring to (Table 10), water productivity of WFD RF, WFD FF, FIP RF and FIP FF were 3.42 kg/m³, 3.30 kg/m³, 2.55 kg/m³ and 2.52 kg/m³ respectively. Water productivity was increased by 25 % in WFD compared to that of FIP. According to Melakuet al., (2016)The average water productivity in the onion plots under the WFD treatment (0.60 kg/m³) and (0.47 kg/m³) obtained in the TDR treatment this shows that WFD 21% of water productivity higher than TDR.

Table 10. Mean value of crop water productivity

Water management	WP (kg/m ³)	
	RF	FF
WFD	3.42 ^a	3.30 ^b
FIP	2.55 ^c	2.52 ^c
CV	3.3	
LCD _(0.05)	0.09	
SE	0.05	

Same letter are not significantly different, WFD=Wetting Front Detect FIP = Farmer Irrigation Practice, RF = Recommended fertilizer, FF = Farmer fertilizer, WP = Water productivity, CV= Coefficient of variance, LSD = list significant difference and SE = Standard error,

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1. Summary and Conclusion

The study evaluated water saving by using wetting front detector and different levels of fertilizer application and influence on potato yield and water productivity. The research was conducted at Koga Irrigation and Watershed Management Project of Mecha Woreda, Ambomesk kebele farmer's farm. The experiments had two factorial, namely water management (Wetting front detector and farmer irrigation practice) and different levels of fertilizer (recommended fertilizer and farmer usual practice fertilizer rate). The experimental plot had randomized complete block design (RCBD) with four treatments and nine replications.

During the experiment, data such as soil moisture content at different growth stages, total nitrogen, available phosphorus, exchangeable potassium, time used in one irrigation, each irrigation discharge, amount of applied water, number of days per consecutive irrigation/irrigation interval/, and agronomic data like height of potato plant at each growth stage and yield of potato crop were taken and analyzed

The result indicates that the amount of applied irrigation water with WFD was 18.5 % less than that of FIP and the yield of potato with WFD RF, WFD FF, FIP RF and FIP FF treatments were observed in the order of 34058 kg/ha, 32864 kg/ha, 31145 kg/ha and 30775 kg/ha. Water supply had been observed to increase fertilizer use efficiency by increasing the availability of applied nutrients. In fact, water and nutrients had been shown to exhibit interactive effects on yield. The water productivity of irrigation with WFD RF was better (3.42 kg/m^3) than other and WFD FF (3.30 kg/m^3) better than the FIP RF (2.55 kg/m^3) and the least was with FIP FF (2.52 kg/m^3).

This result indicates that irrigation with WFD leads to higher potato yields than FIP and recommended fertilizer and is better than farmer's fertilizer. The higher yield, the lower water and fertilizer utilization resulted in high water productivity.

It is concluded that irrigation with the WFD was better than farmer's practice irrigation due to water saving of 18.6%, a higher return for this smaller amount of water, and the minimized water loss through deep percolation. The detector adjusted crop root depth shows how deep the water

has penetrated into the soil after irrigation and informs the irrigator that the wetting front has reached a certain depth. WFD was improving water use efficiency and improve irrigation performance.

When comparing potato productivity, there was a statistically significant deference between recommended fertilizer and farmer's usual practice fertilizer. Recommended fertilizer was better than farmer's usual practice fertilizer. Recommended fertilizer application helps minimize economic losses as well as ecological disturbance and increases productivity.

Using the wetting front detector instruction is highly efficient than farmers' irrigation practice which can create an opportunity to irrigate an additional irrigation potato area of (1,541 ha) with WFD. This is a significant area of land with WFD technology for the farming community by arresting waste of irrigation due to deep percolation and evaporation Thus this instrument solve the water shortage and avoid major problem and conflict between upstream and downstream irrigators.

Generally to use irrigation with wetting front detector and recommended fertilizer farmers would save 1,590 birr/ha for fertilizer purchasing cost, one irrigation season 3.75 day/ha time saved and additional average marketable (2,613 kg/ha) yield gained.

5.2. Recommendations

The results of the experiment showed that WFD guided irrigation saves water and increases yields when compared to farmer's usual practices. The WFD is a simple tool for practical use in the field for small-scale growers to determine irrigation water amounts and helps improve water productivity. However, to determine the next irrigation integrated with other irrigation scheduling technique. The farmers are recommended to use irrigation by WFD for irrigation applied water and this technology should be distributed to other poor water management areas. This experiment was conducted over the course of one season, in only one location. Hence repeating the experiment in the same space and time shall improve the validity of the findings. This tool used to install effective root depth of the crops but the crops are at different growing season at different root depth and at least development, mid season and late season root depth three detector are required to install.

6. REFERENCE

- Abebaw Kebede. 2009. A Comparative Performance Evaluation of Surge and Continuous Flow Irrigation in Short Furrows. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.
- Admasu W, Tadesse K, Hordofa T, Deresse Y, Habte D (2016). Determining of Optimal Irrigation Regimes and NP Fertilizer Rate for Potato (*Solanum tuberosum L.*) at Kulumsa, Arsi Zone, Ethiopia. Acad. J. Agric. Res. 4(6): 326-332.
- Aggarwal, P.K. 2000. Application of system simulation for understanding and increasing yield potential of wheat and rice. Published Ph.D. Thesis, Wageningen, The Netherlands. <http://edepot.wur.nl/197264>.
- Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 1998. Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper No. 56.FAO, Rome.
- Alterra-ILRI, I. I. 2005. Irrigation and Drainage Performance Assessment. Netherlands: CABI.
- Annandale, J.G., Benadé, N., Jovanovic N.Z., Steyn J.M. and Du Sautoy N (1999) Facilitating irrigation scheduling by means of the soil water balance model. WRC Report no: 753/1/99, Pretoria, South Africa.
- Bhattarai M, Sakthivadivel R, Hussein I. 2000. Irrigation impacts on income inequality and poverty alleviation: Policy issues and options for improved management of irrigation systems. Colombo, Sri Lanka: International Water Management Institute (IWMI) Working Paper No.39.
- Bradley, A.k. and Stark, J.C. 1997. Potato irrigation management, Universty of Idalo cooperative extention system, mosctw.
- Charles worth, P.B. 2005 Irrigation Insights No. 1 - Soil WaterMonitoring (2nd edition). National Program for Irrigation Research and Development, CSIRO Publishing, Melbourne, Australia.
- Deribew Shanko. 2007. Performance evaluation of alternate, fixed and conventional furrow irrigation systems for onion production at Shalled Ziway Dugda District, Arsi Zone. M.Sc. Thesis, Haramaya University, Haramaya.

- Drechsel, P., Heffer, P., Magen, H., Mikkelsen, R. and Wichelns, D. (Eds.) 2015. Managing Water and Fertilizer for Sustainable Agricultural Intensification. International Fertilizer Industry Association (IFA), International Water Management Institute (IWMI), International Plant Nutrition Institute (IPNI), and International Potash Institute (IPI). First edition, Paris, France. Copyright 2015 IFA, IWMI, IPNI and IPI. All rights reserved ISBN 979-10-92366-02-0.
- Eguavoen, I., Tesfai, W. 2011. Rebuilding livelihoods after dam induced relocation in Koga, Blue Nile Basin, Ethiopia. Working paper series 83. Zentrum für Entwicklungsforschung, University of Bonn.
- FAO (Food and Agriculture Organization). 1989. Guidelines for Designing and Evaluating Surface Irrigation Systems: Irrigation and Drainage Paper. No. 45. FAO, Rome.
- FAO (Food and Agriculture Organization). 1996. Irrigation scheduling: From theory to practice Proceedings. Food and Agriculture Organization of United Nations. ICID CIID. Water Reports 8. Rome. ISBN 92-5-103968-2.[Online]. Available from: <http://www.fao.org/docrep/W4367E/W4367E00.htm#Contents>. [31 March 2007].
- FAO (Food and Agriculture Organization), 2002. Crop Water Requirement Guide Lines. Water development division, Rome, Italy.
- FAO (Food and Agriculture Organization), 2002. Crops and drops: making the best made of water for agriculture. Paper No 33. FAO, Rome, Italy.
- FAO (Food and Agriculture Organization) 2002. Crops and Drops. Land and Water Development Division. Rome, Italy.
- FAO (Food and Agricultural organization), 2002. Deficit irrigation practice. FAO, Rome, Italy.
- Fares, A. and Alva, A.K. 2000. Soil water components based on capacitance probes in a sandy soil. Soil Sci.soc. Am.J.64:311-318.
- Fekadu, M., Teshome, A. and Mekuria, T. 2000. Existing Constraints and Suggested Strategies for Enhancing Investment in Irrigated Agriculture on Investment in Irrigated Agriculture, Agricultural workshop, Addis Ababa
- Frank, J.D. 2003. Potato Texas Cooperative Extension, Horticulture crop Guides Series. (<http://Haggiehorticulture.town.edu/extension/vegetable/cropguides/potato.html/>).

- Gardner, W. and Kirkham, D. 1952. Determination of soil moisture by neutron scattering. *Soil Sci.* **73** 391.
- Gajri, P.R., Prihar, S.S. and Arora, V.K. 1993. Interdependence of nitrogen and irrigation effects on growth and input-use efficiencies in wheat. *Field Crops Research* 31:71-86.
- Gonzalez-Dugo, V.; Durand, J.-L.; Gastal, F. 2010. Water deficit and nitrogen nutrition of crops: A review. *Agronomy for Sustainable Development* 30(3): 529-544.
- Hansen, V.E., Israelsen, O.E. and Stringham, G.E. 1980. *Irrigation Principles and Practices*. John Willey and Sons, Inc. New York.
- Hawkes, J.G. 1992. Biosystematics of potato. In: panl Harries, *The potato crop (The scientific basis for improvement)*, Chapman in Hall, London, p.909.
- Heiholdt, J.J. 1989. Water use efficiency and dry matter distribution in nitrogen and water stressed winter wheat. *Agronomy Journal* 81:464-469.
- Horst, M.G., Shamutalov, S.S., Gonçalves, J.M. and Pereira, L.S. 2007. Assessing impacts of Surge flow irrigation on water saving and productivity of cotton. *Agricultural Water Management*, 87 (2): 115-127.
- Hussain I., Marikar F. and Thrikawala. S. 2001. Impact of Irrigation Infrastructure Development on Poverty Alleviation in Sri Lanka and Pakistan. *Journal of Development Studies* 21(2): 29-31.
- Hussain I, Hanjra MA. 2004. Irrigation and Poverty Alleviation. *J. Irrig. Drain. Syst.* 53(1):1-15.
- Ismail, S.M. 2006. Effect of tillage on water advance and distribution under surge and continuous furrows irrigation methods for cotton in Egypt, *Irrig. and Drain.* 55: 191–199.
- James, L. G. 1988. *Principles of Farm Irrigation System Design*. John Wiley and Sons, Inc. New York.
- Jalota, S.K., Romesh, K. and Ghuman, B.S. 1998. *Hydraulic property of soil: Method in soil physics*, New Delhi: Narosa Publishing House.
- Jensen, M. E., Burman, R. D. & Allen, R. G (editors). 1990a. *Evapotranspiration and irrigation water requirements*. ASCE Manuals and Reports on Engineering Practice, No. 70. ISBN-10: 0872627632. ISBN-13: 9780872627635.
- Jenny, J., Gordon, R., Alison A. and Andrea V. (2008). *Managing Water for yeild and profit. A training guide for Irrigators in the Australian Vegetable Industry*, Australian, Arris.

- Jurreins, M., Zeriun, D., Boonstra, J. and Feyen, J. 2001. SURDEV: Surface irrigation software: Design operation and evaluation of Basin, Border and Furrow irrigation. ILRI Publication 59, Wageningen, the Netherlands.
- Kassa Teddla. 2001. Performance evaluation of surface irrigation methods at melka worer. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.
- Kassaw Beshaw. 2011. Evaluation of Alternate and Surge Flow Furrow Irrigation Methods for Onion Production at Humbo. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.
- Kanber, R., Koksai, H. Onder, S., Kapur, S. and Sahan, S. 2001. Comparison of surge and continuous furrow methods for cotton in the Harran plain. *Agr. Water Management* 47:119-135.
- Kenneth, H.S. 1988. *Irrigation Systems and Water Application Efficiencies*. California State University, Fresno, California.
- Kijne, J.W., Barker, R., Molden, D. (eds.). 2003. *Water productivity in agriculture: Limits and opportunities for improvements*. Comprehensive Assessment of Water Management in Agriculture Series 1, CABI International, UK.
- Lahiri, A.N. 1980. Interaction of water stress and mineral nutrition on growth and yield. In: Turner, N.C. and P.J. Kramer (eds.). *Adaptation of plants to water and high temperatures stress*. John Wiley and Sons, New York, pp. 87-103.
- Mahmood, S. 2004. Development and calibration of surge irrigation performance evaluation model. PhD Dissertation, university of engineering and technology, Lahore, Pakistan. New York.
- Melaku Tesema. 2015. Evaluating Simple Irrigation Technologies to Improve Crop and Water Productivity of Onion in Dangishta Watershed. M.Sc. Thesis, Bahir Dar University, Bahir Dar, Ethiopia.
- Melaku Tesema, Petra, S., Prossie N., Seifu Admasu, T, Tammo, S. and Simon, L. 2016. Melaku Tesema. (ed.), *Conference of Evaluating irrigation technologies to improve crop and water productivity of onion in Dangishta watershed during the dry monsoon phase*. Faculty of Civil and Water Resource Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Ethiopia.
- Minwiyelet Nigatu. 2004. Evaluation of surge flow on the infiltration process and performance of furrow irrigation at Awash Melkassa. M.Sc. Thesis, Alemaya University.

- MoWR (Ministry of Water Resources). 1998. Tekeze River Basin Integrated Development Master Plan Project. Executive Summary, Federal Democratic Republic of Ethiopia (FDRE), Addis Ababa.
- Ministry of Water Resources (MoWR) 2008. Koga Irrigation Project – Cost Recovery Study. Volume 1: Main Report. Desta Woreda Water Supply Engineering Service. Accessible as hardcopy at Koga Irrigation Project Office in Merawi.
- Morries, M. and Vicki, L. 2006. Measuring and Conserving Irrigation Water. ATTRA Publication No. P280. NCAT.
- Mott MacDonald. 2004. Koga Irrigation and Watershed Management Project, Hydrology Factual Report, 23 pp.
- Mulubrehan Kifle. 2007. Evaluation of surge flow furrow irrigation at Mekelle, Northern Ethiopia. M.Sc. Thesis, Alemaya University, Alemaya, Ethiopia.
- Nigus Demelash .2013. Deficit irrigation scheduling for potato production in North Gondar, Ethiopia, *African Journal of Agricultural Research*, Vol. 8(11), pp. 1144-1154.
- Passioura, J. 2006. Increasing crop productivity when water is scarce from breeding to field management. *Agricultural Water Management* 80: 176-196.
- Palada, M., Bhattarai, S., Roberts, M., Bhattarai, M., Kimsan, R. and Midmore D. 2011. More Crop Per Drop: Using Simple Drip Irrigation Systems for Small-scale Vegetable Production. AVRDC The World Vegetable Center, Shanhua, Taiwan. AVRDC Publication No. 09-723. 83 p.
- Paramweswaran, K.V.M., Graham, R.D. and Aspinall, D. 1981. Studies on the nitrogen and water relations of wheat-I. Growth and water use in relation to time and method of N application. *Irrigation Sciences* 3:29-44.
- Petra S, Amare H, Mengistu D, Seifu A , Yigzaw D, Simon L (2015). Improving water management within the Koga irrigation scheme through an easy irrigation scheduling tool
- Pavlista, A.D. 1995. Potato production stages: Scheduling key practices. UNL Coop Ext Circ 1249.
- Payne, W.A., Drew, M.C., Hossner, L.R., Lascano, R.J., Onken, A.B. and Wendt, C.W. 1992. Soil phosphorus availability and pearl millet water-use efficiency. *Crop Sciences* 32:1010-1015.
- Philip J.R. 1957. The theory of infiltration. 2. The profile at infinity. *Soil Sci.* **83**: 435-448.

- Prihar, S.S., Gajri, P.R. and Arora, V.K. 1985. Nitrogen fertilization of Wheat under limited water supplies. *Fertiliser Research* 8:1-8.
- Rafael M. 2015. Field Devices for Monitoring Soil Water Content, Department of Agricultural and Biological Engineering, UF/IFAS Extension, University of Florida, BUL343
- Richards, L.A. and Neal O.R. 1936. Some field observations with tensiometers. *Soil Sci. Soc. Am. Proc.* **1** 71.
- Rogers, D.H., Mahbub, F.R., Trooien, A., Clark, T.P., Baras, G.A. and Kyle, M. 1997. Efficiencies and water losses of irrigation systems. Irrigation Water Management series. Kansas, U.S.A.
- Rubin J and Steinhardt R. 1963. Soil water relations during infiltration. I. Theory. *Soil Sci Soc Am Proc* **27**: 246-251.
- Schwab, G.O., Fangmeier, D.D. and Elliot, W.J. 1995. Soil and water management systems. Publisher Wiley, J., and Inc, S. ISBN-10: 0471109738. p 255-272.
- Shock, C.C., Flock, R., Feibert, E., Shock, C.A., Pereira, A. and Jeneson, L. 2005. onion response to drip irrigation monitoring using soil water tension. Factsheet No: EM 8900, Oregon state University.
- Shock, F.X. Wang, R. Flock, E. Eldredge, and Pereira, A. 2013. Successful Potato Irrigation Scheduling for Agricultural Water Research in China, China Agricultural University: *Feng-Xin Wang, associate professor* Extension oregonstate.edu/em8911
- Smith, M. 1992. CROPWAT, a computer program for irrigation planning and management. Irrigation and Drainage Paper 46, FAO, Rome, Italy.
- Smith LED (2004). Assessment of the Contribution of Irrigation to Poverty Reduction and Sustainable Livelihoods. *Int. J. Water Resour. Dev.* 20(2):243-257.
- Solomon, K. 1988. Irrigation Systems and Water Application Efficiencies: Irrigation Note. California State University, Fresno, California 93740-0018, CATI.
- Stirzaker, R.J. 2003. When to turn the water off: scheduling micro irrigation with a wetting front detector. *Irrig. Sci.* **22** 177-185.
- Stirzaker, R., Stevens, J., Annandale, J., Maeko, T., Steyn, J., Mpandeli, S., Maurobane, W., Nkgapele, J. and Jovanovic, N. 2004. Building Capacity in Irrigation Management with Wetting Front Detectors. Report to the Water Research Commission Project No. 188: In

- Jackson, Rd., Reginato, Rj. and Idso, Sb. 1977. Wheat canopy temperature: A practical tool for evaluating water requirements. *Water Resour. Res.* **13**:651-656.
- Stirzaker ,R.J. and Hutchinson, P.A .2005. Irrigation controlled by a wetting front detector: field evaluation under sprinkler irrigation. *Aust. J. Soil Res.* **43** 935-943.
- Stirzaker, R.J. 2008. Factors affecting sensitivity of wetting front detectors. In: Goodwin I and O'Connell MG (eds.) *Proc.5thInternational Symposium on Irrigation of Horticultural Crops.Acta Hort.* **792** 647-654.
- Stirzaker, R., Stevens, J., Annandale, J.and Steyn, J, 2009 Stage in the adoption of wetting front detector. *Irrig. Drain.* **59** 376-376.
- Take,W.A., Arnepalli, D.N, Brachman,R.W.I. and Rowe,R.K. 2007. laboratory and field calibration of tdr probes for water content measurement.
- Tesfaye, M. and Fassil, K. 2011. Suitability of Koga Watershed for Irrigated Sugarcane and Onion Production in the Blue Nile Basin, Ethiopia. *Journal of the Drylands* 4(2): 325-332.
- Topp, G.C. and Davis, J.L. 1985. Time-domain reflectometry and its application to irrigation scheduling. *Adv. Irrig.* **3**:107-129.
- Von Braun J., Fan S., Meinzen Dick R., Rosegrant MW, and Pratt AN (2008). International Agricultural Research for Food Security, Poverty Reduction, and the Environment. In: Stansbury, C. (ed.). What to expect from scaling up CGIAR investments and “Best Bet” Programs. International Food Policy Research Institute (IFPRI), Washington, DC., USA. pp. 35-36.
- Wang, B., Liu, W. and Dang, T. 2011. Effect of phosphorus on crop water and nitrogen use efficiency under different precipitation year in dryland. *Proceedings of International Symposium on Water Resources and Environmental Protection,*
- Werner, H. 2002. Measuring Soil Moisture for Irrigation Water Management. *Coprative extension servise/FS* 876, 5.
- White ,I. and Zegelin, S.J. 1995. Electric and dielectric methods for monitoring soil-water content. p.343-385. In “Handbook of vadose zone characterization and monitoring” (Ed. LG Wilson, LG Everett and SJ Cullen). Lewis publishers, London.

- Waraich, E.A.; Ahmad, R.; Ashraf, Yaseen, M.; Saifullah, S.; Ahmad, M. 2011. Improving agricultural water use efficiency by nutrient management in crop plants. *Acta Agriculturae Scandinavica Section B: Soil and Plant Science* 61(4): 291-304
- Yonts, C.D., Joel, E. and Dean, E. 1995. Surge flow irrigation. University of Nebraska. Fact Publication. Electronic version issued July 1995.
- Zur, B., Ben-Hanan, U., Rimmer, A. and Yardeni, A. 1994. Control of irrigation amounts using the velocity and position of a wetting front. *Irrigation Science* 14, 207.

7. APPENDICES

7.1. Appendix Table

Appendix Table 1. Physical and chemical properties of soil

Plot No & Treatme nt	Before harvesting					After Harvesting					moisture content %
	PH (H ₂ O) 1:2:5	EC (ds/m)	Ex.KC mol(+) /kg	TN %	Av.P (ppm)	PH (H ₂ O) 1:2:5	EC (ds/m)	Ex.KC mol(+) /Kg	TN %	Av.P (ppm)	
plot 1 T1											36.28
plot 2 T1											35.3
plot 3 T1	6.27	0.16	0.62	0.23	17.5	4.7	0.084	0.32	0.21	14.38	36.76
plot 4 T1											40.52
plot 5 T1	6.1	0.049	0.94	0.2	5.5	5.39	0.03	0.53	0.21	4.25	38.39
plot 6 T1											39.59
plot 7 T1											38.34
plot 8 T1											40.9
plot 9 T1	5.33	0.042	0.99	0.2	11.88	4.9	0.056	1.09	0.2	6.25	34.91
plot 1 T2											
plot 2 T2											
plot 3 T2	6.27	0.16	0.62	0.23	17.5	4.2	0.125	0.29	0.17	5	
plot 4 T2											
plot 5 T2	6.1	0.049	0.94	0.2	5.5	4.83	0.078	0.51	0.2	9	
plot 6 T2											
plot 7 T2											
plot 8 T2											
plot 9 T2	5.33	0.042	0.99	0.2	11.88	4.9	0.056	1.09	0.2	6.25	
plot 1 T3											38.64
plot 2 T3											36.47
plot 3 T3	6.27	0.16	0.62	0.23	17.5	4.4	0.154	0.35	0.21	12.75	39.87
plot 4 T3											38.07
plot 5 T3	6.1	0.049	0.94	0.2	5.5	5.23	0.027	0.46	0.16	3.88	40.65
plot 6 T3											37.79
plot 7 T3											37.41
plot 8 T3											40.05
plot 9 T3	5.33	0.042	0.99	0.2	11.88	4.9	0.056	1.09	0.2	6.25	34.64
plot 1 T4											
plot 2 T4											
plot 3 T4	6.27	0.16	0.62	0.23	17.5	4.6	0.081	0.56	0.21	7.35	

plot 4 T4											
plot 5 T4	6.1	0.049	0.94	0.2	5.5	5	0.085	0.73	0.23	4.25	
plot 6 T4											
plot 7 T4											
plot 8 T4											
plot 9 T4	5.33	0.042	0.99	0.2	11.88	5.36	0.049	1.65	0.22	9.13	

P = Plot (farmer experimental farm), T= treatment, PH (H₂O) = acidity, alkalinity, base EC = Electrical conductivity, Ex.K = Exchangeable potassium, TN = Total Nitrogen Av.P = Available Phosphorous, plot 1 T1 = farmer experimental land number 1 treatment 1 and plot 1 T2 = farmer experimental land number 1 treatment 2

They have 9 farmer using water management WFD and FIP irrigation. In appendix table 2 one example, that is farmers Bayleyeng Bayeh (Plot 5). Applied water irrigation with WFD or FIP = irrigated time * Discharge of water pass through 2 inch partial flume. E.g. = 0.42 m³/min * 21 min = 8.82 m³.

Total Irrigation amount in growing season = sum of daily applied water = (8.88 + 9.14 + ... + 8.36) = 95.69 m³

Irrigation depth (mm) = (Applied water m³/area of irrigation m²)*1000mm/m = 95.69 m³/100m²= 957mm.

Appendix Table 2. Irrigation based on WFD and FIP single experimental data sheet

Date of irrigation event	2 inch partial flume irrigation water depth (cm)	2 inch partial flume Discharge (m ³ /min)	Time of yellow detector pop up (min)	WFD Irrigation time (min)	WFD Applied water (m ³)	Farmer usual practice Irrigation time (min)	FIP Applied water (m ³)
20/1/16	16	0.42	7	21	8.88	25	10.57
26/1/2016	18	0.51	6	18	9.14	22	11.17
16/2/2016	14	0.34	8	24	8.25	25	8.60
25/2/2015	16	0.42	7	21	8.88	24	10.15
4/3/2016	18	0.51	6	18	9.14	22	11.17
9/3/2016	17	0.46	6	18	8.36	23	10.69
16/3/2016	18	0.51	5	15	7.61	20	10.15
24/3/2016	19	0.55	4	12	6.62	17	9.38
1/4/206	17	0.46	5	15	6.97	17	7.90
8/4/2016	15	0.38	4	12	4.59	14	5.36
16/4/2016	16	0.42	7	21	8.88	23	9.73
25/4/2016	17	0.46	6	18	8.36	25	11.61
Sum				213	95.68	257	116.48
Average	16.75	0.45	5.92	17.75	7.97	21.42	9.71

WFD = Wetting front detector, FIP = Farmer irrigation practice

Appendix Table 3. Irrigation applied water amount each irrigation with wetting front detector

Irrigation event	WFD P1 T1	WFD P2 T1	WFD P3 T1	WFD P4 T1	WFD P5 T1	WFD P6 T1	WFD P7 T1	WFD P8 T1	WFD P9 T1
1	6.89	9.28	8.88	8.04	8.88	10.66	8.04	10.15	8.88
2	6.19	9.76	8.25	5.57	9.14	6.89	6.97	6.89	6.97
3	6.44	7.61	8.04	7.61	8.25	6.09	5.07	5.57	8.04
4	6.19	9.14	12.54	5.07	8.88	5.16	7.61	6.89	8.36
5	5.74	6.09	7.61	7.22	9.14	6.89	6.19	12.18	8.04
6	6.34	5.16	5.16	8.36	8.36	7.22	6.97	7.22	7.61
7	4.87	6.89	8.36	7.22	7.61	7.61	5.16	6.89	6.19
8	5.52	6.97	6.19	13.25	6.62	8.36	9.94	6.97	6.89
9	5.74	6.89	5.74	8.88	6.97	6.97	6.34	7.61	8.88
10	5.07	8.36	5.57	6.89	4.59	8.88	8.36	9.76	6.97
11	5.07	6.97	5.74	7.61	8.88	8.36	7.61	7.61	6.89
12	6.19	7.61	6.89	8.36	8.36	5.16	4.97	7.61	8.88
13	4.60	4.59	8.28	6.34		7.61	6.34	6.97	8.28
14	4.87		7.22	6.09			6.09	5.07	
15	5.16							7.61	
16	5.07								
Sum (m ³ /100m ²)	89.9	95.3	104.5	106.5	95.7	95.8	95.6	115	100.8
depth (mm)	899	953	1044	1065	956	958	956	1150	1008

P1 T1 = Plot 1 Treatment 1, P2 T1 = Plot 2 Treatment 1, P3 T1 = Plot 3 Treatment 1, P4 T1 = Plot 4 Treatment 1, P5 T1 = Plot 5 Treatment 1, P6 T1 = Plot 6 Treatment 1, P7 T1 = Plot 7 Treatment 1, P8 T1 = Plot 8 Treatment 1, P9 T1 = Plot 9 Treatment 1,

Appendix Table 4. Irrigation applied water amount each irrigation with farmer irrigation practice

Irrigation event	FIP P1 T1	FIP P2 T1	FIP P3 T1	FIP P4 T1	FIP P5 T1	FIP P6 T1	FIP P7 T1	FIP P8 T1	FIP P9 T1
1	9.57	12.04	10.99	9.57	10.57	13.20	8.80	12.26	10.57
2	8.25	10.22	9.28	8.36	11.17	9.57	8.83	8.80	8.36
3	8.89	10.15	9.57	10.15	8.60	9.14	5.92	7.90	9.95
4	7.56	9.64	14.87	6.34	10.15	5.85	9.64	7.65	11.15
5	7.27	7.11	9.64	8.60	11.17	9.18	6.88	12.69	8.80
6	9.30	6.53	7.56	10.22	10.69	7.56	9.76	8.60	8.88
7	5.14	9.57	9.29	8.25	10.15	9.73	5.85	7.65	8.60
8	5.52	8.36	6.53	13.25	9.38	10.22	11.59	8.36	8.80
9	6.50	8.42	5.74	10.57	7.90	8.83	8.03	8.88	11.42
10	6.34	9.29	6.50	7.65	5.36	10.57	10.22	11.15	8.83
11	7.19	9.76	7.27	10.66	9.73	9.29	10.66	10.15	8.04
12	6.19	9.14	8.80	10.69	11.61	6.19	7.73	8.88	10.15
13	5.21	6.50	11.59	8.46		10.15	7.61	7.90	9.94
14	6.50		8.60	8.63			8.12	7.19	
15	6.53							10.15	
16	6.34								
Sum (m ³ /100 m ²)	112.3	116.7	126.2	131.4	116.5	119.5	119.6	138.2	123.5
Depth (mm)	1123	1167	1262	1314	1165	1195	1196	1382	1234

The duration of water application to the plot will be determined by the equation (Solomon, 1988; Morris and Vicki, 2006)

Appendix Table 5. Each irrigation applied water irrigation depth in WFD and FIR

Furrow width (m)	Furrow Length (m)	Discharge (l/s)	WFD Irrigation time (hr)	WFD Irrigation depth (cm)	FIP Irrigation time (hr)	FIP Irrigation depth (cm)
0.7	20	7.0	0.35	63	0.42	76
0.7	20	8.5	0.30	65	0.37	80
0.7	20	5.7	0.40	59	0.42	61
0.7	20	7.0	0.35	63	0.40	72
0.7	20	8.5	0.30	65	0.37	80
0.7	20	7.7	0.30	60	0.38	76
0.7	20	8.5	0.25	54	0.33	73
0.7	20	9.2	0.20	47	0.28	67
0.7	20	7.7	0.25	50	0.28	56
0.7	20	6.4	0.20	33	0.23	38
0.7	20	7.0	0.35	63	0.38	69
0.7	20	7.7	0.30	60	0.42	83
Average				57		69

Appendix Table 6. Discharge, time, fertilizer, water, yield and water productivity

Plot No & Treatment	Discharge (m ³ /min)	Time (min/ha)	Fertilizer (kg/ha)	water (m ³ /ha)	yield (Kg/ha)	Water productivity (kg/m ³)
plot 1 T1	0.35	25800	200	8996	32827	3.65
plot 2 T1	0.43	22200	200	9532	29798	3.13
plot 3 T1	0.41	25500	200	10448	29894	2.86
plot 4 T1	0.44	24300	200	10653	34870	3.27
plot 5 T1	0.45	21300	200	9569	38162	3.99
plot 6 T1	0.43	22500	200	9586	34757	3.63
plot 7 T1	0.45	21300	200	9567	38315	4.01
plot 8 T1	0.44	26400	200	11501	37517	3.26
plot 9 T1	0.42	24000	200	10087	30379	3.01
plot 1 T2	0.35	25800	300	8996	31735	3.53
plot 2 T2	0.43	22200	300	9532	29477	3.09
plot 3 T2	0.41	25500	300	10448	26518	2.54
plot 4 T2	0.44	24300	300	10653	34051	3.2
plot 5 T2	0.45	21300	300	9569	37523	3.92
plot 6 T2	0.43	22500	300	9586	33798	3.53
plot 7 T2	0.45	21300	300	9567	36671	3.83
plot 8 T2	0.44	26400	300	11501	37079	3.22
plot 9 T2	0.42	24000	300	10087	28927	2.87
plot 1 T3	0.35	32000	200	11232	30839	2.75
plot 2 T3	0.43	27400	200	11672	28491	2.44
plot 3 T3	0.41	30700	200	12625	26161	2.07
plot 4 T3	0.44	29900	200	13140	32808	2.5
plot 5 T3	0.45	25700	200	11647	35442	3.04
plot 6 T3	0.43	27900	200	11947	32110	2.69
plot 7 T3	0.45	26400	200	11964	34552	2.89
plot 8 T3	0.44	31700	200	13822	34038	2.46
plot 9 T3	0.42	29400	200	12347	25862	2.09
plot 1 T4	0.35	32000	300	11232	29572	2.63
plot 2 T4	0.43	27400	300	11672	29380	2.52
plot 3 T4	0.41	30700	300	12625	25571	2.03
plot 4 T4	0.44	29900	300	13140	31694	2.41
plot 5 T4	0.45	25700	300	11647	34929	3
plot 6 T4	0.43	27900	300	11947	32876	2.75
plot 7 T4	0.45	26400	300	11964	32946	2.75
plot 8 T4	0.44	31700	300	13822	33795	2.45
plot 9 T4	0.42	29400	300	12347	26209	2.12

Appendix Table 7. Applied water in four development stage of potato

Plot No & Treatment	Stage of development			
	Initial	Development	Mid-season	Late season
plot 1 T1	19.51	18.27	21.21	30.97
plot 2 T1	19.04	22.84	25.9	27.54
plot 3 T1	17.13	20.58	27.32	39.44
plot 4 T1	21.22	12.3	44.6	28.41
plot 5 T1	18.02	26.27	29.57	21.83
plot 6 T1	17.55	18.14	30.16	30.01
plot 7 T1	20.08	20.77	29.8	25.02
plot 8 T1	22.61	33.18	31.95	27.27
plot 9 T1	15.85	24.43	29.57	31.02
plot 1 T2	19.51	18.27	21.21	30.97
plot 2 T2	19.04	22.84	25.9	27.54
plot 3 T2	17.13	20.58	27.32	39.44
plot 4 T2	21.22	12.3	44.6	28.41
plot 5 T2	18.02	26.27	29.57	21.83
plot 6 T2	17.55	18.14	30.16	30.01
plot 7 T2	20.08	20.77	29.8	25.02
plot 8 T2	22.61	33.18	31.95	27.27
plot 9 T2	15.85	24.43	29.57	31.02
plot 1 T3	26.71	24.14	23.51	37.96
plot 2 T3	22.26	26.9	32.88	34.69
plot 3 T3	20.28	24.43	33.03	48.5
plot 4 T3	28.08	14.94	49.95	38.43
plot 5 T3	21.74	29.91	38.12	26.7
plot 6 T3	22.76	24.17	36.34	36.21
plot 7 T3	23.55	26.28	35.69	34.12
plot 8 T3	28.96	36.59	38.54	34.12
plot 9 T3	18.93	29.9	37.7	36.95
plot 1 T4	26.71	24.14	23.51	37.96
plot 2 T4	22.26	26.9	32.88	34.69
plot 3 T4	20.28	24.43	33.03	48.5
plot 4 T4	28.08	14.94	49.95	38.43
plot 5 T4	21.74	29.91	38.12	26.7
plot 6 T4	22.76	24.17	36.34	36.21
plot 7 T4	23.55	26.28	35.69	34.12
plot 8 T4	28.96	36.59	38.54	34.12
plot 9 T4	18.93	29.9	37.7	36.95

Appendix Table 8. Soil moisture measurement by TDR at three stages

Plot No & Treatment	After irrigation moisture %			Before irrigation moisture %			Moisture Deference %		
	Dev.	Flow.	Matu.	Dev.	Flow.	Matu.	Dev.	Flow.	Matu.
plot 1 T1	39.83	42.67	40.9	23.15	23.82	22.48	16.68	18.85	18.42
plot 2 T1	40.08	43.97	38.75	23.19	24.2	22.88	16.89	19.77	15.87
plot 3 T1	40.77	35.83	38.68	24.18	23.23	23.72	16.58	12.6	14.97
plot 4 T1	36.48	34.87	38.05	24.92	23.58	24.2	11.57	11.28	13.85
plot 5 T1	46.03	47.94	45.85	23.22	26.11	25.32	22.81	21.83	20.53
plot 6 T1	45.75	40.72	42.47	23.23	22.98	24.17	22.52	17.73	18.3
plot 7 T1	39.83	45.02	39.85	24.13	25.18	23.37	15.7	19.84	16.48
plot 8 T1	47.85	48.28	45.77	24.65	23.87	23.5	23.2	24.42	22.27
plot 9 T1	48.42	39.5	35.38	25.98	23.97	23.78	22.43	15.53	11.6
plot 1 T2	40.17	42.63	40.13	21.22	23.85	22.6	18.95	18.78	17.53
plot 2 T2	40.58	44.1	38.17	23.55	24.07	22.58	17.03	20.03	15.59
plot 3 T2	40.1	36.53	39.2	24.2	23.32	23.52	15.9	13.22	15.68
plot 4 T2	36.78	34.5	38.8	24.72	23.15	24.3	12.07	11.35	14.5
plot 5 T2	45.58	47.88	47.27	23.1	25.73	25.13	22.48	22.15	22.13
plot 6 T2	45.27	40.42	42.47	23.25	23.18	24.18	22.02	17.23	18.28
plot 7 T2	39.83	45.07	39.87	24.45	24.66	22.95	15.38	20.41	16.92
plot 8 T2	47.87	48.17	45.35	24.53	24.27	23.48	23.33	23.9	21.87
plot 9 T2	48.47	39.6	35.57	25.37	24.18	23.78	23.1	15.42	11.78
plot 1 T3	42.37	46.67	42.63	23.62	23.73	23.2	18.75	26.9	19.43
plot 2 T3	43.45	47.17	43.35	23.9	24.33	22.86	19.55	22.83	20.49
plot 3 T3	43.67	38.48	41.72	24.5	23.22	23.93	19.17	15.27	17.78
plot 4 T3	39.58	36.7	41.2	24.88	24.05	24.42	14.7	12.65	16.78
plot 5 T3	50.25	51.95	50.33	23.95	25.68	25.42	26.3	26.28	24.92
plot 6 T3	46.5	43.3	45.27	23.35	23.25	24	23.15	20.05	21.27
plot 7 T3	43.07	47.27	41.1	24.58	25.03	23.32	18.48	22.24	17.78
plot 8 T3	51.88	50.63	46.75	25.08	24.23	23.57	26.8	26.4	23.18
plot 9 T3	50.78	42.35	38.03	25.73	25.88	23.98	25.05	16.47	14.05
plot 1 T4	42.1	46.23	43.77	23.55	23.82	23	18.55	22.42	20.77
plot 2 T4	43.22	46.68	43.63	23.97	24.1	22.79	19.25	22.58	20.84
plot 3 T4	43.78	38.52	41.68	23.92	23.37	23.55	19.87	15.15	18.13
plot 4 T4	39.63	37	41.67	24.17	23.75	24.37	15.47	13.25	17.3
plot 5 T4	50.08	51.53	50.38	23.72	25.82	25.28	26.37	25.72	25.1
plot 6 T4	47	43.28	45.67	23.57	23.15	24.33	23.43	20.13	21.33
plot 7 T4	42.75	46.82	41.9	24.73	25.07	23.42	18.02	21.75	18.48
plot 8 T4	51.97	50.52	47.05	24.7	23.72	23.18	27.27	26.8	23.87
plot 9 T4	49.77	42.03	38.35	25.72	26.03	23.87	24.05	16	14.48

Appendix Table 9. Irrigation interval the study area determined by WFD for next season

Plot No & Treatment	volumetric m.c. after irrigation	Volumetric m.c. before irrigation	moisture deference before & after irrigation	moisture deference changed to percent	depth of yellow detector in mm	ETo	Irrigation interval
	1	2	3=(1-2)	4= 3/100	5	6	7=(5*4)/6
plot 1 T1	39.83	23.15	16.68	0.17	200	5.06	6
plot 2 T1	40.08	23.19	16.89	0.17	200	5.06	6
plot 3 T1	40.77	24.18	16.58	0.17	200	5.06	6
plot 4 T1	36.48	24.92	11.57	0.12	200	5.06	4
plot 5 T1	46.03	23.22	22.81	0.23	200	5.06	9
plot 6 T1	45.75	23.23	22.52	0.23	200	5.06	9
plot 7 T1	39.83	24.13	15.7	0.16	200	5.06	6
plot 8 T1	47.85	24.65	23.2	0.23	200	5.06	9
plot 9 T1	48.42	25.98	22.43	0.22	200	5.06	8
plot 1 T2	40.17	21.22	18.95	0.19	200	5.06	7
plot 2 T2	40.58	23.55	17.03	0.17	200	5.06	6
plot 3 T2	40.1	24.2	15.9	0.16	200	5.06	6
plot 4 T2	36.78	24.72	12.07	0.12	200	5.06	4
plot 5 T2	45.58	23.1	22.48	0.22	200	5.06	8
plot 6 T2	45.27	23.25	22.02	0.22	200	5.06	8
plot 7 T2	39.83	24.45	15.38	0.15	200	5.06	5
plot 8 T2	47.87	24.53	23.33	0.23	200	5.06	9
plot 9 T2	48.47	25.37	23.1	0.23	200	5.06	9
average							7 day

m.c = moisture content

$$I=d (\theta_{wf} - \theta_{rf})/Et$$

Irrigation interval = depth of detector (m.c. after irrigation m.c. before irrigatio

Appendix Table 10. Monthly Reference evapotranspiration of the crop

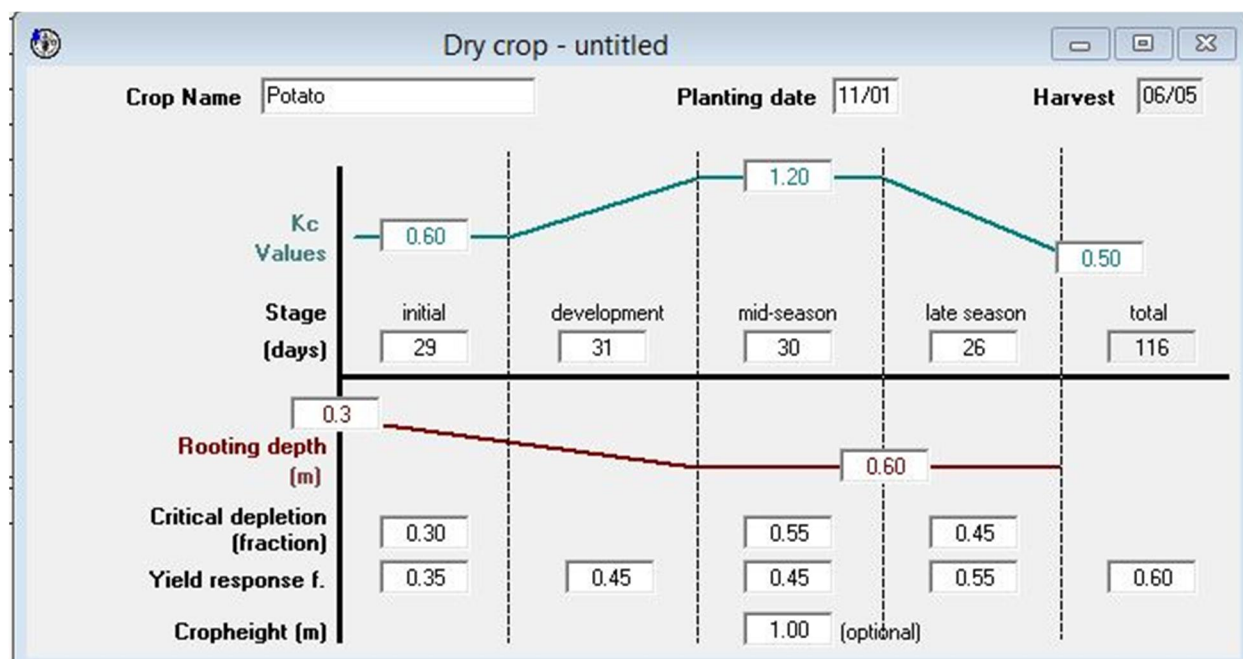
Monthly ETo Penman-Monteith - untitled

Country: Station:

Altitude: m. Latitude: °N Longitude: °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	m/s	hours	MJ/m ² /day	mm/day
January	8.5	27.0	50	0.7	9.6	21.1	3.64
February	10.0	29.0	43	0.8	9.3	22.1	4.12
March	13.0	30.0	41	0.9	9.2	23.3	4.72
April	15.0	30.5	42	1.0	9.2	23.7	5.06
May	15.0	29.5	53	0.9	7.5	20.7	4.47
June	14.0	27.6	67	0.9	6.5	18.9	3.99
July	14.0	24.7	77	0.8	4.7	16.3	3.28
August	14.0	24.6	84	0.7	4.6	16.4	3.20
September	13.0	25.8	73	0.7	6.5	19.2	3.67
October	13.6	26.7	64	0.8	8.6	21.4	4.03
November	11.0	26.8	57	0.7	9.5	21.2	3.83
December	8.8	26.6	52	0.6	9.8	20.8	3.56
Average	12.5	27.4	59	0.8	7.9	20.4	3.96

Appendix Table 11. Potato crop parameters used for CROPWAT model



Appendix Table 12. ANOVA plant height at 50 day

Source of variation	Degree of Freedom	Sum Square	Mean Square	F - Value	probability
Replication	8	1229.5	153.7	25.1	<.0001
Treatment	3	37.9	12.6	2.1	0.1322
experimental error	24	147.1	6.1		
Total	35	1414.5			

ns = no significant at treatment but significant in replication

Appendix Table 13. ANOVA plant height at 100 day

Source of variation	Degree of Freedom	Sum Square	Mean Square	F - Value	probability
Replication	8	2654.5	331.8	40.1	<.0001
Treatment	3	94.4	31.8	3.81	0.0231
experimental error	24	198.5	8.3		
Total	35	2947.4			

*, significant at 5 % level

Appendix Table 14. ANOVA applied water

Source of variation	Degree of Freedom	Sum Square	Mean Square	F - Value	probability
Replication	8	1981.74	247.7	431.79	<.0001
Treatment	3	4649.87	1549.95	2701.69	<.0001
experimental error	24	13.76	0.57		
Total	35	6645.37			

**, highly significant at 5 % and 1 % level

Appendix Table 15. ANOVA Marketable Yield

Source of variation	Degree of Freedom	Sum Square	Mean Square	F - Value	probability
Replication	8	44104	5513	105.8	<.0001
Treatment	3	6834.9	2278.3	43.7	<.0001
experimental error	24	1251	52.1		
Total	35	52189.9			

**, highly significant at 5 % and 1 % level

Appendix Table 16. ANOVA Total Yield

Source of variation	Degree of Freedom	Sum Square	Mean Square	F - Value	probability
Replication	8	39882.44	4985.3	83.95	<.0001
Treatment	3	6333.2	2111.07	35.55	<.0001
experimental error	24	1425.2	59.38		
Total	35	47640.84			

**, highly significant at 5 % and 1 % level

Appendix Table 17. ANOVA Non makeable Yield

Source of variation	Degree of Freedom	Sum Square	Mean Square	F - Value	probability
Replication	8	1029.4	128.7	158.9	<.0001
Treatment	3	11.3	3.8	4.6	0.0108
experimental error	24	19.4	0.8		
Total	35	1060.1			

*, significant at 5 %

Appendix Table 18. ANOVA Potato crop water productivity

Source of variation	Degree of Freedom	Sum Square	Mean Square	F - Value	probability
Replication	8	4.4	0.55	59.5	<.0001
Treatment	3	6.3	0.009	226.34	<.0001
experimental error	24	0.2	49.65		
Total	35	10.9			

**, highly significant difference at 5 % and 1 % level

7.2. Appendix Figure



Appendix Figure 1. Installation of WFD



Appendix Figure 2. Discharge measurement by Parshall flume



Appendix Figure 3. Flowering to maturity stage of the potato crop



Appendix Figure 4. Potato crop yield at plant label