BAHIR DAR UNIVERSITY

Bahir Dar Institute of Technology

Faculty of civil and water Resource Engineering

Master Thesis

Partial Nutrient Balance at Farm plot level under Different Irrigation Water Management for Tomato production

BY: Muluye Gedfew Hune

Bahir Dar University

Bahir Dar; Ethiopia

November; 2016

Partial Nutrient Balance at Farm plot level under Different Irrigation Water Management for Tomato production

The Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in “Water Resource Engineering” Specialization “Engineering Hydrology”.

Presented to the Faculty of Civil and Water Resource Engineering, Bahir Dar Institute of Technology, Bahir Dar University.

BY: Muluye Gedfew

Supervised by: Dr Seifu.A Tilahun

Co-supervisor: Dr. Petra Schmitter

Dr.prossie Nakawuka

November; 2016, Bahir Dar

Declaration

I, Muluye Gedfew Hune; declared the work in this thesis entitled by '**evaluation of irrigation scheduling strategies on partial nutrient balance for tomato production in Robit Bata study site'** Under the supervision of Dr. Seifu Adimasu, and co supervision of Dr.Petra schmitter and Dr.Prossie Nakawaka. All the information taken from difference literature and other sources follows scientifical ethics and cited properly. No former publication of the part of this thesis work is there in any of institutions.

Signature ------------------------------

Date ------------------------------------

Muluye Gedfew Hune

BAHIR DAR UNIVERSITY

Bahir Dar Institute of Technology

Faculty of civil and water resource Engineering

Partial Nutrient Balance at Farm plot level under Different Irrigation Water Management for Tomato production

By: Muluye Gedfew Hune

Approved by board of examiners

______________________	________________	_______________
Faculty Dean	Signature	Date
______________________	________________	_______________
Advisor	Signature	Date
______________________	________________	_______________
External Examiner	Signature	Date
______________________	________________	_______________
Internal Examiner	Signature	Date

This thesis is dedicated to my father; Gedfew Hune, my mother Abeba Anilay & my advisor Dr.Seifu Tilahun for their unmeasurable support.

Abstract

Reasonable and efficient utilization of the water and soil resources are viable so as to maximize the production and productivity of the farm land. Unwise utilization of those two most critical resources results in the decline of production and productivity. Managing irrigation water delivered to the irrigation field could able to increase the yield by controlling the nutrient flow system in the soil media. The objective of this study is to evaluate the different water management methods on yield maximization by providing a great attention to the partial nutrient balance system. The study have a brief on the quantification of irrigation water required to a given plot by following technical approach of continues soil moisture measurement using sensor device Time Domain reflect meter (TDR) and through the use of 10 years back climatic historical data from Bahir Dar weather station data. The usual farmers practice have become evaluated and compared with the technical management methods in terms of water demand at each plot and partial nutrient balance pattern. To achieve the comparison, the experimental plots were prepared and grouped in to three categories. The comparison result shows that usual farmers practice have used less water at the initial stage and too much water at maturity stage not matching exactly on the requirement level of the crop; less crop yield and more positive partial N balance and negative P and K balance other than the technical management methods. The average partial Nitrogen (N)depletion balance for TDR, CWR,FARM were,-90.6 kg/ha, -151.3 kg/ha and 18.8 kg/ha ; Phosphorus (P) depletion balance were -0.6 kg/ha, -0.5 kg/ha, and – 0.2 kg/ha and potassium(K) depletion balance were; -284 kg/ha ,-270 kg/ha and -97.2 kg/ha respectively. The Average crop yield was 33.2 Mg ha-^{1}; 31.67 Mg ha^{-1}; 20.8 Mg ha^{-1} for CWR; TDR; and FARM water management groups respectively. The respective average water consumption of CWR, TDR and FARM were 590 mm, 476 mm and 575 mm respectively.

Acknowledgement

First of all I would like to thank the almighty **GOD** and his mother **St. Marry** for keeping me courageous and inspired to go through all of my work.

I would like to express my hearted gratitude to my advisor **Dr. Seifu Adimasu**, for his precious advice, suggestions and constructive comments during my stay in the research. I have no term to express his total contribution for my successful accomplishment of studying the class session and the research. I have benefited a lot from his experience and knowledge during my stay at the department of engineering hydrology and till now.

Heartily; I would like to Acknowledge; my co-advisors Dr. Ir. Petra Schmitter and Dr.Prossie Nakawaka for their unlimited support and motive. The thesis from the start to end for the basic design, layout and also any of relevant measurement and analysis that able to be successful accomplishment.

Gratefully I would like to say thanks for Ethiopian road authority (ERA) for securing a full sponsorship for the opportunity given to Carry out Master's Degree in Engineering Hydrology and for the long mission of capacity building on master of science for numerous disciplines. I would like to acknowledge Bahir Dar University for safe program settlement with ERA sponsorship.

Acknowledgement is expressed to my research supporting friends; Melaku Tesema, Debebe Lijalem, as well as Data collectors. I also deeply acknowledge my families and relatives for their great encouragement.

The research for this MSc thesis was made possible through the support of the Feed the Future Innovation Lab for Small-Scale Irrigation (ILSSI) project, a cooperative research project implemented through the United States Agency for International Development (USAID) in support of the Feed the Future (FtF) program. The research was implemented under a collaborative partnership between the International Water Management Institute and Bahir Dar University. The contents of the paper are the responsibility of the authors and do not necessarily reflect the views of USAID or the United States government.

Table of Contents

List of Tables

List of Figures

List of Acronyms and abbreviations

AMD ------Available Moisture Deficit

CWR ------Crop Water Requirements

DA ---------Development Agent

DAP -------Day after planting

CEC -------- cation exchange capacity

ETc ---------Crop Evapotranspiration at standard condition.

ETo --------Reference Evapotranspiration

FAO --------- Food and Agricultural Organization of the United Nation

FC -----------Field Capacity

Ha ------------hectares

ILSSI --------Innovation laboratory for small scale irrigation

IR -------------Irrigation requirements

IWMI ----------International Water Management Institute

IWR ------------Irrigation Water Requirements

MHD ------- Mahalanobis Distance

PWP ------------Permanent Wilting Point

SMPR -----------Soil moisture profiler reading

TDR -------------Time domain reflect meter

USAID -----------United States Agency for International Development

1 Introduction

1.1 Background and Justification

The Ethiopian farming system depends strongly on rainfed smallholder farm as a means of food and income for its population; virtually all food crops come from rainfed agriculture system (Hordofa et al., 2008). Rainfed agriculture products are not sufficient to ensure food security and market demand of the society. Irrigated agriculture is as crucial as it does not only to provide resilience under variable climatic conditions but also to provide agricultural products outside of the main cropping season, ensuring availability of products throughout the year. Irrigated agriculture uses surface water or groundwater to ensure crop production outside of the rainy season or, when supplementary, improves resilience during the rainy season. Systematic application of irrigation water is crucial to ensure efficient utilization of water and other resources (Etissa et al., 2014b). Irrigation application plays a vital role in the water and crop productivity, safe nutrient movement in the soil and sustainable use of land resources (Awulachew et al., 2005, Ali and Talukder, 2008). Traditionally irrigation water is applied in the field without considering the daily crop water requirement as per the prevailing climatic conditions and the crop development as well as the existing soil moisture content. As such, many of the irrigation systems like flood irrigation and surface irrigation are excessive and have a low efficiency, leading to high water, soil and nutrient losses.

For a specific crop, the crop water requirement during its various growth stages is different, and influenced by the weather conditions as it influences the rate of water movement from both the plant (i.e. transpiration) and the soil (i.e. evaporation). The efficient use of water is also dependent upon the relationship of both deficiencies and excesses of water to plant growth (Ali and Talukder, 2008). Efficient water usage must be based upon a thorough understanding of climatic, soil, crop and management factors. Climate is uncontrolled but it is possible to modify its effects through good irrigation and crop management. The practical questions are therefore: what are the effects of over-watering, how much water should be used, and what is the proper rate of watering?" (Wheater and Evans, 2009). Excess irrigation can lead to permanent loss of land resources and leaching out of nutrients through lateral flow and deep percolation. Water as well as nutrients are lost within the system leading to severe on-site (e.g. decreasing soil fertility, soil compaction) and off-site effects (e.g. eutrophication of water bodies).

Irrigation water is stored in the soil and removed by crops through evaporation or lost through runoff or seepage. The amount of water lost through these processes is affected by irrigation system design and irrigation management (Loucks and Van Beek, 2005). Efficient scheduling minimizes runoff and percolation losses, which in turn usually maximizes irrigation efficiencies by reducing energy and water use. Irrigation scheduling is a systematic method by which a producer can decide on when to irrigate and how much water to apply. The goal of an effective scheduling program is to supply the plants with sufficient water while minimizing loss to deep percolation or runoff (Zotarelli et al., 2009). Soil water relationship, atmospheric situation, crop variety, irrigation system and other operational factors determines irrigation scheduling (Goldhamer and Fereres, 2004). Proper irrigation scheduling requires a sound basis for making decisions. The decision making rides from personal experience to following neighbors' practices and techniques based on expensive computer-aided instruments that can assess soil, water and atmospheric parameters (Pereira et al., 2007). Irrigation scheduling techniques can be based on soil water measurement, meteorological data or monitoring plant stress. Conventional scheduling methods are to measure soil water content or to calculate or measure evapotranspiration rates. However, research in plant physiology has led to scheduling methods by monitoring leaf water pressure, trunk diameter and sap flow (Pereira et al., 2007). Irrigation is an important determinant of crop yield and growth because it is associated with many factors of plant environment, which influence growth and development. Availability of adequate amount of moisture at critical stages of plant growth not only optimizes the metabolic process in plant cells but also increases the effectiveness of the mineral nutrients available to the plants (Allen, 1996).

Apart from the water availability, soil fertility and availability of micro and macro nutrients is equally important for crop growth. Soil physicochemical properties are strongly influencing water movement and leaching of nutrients from it. Soils have specific nutrient absorptive capacities, and increasing the rate of irrigation may result in a reduction of total uptake. For example, soils containing mainly fine clay particles are more vulnerable to erosion and nutrient loss (e.g. vertisols) (Ali and Talukder, 2008) whereas soils with mainly coarse sand particles are less vulnerable as those soils have higher infiltration rates. Crops have different nutrient preference and nutrients occur in different forms, influencing their mobility and uptake rate. Furthermore different crops have different nutrient requirements. Soil test used to estimate the fertility level of the soil requires the measurement of the plant available quantity as the measurement of total nutrient content of the soil is not a suitable indicator for plant growth given fact the small proportion of plant available nutrients (Marx et al., 1999). As such, fertilizer input requirement depends on the plant available nutrients present in the soil and the crop nutrient requirement. Soil intrinsic soluble nutrients and fertilizer are potentially washed out when the dose of water applied is above the crop water requirement and the soil up take rate (Rego et al., 2002). Nitrogen (N) under the form of nitrate is mobile and volatilize in the form of ammonium while phosphorus (P) under PO_4^{3-} is mostly leached to soil particles and less mobile. Even though P may also washed out as dissolved phosphorus, it increases in saturated soil conditions due to ongoing redox reactions. Mobile nutrients will be easily removed via runoff or leached through deep percolation, reducing nutrient availability for the crop. On the other hand, when the applied water is inadequate, the available soil moisture content will be insufficient and plants will welt and die. In such conditions the nutrient uptake by plants is hampered in absence of water. Over and under irrigation reduces crop yield as, it affects soil aeration capacity if applied in excess, causes plant stress if applied in scarce (Ali and Talukder, 2008), influencing the nutrient balance in the root zone and reducing its availability. As such, it is important to evaluate nutrient uptake under various irrigation scheduling scenarios for various soil types to ensure optimal nutrient uptake, water and crop productivity and minimal soil nutrient leaching or losses.

1.2 Statement of the problem

Rainfed agricultural system is the most common production system in Ethiopia. However, given the rising population and climatic variability, the provision of food security is a challenge. Irrigation can aid in ensuring food security during the dry season and improve people livelihoods. However, water is a scarce resource in many parts of the world requiring an efficient and sustainable use both in quality and quantity. As such, irrigation water using surface or groundwater needs to be used in an efficient way. On the other hand, in areas where water is sufficiently available there is no consideration of water as a valued resource leading to soil degradation and reduced yields (Etissa et al., 2014b). In common irrigation practices the irrigation water is applied over the irrigable area without considering the amount needed and time of the requirement by plant. Within Ethiopia, irrigation of farmland is often practiced through a flood or a furrow system resulting in high water losses through runoff and leaching and therefore the removal of available plant nutrients. Furthermore, the used fertilizer rates are often not related to the actual nutrient status of the soil. Improper input and irrigation water application does not only lead to loss of those resources but also leads to unsustainable production capacity of the land and water resources. On the other hand, the use of manual water lifting devices used in smallholder irrigation often are labor intensive which could lead to under –irrigation and insufficient uptake of nutrients leading to low water and crop productivity. Smallholder irrigation using manual and motorized water lifting devices are being strongly promoted in Ethiopian Governmental programs like the agricultural growth program (AGP) I and II to improve food security during the dry season. In Ethiopia the production of high value vegetable production such as tomato are being promoted (Gebreselassie, 2003). As such, the number of small scale irrigation plots has increased rapidly especially in the northern part of Ethiopia (Woldewahid et al., 2011). However, the scheduling and application of irrigation water as well as fertilizer is used whenever the farmer is able to access water or has the means to buy fertilizer and does not necessarily follow the crop requirement (Gebreselassie, 2003). Little is known in Ethiopia on the optimal irrigation requirement for small holder farms using manual water lifting technologies for the cultivation and irrigation of high value crops such as vegetables. Furthermore, the effect of irrigation practices and different irrigation scheduling methods on soil nutrient balances (N, P and K) are poorly understood within this context.

Research is needed to understand the effect of different irrigation scheduling methods on crop and water productivity as well as on soil nutrient balances for smallholder vegetable production. The research will help to understand the opportunities for irrigation scheduling and effects on soil nutrient balances for small holder irrigators using small plot sizes and groundwater. The research examines the partial nutrient balance of the soil by measuring the nutrient (i.e. N, P and K) inputs (i.e. atmospheric deposit, fertilizer and irrigation water) to the soil and the nutrient outputs (i.e. harvested products and residuals)

1.3 Research question

- Does the irrigation water applied during irrigation scheduling differ from farmers practice for smallholder irrigation using manual water lifting technologies?
- Which irrigation method leads to higher crop and water productivity?

- How does the irrigation method influence partial nutrient balances of N, P and K?

1.4 Objective

The objective has two parts a general objective and specific objective. The general objective of the study is:

1.4.1 General objective

To investigate the role of irrigation scheduling on crop and water productivity and partial nutrient balances (i.e. N, P and K) for tomato in the dry season.

1.4.2 Specific objectives

1. To compare irrigation water applied for three different irrigation methods (Farmers' practice, soil moisture based scheduling and crop water requirement scheduling)

2. To compare differences in crop and water productivity for three different irrigation methods (Farmers' practice, soil moisture based scheduling and crop water requirement scheduling)
3. To investigate the impact of three irrigation methods on partial nutrient balances.

2 Literature Review

2.1 Irrigation water management

Efficient irrigation water management encourages the application of water amount that meets the need of the growing plant in a manner that avoids extended soil saturation and runoff. Water management is an important element of irrigated crop production. Efficient irrigation systems and water Management practices can help to maintain farm profitability in an area of limited or higher-cost water supplies. Efficient water management may also reduce the impact of irrigated production on off-site effects of water quantity and quality. Water savings through improved management of irrigation supplies are considered essential to meeting future water needs (Wheater and Evans, 2009). Different crops have different water requirement at different development stage so that crop type and its development stage identification is critical to quantify the volume and time of irrigation. The traditional local irrigation method does not consider prevailing climatic and soil moisture conditions. Farmers often use a rough observation of crop water stress. Traditional irrigation is responsible for different loss including percolation below the root zone, nutrient leaching due to excess water and water stress of the crop due to non-periodical application(Ley et al., 1994).

Irrigation water management plays a great role for both water[1] and crop productivity (Werner, 1992) and can be improved by irrigation scheduling techniques. Irrigation scheduling is the use of water management strategies to prevent over and under application of water while minimizing yield loss due to water shortage or nutrient losses resulting in obtaining optimum yield (Woldewahid et al., 2011). Irrigation scheduling helps to manage the water for maximum yield production by creating the conducive environment for the nutrient movement within the soil and good nutrient up take of the plant (Etissa et al., 2014b). Therefore, irrigation scheduling is an extremely important management practice for irrigators (Pereira et al., 2007).The quantity of water pumped can often be reduced without reducing yield. Soil moisture and climatic data are crucial

[1] Water productivity is measured by the total yield obtained by the total water applied ZWART, S. J. 2010. *Benchmarking water productivity in agriculture and the scope for improvement-remote sensing modelling from field to global scale*, TU Delft, Delft University of Technology.

factors for irrigation scheduling to calculated the appropriate water volume to be applied to the field (Zotarelli et al., 2014). For example, studies have shown that irrigation scheduling using soil water balance methods can save 15 to 35 percent of the water normally pumped without reducing yield (Allen, 1996).

2.2 Irrigation scheduling

Irrigation scheduling is the technique of determining how much water and when the given volume is applied in to an irrigated area. Determining when the crop requires water and how much water is needed requires the understanding of the soil characteristics particularly its moisture holding ability, environmental condition, the crop type and development stage (Goldhamer and Fereres, 2004). Irrigation scheduling could be done by measuring the daily soil moisture content using tensiometer or Time domain reflect meter (TDR) (Werner, 1992). The application of TDR measurement was firstly reported by (Topp et al., 1980) who described the advantages of the TDR. The study reported the high accuracy (1-2 % of volumetric water content), low calibration requirement and lack of radiation hazard (e. the case of the neutron probe or gamma ray attenuation techniques) allowing easy spatial and temporal measurements. When the field capacity of the specific soil is known, the amount of water needed to bring the measured soil moisture back to field capacity can then be calculated. The irrigation interval can easily be determined once the average water depletion due to evapotranspiration and the maximum allowable depletion is known (Alemu, 2015)

Among the methods used for determining when and how much to irrigate to the field are wetting front detector (WFD), tensiometer, FAO CROPWAT model and TDR are some irrigation scheduling techniques Frequently a minimum of 10 years climatic data is used representing the average conditions on site. The method is easier and less costly compared to the soil moisture based TDR as it does not require equipment and frequent measurements, however depending on the climatic variability the method might over or underestimate the irrigation requirement. In some cases a combination of both methods is used to correct for climatic variations or real time climatic data is used.

2.3 Irrigation application

The efficiency of irrigation water is partially influenced by the irrigation application method i.e. how water is applied. Common irrigation methods in tomato production are overhead, sprinkler, furrow irrigation or, micro (drip) irrigation. Irrigation methods have different application efficiencies, e.g. efficiency of sprinkler is 60% -80%,furrow 40% -60% and drip 75% - 90% (Etissa et al., 2014b). Furrow irrigation needs low initial cost compared to the other application methods. Drip irrigation requires skilled manpower to install, high maintenance, relatively expensive despite its highest efficiency. Usually, despite the application method, farmers tend to over-irrigate when availability is not a constraint whereas under limited water supply farmer tend to increase the irrigation interval, resulting in crop stress and subsequent low and poor quality yields(Goldhamer and Fereres, 2004). However, under limited water availability and manual water lifting devices, labor is often a constraint and overhead application is used. Overhead irrigation with its ability to provide controlled and frequent water applications directly in the vicinity of the crop root zone can be relatively efficient compared to furrow irrigation, decreasing water losses. As the soil is only partially wetted around the plants, soil evaporation losses are lower when sufficient plant cover is reached, resulting in a longer interval of sufficient soil moisture for plant uptake.

2.4 Irrigation of high value crops in Ethiopia using groundwater

Although, Ethiopia is considered as a water tower of Africa, only 5% irrigation potential is developed yet (Bekele, 2014). Ethiopia has a long history of traditional irrigation. The irrigation trend is simple river diversion. According to Gebremedhin and Pedon (2002), until recently, irrigation of high value crops in Ethiopia was not very common except for the long traditional commercial irrigated production of tomato and onion production near to Mojo River Ethiopia for commercial production (Gebreselassie, 2003). Due to governmental support, irrigated cultivation of high value crops such as vegetables (e.g. tomato and onion) is increasing rapidly (Gebreselassie, 2003). Governmental support exists out of capacity building of farmers in techniques to diverting or lift water for productive use (Gebreselassie, 2003). Whereas, in the northern part of Ethiopia (Tigray) the knowledge of the extraction of groundwater using water lifting technologies for irrigation has been increased, the use of groundwater for the production of high value crops remain (Woldewahid et al., 2011). Nevertheless, frequently in those sites where groundwater is used for irrigation, no irrigation scheduling is practiced and farmers often decide when and how much to apply based on experience and visual drying of the soil and/or plant. Furthermore, in places were tomato and onion are cultivated for commercial purposes often furrow irrigation is applied resulting in low application efficiencies (Gemechis et al., 2012). Irrigation requirement for tomato production in smallholder farmers plays a vital role due to high marketability even though there is market fluctuation in Ethiopia (Gemechis et al., 2012).

2.5 Partial nutrient balances under irrigated agriculture

Agricultural land is dynamic in nature. Its soil types, genesis and historical land use practice determine the organic matter content as well as plant available nutrients like available P, available K and N. In Ethiopia, using full nutrient balance calculations for N, P, K for small holder farmers rainfed fields are reported to have a depletion rate of -122 kg $ha^{-1}yr^{-1,}$ -13 kg $ha^{-1}yr^{-1}$, and -82 kg $ha^{-1}yr^{-1}$ at national level and -147 kg $ha^{-1}yr^{-1}$,-22 kg ha^{-1} yr^{-1} and -104 kg $ha^{-1}yr^{-1}$at Amhara regional level respectively (Haileslassie et al., 2005).In a similar paper partial nutrient balances reported for rain fed agriculture in Ethiopia are of 10 kg N $ha^{-1}yr^{-1,}$ 11 kg P $ha^{-1}yr^{-1}$, and 7 kg K $ha^{-1}yr^{-1}$ and -1 kg $ha^{-1}yr^{-1}$ of N,6 kg ha^{-1} yr^{-1} of P and -2 kg ha^{-1} $yr^{-1}$of K at regional level by the production year 1999/2000 which was enrichment.

Depending on the application, scheduling and overall irrigation method the nutrient balances under intensive irrigated vegetable production can differ strongly from those observed in rainfed agriculture as often nutrient uptake is high, leaching could be substantial, As such, and the application method of irrigation determines the use efficiency of water and nutrients. In Ethiopian, the irrigation method used throughout the country is furrow irrigation which is less efficient than drip, sprinkler, and overhead irrigation in terms of water usage and soil management (Werner, 1992). In the northern Ethiopia for the vegetable production irrigation application is done on furrow which has a low application efficiency due to over-irrigated (high nutrient losses) and under irrigated results crop stress (Awulachew et al., 2005) but, may also under irrigated. Less nutrient losses are expected with overhead application as mentioned in the section on irrigation application. On the other hand in cases of under- irrigation, physiological activity of the plant will be low resulting in reduced nutrient uptake and minimal to no yield. Furthermore, the crop type also influences which nutrients are taken up. For optimal yield, nutrient uptake by tomato is primarily in the form of nitrites, ammonium and available phosphorus (Zotarelli et al., 2009). Those nutrients are removed from the soil in different forms during various processes or taken up by tomato. The required amounts of the various N forms can be redistributed disturbed during irrigation.

Nutrient balance is a mathematical approach that computes what amounts are added and removed from the soil system (Rego et al., 2002).The balance computation for nutrient follows the conservation of mass. Estimates of nutrient additions, removals, and balances in the agricultural production system generate useful, practical information on whether the nutrient status of a soil (or area) is being maintained or depleted (Samar et al., 2001). Simple estimates of nutrient input and output allow the calculation of nutrient balance both for individual fields. Full nutrient balance incorporates all fluxes input and output in the soil, air and water media (Kiros et al., January, 2014). The full nutrient balance equation for each parameter (N, P and K) can be formulated as follows (Cobo et al., 2009).This is generalized equation for full nutrient balance estimation.

$$IN_1 + IN_2 + IN_3 + IN_4 + IN_5 + IN_6 = OUT_1 + OUT_2 + OUT_3 + OUT_4 + OUT_5 \qquad 2.1$$

Where: IN_1 are nutrients from the inorganic (i.e. mineral) fertilizer added, IN_2 nutrients from the organic fertilizer (e.g. compost/manure of cattle, small ruminants, mulching etc.), IN_3 nutrients added through wet atmospheric deposition from rainfall, IN_4 is the nitrogen added through nitrogen fixation (only for N), IN_5 are nutrients added through sedimentation, IN_6 the nutrients in irrigation water, OUT_1 are the nutrients removed by the harvest product, OUT_2 are the nutrients removed by crop residues, OUT_3 are the nutrients removed through leaching, OUT_4 are the gaseous losses (e.g. for nitrogen) and OUT_5 are the nutrients removed through erosion.

Although full nutrient balances take into account the various nutrient forms in the atmosphere-plant-soil-water continuum some of the parameters (e.g. fixation, gaseous losses and leaching) are difficult to estimate (Tandon, 2007). Hence, frequently partial nutrient balances are frequently used in studies.

2.5.1 Partial nitrogen balance

The total N pool in the soil depends on inorganic (nitrate [NO_3^-], nitrite [NO_2^-] and ammonium [NH_4^+]) and organic N (i.e. organic matter). NO_3^- - N is easiest form up taken by plants (Hutchinson and Davidson, 1993). N-NO_3^- is readily absorbed by root tissues via water uptake, assuring constant nitrogen supply except for extreme dry soil conditions (Rego et al., 2002). Furthermore, it is the common form in the soil following nitrification of ammonium fertilizers (e.g. urea, DAP or organic fertilizers) (Figure 1). The three common sources of N in mineral fertilizer are urea, ammonium and nitrite (Locascio et al., 1997). Hence, N-NO_3^- is the most abundant form of nitrogen available for plant uptake. Some terms used in the nutrient balance are defined as follows;

Nitrate uptake; Nitrate uptake is rapid due to high particle mobility most plants therefore prefer nitrate over ammonia. **Ammonium uptake;** the uptake rate for ammonium is slower than nitrate because of ammonium is bound to clay particles in the soil and there is limitation by roots to reach it. Corresponding to this phenomenon most of ammonium is nitrified before up taken by plants.

Nitrification; Nitrification is the process by which ammonium is converted to nitrate within a few days and a few weeks. During the process Nitrous oxide and nitric oxide are lost to the atmosphere.

Denitrification; conversion of nitrate and nitrite to gaseous Nitrous oxide, nitric oxide, and nitrogen through the action of soil bacteria. Denitrification favored by lack of oxygen /water logging/

Immobilization and Mineralization; immobilization is conversion of mineral nitrogen in to soil organic matter by soil microbes whereas mineralization is the release of ammonium from soil organic matter, manure and the like.

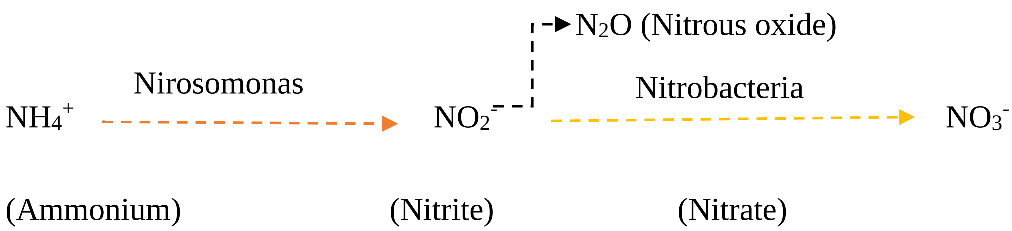


Figure 2-1: Nitrate conversion process through nitrification.

Even though uptake of nitrate is more rapid than ammonia due to particle mobility (Gessler et al., 1998, Mengel and Kirkby, 1987) it does not mean nitrate is always the most beneficial and/or preferred form of nitrogen for good plant growth and development. N-NH_4^+ is important building block in plant and soil metabolism (Fixen and Ludwick, 1983). Management techniques favoring more efficient nitrogen application includes specific placement (near to the root), split nitrogen application and the incorporation of nitrogen inhibitors. Nitrification inhibitors have been effective in light textured soils in reducing nitrogen losses through leaching and for soils under water logging conditions in reducing nitrogen losses through denitrification process (Seitzinger and Giblin, 1996):

$$NO_3^- \longrightarrow NO_2^- \longrightarrow N_2O \longrightarrow N_2 \uparrow$$

Figure 2-2: Denitrification process

Generalized process of the nitrification and denitrification processes in soils can be sketched as:

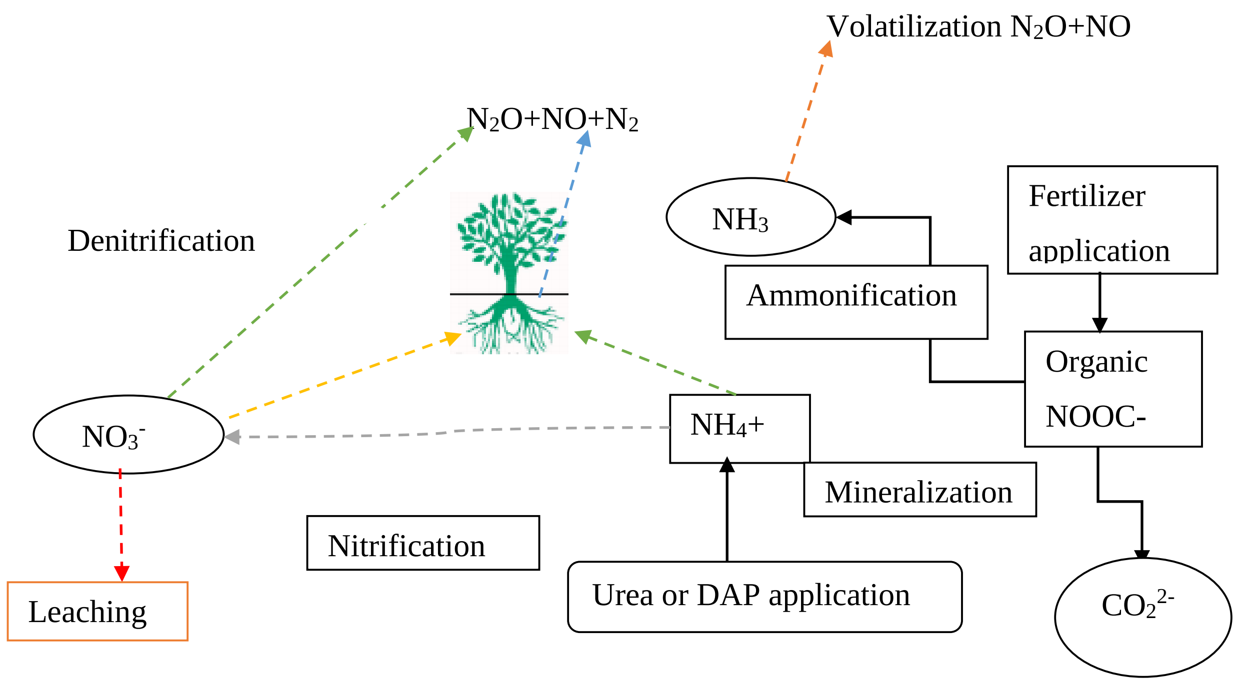


Figure 2-3: Ammonium and nitrite formation and movement (Tan et al., 2005).

Accumulation of ammonium in the soil depends on various factors: soil pH, presence/absence of soil bacteria, soil type and water (Mengel and Kirkby, 1987) (Figure 2). The N-NO_3^- has advantages over N-NH_3 due to its non-volatility, mobility in the soil and easy uptake for plants (Mengel and Kirkby, 1987). Addition of NH_4^+ as replacement of NO_3^-reduces the uptake of other cations like K^+,$Ca^{2+}$and Mg^{2+}(Gessler et al., 1998).

Capturing the various processes as depicted in Figure 2 and quantifying all the input and output sources is complex. As such, frequently partial nutrient balances are used to roughly evaluate whether soils are being depleted over time given a particular agricultural practice, assuming that the other microbial processes remain the same over time.

2.5.2 The partial phosphorus balance

Phosphorus is important macro nutrient for plants which constitutes about 0.2% of plants dry weight. P is the key component of molecules like nucleic acid, phospholipids, and ATP and consequently plants including tomato cannot grow without a reliable supply of this macronutrient. If there a concentration of p in a given farm area led to P transfer from grain to animal production areas. This transfer creates a surplus in P from the inputs of fertilizer, soil p in excess of crop uses results the losses of P from land to water bodies. This p flow towards the water environment that essential nutrient for plant and animal could accelerate eutrophication (Roy et al., 2003).the nutrient enrichment of surface water leading nuisance aquatic plant growth.

P balance could be related with its cycle in the different media;

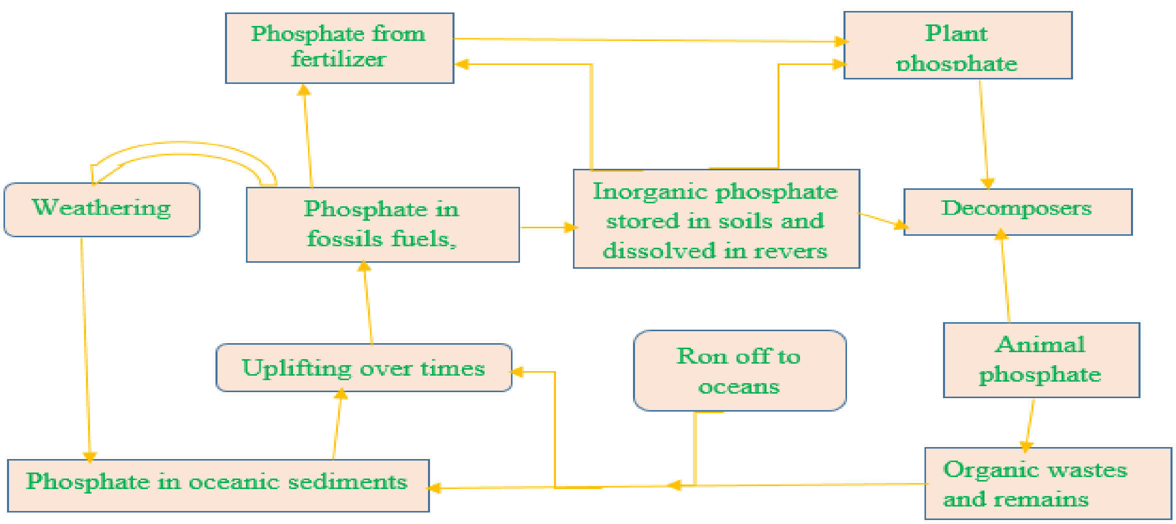


Figure 2-4 the phosphorus balance, inputs-outputs and losses (Elena M. Bennett, 1999).

As a global concept the amount of P with in the soil is too much but this total amount exist in the soil and present in unavailable form for plants or in the forms that are only available outside of rhizosphere. Unfertilized soils mostly release very fast to support the high growth rates of crop plant species. Which means plants use their maximum nutrient extraction capacity to sustain.

2.5.3 Partial potassium balance

Potassium (K) is the only monovalent cation essential for the biological and physiological processes as well as osmoregulation of the plant as it is linked to the photosynthesis regulating the stomata and therefore CO_2 uptake as well as the production of Adenosine Triphosphate (ATP) (Nzanza, 2006). Potassium used for diseases control and metabolic facilitation of the crop. Frequently in rainfed agriculture the potassium is supplied through organic fertilizers. Potassium maintains the ionic balance and water status in the plant. .it is involved in the production & transport of sugars in the plant, enzyme activation and synthesis of proteins. Potassium is also required for pigment synthesis, notably lycopene.

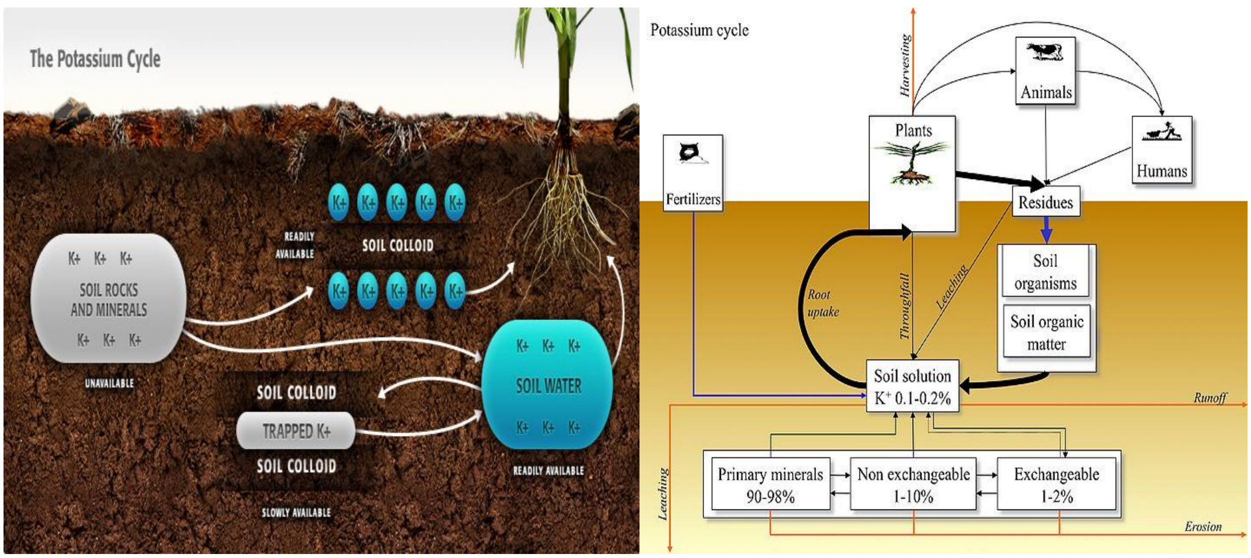


Figure 2-5 Potassium balance & its availability in the soil (A. Dobermann a, 1998).

Potassium is important at different stage to accomplish corresponding tasks.as such at the initial promoting early growth at Vegetative growth maintain plant growth and maximize flower numbers and also at the Fruit ripening (maturity) stage it maximize high potassium levels in the fruit and minimize disorders. Tomato have a relatively high potassium requirement compared to nitrogen. Even though it’s too much occurrence restricts the uptake rate of other crop essential nutrients like calcium and magnesium and its high level is recommended for saline soils.

3 MATERIALS AND METHODS

3.1 Description of the study area

The study area is Robit kebele, situated within the Robit watershed (1292115 N and 332250 E), and located northeastern of Bahir Dar city (approximately 10 km) (Figure 3). The average annual rainfall is 1400mm with minimum temperature of 23 C^o and maximum temperature of 31 ^oC. A main asphalt Bahir Dar to Gondar road crosses the watershed from south to north. The selected outlet at the Tikur Wuha River in the watershed drains a total area of 911 ha and flows into Lake Tana. The selected outlet lies approximately 5-6 km from the lake. From past field surveys the major soils in the watershed are classified as Nitisols. Luvisol, Fluvisols along the rivers and Leptosol (ADSWE, 2013).The area has a relatively good ground water potential and therefore a large number of hand dug wells (i.e. 3736) with well depth ranging from 8 m to 20 m (Ewunetie, 2015).

The farming system of the area is mixed (crop-livestock) farming. Main rainfed crops grown are finger millet, teff, maize and other grains. The area has vast area coverage of the commercial crop *chat* which is the main source of income. *Kat* is irrigated in the dry season and supplementary in the rainy season in cases of long dry spells using both surface and groundwater. Irrigation of *Kat* is mainly practiced through the use of ground water lifting technologies (i.e. mainly manual water lifting), motor pumping of surface water and river diversions. Due to the extensive irrigation practices and the large surface water abstractions the Tikur Wuha River dries up in the mid of January to the end of May depending on the rainy season occurrence.

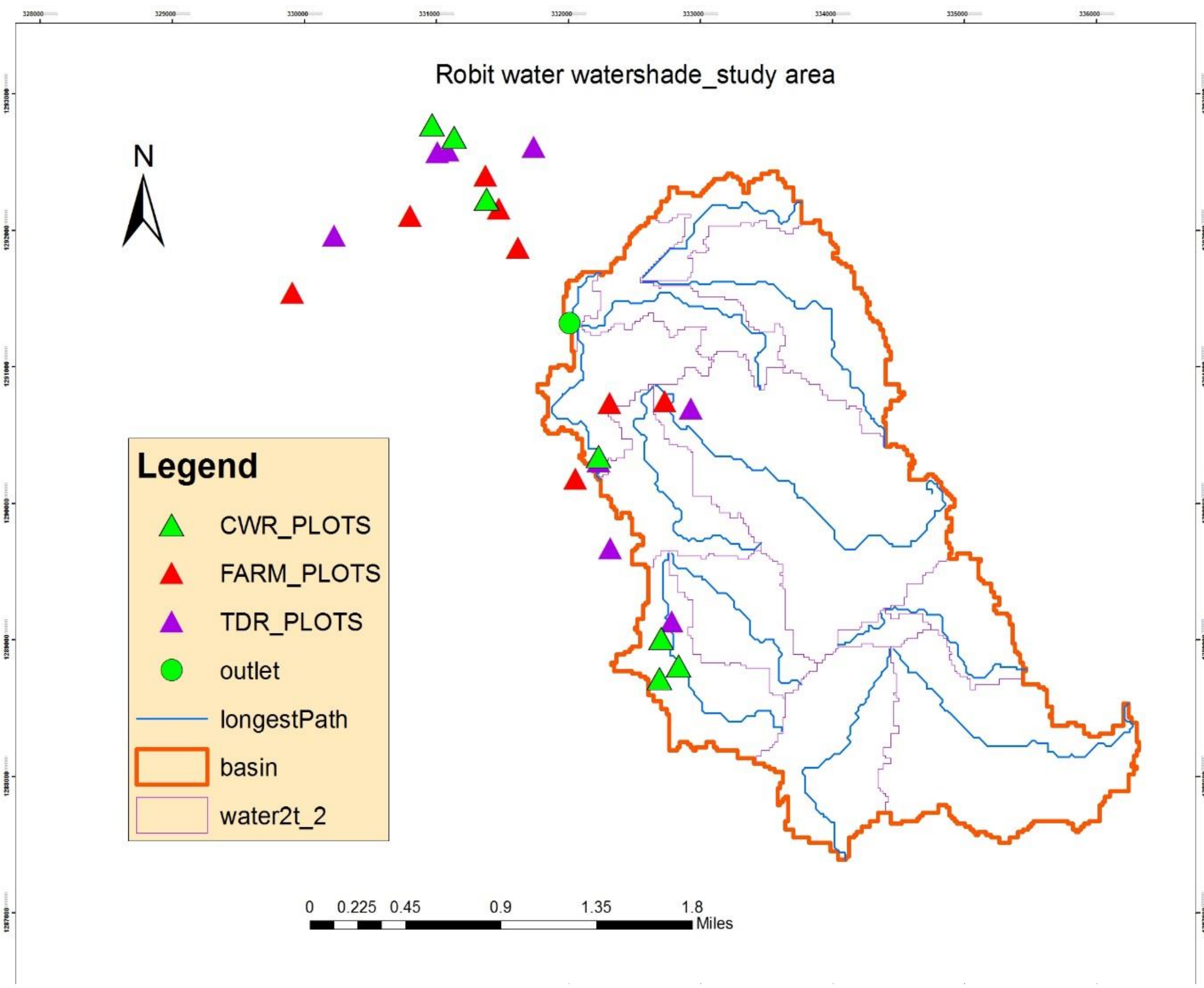


Figure 3-1: Description of the study area

3.2 Experimental design

Community meeting was conducted at the kebele center of Robit in order to discuss the objective and main idea of the study with the farmers, development agents (DA's), kebele facilitator, woreda agricultural office coordinator and the researcher group of innovation laboratory for small scale irrigation (ILSSI). In total 24 farmers who met the project criteria were interested to participate in the study. The criteria was that the farmer had a productive well, especially during the main dry season, has taken up a water lifting technology from the ILSSI project and agreed with the scientific measurements conducted on their fields (e.g. soil sampling, irrigation quantity, plant height, yield etc.). Out of the 24 farmers, 13 were farmers from the first ILSSI project in 2014/2015 year and 11 were new farmers interested to join the project in 2015/2016.

The 24 farmers were randomly divided into three groups that would represent the 3 irrigation scheduling methods: crop water requirement, soil moisture based (TDR) and farmers' practice. As such, in the first group the irrigation for 8 farmers would be based on the measured soil moisture (TDR), in the second group 8 farmers would irrigate according to the calculated crop water requirement and in the third group, 8 farmers would follow their traditional knowledge and not receive any recommendation (Figure 4). The spatial location of the participating farmers is given in Figure 5.

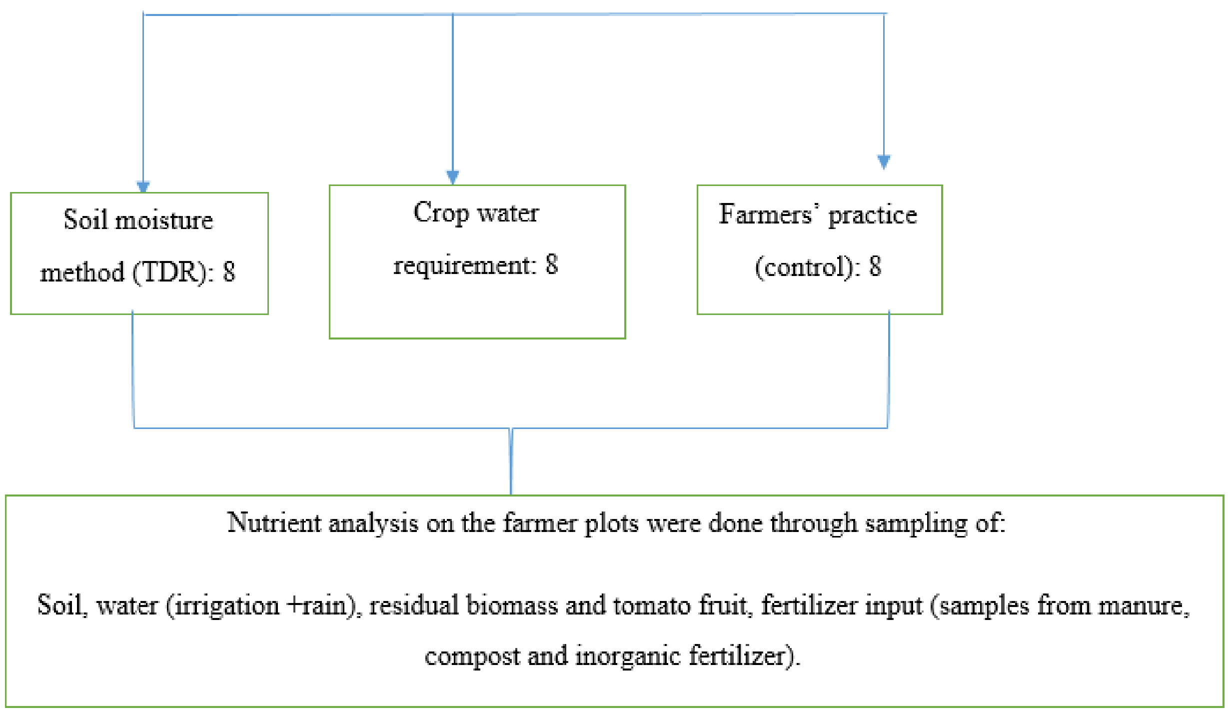


Figure 3-2: flow chart for the overall activities delivered and ways for the experiment design

Main activities conducted at the onset of the experiment were:

- Training about nursery preparation was given by a professional agronomic expert before transplanting has conducted. The training involved: spacing of seeds, weed and pest management, bed mulching (incl. time of mulch removal) and water application.
- The nursery beds were prepared in order to produce between 170 to 280 seedlings of the SHANTI variety. However, the variety was very sensitive to diseases and mortality rate

was high. A second variety cochero was additional seeded using the same nursery technique. This study uses the data recorded from the cochero variety only as very few SHANTI plants had been transplanted.

- The farmer plots varied between 36 to 115 m^2 in which the cochero seedlings were transplanted with a 40 cm by 50 cm spacing within plants and between rows, respectively.
- In each treatment group, 3 farmers were selected to monitor the N, P and K content in the irrigation water due to budget limitations. Additionally 3 rainfall samples were taken in the watershed. All the other items for the partial N, P and K balances was measured for all farmers.
- In each treatment group, 3 farmers were selected and one soil moisture profiler access tube was installed per farmer. The soil moisture profiler measures the soil moisture at a depth of 10, 20, 30, 40, 60 and 100cm.
- The volume of the buckets used in irrigation were quantified for each of the participating households so irrigation quantity could be recorded.
- Experimental plots were coded. Codes explained whether soil sampling was performed, which irrigation treatment the farmer belonged too and whether samples were taken from the wells for nutrient analysis in groundwater: soil profile sampling (PRi), number (1 to 24) followed by the water management (WM) group (i.e. TDR as T, CWR as CW and farmer practice as FR), followed by _NUT for nutrient sampling. For example PR8T_NUT means soil profile sampled plot 8 following the soil moisture (TDR) based irrigation method with well sampling for N, P and K; PR23CW_NUT means sampling plot 23 where the farmer followed the estimated crop water requirement method and well sampling was conducted for N, P and K.

During the experiment among the 24 farmer's participated 4 were dropout due to different reasons, Plot PR2FR and PR20T owners were lost due to poor management (no fence) that is tomato eaten by cows and plot PR13FR owner were lost his tomato due to the competing interest of chat, he was invest much time to commercial Kat crop and he was got water shortage the fourth plot PR1FR were got damping off at the initial stage of the crop, he is requesting a solution to his soil, qualitative soil analysis result shows that as his soil is as not significant different from others and seems like good productive plot but the truth was in the opposite. Due to those plots losses at the end the experiment the study considers only 20 farmers. Then the number of farmers from each experimental groups were 8 from CWR based farmers 7 from TDR followed farmers and 5 from the farmer's local practice.

3.3 Tomato production

Tomato was introduced in Ethiopia around 1935 to 1940 (Samuel et al., 2009). Tomato (*solanum lycopersicum* Mill) has a branching, fibrous root system, rather than one main tap root. In good soil conditions, roots will penetrate beyond 1 m in depth, but the majority of the active root zone is within 60 cm (Gemechis et al., 2012). Tomato requires water throughout its life span (from sowing to harvesting). The length of the various growth stages for tomato vary across variety, climate, soil and management. For Ethiopia the reported lengths are (Gemechis et al., 2012): 25 days for the initial stage,30 days for the development stage, 40 days for the mid stage and 30 days for the final stage(Savva and Frenken, 2002). In the study 40 day old tomato seedlings were transplanted. The management of tomato during the growing stages involved shallow ploughing of the soil to control weeds and to create aeration, protecting the crop from pest, fencing.

Irrigation was performed using overhead irrigation. Nutrient movement is dependent on the irrigation method. Different irrigation methods have different means of providing water to the plant. Since the pressure of water through each method is different, the various systems could have an influence on the nutrient removal. Using overhead irrigation could disturb plant available nutrients if the application is forceful. However when systematic small and slow irrigation applications are undertaken nutrient disturbance will be minimal.

Pests occurred at seedling and fruit stage. At the seedling stage night cutworm occurred which cuts the roots of seedling leading to wilt and seedling mortality. This was the main reason for losing the Shanti variety in the nursery. The treatment included farmers hunting the cutworm at night using flashlights and eradicate them. At the fruiting stage number of diseases were observed on the fruit. Farmers applied Diazinon and Diamong pesticides which are common pests used for *chat* production. Since tomato was the only fruiting crop during the season, birds attacked the product. Mitigation measures were invented by one creative farmer who killed a bird and hang it on the tomato fence to protect the tomato from other bird attacks. He also used old cassette tapes which is a common practice in other countries. He shared his experience and success with other farmers.

3.4 Land use history of the selected plots

During the research period the tomato performance differed strongly between farmers which could be related to the soil fertility status. As such, a land use history survey was conducted for all the participating farmers. The land use survey shows that farmers located at the downstream part of the watershed have excellent to good soil fertility status whereas at the upstream part soil fertility is significantly lower. Even though, the geomorphology and soil formation as well as erosion processes strongly influence soil fertility which could explain the observed differences in soil fertility, the land management practice in both locations were also found to be different. Better long term land management practices were observed at the downstream part of the watershed (see detailed descriptions in appendix A). At the upstream part the plots coded PR3T and PR24CW showed a poor sustainable land use history and therefore soil fertility is low compared to the fertile plots of PR16T_NUT, PR23CW_NUT, and PR19FR found downstream (Table 1).

Table 3.1: Land use history summary from the field observation and from the farmers.

Plot code and yield performance description	Irrigated crop (2015/2016)	Most usual cultivated crops on the plot during the rainy season.	Historical land use including inorganic and organic fertilizer usage
PR16T_NUT (Highly productivity)	Tomato	Maize and pepper	Highly decomposed organic fertilizer, good fertile soil without any inorganic fertilizer usage. Plot was a residential plot prior to cultivation started.
PR23CW_NUT (Highly productivity)	Tomato	Maize and pepper	Highly decomposed organic fertilizer; good fertile soil without any inorganic fertilizer usage. Plot was a residential plot prior to cultivation started.
PR17CW_NUT (High productivity)	Tomato	Maize and finger millet	Long inorganic fertilizer usage with some compost and other organic? Wastes dumped.

PR22FR_NUT (Low productivity)	Tomato	Maize and finger millet	Poor soil fertility, crop production in the rainy season depends strongly on inorganic fertilizer.
PR21FR_NUT (Low productivity)	Tomato	Maize and finger millet	Poor soil fertility, crop production in the rainy season depends strongly on inorganic fertilizer.

3.5 Determining irrigation quantity and interval

3.5.1 Crop water requirement (climate) based irrigation scheduling

Whenever one wants to deal with crop water requirement, it is important to deal first with evaporation and evapotranspiration. Evaporation is the process in which water vapor is released from the open surface including rock, land surface and water body whereas evapotranspiration the term that includes the vapor is lost from the plants body. The crop water requirement is the amount of water a plant needs to compensate the evapotranspiration the plant is subjected to (i.e. actual evapotranspiration or crop evapotranspiration) (Savva and Frenken, 2002). The calculation of crop evapotranspiration (ET_c) is done by the determination of the potential evapotranspiration (ET_o) and multiplying it with the crop coefficient (K_c) for a specific crop stage. Afterwards the gross irrigation water requirement is calculated using the application efficiency whilst the irrigation interval is calculated taking into account the maximum allowable moisture deficit. For tomato this is 50 %. For the determination of the crop water requirement and its scheduling the freely available CROPWAT computer programing model was used (Savva and Frenken, 2002).

3.5.1.1 Calculating potential evapotranspiration

Potential evapotranspiration (ETo) is defined as the rate at which readily available soil water is vaporized from specified vegetated surfaces (Jensen et al., 1990) and can be computed from weather station data even though certain uncertainties will occur from data analysis and reading uncertainties or data gaps. Data gaps were filled by an arithmetic mean empirical technique for its simplicity. The FAO Penman- Monteith method was used to calculate the potential evapotranspiration using 10 years of historical data (2005-2015) from the Bahir Dar Meteorological station. Data included daily values for both maximum and minimum temperature, precipitation, wind speed, relative humidity, and solar radiation.

General Penman-Monteith equation used was:

$$ET_o = \frac{0.408\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)} \qquad 3.1$$

Where	ETo	reference evapotranspiration [mm day-1],
	Rn	net radiation at the crop surface [MJ m-2day-1],
	G	soil heat flux density [MJ m-2 day-1],
	T	air temperature at 2 m height [°C],
	u_2	wind speed at 2 m height [m s-1],
	e_S	saturation vapour pressure [kPa],
	e_a.	Actual vapour pressure [kPa],
	e_S-e_a.	Saturation vapor pressure deficit [kPa],
	Δ	Slope vapor pressure curve [kPa °C-1],
	γ	psychrometric constant [kPa °C-1].

3.5.1.2 Calculating the actual crop evapotranspiration

The monthly averaged daily ET_C (mm day^{-1}) was calculated by multiplying the average monthly potential evapotranspiration (ETo, mm day^{-1}) with the crop coefficient at different development stages. The length of the development stages and corresponding crop coefficient (k_c) for tomato are: early stage (25 days), development stage (30 days), mid stage (40 days) and final maturity stage (30 days): 0.45, 0.75, 1.15, 0.8 are Kc values respectively (Zotarelli et al., 2009):

$$ET_c = ET_o * K_c \qquad 3.2$$

3.5.1.3 Calculating the soil water balance

After the value of ETc is determined the irrigation water required is known by solving the soil water balance equation:

$$ET_c = I + P - R - D + CR \pm \Delta S \qquad 3.3$$

with ET_C estimated from equation 3.2 (mm day^{-1}), I the irrigation depth (mm), P the effective rainfall (mm), R the runoff (mm), D the deep percolation (mm), CR the capillary rise (mm) through shallow groundwater and ΔS the change in soil moisture (mm). CR, R and D are negligible in the

Robit Bata watershed during this dry season irrigation as the irrigation method is overhead and no excess water is applied. The effective rainfall instead of total rainfall is used which is calculated from the measured rainfall by multiplying 0.8 for rainfall greater than75mm/month and by 0.6 for rainfall less than 75mm/month.

The equation can be re-organized as follows:

$$SMC_t = SMC_{t-1} - ET_c + P - I_{t-1} \quad 3.4$$

$$I_{t-1} = ((FC - SMC_{t-1})/100)*D/1000 \quad 3.5$$

$$TAW = ((FC-PWP)/100)*D*1000 \quad 3.6$$

Where TAW is the total available water content of the soil in (mm) in the root zone, FC field capacity (%), PWP permanent welting point (%) and D is effective root depth (m) which is taken as 0.6 for tomato, SMC is soil moisture content of the succeeding date (mm) whereas SMC_{t-1} is the previous soil moisture content (mm), P is the effective rainfall (mm) and I is the irrigation (mm) at time step t. At the onset of the irrigation season SMC_{t-1} is the initial soil moisture measured or estimated in the field to calculate the initial amount of water irrigated. Soil water near the permanent welting point is not readily available resulting in crop stress. Hence, TAW cannot be fully used by the plant and hence irrigation frequency cannot be determined from TAW. The factor at which crop water stress occurs is multiplied with the TAW to derive the manageable allowable depletion or sometimes called maximum allowable depletion (MAD) (Zotarelli et al., 2014). This is different for each crop. Hence irrigation is needed before the SMC reaches the MAD level.

The calculated irrigation depth (mm) is finally converted to irrigation volume through multiplication of irrigation depth by the area:

$$Irr_{vol} = Irr * A \quad 3.7$$

With Irr_{vol} the irrigation volume (m^3), Irr the irrigation depth (mm) and A the plot area (m^2).

3.5.1.4 FAO CROPWAT for irrigation scheduling.

The ETo using the Penman Monteith was calculated using CROPWAT (Savva and Frenken, 2002).CROPWAT is an interactive computer program that enables to easy calculation of the crop water requirement, irrigation requirement, irrigation scheduling under various management conditions and daily soil moisture balance by using the climate, crop and soil data as input.

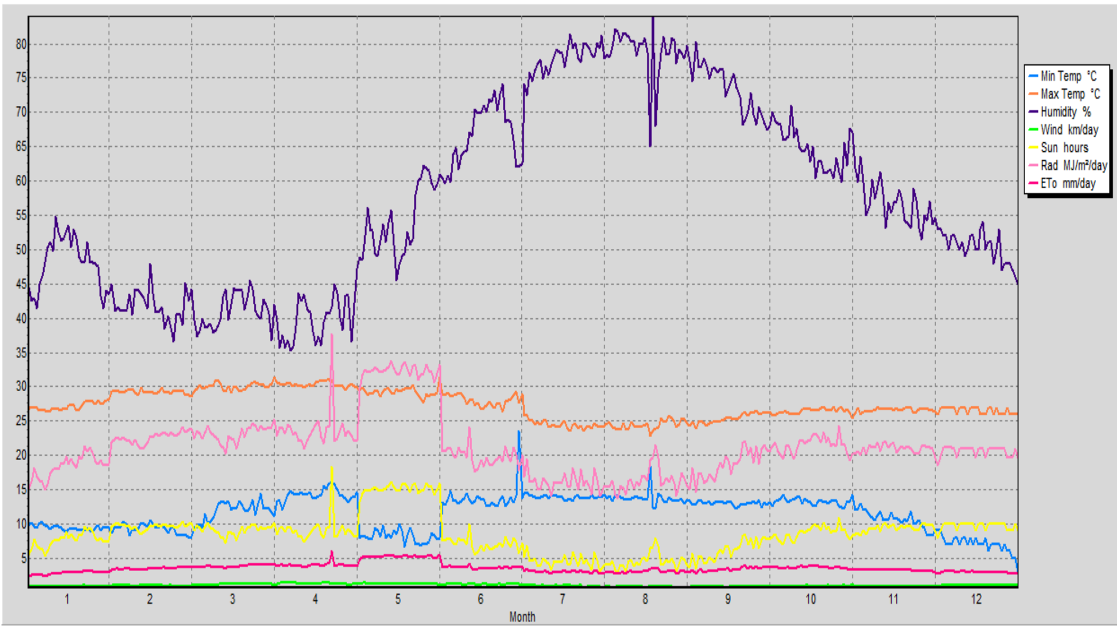


Figure 3-3: Plot of 10 years weather data & ETo (mm) from Bahir Dar using CROPWAT.

The climatic data used are maximum and minimum temperature, wind speed, solar radiation and relative humidity. CROPWAT automatically schedules and computes the net & gross depth of irrigation and other factors. The automatic scheduling by CROPWAT ranged between 4 to 8 days which is not convenient for the groundwater irrigated tomato in Robit (Table 2 and Figures 6 and 7). The recharge of the wells is low and hence the amount needed to irrigate 100- 150 m² with a 4 to 8 day interval will frequently exceed the available water. Hence, the scheduling interval was fixed at 1 day. Hence, the calculation was computed manually and compared against CROPWAT (appendix T) and CROPWAT did not differ much despite the difference in application frequency.

Table 3.2: Automatic scheduling through CROPWAT software version 8 (Ks is the crop water stress coefficient, Eta is adjusted evapotranspiration, IrrN net irrigation depth and Irrg is gross irrigation.

	Date	Day	Stage	Rain	Ks	Eta	Depletion	Irr_N	Irr_g	Flow
Interval				mm	Fraction.	%	%	mm	mm	l/s/ha
5	23-Dec	1	initial	0	0.77	77	56	10.2	14.6	1.69

5	28-Dec	6	initial	0	1	100	36	7.2	10.3	0.24
7	3-Jan	12	initial	0	1	100	37	8.2	11.7	0.23
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
6	3-Apr	102	End	0	1	100	59	21.1	30.1	0.7
10	9-Apr	108	End	0.1	1	100	56	20.3	29	0.56
2	19-Apr	118	End	0	1	100	56	20.1	28.8	0.33
	21-Apr	End	End	0	1	0	9			
Total								363.7		

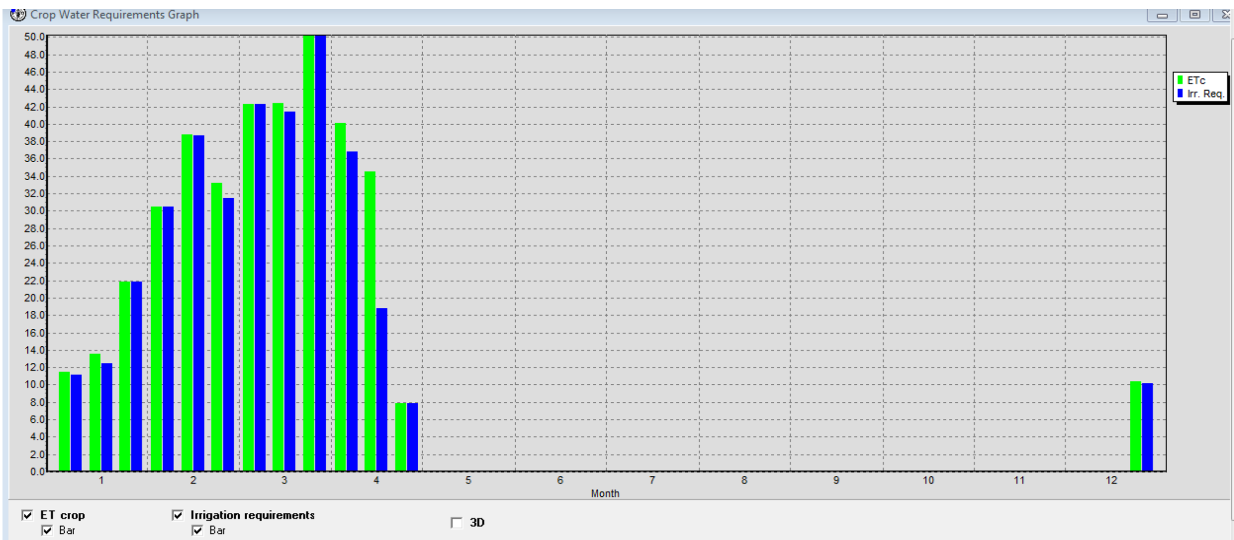


Figure 3-4: the ETc versus irrigation requirement chart during the irrigation season.

3.5.2 Soil moisture based (TDR) scheduling

The scheduling requires field capacity (FC) and permanent welting point (PWP) of the soil to determine the TAW in the root zone (equation 3.6) and the MAD:

$$MAD = TAW * D_P \qquad 3.8$$

With MAD the maximum allowable deficit (mm), DP the allowable depletion for tomato i.e. 50 % and TAW the total available water content of the soil in (mm).

When measuring the soil moisture in the field using the TDR, the irrigation amount is calculated according to:

$$Irr = ((FC-SMC)/100)*D*1000 \quad 3.9$$

with Irr the irrigation depth (mm), FC the field capacity (%), PWP the permanent wilting point (%), SMC the soil moisture content (%) and D the rooting depth (m) which is 0.6 m for tomato in this study.

The calculated irrigation depth is then converted to irrigation volume (Irr_{vol}) using equation 3.7

The irrigation interval was determined by dividing the calculated irrigation depth by the maximum allowable depletion (see Appendix C):

$$F = Irr/MAD \quad 3.10$$

Where F is the irrigation interval or frequency, Irr is the amount of water depth applied (mm), MAD the maximum allowable deficit (mm).

3.6 Data collection

3.6.1 Meteorological data

Weather data from 2005 to 2015 was collected from Bahir Dar Meteorological Agency. The data contained maximum and minimum temperature (°C), wind speed (m s^{-1}), solar radiation (MJ m^{-2} day^{-1}) and relative humidity (%). The daily rainfall during the cropping season was calculated by summarizing the 10 minute recordings from the automatic rain gauge located in the watershed.

3.6.2 Soil physiochemical properties

The soil sampling consisted of two sampling campaigns for all 24 plots: one before transplanting and one after harvesting. Soil samples were taken depth integrated from 60 cm depth for the nutrient farmers (i.e. 9 farmers) and from 20 cm for the other farmers. Samples were analyzed in the laboratory. Soil analysis were done for: pH, electrical conductivity (EC), texture, Fe, K_{av}, cation exchange capacity (CEC), organic matter (OM), TN, P_{av}, NO_3^- and NH_4^+. Additional samples were taken from the topsoil (20 cm) for the 11 new farmers and analyzed for field capacity (FC) and permanent wilting point (PWP).

Electrometric method with the suspension of soil-water ratio of 1 to 2.5 stirred for 30 minute was used to determine the pH. Electrical Conductivity (EC) Bridge was used to determine the EC (dS m^{-l}) of the 60 min stirred suspended soil (1:5 H_2O ratio). The water content at field capacity and wilting point was determined in the laboratory by using a pressure (Porous) plate apparatus of a saturated soil sample at a pressure of at -0.33 bar and -15 bar, respectively. When water is no longer leaving the soil sample (i.e. at -15 bar), the determined soil moisture is taken as permanent wilting point. Soil texture was determined in the laboratory using the Hydrometer method.

For TN, the Kjeldahl procedure was used. The method is based on the principle that organic matter is oxidized by titrating the soil with concentrated sulfuric acid as potassium sulfate is added to the mixture during digestion (copper sulfate and selenium powder mixture is added as a catalyst). The procedure determines all soil nitrogen (including adsorbed NH_4^+) except the NO_3^- form. The organic bound nitrogen is converted to ammonium sulfate during the oxidation. The acid traps the NH_4^+ ions in the soil which are dissolved by distilling the solution with NaOH. The dissolved NH_4^+ is absorbed in boric acid and back titrated with standard H_2SO_4.

The plant available nitrogen (NO_3^- and NH_4^+) were analyzed in the laboratory by Amhara design and supervision work enterprise using a Kjeldahl technique. Determination was done by steam distillation using heavy MgO for NH_4^+ and Devardas alloy for NO_3^-.The distillate is collected in saturated boric acid H_3BO_3 and titrated to PH 5.0 with diluted H_2SO_4 (0.01 N). The amount of sulfuric acid used during the titration is recorded in order to calculate the quantity of N according to:

$$NH4 – N \text{ or } NO3 – N \text{ (ppm)} = ((V-B) \times N \times 14.01 \times 1000) / V1 \qquad 3.11$$

With V = volume of H_2SO_4 titrated (ml); B = volume of H_2SO_4 titrated in the blank sample (i.e. distilled water) (ml); V1=volume of distilled water used for distillation (ml) and14.01= Atomic weight of nitrogen.

Plant available phosphorus P was obtained from extraction of acid-soluble and adsorbed phosphorus with fluoride containing solution according Bray II test (procedure for acid soils). K of the soil were determined by the curve method.it works by establishing the graph with mg/l k on the Y axis and the % of transmittance on the x- axis and then take the reading from the standard curve.OM is determined by ferns burner and back titration method, such that sulfuric acid is added to the prepared sample soil to oxidized and extract carbon then the extracted carbon is multiplied by a factor 1.72 in order to get OM, whereas CEC was by distillation with Ammonium acetate back titration method.

3.6.3 Soil moisture

3.6.3.1 Soil moisture using the profiler probe

The soil moisture profiler was used to measure volumetric soil moisture content at the interval of 10, 20, 30, 40, 60 and 100 cm. In this study the probe PR2 DELTA-T device was used. Measurement were taken at 5 to 6 days interval (Figure 8). The detailed measurements using the moisture profiler is shown in Appendix H. The measurements were used to compare the effect of irrigation on soil moisture changes within the profile for the three irrigation treatment groups and identify potential deep percolation of irrigation water.

Figure 3-5: Soil moisture measurements using the profiler tube.

3.6.3.2 Soil moisture through TDR measurement

The use of the Time domain reflect meter (TDR) allows for direct volumetric soil moisture measurements (Klemunes Jr, 1998). It is a well-known method for measuring soil water content and electrical conductivity. Both of these quantities are important for a variety of hydrological processes and the interaction between soil and atmosphere for climate predictions (Malicki and Skierucha, 1989). TDR readings were taken at a 1 day interval from transplanting to harvest and used in the soil moisture based scheduling group (i.e. TDR group) to calculated the required irrigation amounts and time of application. The measurements and calculation for the TDR group is shown in Appendix C.

3.6.4 Agronomic performance of tomato

Agronomic performance of tomato was monitored from transplanting to harvesting stage (Figure 9) for 4 farmers. The number of plants and plant height were recorded at each stage to check whether the irrigation method resulted in higher plant mortality or reduced plant growth. Yield was recorded during 5 times harvests from 24/3/2016 to 14/4/2016 of main harvest season. The total yield was obtained by summarizing all the harvest events for each farmer. Additionally, residual biomass above ground was measured to calculate the total nutrient content. A meter was used for the height measurements and a spring balance was used for yield measurement.

A: TDR method plot B: CWR method plot

Figure 3-6: Agronomic performance of tomato at the flowering and start of fruiting stage at 3/2/2016 (A is for plot PR16T_NUT and B is for plot PR14CW_NUT).

3.6.5 Analysis of nutrients in water, fertilizer and plant tissue

3.6.5.1 Water sampling and analysis

For the nutrient analysis water samples were taken 2 times from three wells in each of the treatment groups at the top layer of the well through bucket. First sampling was done at the development stage of the crop at 25/1/2016 and second sampling was done at the harvesting stage 25/3/2016. Additionally 3 rainfall samples were collected at 25/6/2016.The samples were analyzed using the Palintest Spectrophometer and the respective reagents. Triplicate readings were conducted to reduce material contamination and errors. Afterwards the reading was followed by a blank.

The water sample were collected and analyzed for TN, NO_3^- and NH_4^+, K_{av} and P av. The method for nitrate nitrogen were palintest Nitrates method and ammonia nitrogen was based on the indophenol method. In drinking water and waste water analysis the main important N-forms are NO_3^- – N, NO_2^- –N, NH_3 and N-organic. Ammonia occurs in surface and waste water but is often very low in groundwater due to the absence of soil particles (mainly clay). The NH_4^+ content in the studied wells was found out of the detection limit of 0 1.0 mg l^{-1}. High content of NO_3^- in drinking water can lead to high health risks e.g. methemoglobinema as NO_3^- is converted into NO_2^- in the intestine and prevents the transport of oxygen through hemoglobin. However, for irrigation high NO_3^-–N is good as it serves as an additional source. For the analysis of NO_3^-–N the Palin test was used by adding one spoon of Nitrates powder and one nitricol tablet. The solution is read at the automatic wavelength selection Photometer.

Phosphates are found in a wide range of products and applications such as detergent, washing powders, food processing industry and industrial water treatment process (Palintest House) Phosphorus was analyzed using the Palintest Phosphate LR method. For the extraction of P two tablets (1 LR and 2 LR) added to the water sample, shaken and kept for 10 minutes until full color development occurred the automatic wavelength detection limit for ranges within 0-1.3 mg l^{-1}. The solution was read at the automatic wavelength selection through Photometer method. The palintest potassium test provides threshold concentration for potassium, in water according to palintest House, ranges between 0 to 12 mg l^{-1}. For the extraction of potassium one reagent tablet (sodium tetraphenylboron) is used in a 10 ml test tube and mixed well. A cloudy solution will develop if K is present. The solution is read at the automatic wavelength selection through Photometer method.

3.6.5.2 Fertilizer sampling and analysis

Both organic and inorganic fertilizer were used during the production season. Fertilizer application was different for all farmers. Scientifically recommended fertilizer application quantity and quality for tomato production is 200 kg/ha DAP at the time of transplanting and 200 kg/ha at the mid growth stage of tomato (Kebede and Woldewahid).Out of 20 farmers the application quantity for 7 farmers were range 100- 200 kg/ha urea at the mid growth stage (55^{th} after planting) , 6 farmers were applied within 200 kg/ha – 300 kg/ha and the rest 7 were applied with the range of 300 kg/ha – 700 kg/ha. Average application for all farmers were 300 kg/ha urea. DAP were used only by three farmers one from the TDR group and 2 from the CWR group. The method of application was the same for all farmer's that is around the root. In addition to mineral fertilizer mixed manure (dung, kitchen, and donkey) wastes were used by only 8 farmer plots (i.e. 3 from TDR group and 5 from CWR) group. The application for the manure was done at the initial stage of the crop through the whole plot not to plant root as like mineral fertilizer.

3.6.5.3 Tomato plant sample nutrient analysis

Plant nutrient (N, P and K) analysis of the tomato fruits and the residual biomass was conducted for 21 farmers. Triplicate analysis have done for all samples in order to minimize analysis errors at BDU by food engineering Laboratory at the Faculty of Food and chemical Engineering. For nitrogen analysis the Kjeldahl method was used. The plant extraction was diluted to a 100:1 ratio and a K_2SO_4 catalyst was used. Phosphorus was analyzed using spectrophotometric wet-digestion method Potassium was analyzed using coupled induction plasma (CIP) method through hydrogen peroxide (H_2O_2) digester. The fresh weight was measured of both the tomato fruits and the residual biomass prior to oven drying to compute the moisture content and used to calculate the nutrient load of the tomato fruit and the residual biomass.

3.7 Data analysis

3.7.1 Calculating water productivity and water use efficiency

Water productivity is the measure of the physical or economical value generated from a given quantity of water. Water productivity of a crop for a particular plot could be quantified by the ratio expression of yield produced within that particular area to the total sum of irrigation water applied and rainwater received by that area.

$$WP = Y/ (I + P) \qquad 3.11$$

Where WP is the water productivity (kg m^{-3}), Y is yield produced in (kg ha^{-1}), I the irrigation depth (m^3) and P the effective rainfall (m^3).

Water use efficiency (WUE): it is defined as the crop yield per seasonal ETc. It explains about how much the field applied irrigation water is efficiently used by the crop. The calculation for WUE could be given as

$$WUE = Y/ETc \qquad 3.12$$

Where WUE is water use efficiency; Y is yield produced in kg and ETc is the seasonal crop evapotranspiration.

3.7.2 Partial nutrient balances

For NPK, partial balance; soil laboratory analysis, water (irrigation +rain) sample analysis, fertilizer N, P, K measurement, plant fresh biomass and fruit lab analysis were done. N is analyzed in the form of TN, nitrite and ammonium due to these component relevancy and up taking mechanism for plant (Locascio et al., 1997).The balance computation for nutrient follows the conservation of mass. Estimations of nutrient additions, removals, and balances in the agricultural production system generate useful, practical information on whether the nutrient status of a soil (or area) is being maintained or depleted (Samar et al., 2001). Simple estimates of nutrient input and output allow for the calculation of nutrient balance for individual fields. The input and output flows for this study is given in Figure 10.

The partial nutrient balance for nitrogen; can be computed as (David and Gentry, 2000):

$$\sum N_{in} - \sum N_{out} = \Delta N_{St} \qquad 3.13$$

Where N_{in} is the nitrogen input (kg ha^{-1}) (i.e. wet atmospheric deposition, organic and inorganic fertilizer), N_{out} is the nitrogen output (kg ha^{-1}) (i.e. harvested produce and residual biomass) and ΔN_{St} is the change in nitrogen storage (kg ha^{-1}).

The partial potassium balance; can be written as:

$$\sum K_{in} - \sum K_{out} = \Delta K_{St} \quad 3.14$$

Where K_{in} is the potassium input (kg ha^{-1}) (i.e. wet atmospheric deposition, organic fertilizer), K_{out} is the potassium output (kg ha^{-1}) (i.e. harvested produce and residual biomass) and ΔK_{St} is the change in potassium storage (kg ha^{-1}).

The partial Phosphorus balance; can be written as (Tandon, 2007):

$$\sum P_{in} - \sum P_{out} = \Delta P_{St} \quad 3.15$$

Where P_{in} is the phosphorus input (kg ha^{-1}) (i.e. wet atmospheric deposition, organic and inorganic fertilizer), Pout is the phosphorus output (kg ha^{-1}) (i.e. harvested produce and residual biomass) and ΔP_{St} is the change in phosphorus storage (kg ha^{-1}).

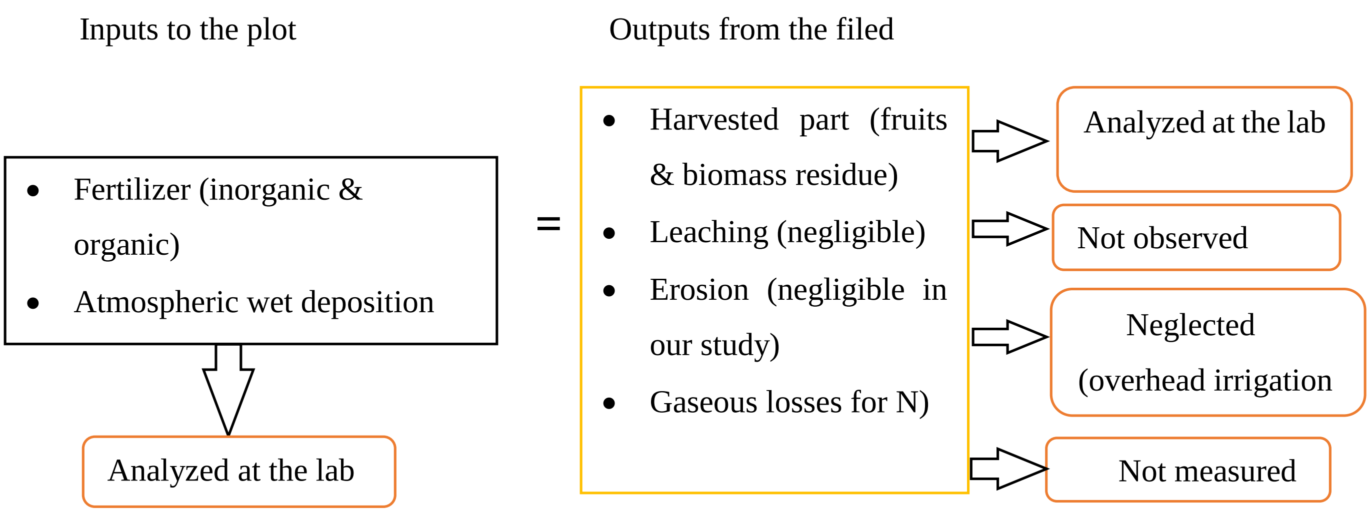


Figure 3-7: Plot level input –output schematization for this study.

The full nutrient balance equation (2.1) was reduced as follows:

$$IN_1 + IN_2 + IN_3 + IN_4 = OUT_1 + OUT_2 \quad 3.16$$

Where: IN_1 are nutrients from the inorganic (i.e. mineral) fertilizer added, IN_2 nutrients from the organic fertilizer (e.g. compost/manure of cattle, small ruminants, mulching etc.), IN_3 nutrients added through wet atmospheric deposition from rainfall, IN_4 the nutrients in irrigation water, OUT_1 are the nutrients removed by the harvest product, OUT_2 are the nutrients removed by crop residues.

Leaching was evaluated throughout the cropping season using the soil moisture profilers. However, no leaching was observed below 60 cm. The sedimentation was neglected in this study as the study was conducted during the dry season with little rainfall. Erosion was equally neglected as overhead application was used which minimizes irrigation induced erosion.

For each farmer in each treatment group the in-and output parameters for the partial nutrient balance was calculated (Table 3). A negative balances shows depletion of the nutrient whereas a positive balance shows a potential enrichment.

Table 3.3 Overview of the nutrient input and output measured in this study

Nutrient component	Input/output	Nutrient analysis	Method of estimation
Organic and Inorganic fertilizer	Input	Laboratory analysis for organic fertilizer	Dry matter quantity measured in the field and multiplied with the measured nutrient concentrations
Atmospheric wet deposition	Input	Laboratory analysis	Effective rainfall during the irrigation were calculated and multiplied with the measured nutrient concentration
Irrigation water	Input	Laboratory analysis	Irrigation water quantified and multiplied with the measured nutrient concentration
Harvested tomato	Output	Laboratory analysis	Dry matter yield quantified and multiplied with the measured nutrient concentrations
Crop residue	Output	Laboratory analysis	Dry matter yield quantified and multiplied with the measured nutrient concentrations

3.8 Statistical analysis

Statistical analyses were performed using GLM under SPSS (SPSS 20) to determine treatment effects for average plant height, yield, water productivity (WP), the comparison of the estimated ET_c using 10 year historical data with the estimated ET_c in 2016 using the soil moisture balance and irrigation depth applied vs. recommended (irrigation season) variation and the nutrient balance. The Mahalonobis distance outlier test was performed for the separate treatments WP and showed that no outlier. Prior to the analysis, a normality test was conducted for all the parameters SPSS 20 (Appendix O) and the Q-Q plots were plotted as well as the normal distribution histogram and distribution curve (Appendix S). Additionally box plots were also plotted (appendix Q). All soil physic-chemical parameters among water management groups were analyzed and compared. When the F-value was significant, a multiple means comparison was performed using Scheffe's Multiple Range Test at a p-value of 0.05. Furthermore, the variables (e.g., total yield of the crop and water productivity) have been plotted and the three scheduling strategies so as to relate relevance of water management strategy through satisfactory yield. The nutrient losses were plotted and compared between the three methods using the same statistical methods as described above.

4 Result and Discussion

4.1 Soil physicochemical properties before tomato transplanting

In this study soil samples from 24 experimental plots (i.e. 8 plots per treatment) were analyzed. Soil pH analysis result values within 20 cm depth were ranging for TDR treatments within 5.9-6.4, CWR treatment's within 5.8-6.3 and control groups within 5.8-6.8 which is equivalent to tomato requirement in terms of pH. Cation exchange capacity of the soil ranges 0.01-0.3, 0.1-0.2 and 0.1-0.3 for TDR, CWR and FARM treatments respectively which is somewhat less from the standard tomato requirement. Soils with a pH range of 5.5- 6.8 and EC of 1-3 dS m^{-1}, with optimum concentration of available N-P-K, and Fe with a clay loamy texture soils are suitable and have a high yield potential for tomato production in altitudes ranging from 700 to1400 mm. For all other parameters measured, the soils in 3 treatment groups seem suitable for tomato production (Table 4.1). It is observed that some parameters vary strongly within a group. For example organic matter (OM) content for plot PR11T has 6.9 % which is higher compared to other plots (e.g. 1.8 for PR2FR and 2.0 for PR3T – Appendix A). As discussed in section 3.4 higher - lower organic matter was linked to historical land use and fertilizer management

Table 4.1: Mean and standard deviation (SD) and coefficient of variation (CV, %) for the soil physiochemical parameters at 20 cm depth.

Water management groups						
	TDR		CWR		FARM	
Soil Parameters	Mean ±SD	CV %	Mean ±SD	CV %	Mean ±SD	CV %
PH	6.2±0.2	2.9	6±0.2	3.7	6.6±0.4	6.3
EC ds/m	0.1±0.1	96.5	0.1±0.1	38.2	0.2±0.1	62.7
CEC %	34±9.7	28.3	40±10.7	26.8	42±7	16.5
OM %	4±1.9	48.4	3±0.8	25.1	4.6±1.8	38.6
TN %	0.2±0.1	48.8	0.2±0.04	23.6	0.2±0.1	38.6
Av. P ppm	18.4±12	64.9	14.5±8.8	60.8	15.4±7.4	47.7
Fe %	13±11	84.7	8.5±1.5	18.0	14.8±6	40
FC %	33±4	12.3	34±4.6	13.3	37±5	13.3
PWP %	22±2	7.7	21±1.9	8.9	23.7±2.8	11.9
K ppm	642±780	121.5	244.7±125.6	51	905±708	86.3

According to Wei et al.,(2007) soil property variation can be described in terms of coefficient of variation (CV) with CV < 10 % showing low variability and CV > 90 % indicating high variability. For the soil samples taken at 20 cm, 5 from each treatments, results showed that the pH was less varied with in plots in each treatments additionally PWP was less varied with in TDR and CWR treatments. On the other hand K, was highly varied in the TDR treatments. The coefficient of variation was found between 10 % and 90 % which indicates moderate variation for the rest of soil properties within the treatment group. The coefficient of variation for pH was very low for 20 cm depth sample (i.e. 2.9 – 6.3 %) whereas for K values ranged from moderate 51 % in the CWR to 86.3 % in the FARM and very highly varied in the TDR 121.5 % treatments.

Table 4.2 Mean and standard deviation (SD) and coefficient of variation (CV, %) for the soil physiochemical parameters at 60 cm depth

Water management groups						
	TDR		CWR		FARM	
Parameters	Mean ±SD	CV %	Mean ±SD	CV %	Mean ±SD	CV %
PH	6.7±0.42	6.2	5.9±.7	11.6	6±0.6	10.4
EC ds/m	0.2±0.14	70.6	0.1±0.1	74.8	0.1±0.1	69.3
CEC %	35.4±9.1	25.7	30.7±4.4	14.4	30±7.2	23.8
OM %	3.9±0.9	23.9	3.8±0.7	19.4	3.7±7.2	193.3
TN %	0.2±0.1	23.9	0.2±0.05	26.5	0.2±0.1	27.0
Av. P ppm	15±6.7	44.2	27.2±23.2	85.4	9.8±2.3	29.3
Fe %	9.5±3	31.4	9.6±3.5	36.5	6.8±2.0	28.3
FC %	33.2±5.3	15.9	30.8±2.5	8.2	27±3.8	14.2
PWP %	21.8±2	9.3	20.8±2.3	11.0	19±3.3	17.3
K ppm	986.8±926.7	93.9	391±258	66.1	518±532	102.6

A similar analysis for the CV measured at both 20 and 60 cm depth showed a significant difference between the three treatment groups except for potassium (detailed data and statistical analysis are in Appendices A and T, respectively). The potassium values in the TDR group at 20 cm and 60 cm depth were 642 and 986.8 ppm respectively, which were significantly higher than those in the

CWR and not significantly from FARM group. This might influence potential differences in tomato growth between the three treatment groups if not replenished by fertilizer. CV of pH and PWP was less varied for TDR treatment whereas moderately varied for CWR and FARM treatments.

4.2 Soil water balance

4.2.1 Irrigation water applied

During the irrigation season, irrigation water was quantified based on different treatments: climate based method using crop water requirements (CWR), soil moisture measurement using TDR and farmer's local practice (FARM). Water quantity applied was determined and recommended to the farmers. Those values were compared against the amount of water actually applied by the different farmers in the CWR and the TDR groups. Detail irrigation water used by each plot with corresponding water management method and other parameters is shown in Appendix G and the average values are displayed in Figure 4.1.

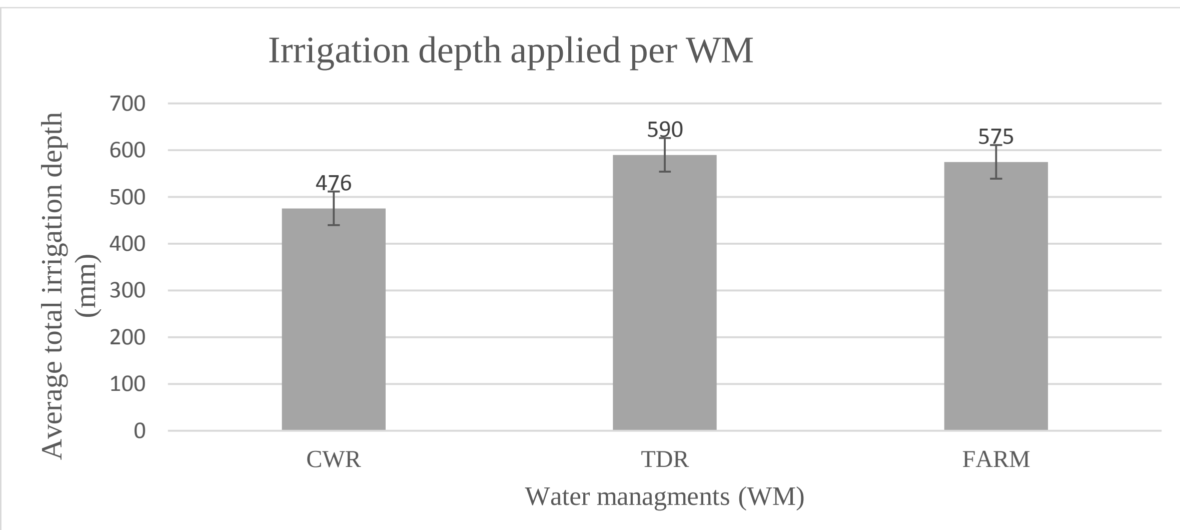
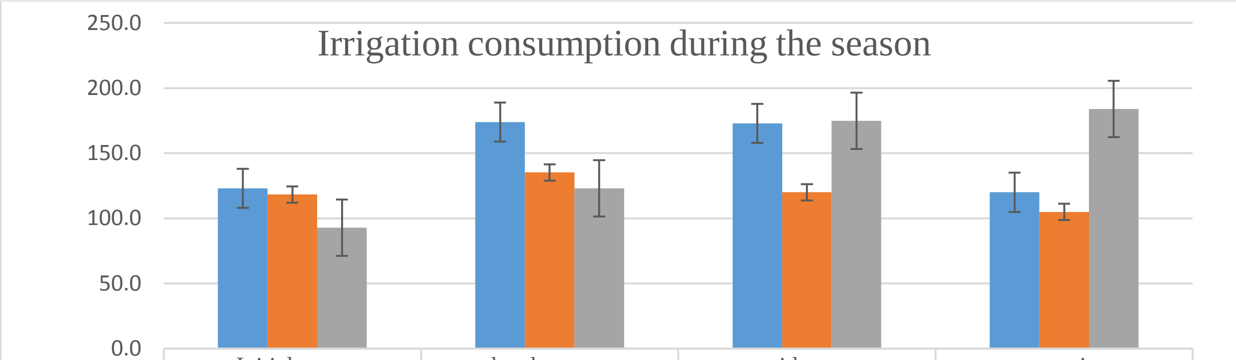


Figure 4-1: Average irrigation depth (mm) applied with error bars in the three different irrigation treatment groups (i.e. 8 in CWR, 6 in TDR and 5 in FARM).

For the CWR group the average applied irrigation depth during the season was 435 mm whereas 520 mm was applied. For the TDR group the average recommended irrigation depth was 645 mm with 587 being actually applied. The number of sample observations were 8 for the CWR and 7 for TDR as 1 were lost due to water shortage and crop eaten by cows and 5 were for farmers practice 3 were lost due to labor shortage, root damping off and cows ate the crop. There were no significant differences observed between the recommended and applied irrigation depth within both the CWR and TDR group. Additionally there was no significant difference between groups in terms of total irrigation applied. This non-significant difference between the directly field applied water and estimated water based on both irrigation methods implies that farmers more applied the necessary amounts and excess irrigation was minimal resulting in negligible deep percolation losses. The average amount of water applied within the FARM group was 575 mm (Figure 4.1).

The result for analysis of variance showed no significant difference in amount of water applied in the CWR, TDR, and FARM group ($p>0.05$) appendix (V). There were a saving possibility of 12 % by CWR over farmer's local practice on the other hand TDR and FARM are nearly the same. Even though the average irrigation is nearly the same whereas the standard deviation was very high in the farmer's local practice. The standard deviation from the farmer's treatment was 196 whereas the standard deviation from the TDR and CWR were 57 and 16 respectively. The CWR group saved slightly more water compared to the TDR. The TDR measurements showed the daily pattern of soil moisture behavior whereas the CWR method based on historical data was not corrected for the occurring climate in 2016. Furthermore, in the TDR group, irrigation is based on the measurements taken. If the contact between the sensor and the soil is not adequate such as in cases with highly aerated soil (e.g. at the onset of the season) then the readings are underestimated leading to overestimation of the estimated irrigation requirement. Even if the average water usage statistical analysis shows that as there is no significant difference between treatments the standard deviation is very high in the farmer's local practice other than TDR and CWR treatments.

The overall nutrient balance positivity for FARM plots and negativity discussed in section 4.7 of Table 4.10 for CWR and TDR plots directly linked with the water amount applied at the initial stage of the crop and the corresponding fertilizer application. Optimum moisture is required during fertilizer application so as to dilute the nutrients and converting it in to usable form. The four stage water consumption and initial stage consumption of water indicated in the data view under figure 4.2



	Initial stage	development	mid stage	maturity
TDR	123.0	174.0	173.0	120.0
CWR	118.3	135.3	120.0	105.0
FARM	92.8	123.0	175.0	184.0

Figure 4-2: water consumption at each growth stage of the crop

As shown from the above figure 4.2 the average water consumption for the farmers group was 92.8 mm at the initial stage. On the other hand the water for TDR and CWR was 123 and 118.3 mm respectively for the same stage. Whereas at the maturity stage, higher amount of water was applied by farmer practice (184mm) as compared to TDR group (120mm) and CWR group (105mm). The average fertilizer applied at the beginning of the initial stage was 1.3 kg plot^{-1}, 1.6 kg plot^{-1} and 1.8 kg plot^{-1} for TDR, FARM and CWR groups respectively.. Statistically, the amount of water applied at the different growth stage of the crop was not significantly different as shown in appendix G. Howver, figure 4.2 clearly shows that the right amount of water at the right stage is not applied for the farmer practice.

4.2.2 Irrigation water used according to the soil moisture balance

The ET_c for the irrigation period was calculated by using the soil moisture balance equation (3.3) after calculating the soil moisture change over the season for 9 farmers where soil moisture was measured using the soil moisture profiler (Table 4.3). Values of the calculated ET_c compared with the estimated ET_c using 10 years weather data with the irrigation season weather for the CWR group. No significant differences were observed between both ET_c values. Secondly, the ET_c estimated from the 3 farmers using the soil water balance in each group were compared with manual excel computation which show a significant difference among groups (Appendix s). This is logical as the crop is cultivated in the same site and hence climatic variability is little. It also indicates that crop performance might not differ between the groups as the overall crop specific evapotranspiration was relatively similar. The analysis of variance for the water balance based ETc calculated value and climatic data based shows as there is significant difference between two methods with in the treatment groups (appendix S).

Table 4.3: Average standard deviation, minimum & maximum of irrigation depth applied (mm), ETc calculated (mm), P (mm) & ΔS (mm) for 3 farmers in the CWR, TDR and FARM group.

			I applied (mm)	P (mm)	ΔS (mm)	$ET_{c\text{-}WB}$ (mm)	ETc-CL (mm)
Water management groups	TDR_GROU.P	Minimum	545	94	-163	803	372
		Maximum	655	94	128	877	440
		Average	590	94	-13	697	405
		Standard deviation	57	0	146	90	25.4
	CWR_GROUP	Minimum	461	94	-119	674	386
		Maximum	492	94	99	685	445
		Average	476	94	0	570	418
		Standard deviation	16	0	110	64	24.8
	FARM_GROUP	Minimum	419	94	-162	675	293
		Maximum	796	94	126	1016	418
		Average	575	94	4	674	344
		Standard deviation	196	0	149	197	48.5

$ETc_{\text{-WB}}$ is evapotranspiration by water balance and $ETc\text{-}_{CL}$ is by climatic data of irrigation season

4.3 Soil moisture changes in the soil profile.

In the three water management groups no deep percolation was observed below the root zone throughout the cropping period (Appendices H and I) and (Figure 4.2). Field capacity of the soil profile was assumed to be similar to the topsoil samples analyzed. Throughout the period, the measured soil moisture did not exceed the average field capacity at 60 cm depth (Figure 4.3). The observations for the TDR group correspond with previous studies conducted by Ewunetie (2015) and Tesema (2015) in Robit and Dangila when using the TDR scheduling method for tomato and onion production, respectively. Similarly for the CWR and the FARM group no percolation losses were observed after irrigation (Figure 4.3). Furthermore, rainfall amount was low during the cropping period, hence percolation losses of precipitation is equally assumed negligible.

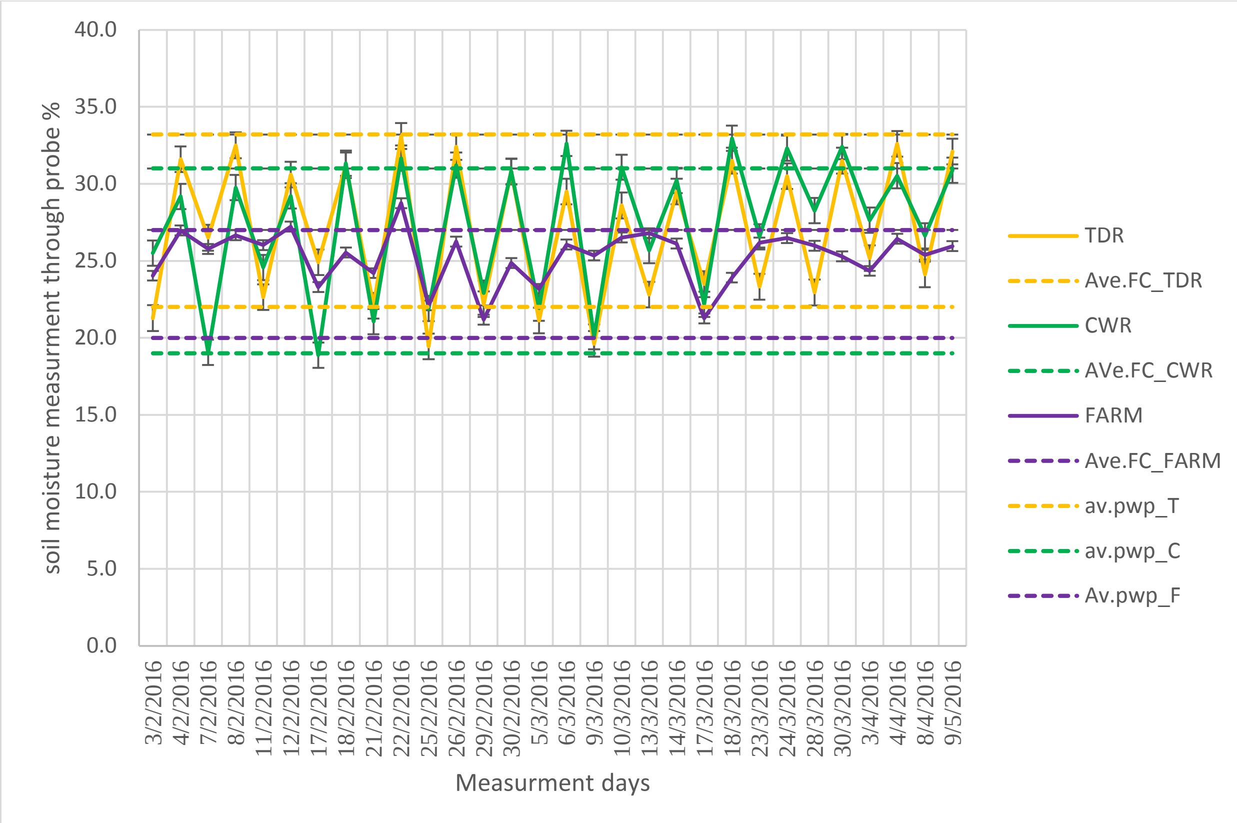


Figure 4-3: the average soil moisture at 60 cm depth for the three treatments with respective average Field capacity.

As shown from figure 4.3 the irrigation applied were not exceeded the field capacity of the corresponding treatment groups. within the irrigation duration the were no any event that exceeds the field capacity that measured after irrigation approximate time delay of 30 minute implies no percolation could exist. The plot is about the average soil moisture at 60 cm depth with average field capacity and permanent welting point in each treatment.

4.4 Agronomic performance of tomato

4.4.1 Plant height

The height of tomato at various growing stages was measured for each farmer in each treatment. There was no statistical significance difference in terms of height between treatments for any of the stages (Figure 4.4 and Table 4.4). Number of observation analyzed for plant height are 8 for CWR, 6 for TDR and 5 for FARM (farmers' local practice).

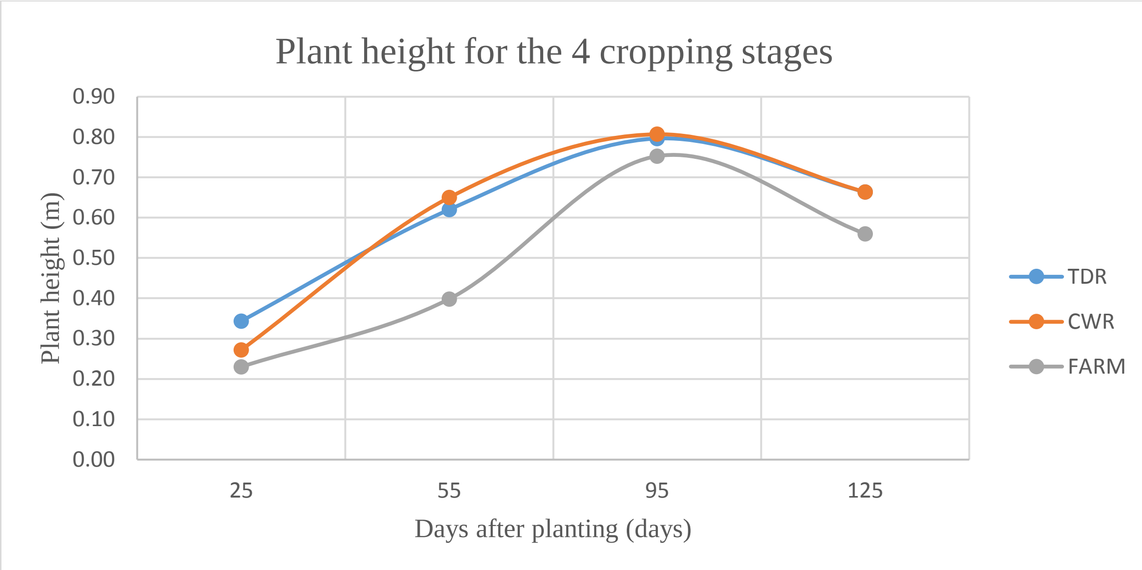


Figure 4-4: Plant height (m) measured at 25, 55, 95 and 125 days after transplanting at the initial, development, mid and end stage, respectively.

Table 4.4: Average and standard deviation plant height (m) within each irrigation group at initial, development, maturity and fruiting stage.

Development stage	CWR	TDR	FARM
Initial stage (25 days)	0.27±0.01[a]	0.34±0.01[a]	0.23±0.04[a]
Development stage (55 days)	0.51±0.03[a]	0.56±0.02[a]	0.40±0.05[a]
Mid stage (95 days)	0.86±0.04[a]	0.87±0.02[a]	0.75±0.08[a]
Maturity stage (125 days)	0.75±0.01[a]	0.78±0.02[a]	0.72±0.31[a]

*TDR time domain reflect meter based water management * CWR- climate based water management * FARM- farmers local practice water management.

Even if statistically no difference was there in biomass between the groups, there was observed difference. From development to maturity stage the maximum biomass was found for the TDR and CWR groups (Figure 4.4) and Table 4.4. The taller plants in the development stage might result in larger biomass accumulation and potentially lead to higher yields. Plots with very good soil fertility (e.g. PR11T) in any of treatment groups showed a higher biomass accumulation compared to poor soil fertility plots within the same group. These differences are not only related to the observed difference in land use history and soil fertility but also the type and quantity of fertilizer applied.

4.4.2 Yield

4.4.2.1 Yield based on water management

The average tomato yield obtained during the irrigation season in Robit was recorded as 33.2 Mg ha^{-1}, 31.67 Mg ha^{-1} and 20.8 Mg ha^{-1} for CWR, TDR and farmers local practice, respectively (Figure 4.5). The number of observations for each group were 8, 6 and 5, respectively. Short summery of yield response had given in Table 7 and detail description and analysis has shown in (Appendix B). In 2015 average tomato production of 45.02 Mg ha^{-1} was record for the TDR irrigation method (Ewnetie, 2015) which is 11.82 Mg ha^{-1} more than this year average production. However, in that study a different tomato variety was used (i.e. Shanti) a hybrid variety compared to the improved ARARI variety used in this study. According to FAO (FAOSTAT, 2015) the average yield of tomato in Ethiopia ranges from 6.5 Mg ha^{-1} to 24 Mg ha^{-1} and is low compared to the average yield of 51 Mg ha^{-1}, 41 Mg ha^{-1}, 36 Mg ha^{-1} and 34 Mg ha^{-1} in America, Europe, Asia and the entire world, respectively. The obtained average yields for the TDR and the CWR group are close to the global average stated by FAOSTAT (2010).

Table 4.5: Minimum (Min), maximum (Max.), Average, standard deviation (SD) and coefficient of variation of tomato yield (Mg ha-1) response obtained in each water management group (i.e. CWR, TDR and FARM).

Statistical descriptors	TDR	CWR	FARM
Min	12.15	7.6	7.4
Max	48.0	67.2	42.2
Average	33.2[a]	31.7[a]	20.8[b]
Standard deviation	13.8	21.3	15.9
CV (%)	41.5	67.2	76.4

The climatic conditions influence tomato performance with suitable altitudes ranging between 700 to 2000 masl. and an annual rainfall between 700 to 1400 mm (Gemechis et al., 2012). The climatic and geographical requirements in Robit suitable with the favorable conditions for tomato. Tomato yield is strongly influenced by soil physicochemical parameters like pH and EC as well as plant available nutrients. The pH and EC requirement of crops are variable based on the regional climatic condition and the seasonal fluctuation of that region. Most vegetable crops prefer acidity condition with the range of 6.5 to 6.8. Tomatoes prefer a little more acidity with pH in the range of 5.8 to

6.8 (Etissa et al., 2014a). In some rare case there may be cultivated on even more acidic soils. Furthermore, the soil Ca-Mg ratio of less than one can have a significant reduction of yield and fruit quality whereas increasing soil - K content increases the yield and fruit quality of tomato.

The highest yield was observed for the CWR group (67.2 Mg ha^{-1}) which was significantly higher compared to those observed in both the TDR and the FARM group. The lowest yield was obtained for both the CWR and the FARM group (7.6 and 7.4 Mg ha^{-1}, respectively). Overall, the average yield in the TDR and the CWR group did not differ significantly from each other despite the lower averaged K content in the soil observed in the TDR group. However, the yields observed in both irrigation scheduling groups did differ significantly from the farmers' practice. Both the standard deviation and the CV showed a medium variability within each of the treatment groups. This might be related to the differences in land use history and soil fertility as well as differences in fertilizer type and quantity. Both organic and inorganic fertilizer are viable to increase the fertility status of the soil (Locascio et al., 1997). During the experiment some plots used combined inorganic and organic fertilizer whereas some only used inorganic fertilizer. As such the yield was analyzed for different fertilizer groups in the next section.

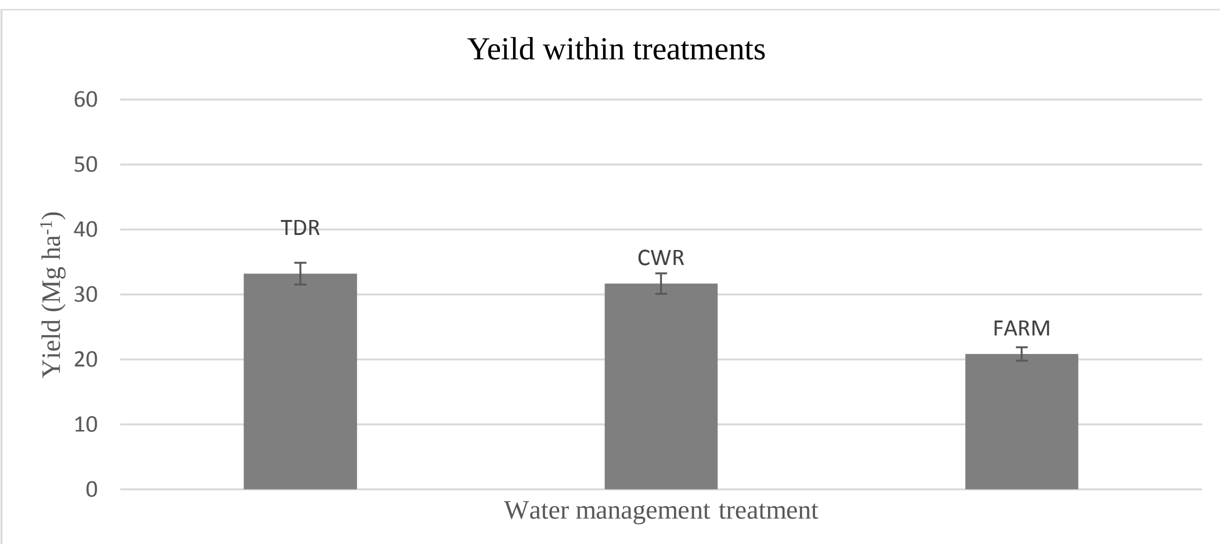


Figure 4-5: Average tomato yield (Mg ha-1) for the three different treatment groups (TDR, CWR and FARM).

4.4.2.2 Yield with manure and inorganic fertilizer application

Only in the CWR and the TDR group, some farmers did combine the application of inorganic and organic fertilizer throughout the cropping period. In total 5 farmers in the CWR group and 3 farmers in the TDR group used additionally organic fertilizer under the form of manure. The average yield obtained in the CWR groups was 27.6 Mg ha^{-1} and TDR was 26.8 Mg ha^{-1} (Figure 4.6). Statistically there were no significant difference obtained in yield between the two irrigation methods.

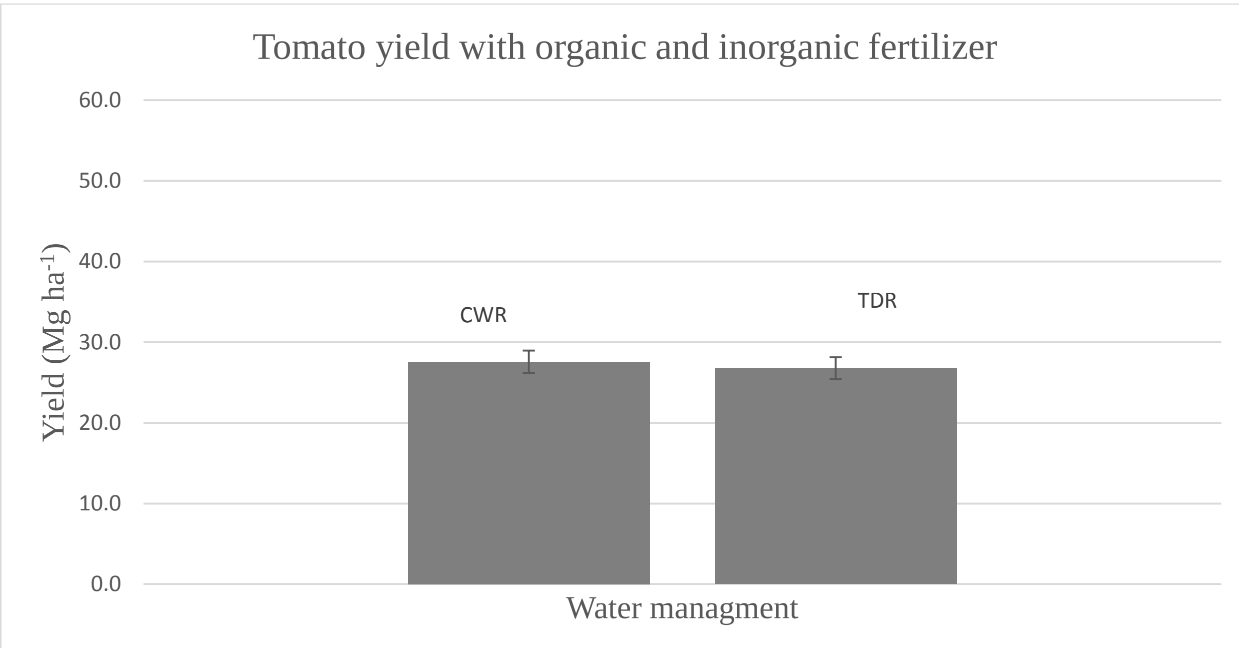


Figure 4-6: Yield (Mg ha-1) obtained in the plots where farmers applied both organic (manure) and inorganic fertilizer.

4.4.2.3 Yield with inorganic fertilizer application only

Fertilizer can increase yield when it applied appropriately. The dose of mineral fertilizer for tomato 200 kg ha^{-1} di-ammonium phosphate (DAP, 18 % N, 46 % P) at the time of sowing and 200 kg ha^{-1} of urea (46 % N) at the development stage (Kebede and Woldewahid). In Robit, urea application is higher than the recommended dose and ranges between 200 and 300 kg ha^{-1}. The number of farmers using only inorganic fertilizer was 3 for CWR, 3 for TDR and 4 for farmers' practice (Figure 4.7). Those farmers apply urea fertilizer above the dose recommended to the crop to be applied per season whereas those farmers who apply both organic fertilizer could able to reduce the mineral fertilizer applied even below the recommended dose keeping that better production could addressed than the only mineral fertilizer users. Farmers those could apply more organic fertilizer used minimum quantity of mineral fertilizer where as non-users for organic fertilizer are more users for mineral fertilizer.

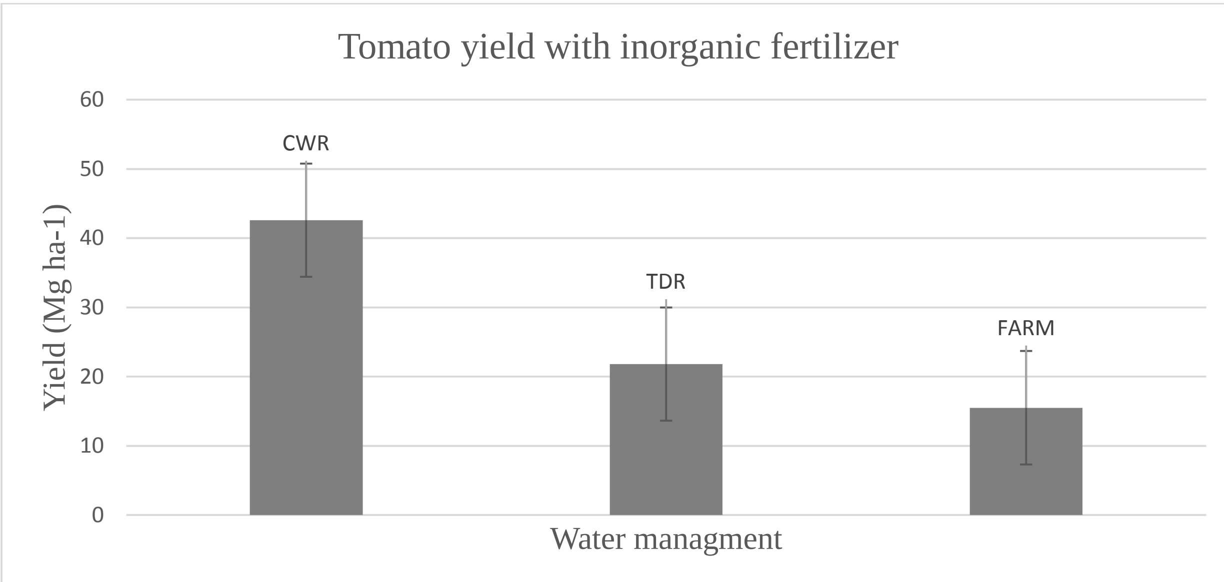


Figure 4-7: Experimental plots with in organic fertilizer application

As shown in Figure 4.7 a yield, using only inorganic fertilizer, of 42.5 Mg ha^{-1}, 36.6 Mg ha^{-1} and 15.5 Mg ha^{-1} was recorded for the CWR, TDR and FARM treatment, respectively. In each of the groups more or less the same amount of fertilizer was applied. Hence the differences in yield observed for the farmers only using inorganic fertilizer can be linked to the irrigation treatment, the land use history and the soil fertility observed in the plots. There were significant different in terms of fertilizer between treatments in terms of productivity.

4.6 Water productivity and water use efficiency of three Methods.

Table 9 shows the water productivity for the three groups using the fresh tomato yield and the details are given in appendix D. The number of observations used for water productivity were 8 for CWR, 6 for TDR and 5 for farmers local practice treatments.

Table 4.6 : The average, minimum, maximum and standard deviation (SD) of water productivity and yield for the three management groups (CWR, TDR and FARM).

	CWR		TDR		FARM	
	WP (kg m^{-3})	Yield (kg ha^{-1})	WP (kg m^{-3})	Yield (kg ha^{-1})	WP (kg m^{-3})	Yield (kg ha^{-1})
Min	3	12143	1	7604	1	7423
Max	11	48000	12	67167	9	42222
Average	8^{a}	33203^{a}	5^{a}	31675^{a}	4^{a}	20843^{b}
SD	3	13857	4	21257	3	15953
CV %	41	42	30	74	91	73

As shown in Table 8 the water productivity ranged between 3 and 11 kg m^{-3} for CWR, 1 and 12 kg m^{-3} for TDR, 1 and 9 kg m^{-3} for FARM. Although, no significant differences are observed between the three irrigation treatments higher values were observed in the TDR group compared to the CWR and the FARM group.As discussed in section 3.6.1 water productivity is the measure of quantity of production per the volume of water consummed for these production. The average value of WP does not show significant different where as the cofficient of varation is medium in the CWR and TDR group treatments whereas the FARM treatments had high cofficient of varation in the water productivity up on the the range 10-90 % medium varation rule of Wei et.al.,2007

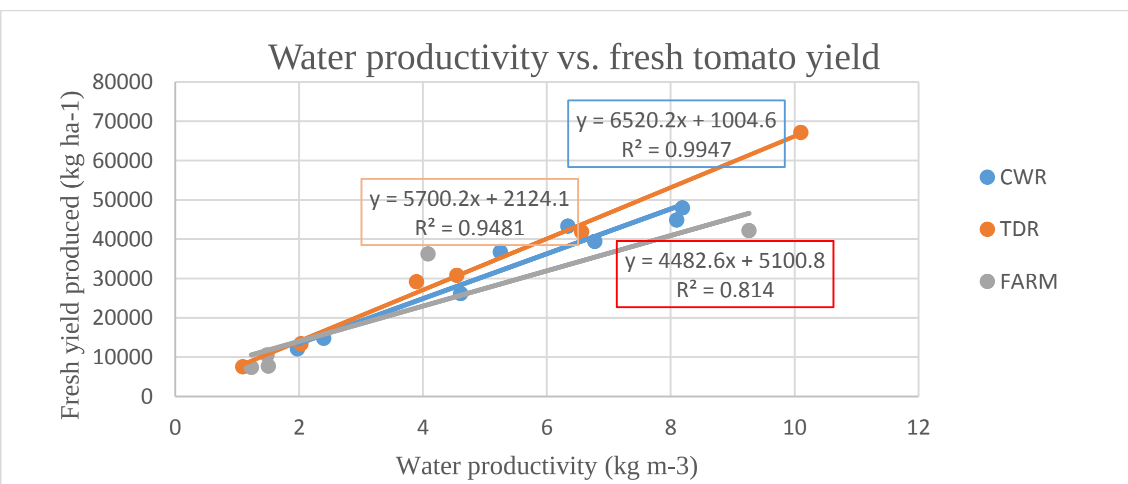


Figure 4-8: Scatter plot of total fresh yield (kg ha-1) observed at plot level. Water productivity (Kg m-3) for the three treatment groups.

The regression functions established for each water management group between the water productivity and the yield is shown in Figure 4.8. Correlations coefficients (r^2) were 0.99 for TDR, 0.95 for CWR and 0.81 for FARM. The yield with water productivity was higher slope at the TDR groups followed by CWR groups and then the FARM were also good slope and R^2 relationship relatively.

4.5 Effect of water treatment on nutrient uptake

The nutrient concentration of the tomato fruit was checked for 8 samples in the CWR, 6 in the TDR and 5 in the farmer's local practice group. For N, P and K, the irrigation and rain water quality as discussed in section 4.7 there were no significant difference. The NPK uptake was not significantly different between treatment groups. Table 4.7 shows as there were no significant difference in terms of nutrient uptake by observing simple average value. Parameters along the column within each treatment labeled with the same superscript explains that as there is no significant difference between parameter's in the treatment.

Table 4.7: Average nutrient content (%) observed in the fruit for each water management technique.

WM	N	P	K
CWR	8.2^a	0.05^a	7.6^a
TDR	8.8^a	0.05^a	9.8^a
FARM	8.7^a	0.05^a	7.5^a

4.6 Soil physicochemical properties after harvest.

Soil analysis after harvest could show potential short term effects of the irrigation treatment on the nutrient status of the soil. Average, standard deviation and coefficient of variation among the treatments are given in Table 4.8. The analysis was done for 8 farmers in the CWR, 7 in the TDR and 5 in the farmers' local practice group.

Table 4.8: Soil physicochemical properties after harvest at 20 cm depth

Water management groups						
	TDR		CWR		FARM	
Parameters	Mean ±SD	CV %	Mean ±SD	CV %	Mean ±SD	CV %
PH	6.6 ±0.2	3	6.2 ±0.4	6	5.3 ±0.6	11
EC ds/m	0.2 ±0.1	71	0.1 ±0.1	75	0.1 ±0.1	69
CEC %	30.6 ±2.2	7	33 ±9.5	29	27 ±3.2	12
OM %	1.4 ±0.3	21	1.8 ±0.4	23	1.3 ±0.5	41
TN %	0.1 ±0.03	20	0.2 ±0.04	23	0.1 ±0.05	44
Av. P ppm	21.7 ±15	69	17.5 ±12	70	20±8.3	41
Fe %	10.8 ±0.4	4	12 ±2.7	22	11.5±3	24
FC %	33.2 ±5.3	16	30.8 ±2.5	8	27±4	14
PWP %	21.8 ±2	9	20.8 ±2.3	11	19±3	17
K ppm	783 ±568	73	788 ±194	25	398±398	100

At the 20 cm soil depth analysis result on coefficient of variation at with the same literature as in section 4.1,variables coefficient of variations within the range of 10- 90 % medium varies, less than 10 % are less varies and greater than 90 % are more varies. Most of the soil physiochemical parameters except pH, CEC, Fe, and PWP were low variation at the TDR group (i.e. 3 % for pH, 7 % for CEC, 4 % for Fe and 9 % for PWP). On the same manner from CWR treatment pH and FC were less varied. On the contrary K was highly variable in the FARM treatment. The rest of variables in each treatment lays within the range. This implies that variables have medium variability for those parameters in all water management groups. No differences were observed for any of the measured parameters between the three treatment groups when all data were combined. However, as mentioned in section 4.4.2 differences in fertilizer application was observed between farmers within the treatment group. This could potentially mask differences in nutrient uptake and therefore the depletion or the enrichment factor for N, P and K. Based on the overall inputs used and outputs removed from the system there were depletion of nitrogen balance from TDR and CWR treatments and enrichment of N from farmers practice followed by depletion of P and K at the partial balance experimental plot. Even though the soil lab analysis result for the before and after of NPK and OM statistical insignificancy manual computation shows some level depletion. Detail statistics for the before and after lab result NPK and OM with in treatments and between groups has shown in appendix (U).

Table 4.9: soil physiochemical analysis after harvest at 60 cm depth integrated analysis

Water management groups						
	TDR		CWR		FARM	
Parameters	Mean ±SD	CV %	Mean ±SD	CV %	Mean ±SD	CV %
PH	6.5±0.2	3	6.2±0.7	6.0	6±0.1	15.1
EC ds/m	0.2±0.1	71	0.1±0.1	74.8	0.1±0.8	86.8
CEC %	30.6±4.5	7	33±3	28.9	27±3	11.8
OM %	1.4±0.6	21	1.8±0.4	22.9	1±0.5	40.8
TN %	0.1±0.06	20	0.2±0.05	22.9	0.1±0.7	43.5
Av. P ppm	21.7±9.5	69	17.5±7.5	70.2	20.1±8	41.1
Fe %	10.8±3	4	12.3±3.5	21.7	11.5±3	23.5
FC %	33.2±4	16	30.8±6.5	8.2	27±4	14.2
PWP %	21.8±4	9	20.8±3.3	11.0	19±3.8	17.3
K ppm	783±586	73	788.01±193	24.6	723.7±397	55.0

Like that of the former 20 cm depth analysis result on coefficient of variation at with the same literature variables coefficient of variations within the range of 10- 90 % medium varies, less than 10 % are less varies and greater than 90 % are more varies. From the analysis result shown in table 12 the pH, CEC, Fe and PWP in the TDR group and pH & FC in the CWR were less varied while the rest parameter's in each treatment were varied at medium level.

4.7 Average partial nutrient balance in the tomato root zone (based on input-output)

Nutrient balance is dependent on the inputs added to and outputs removed from the farm system. For this study, fertilizers (manure and inorganic), rain and irrigation water were analyzed as sources of nutrient inputs whilst tomato fruit yield and crop residue were considered as outputs. Details are given in Appendix L. Statistically, the input variables (i.e. fertilizer, irrigation quantity and rainfall) among farmers were not significantly different. Irrigation water quality analysis was done for 9 farmers (3 in each treatment group) whose wells were distributed well through the study area. Average of values of 1.62 mg l^{-1} for N, 0.11 mg l^{-1} for P and 4.32 mg $l^{-1}$for K in for TDR management; 3.25 mg l^{-1} for N, 2.89 mg l^{-1} for P and 6.05 mg l^{-1} of K in for CWR management and 2.04 mg l^{-1} N, 1.87 mg l^{-1} P and 3.66 mg l^{-1} of K for in FARM management were measured. For N, P and K no significant differences were observed between the three treatment groups despite the variance found especially for N and K. As such, the average irrigation nutrient content was calculated and used for all farmers. The average value used was 2.4 mg l^{-1} for N, 0.14 mg l^{-1} for P and 4.6 mg l^{-1} of K. The average measured nutrient quality of the rainfall was 2.6 mg l^{-1} for N, 0.06 mg l^{-1} for P and 3.5 mg l^{-1} of K. The overall partial nutrient (N, P, K) balance statistical analysis result shows that as there is no significant difference among the treatment groups Appendix

Table 4.10: The average TN load (kg ha-1) for each input and output parameter for the three treatment groups.

	Measured parameters	CWR	FARM	TDR
Input	Atmospheric wet deposition	2.4±0.46^{a}	2.4±0.64^{a}	2.4±0.57^{a}
	Fertilizer (inorganic and organic)	154.4±56.0^{a}	174.4±80.7^{a}	182.4±59.2^{a}
	Irrigation	20.0±0.03^{a}	13.9±0.04^{a}	15.5.0±0.02^{a}
Output	Tomato fruit	204.4±14.6^{a}	112.0±41.5^{b}	180.0±41.0^{a}
	Crop residue	124.3±25^{a}	59.5±30^{b}	111±22.5^{a}
	Balance	**-151.3±17^{a}**	**18.8±10^{b}**	**-90.6±3.7^{a}**

As shown in Table 4.10 the nutrient removed with the tomato yield and crop residue for both the TDR and CWR group were higher compared to the farmer's local practice. The CWR treatment removed 204.4 kg and TDR treatment removed 180 kg N when tomato fruits harvested which is 92.4 kg and 68 kg more N as compared to the FARM treatment of 112 kg N removed. The N removed with the residual biomass in the CWR were almost double that in the FAMR group. The partial N balance is plotted in Figure 4.8 showing that the higher removal of nutrients in the CWR and TDR group was not compensated by the applied fertilizer. Hence for TDR and CWR treatments there was a negative balance of N to the field and was high depletion as compared to FARM. The positive N balance obtained in the FARM group was significantly higher compared to the CWR and the TDR. There was a significant difference in the N depletion between the TDR and the CWR this is due to the more production and residue N removal from this treatment. The N enrichment from the FARM is due to less production of both yield and biomass.

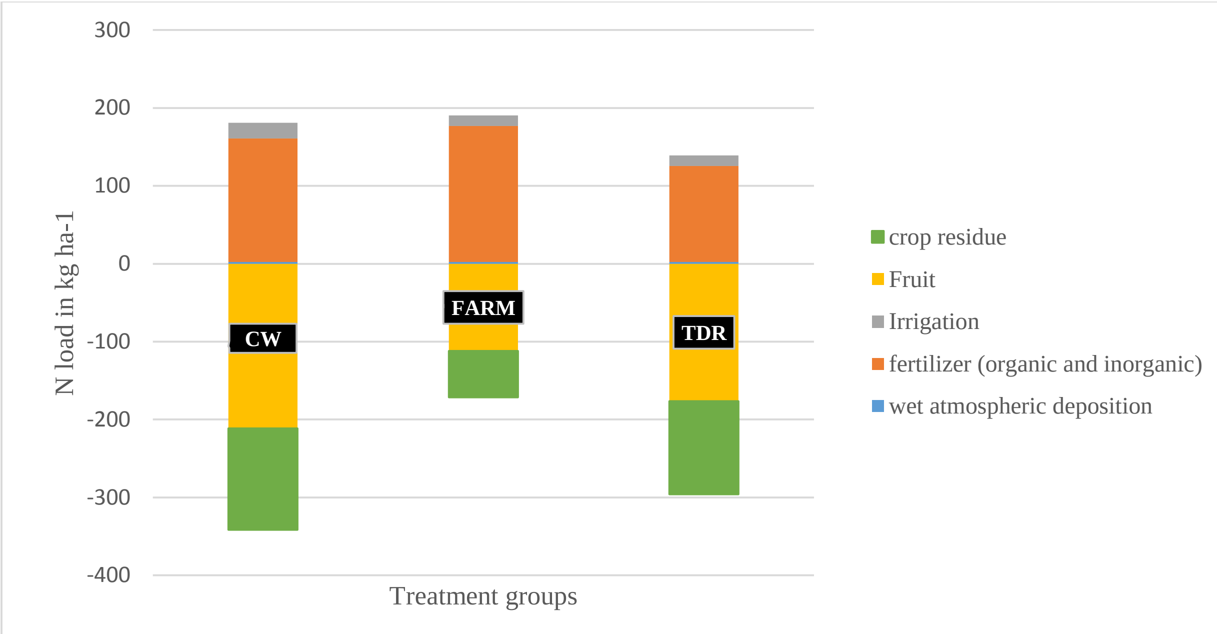


Figure 4-9: Average partial nitrogen balance for the three treatment groups.

Similar calculations were done for P and K. The wet atmospheric deposition was neglected as the values were very low.

Table 4.11 : Partial P & K balance based on input-output measurement for the three treatment groups (kg ha-1)

	Measured parameters	P			K		
		CWR	FARM	TDR	CWR	FARM	TDR
Input	Fertilizer (inorganic and organic)	0.13±0.04[a]	0.00±0.06[b]	0.04±0.01[a]	3.7±2.8[a]	0.001±0.0[b]	2.9±2.4[a]
	Irrigation	0.84±0.01[a]	0.74±0.0[a]	0.73±0.0[a]	27.4±0.14[a]	22.1±0.06[a]	27.6±0.08[a]
Output	Tomato fruit	1.0±0.02[a]	0.5±0.01[b]	0.9±0.03[a]	165.5±0.8[a]	76.7±0.4[b]	170.2±0.5[a]
	Crop residue	0.5±0.02[a]	0.4±0.001[b]	0.5±0.01[a]	135.3±1[a]	42.6±0.8[b]	144.3±0.7[a]

Balance	-0.5±0.05[a]	- 0.2± 0.06[a]	-0.6± 0.01[a]	-270± 1.1[a]	-97.2± 1.[b]	-284± 1.3[a]

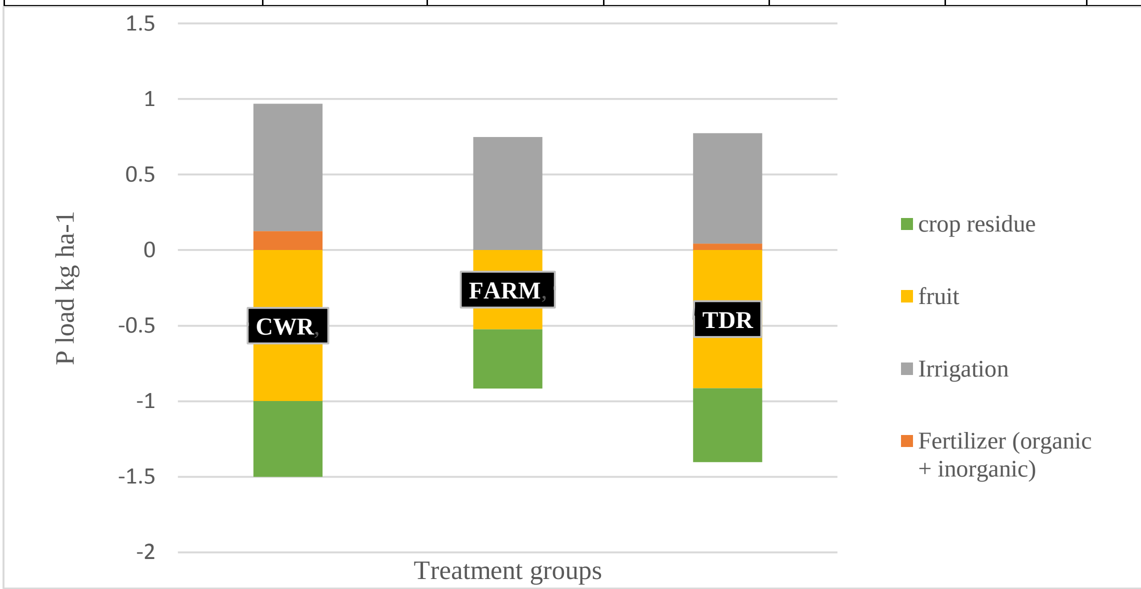
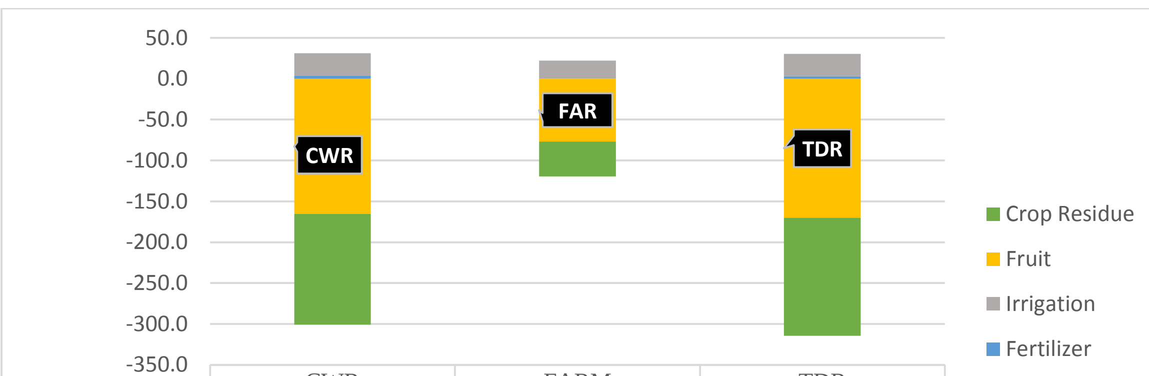


Figure 4-10: Average partial phosphorus balance for the three treatment



	CWR	FARM	TDR
Crop Residue	-135.4	-42.6	-144.3
Fruit	-165.5	-76.7	-170.2
Irrigation	27.4	22.1	27.6
Fertilizer	3.7	0.0	2.9

Figure 4-11: Average partial potassium balance for the three treatment groups

As shown in table 4.11 and the partial balance plot in figure 4.10 and 4.11 the P and K load from different component with kg ha-1 explained here. The uptake was greater in the CWR and TDR groups over that of the farmers practice from the harvested fruit and crop residue. In the CWR group average P and K was 0.9 kg, 1.1 kg from fruit and 0.5 kg, 0.9 kg from crop residue. The TDR treatments average P and K was 1 kg, 170.2 from fruit and 0.5 kg and 144.3 kg from residue respectively. On the other hand from farmers local practice the P and K uptake were 0.5 and 76.3 kg from the fruit and 0.4 and 42.6 from residue respectively. From the mineral fertilizer farmers DAP users were only 3 and in minimal amount of P component and even the organic (manure) user doesn't compensate the amount in the removal the balance have become negative. P is very essential and highly up taken by the crop so that sufficient P source organic fertilizer need to applied. The lower nutrient input results negative balance in the three treatment groups correspondingly less negative for FARM implies as there were no manure application from farmers local practice. Farmers practice only applies urea and dap and these mineral fertilizers haven't P that implies less negative. K is negative in the farmer's practice this is the same to P the input nutrient source of organic fertilizer were not added to the plots in the farmers practice. Whereas the K balance in the TDR and CWR treatments was positive implies that sufficient input from organic fertilizer-manure were added. Even though higher K nutrient uptake was measured in the CWR and TDR treatments than FARM the input K-nutrient from manure was sufficient enough to recover the lost and maintain positive balance. Generally from overall nutrient balance the reason for higher balance of nutrients for farmers practice could likely no enough application of sufficient water at the initial stage of the veggie (Figure 4.2) that makes the nutrient not easily dissolve and taken-up easily.

The positive effect of organic fertilizer was shown in the partial P and K nutrient plot (Figures 4.10 and 4.11) where no organic fertilizer was used in the farmers plot leading to slightly negative values. From the farmer's local practice the application of organic fertilizer were nil that have great negative influence on P and K partial balance. Soils with high organic matter have a better soil drainage, aeration, water holding capacity, and the ability to hold nutrients. Whereas organic fertilizer contributes positively towards the soil structure, inorganic fertilizer only increases the production of the land short term. The beneficial effects of organic matter on soil structure can have a greater effect on plant growth. Although differences were observed in land use history (Appendix E) and soil fertility was variable. There is a clear linkage between the total yield produced in the two irrigation scheduling treatment and the total amount of nutrients removed by the produce and the residual biomass. The effect of fertilizer type on these balances was further investigated for the inorganic group and the inorganic and organic fertilizer group within the water management treatment.

4.7.1 Partial depletion balance only for mineral fertilizer users

Mineral fertilizers increase the soil nitrogen content and allows for the N to be immediately converted to the plant usable form (nitrate) through nitrification. This form of nitrogen could prevent soil depletion. Analysis for this case was done using 3 farmers for CWR, 3 for TDR and 4 for farmer's local practice.

Table 4.12 : Partial depletion balance of N- P- K (kg ha-1) for the three treatment groups when only mineral fertilizer is used.

Treatment	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
CWR	-260±61.5^{a}	-1.4±0.0.5^{a}	-375.2±206.8^{a}
FARM	18.8±110.5^{b}	-0.17±0.0.8^{a}	-75.2±140^{a}
TDR	-198.5±93.8^{a}	-1.07±1.2^{a}	-318.8±198^{a}

*Average of NPK -depletion balance: different superscript within the column shows significant differences between the treatments.

The average partial N balance was found negative for CWR and TDR treatment plots with the highest enrichment was found from farmers local practice (18.8 kg ha^{-1}) compared to the climate based plot's (-260 kg ha^{-1}) and the TDR (-198 kg ha^{-1}) (Table 4.12) which is significantly different from farmers treatment groups these is due to the low fruit and biomass production at the farmers practice that results less nutrient removal.. The partial P depletion balance did not show a significant difference between the three treatments. The partial balance from FARM treatment were positive and more negative in the TDR and CWR group. These positive value is due to the poor P nutrient up taken concentration from both fruit and residue in farmer's treatment. The average in FARM treatment were low P uptake with concentration of fruit 0.5 kg ha^{-1} and residue 0.4 kg ha^{-1} with the supplied irrigation P amounted 0.7 kg ha^{-1}. The partial K balance clearly showed a strong nutrient depletion in the two treatment groups. Although the K depletion did not differ among the treatment groups, the values were most negative for the TDR and CWR treatments followed by the FARM. According to Cobo et al., (2009) N and K balances are often negative in Africa compared to P. The high positive partial balance of N for the FARM group is clearly linked to the high mineral fertilizer application and the low yield and crop residual biomass obtained in the field. This indicates that the fertilizer use efficiency was potentially lower compared to the other groups. Irrigation scheduling enables the right amount of water at the right time clearly has an effect on the nutrient balance.

4.7.2 Partial depletion balance for mineral and manure fertilizer users

Organic and inorganic fertilizers positively contribute towards soil fertility and yield maximization. Aside from the N, P and K elements manure supplies a number of macro and micro elements positively affecting yield. The number of observation/samples for the analysis of farmers using both manure and mineral fertilizer were 5 for CWR and 3 for TDR treatments.

Table 4.13 : Partial depletion balance of N- P- K (kg ha-1) for the three treatment groups when manure and mineral fertilizer is used.

Treatment	**N (kg ha^{-1})**	**P (kg ha^{-1})**	**K (kg ha^{-1})**
CWR	-86.5±84.5^{a}	0.02±0.08^{a}	-206±200^{a}
TDR	53.2±96^{b}	-0.04±0.4^{b}	-238±206^{a}

As shown in Table 4.13 the addition of manure positively affected the K balance as the various types of manure had high concentration of K. Even though K is lost from the soil by different processes, organic fertilizer application counteracts the losses significantly. The effect of organic fertilizer on the N balance remained relatively similar to those for the mineral fertilizer group as the manure was low conversion rate to the organic matter decomposition and N formation even though the reason behind for the positivity of the balance at the TDR is due to the very high application of mineral fertilizers i.e. the mineral fertilizer application was almost double. P balance at the TDR was negative and at CWR are slightly positive. Like that of K various composition organic fertilizer contains high P concentration. The nutrient up take rate in the CWR group were not much more than the inputs supplied in the form of manure, fertilizer, irrigation water and rain water whereas there were more nutrient uptake from the fruit and residue of the TDR treatments over the input nutrient added in terms of P nutrient. The k partial balance is less negative in both TDR and CWR treatments as compared to those farmers used only mineral fertilizer. Manure's are crucial source of numerous macro and micro nutrients including k. These is the reason for the less negative balance resulted from manure applied farmers in terms of k. Treatment those were used mineral fertilize were had a balance of -375.2 kg ha-1 in CWR and -318 kg ha-1 in TDR whereas for farmer's those applied manure k balance was -206 kg ha-1 for CWR and -238 kg ha-1 for TDR treatments.

4.8 Limitation of the study

The leaching was assumed negligible based on the soil moisture profiler readings. As measurements were not taken continuously some leaching might have occurred after rainfall events and has not been accounted for. The use of piezometers to measure elevated levels was not feasible given the deep groundwater level during the dry season (< 10 m). Installation for the moisture access tubes through auger has greater diameter and the hole have become somewhat wide. The moisture sensor does not have direct contact on the normal bulk of soil instead on the aerated soil these may lead wrong volumetric water content reading of the separate depth.

5 Conclusions and recommendation

5.1 Conclusion

Both the climate based as well as the soil moisture based scheduling improved crop yield but did neither increase nor decrease the amount of water used during the irrigation season. Results indicate that the farmers apply approximately the right amount of water but potentially not at the right time. Farmers following one of the two irrigation scheduling methods did benefited from the water management in terms of yield. On average 37 % and 34 % more yield was obtained through CWR and TDR methods, respectively compared to the farmer's local practice. This illustrated the importance of the right amount of water at the right time which translated in sufficient nutrient uptake resulting in higher yield.

Water productivity were high at the TDR group and CWR than the farmer's local practice. Water productivity were also good but the coefficient of variation was very high in the FARM treatment (CV = 91 %) on the other hand the TDR and CWR treatments were medium with CV of 30 % and 41 % respectively.

The effect of improved water management resulted not only in higher yields but also increased the N, P and K removal from the fields both via the product of fruits and via the crop residue. The largest removal of nutrients was found for CWR followed by TDR and the farmers practice. The effect of the irrigation treatment on the depletion of N, P and K was highly dependent of the amount and type of fertilizer used (i.e. manure or inorganic fertilizer). The use of organic fertilizer positively influenced the K balance to a large extend and the N and P balance to a moderate extend. Aside from the fertilizer type and quantity used in this study the land use history and consecutive soil fertility was an important factor influencing the large variability found within the treatment groups. Both the land use history and this experiment showed the importance of using manure within the cropping system whether it is irrigated or rainfed. Particularly the use of organic fertilizer is advisable so that organic fertilization as it maintains the soil biota and ensures sustainable production of the farm land.

5.2 Recommendation

To improve yield on smallholder farmers plots irrigation scheduling is not sufficient, nutrient scheduling is equally important. Hence, the conversion of rainfed plots into intensified production systems requires a well balanced approach where the nutrients are sufficiently replenished on a continuous bases through a good combination of both inorganic and organic fertilizer to compensate for the increased nutrient removal by additional cropping seasons even if improved irrigation management techniques are not applied.

Additionally, further research on full nutrient balance should be done to incorporate all fluxes. For example, leaching could occur when irrigation events fall simultaneously with rainfall events. On the other hand, nitrogen gaseous losses can occur during irrigation when fertilizer is applied. The quantification of these components would allow for a full evaluation on the sustainability of the irrigation system as well as its long term potential impact on soil fertility.

More work should be done on soil fertility improvement in order to enhance the sustainable production and productivity of the land from smallholder to larger farmers. The study showed that using scientific irrigation scheduling techniques improves the water and nutrient productivity and hence could maximize production. The application of these scheduling tools together with the quantification of their effect on nutrient balances need to be assessed as in cases of over-irrigation the benefits go beyond water saving.

6. Reference

ADSWE 2013. Tana sub basin lagre scale soil resource inventory report. *fund rising report*.

ALEMU, M. T. 2015. Evaluating Simple Irrigation Technologies to Improve Crop and Water Productivity of Onion in Dangishta Watershed. *graduating paper***,** 45.

ALI, M. & TALUKDER, M. 2008. Increasing water productivity in crop production—a synthesis. *Agricultural water management,* 95**,** 1201-1213.

ALLEN, R. G. 1996. Assessing integrity of weather data for reference evapotranspiration estimation. *Journal of Irrigation and Drainage Engineering,* 122**,** 97-106.

AWULACHEW, S. B., MERREY, D., VAN KOPPEN, B., KAMARA, A., PENNING DE VRIES, F. & BOELEE, E. Roles, constraints and opportunities of small scale irrigation and water harvesting in Ethiopian agricultural development: Assessment of existing situation. International Water Management Institute Conference Papers, 2005.

BEKELE, A. E. 2014. Five Key Constraints to Small Scale Irrigation Development in Ethiopia: Socio-Economic View. *Global Advanced Research Journal of Management and Business Studies (ISSN: 2315-5086 Available online* Vol. 3(10)**,** pp.441-444,.

COBO, J. G., A, B., , G. D., A, , G. C. & ALAMIREW, T. 2009. Nutrient balances in African land use systems across different spatial scales: A review of approaches, challenges and progress. www.elsevier.com/locate/agee.

DAVID, M. B. & GENTRY, L. E. 2000. Anthropogenic inputs of nitrogen and phosphorus and riverine export for Illinois, USA. *Journal of Environmental Quality,* 29**,** 494-508.

ETISSA, E., DECHASSA, N., ALAMIREW, T., ALEMAYEHU, Y. & DESALEGN, L. 2014a. Growth and physiological response of tomato to various irrigation regimes and integrated nutrient management practices. *African Journal of Agricultural Research,* 9**,** 1484-1494.

ETISSA, E., DECHASSA, N., ALAMIREW, T., ALEMAYEHU, Y. & DESALEGNE, L. 2014b. Irrigation Water Management Practices in Smallholder Vegetable Crops Production: The Case of the Central Rift Valley of Ethiopia. *Science, Technology and Arts Research Journal,* 3**,** 74-83.

EWUNETIE, T. 2015. Assessing the performance of manual operated water lifting technologies and irrigation scheduling based on measured soil moisture and farmers practice on irrigated tomato production, and comparing soil moisture measuring and estimation methods: the case of Western Amhara sub- region. *unpublished document*.

FAOSTAT 2015. small holder commercial crop production in ethiopia Northern part.

FIXEN, P. & LUDWICK, A. 1983. Phosphorus and potassium fertilization of irrigated alfalfa on calcareous soils: I. Soil test maintenance requirements. *Soil Science Society of America Journal,* 47**,** 107-112.

GEBRESELASSIE, S. 2003. Helping small farmers to commercialise: Evidence from growing onion and tomatoes for sale in central Ethiopia. *A Research Update of the Future Agricultures Consortium*.

GEMECHIS, A. O., STRUIK, P. C. & EMANA, B. Tomato production in Ethiopia: Constraints and opportunities. International Research on Food Security, Natural Resource Management and Rural Development Conference, 2012.

GESSLER, A., SCHNEIDER, S., VON SENGBUSCH, D., WEBER, P., HANEMANN, U., HUBER, C., ROTHE, A., KREUTZER, K. & RENNENBERG, H. 1998. Field and laboratory experiments on net uptake of nitrate and ammonium by the roots of spruce (Picea abies) and beech (Fagus sylvatica) trees. *New Phytologist,* 138**,** 275-285.

GOLDHAMER, D. & FERERES, E. 2004. Irrigation scheduling of almond trees with trunk diameter sensors. *Irrigation Science,* 23**,** 11-19.

HAILESLASSIE, A., PRIESS, J., VELDKAMP, E., TEKETAY, D. & LESSCHEN, J. P. 2005. Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. *Agriculture, ecosystems & environment,* 108**,** 1-16.

HORDOFA, T., MENKIR, M., AWULACHEW, S. B. & ERKOSSA, T. 2008. Irrigation and rain-fed crop production system in Ethiopia.

HUTCHINSON, G. & DAVIDSON, E. A. 1993. Processes for production and consumption of gaseous nitrogen oxides in soil. *Agricultural ecosystem effects on trace gases and global climate change***,** 79-93.

JENSEN, M. E., BURMAN, R. D. & ALLEN, R. G. Evapotranspiration and irrigation water requirements. 1990. ASCE.

KEBEDE, A. & WOLDEWAHID, G. Fruit Quality And Net Income Response Of Tomato (Lycopersicon Esculentum Mill.) To Different Levels Of Nitrogen And Plant Population In Alamata, Ethiopia.

KIROS, G., 1*, , M. H., 2, GEBRESAMUEL, A. G. & 2 January, 2014. Assessing the Input and Output Flows and Nutrients Balance Analysis at Catchment Level in Northern Ethiopia. *Journal of Soil Science and Environmental Management*, Vol. 5(1), , **,** pp. 1-12.

KLEMUNES JR, J. 1998. Determining soil volumetric moisture content using time domain reflectometry.

LEY, T., STEVENS, R., TOPIELEC, R. & NEIBLING, W. 1994. Soil Water Monitoring and Measurement: A Pacific Northwest Publication PNW0475. *Washington State University: Pullman, WA, USA.*

LOCASCIO, S. J., HOCHMUTH, G. J., RHOADS, F. M., OLSON, S. M., SMAJSTRLA, A. G. & HANLON, E. A. 1997. Nitrogen and potassium application scheduling effects on drip-irrigated tomato yield and leaf tissue analysis. *HortScience,* 32**,** 230-235.

LOUCKS, D. P. & VAN BEEK, E. 2005. Water Resources Systems Planning and Management-Facts about Water.

MALICKI, M. A. & SKIERUCHA, W. M. 1989. A manually controlled TDR soil moisture meter operating with 300 ps rise-time needle pulse. *Irrigation Science,* 10**,** 153-163.

MARX, E., HART, J. & STEVENS, R. 1999. Soil Testing Interpretation Guide, Oregon State University. *Corvallis. USA.*

MENGEL, K. & KIRKBY, E. 1987. Principles of plant nutrients. *International Potash Institute, Bern, Switzerland***,** 62-66.

NZANZA, B. 2006. *Yield and quality of tomato as influenced by differential Ca, Mg and K nutrition.* University of Pretoria.

PALINTEST HOUSE, K., TEAMVALLEY, GATESHEAD, TYNE & WEAR, ENGLAND NE11 ONS PHOTOMETER SYSTEMS FOR WATER ANALYSIS Palintest® Photometer 7100 ,palintest® Photometer 7500 *DIRECT-READING PHOTOMETERS,* PHOT.0.AUTO.

PEREIRA, L., GONCALVES, J., DONG, B., MAO, Z. & FANG, S. 2007. Assessing basin irrigation and scheduling strategies for saving irrigation water and controlling salinity in the upper Yellow River Basin, China. *Agricultural Water Management,* 93**,** 109-122.

REGO, T., SEELING, B., RAO, V. N., PARDHASARADHI, G., RAO, J. K., MYERS, R. & JOHANSEN, C. 2002. Nutrient balances: A guide to improving the sorghum-and groundnut-based dryland cropping systems in semi-arid tropical India. *Food Security in Nutrient-Stressed Environments: Exploiting Plants' Genetic Capabilities.* Springer.

ROY, R. N., DIVISION, F. L. A. W. D., ROME, MISRA, R. V., CONSULTANT, F., LESSCHEN, J. P., UNIVERSITY, W., NETHERLANDS, T., SMALING, E. M., UNIVERSITY, W. & NETHERLANDS, T. 2003. Assessment of soil nutrient balanceApproaches and methodologies *FAO FERTILIZER AND PLANT NUTRITION BULLETI*.

SAMAR, E., EVANGELISTA, P., URRIZA, G., MAGNO, B., BLAMEY, P. & LEFROY, R. 2001. Partial nutrient balances from agronomic and economic viewpoints: the case of corn cultivation in the acid upland soils of Isabela, the Philippines. *Southeast Asia,* 20**,** 22.

SAVVA, A. P. & FRENKEN, K. 2002. *Crop water requirements and irrigation scheduling,* FAO Sub-Regional Office for East and Southern Africa Harare.

SEITZINGER, S. P. & GIBLIN, A. E. 1996. Estimating denitrification in North Atlantic continental shelf sediments. *Biogeochemistry,* 35**,** 235-260.

TANDON, H. 2007. Soil nutrient balance sheets in India: Importance, status, issues, and concerns. *Better Crops India,* 1**,** 15-91.

TOPP, G., DAVIS, J. & ANNAN, A. P. 1980. Electromagnetic determination of soil water content: Measurements in coaxial transmission lines. *Water resources research,* 16**,** 574-582.

WERNER, H. 1992. *Measuring soil moisture for irrigation water management*, Cooperative Extension Service, South Dakota State University, US Department of Agriculture.

WHEATER, H. & EVANS, E. 2009. Land use, water management and future flood risk. *Land Use Policy,* 26**,** S251-S264.

WOLDEWAHID, G., GEBREMEDHIN, B., BERHE, K. & HOEKSTRA, D. 2011. Shifting towards market-oriented irrigated crops development as an approach to improve the income of farmers: Evidence from northern Ethiopia.

ZOTARELLI, L., DUKES, M. D., ROMERO, C. C., MIGLIACCIO, K. W. & MORGAN, K. T. 2014. Step by step calculation of the Penman-Monteith Evapotranspiration (FAO-56 Method).

ZOTARELLI, L., SCHOLBERG, J. M., DUKES, M. D., MUÑOZ-CARPENA, R. & ICERMAN, J. 2009. Tomato yield, biomass accumulation, root distribution and irrigation water use efficiency on a sandy soil, as affected by nitrogen rate and irrigation scheduling. *agricultural water management*, 96**,** 23-34.

ZWART, S. J. 2010. *Benchmarking water productivity in agriculture and the scope for improvement-remote sensing modelling from field to global scale*, TU Delft, Delft University of Technology.

APPENDIX

Appendix A; before transplanting and after harvest soil physiochemical analysis result

pH = H_2o (1:2.5)			Before transplanting soil laboratory analysis result											
Farmer code	pH	EC ds/m	Sand %	Clay %	Silt %	Soil class	CEC %	OM %	TN %	Av. P ppm	Fe %	FC %	PWP %	K ppm
PR3T	6.3	0.0	27.0	40.0	33.0	clay loam	33.4	2.0	0.1	6.5	5.7	34.9	21.3	103.2
PR8T_NUT	6.6	0.1	13.0	56.0	31.0	clay	39.4	2.8	0.1	8.5	9.8	28.9	19.6	164.6
PR5T_NUT	7.1	0.3	43.0	22.0	35.0	loam	25.0	4.4	0.2	21.9	6.4	39.0	23.6	805.0
PR6FR_NUT	6.7	0.2	33.0	36.0	31.0	clay loam	35.0	4.7	0.2	13.1	7.4	31.5	22.7	1100.2
PR7T	6.3	0.0	21.0	48.0	31.0	clay	27.2	3.1	0.2	5.4	7.4	32.9	21.7	145.6
PR11T	6.4	0.3	57.0	12.0	31.0	sandy loam	50.8	6.9	0.4	31.3	32.4	38.9	24.6	1996.4
PR16T_NUT	6.3	0.2	41.0	18.0	41.0	loam	41.8	4.4	0.2	15.0	12.4	31.6	22.2	1991.0
PR18T	5.9	0.1	27.0	36.0	37.0	clay loam	31.0	4.8	0.2	26.3	10.2	30.0	20.9	543.8
PR4CW	6.1	0.1	17.0	54.0	29.0	clay	26.0	3.4	0.2	13.1	6.3	31.2	19.7	281.0
PR2FR	6.1	0.1	23.0	40.0	37.0	clay loam	42.6	1.8	0.1	10.3	8.7	39.5	28.6	129.0
PR1FR	5.8	0.1	17.0	58.0	25.0	clay	32.0	4.1	0.2	7.4	8.5	37.2	22.6	114.4
PR9CW	5.8	0.2	27.0	36.0	37.0	clay loam	48.6	2.0	0.1	9.6	7.6	41.5	23.8	116.8
PR24CW	6.3	0.2	17.0	54.0	29.0	clay	42.4	2.6	0.1	8.5	8.9	35.1	21.2	111.6
PR10CW	6.0	0.2	35.0	32.0	33.0	clay loam	51.0	3.1	0.2	11.4	10.1	34.4	18.9	392.4
PR14CW_NUT	6.2	0.1	19.0	46.0	35.0	clay	31.2	3.1	0.2	16.9	10.3	29.1	19.1	562.2
PR17CW_NUT	5.4	0.1	13.0	62.0	25.0	heavy clay	26.0	3.5	0.2	10.9	5.9	29.6	19.9	93.6

PR15CW	5.9	0.1	19.0	52.0	29.0	clay	32.0	3.9	0.2	30.0	9.6	29.7	21.5	321.6
PR12FR	6.5	0.3	53.0	12.0	35.0	sandy loam	51.0	6.5	0.3	15.0	21.7	44.1	23.4	1590.4
PR23CW_NUT	6.7	0.2	35.0	28.0	37.0	clay loam	34.8	4.9	0.2	53.8	12.8	33.8	23.4	517.8
PR13FR	6.7	0.1	39.0	18.0	43.0	loam	45.0	5.1	0.3	18.1	17.8	32.5	21.5	925.0
PR22_NUT	5.7	0.1	17.0	52.0	31.0	clay	34.0	3.7	0.2	8.6	8.4	25.5	18.4	398.0
PR21_NUT	5.5	0.1	9.0	72.0	19.0	heavy clay	22.0	2.8	0.1	7.8	4.7	24.3	16.2	57.0
PR20T	6.3	0.1	17.0	54.0	29.0	clay	28.0	3.2	0.2	10.6	9.3	28.6	20.4	419.6
PR19FR	6.8	0.3	47.0	16.0	37.0	loam	40.2	5.5	0.3	26.3	17.7	32.4	22.3	1765.6
After harvest soil analysis result								OC						
PR3T	6.4	0.0	27.0	40.0	33.0	clay loam	37.4	1.0	0.1	17.5	13.7	34.9	21.3	532.4
PR8T_NUT	6.3	0.1	13.0	56.0	31.0	clay	30.0	1.2	0.1	15.4	11.2	28.9	19.6	605.2
PR5T_NUT	6.6	0.3	43.0	22.0	35.0	loam	28.8	1.8	0.2	10.9	10.3	39.0	23.6	325.8
PR6FR_NUT	5.0	0.2	33.0	36.0	31.0	clay loam	31.0	1.1	0.1	19.4	11.5	31.5	22.7	1161.7
PR7T	5.4	0.0	21.0	48.0	31.0	clay	30.8	1.4	0.1	14.4	13.3	32.9	21.7	793.8
PR11T	6.7	0.3	57.0	12.0	31.0	sandy loam	31.0	2.7	0.2	10.9	23.1	38.9	24.6	343.3
PR16T_NUT	6.6	0.2	41.0	18.0	41.0	loam	33.0	1.4	0.1	38.8	10.8	31.6	22.2	1419.0
PR18T	6.1	0.1	27.0	36.0	37.0	clay loam	31.0	2.0	0.2	15.6	14.8	30.0	20.9	1103.9
PR4CW	6.3	0.1	17.0	54.0	29.0	clay	28.0	1.3	0.1	28.8	13.7	31.2	19.7	518.7
PR9CW	5.7	0.2	27.0	36.0	37.0	clay loam	43.0	1.2	0.1	47.5	6.0	41.5	23.8	367.2
PR24CW_NUT	6.3	0.2	17.0	54.0	29.0	clay	36.0	1.0	0.1	30.0	8.9	35.1	21.2	735.7
PR10CW	6.2	0.2	35.0	32.0	33.0	clay loam	44.8	1.6	0.1	47.5	12.5	34.4	18.9	352.8
PR14CW_NUT	6.4	0.1	19.0	46.0	35.0	clay	32.0	1.8	0.2	5.5	15.3	29.1	19.1	778.4
PR17CW_NUT	5.8	0.1	13.0	62.0	25.0	heavy clay	24.0	1.4	0.1	16.9	10.0	29.6	19.9	599.2

PR15CW	6.1	0.1	19.0	52.0	29.0	clay	28.4	1.6	0.1	9.1	12.5	29.7	21.5	587.7
PR12FR	6.8	0.3	53.0	12.0	35.0	sandy loam	42.2	2.5	0.2	43.8	14.6	44.1	23.4	1694.0
PR23CW_NUT	6.4	0.2	35.0	28.0	37.0	clay loam	43.0	2.2	0.2	30.0	11.7	33.8	23.4	986.7
PR22FR_NUT	6.0	0.1	17.0	52.0	31.0	clay	25.0	2.0	0.2	28.8	14.2	25.5	18.4	625.1
PR21FR_NUT	4.9	0.1	9.0	72.0	19.0	heavy clay	26.0	1.0	0.1	12.3	8.8	24.3	16.2	384.3
PR19FR	5.1	0.3	47.0	16.0	37.0	loam	34.4	2.0	0.2	40.0	14.8	32.4	22.3	281.6

Appendix B; Yield in each plot for the three water management groups;

plot code	Water management methods	Fresh Yield in kg/ha	Dry yield in kg/ha
PR23CW_NUT	CWR	44896	8433
PR4CW	CWR	43393	6351
PR9CW	CWR	12143	3016
PR24CW	CWR	14773	3082
PR10CW	CWR	36786	6616
PR14CW_NUT	CWR	26173	5138
PR17CW_NUT	CWR	48000	8560
PR15CW	CWR	39464	6766
Average		**33203**	**5995**
standard deviation		**13857**	**2129**
PR3T	TDR	7604	1668
PR8T_NUT	TDR	41923	7627
PR5T_NUT	TDR	29167	5407
PR11T	TDR	30789	6320
PR16T_NUT	TDR	67167	23388
PR18T	TDR	13400	2379
Average		**31675**	**7798**
standard deviation		**21378**	**7974**
PR6FR_NUT	FARM	36304	6646
PR12FR	FARM	10556	1519
PR22_NUT	FARM	7708	508
PR21_NUT	FARM	7423	1529
PR19FR	FARM	42222	9006
Average		**20843**	**3841**
standard deviation		**16990**	**3755**

Appendix C; Time domain reflect meter data collection sheet for each of plot.

TDR reading data collection format;   Farmer name   --------------------   FC = 31.56 %

No	reading date	TDR in % reading within a plot/replications.					Average of TDR	Amount of water to be applied daily updated
---	-------	TDR 1	TDR 2	TDR 3	TDR 4	TDR 5	∑(TDR1-TDR5)/5	(FC-TDR)/100*D(m)
1	23/12/2015	25.70	27.50	31.00	28.00	25.00	27.44	
2	25/12/2015	28.50	31.00	33.00	31.00	29.00	30.50	
3	27/12/2015	29.30	23.40	28.50	17.50	25.60	24.86	
4	2912/2015	27.40	28.30	27.50	25.80	27.70	27.34	
----	--	--	---	----	---	---	----	--------
Up to end of irrigation for each of the 8 plots.								

Way of calculation as discussed above and the brief is below for individual plot during the time of irrigation. Let us see for one typical plot TDR irrigation recommendation; plot PR16T_NUT

The field capacity FC of plot = 31.56 %; and the permanent wilting point PWP is =22.24 %

Effective root depth of tomato = 60 cm or 0.6 m

Water holding capacity of this plot calculated as; (FC –PWP)/100* Rd

= (31.56 %- 22.24 %)/100*60cm

= 5.6 cm

The day soil moisture reading taken is 28.98 % then the amount of water to be applied would be calculated as; (FC % - TDR $_{reading}$ %) /100*Rd which equals to (31.56 -28.98)/100*60cm

= 0.86 cm or 0.0086 m depth of water required.

Area of the plot PR16T_NUT =60 m^2 then the water volume required to the plot at this day is equal to 0.0086m *60 m^2 = 0.52 m^3 =0.52*1000 =520 litter.

Allowable deficit of tomato is 50 % from this Maximum allowable deficit will be calculated as;

Water holding capacity from previous calculation, allowable deficit = 5.6 cm*50/100= 1.12 cm now irrigation interval could calculated as I = AI/MAD =0.86/1.12= 0.8 that is approximate one day gap. So the irrigator should irrigate 0.86 m or 0.086 m3 water to the plot one days later.

TDR reading at the initial stage during early 15 days after planting of tomato.

Appendix D; Climate based calculation sheet for individual plot for plot PR14CW_NUT

	FARMER NAME:				Tilahun Abebe					
PLOT AREA:	81 m2	Transplanting date		TDR reading	26.45					
	FC:	29.13	**PWP:**	19.12	**AWC:**	10.01				
Dates	**Daily ETo (mm)**	**Daily Kc**	**ETc (mm)**	**Effective Rain (mm)**	**permanent wilting point(mm)**	**Field capacity (mm)**	**soil moisture content (mm)**	**soil moisture deficit (mm)**	**depth of water recommended(mm)**	**volume in m3**
12/8/2015	3.35	0.45	1.51	0.17	114.72	174.78	158.70	16.08	16.08	1.30
12/9/2015	3.32	0.45	1.49	0.08	114.72	174.78	173.45	1.33	1.33	0.11
12/10/2015	3.43	0.45	1.54	0.03	114.72	174.78	173.36	1.42	1.42	0.11
12/11/2015	3.31	0.45	1.49	0.02	114.72	174.78	173.26	1.52	1.52	0.12
12/12/2015	3.42	0.45	1.54	0.00	114.72	174.78	173.31	1.47	1.47	0.12
12/13/2015	3.29	0.45	1.48	0.00	114.72	174.78	173.24	1.54	1.54	0.12
12/14/2015	3.39	0.45	1.52	0.00	114.72	174.78	173.30	1.48	1.48	0.12
12/15/2015	3.43	0.45	1.54	0.00	114.72	174.78	173.26	1.52	1.52	0.12
12/16/2015	3.33	0.45	1.50	0.00	114.72	174.78	173.24	1.54	1.54	0.12
12/17/2015	3.38	0.45	1.52	0.00	114.72	174.78	173.28	1.50	1.50	0.12
12/18/2015	3.27	0.45	1.47	0.00	114.72	174.78	173.26	1.52	1.52	0.12
12/19/2015	3.36	0.45	1.51	0.00	114.72	174.78	173.31	1.47	1.47	0.12
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
3/29/2016	5.06	0.80	4.05	0.00	114.72	174.78	171.22	3.56	3.56	0.29
3/30/2016	5.14	0.80	4.11	0.00	114.72	174.78	170.73	4.05	4.05	0.33
4/1/2016	5.13	0.80	4.10	0.00	114.72	174.78	170.67	4.11	4.11	0.33
4/2/2016	4.25	0.80	3.40	0.00	114.72	174.78	170.68	4.10	4.10	0.33
4/3/2016	4.29	0.80	3.43	0.00	114.72	174.78	171.38	3.40	3.40	0.28
4/4/2016	4.27	0.80	3.41	0.00	114.72	174.78	171.35	3.43	3.43	0.28
4/5/2016	4.23	0.80	3.39	0.00	114.72	174.78	171.37	3.41	3.41	0.28

Appendix E: effect of Land use history of different plots in on crop performance.

Tomato grown at plot of different land use history with the same growth stage.

The parallel photos those sated side by side are differ really come from land use history difference keeping that more other factors are similar for the latest cropping season but the determinant factor is long fertilization and management history of the land. NB side photos are at the same growth stage.

Appendix F; Discharge calibration for the pulley with tanker and rising bucket.

Farmer code	well depth	Technology calibrated	Repetition	Bucket volume in litter	Bucket volume in m3	Time started	Time stopped	Time total in minute	Discharge m3/minute	Discharge m3/second
PR_3	11	2	1	150	0.15	8:30	9:00	30	0.005	0.000083
			1		0.15	10:30	g	20	0.0075	0.000125
PR8T_NUT	3	2	1	200	0.2	10:45	11:00	15	0.013	0.00022
			1		0.2	10:40	11:00	20	0.01	0.00017
			1		0.2	10:45	11:00	15	0,013	0.00022
PR5T_NUT	17	2	1	200	0.15	10:30	10:55	20	0.0075	0.000125
			1		0.15	11:00	11:15	15	0.01	0.00017
PR6FR_NUT	20	2	1	200	0.2	9:30	9:45	15	0.013	0.00022
			1		0.2	9:30	10:00	30	0.0067	0.00011
			1		0.2	10:00	10:20	20	0.01	0.00016
PR7T	10	2	1	150	0.15	10:00	10:40	40	0.00375	0.000625
			1		0.15	10:00	10:20	20	0.0075	0.000125
PR11T	10	2	1	150	0.15	10:30	10:50	20	0.0075	0.000125
			1		0.15	10:40	11:00	20	0.0075	0.000125
PR16T_NUT	17	2	1	200	0.2	11:00	11:15	15	0.013	0.00022
PR18T	15	2	1	200	0.2	10:30	10:45	15	0.013	0.00022
	.									
PR4CW	9	2	1	150	0.15	11:00	11:15	15	0.01	0.00017
			1		0.15	10:40	11:00	20	0.0075	0.000125
			1		0.15	10:40	11:10	30	0.005	0.000083
PR9CW	15	2	1	150	0.15	10:30	11:00	30	0.005	0.000083
			1		0.15	10:30	10:50	20	0.0075	0.000125
PR24CW	10	2	1	150	0.15	10:40	10:55	15	0.01	0.00016

			1		0.15	10:50	11:10	20	0.0075	0.000125
PR10CW	4	2	1	150	0.15	11:00	11:25	25	0.006	0.0001
			1		0.15	10:50	11:10	20	0.0075	0.000125
			1		0.15	10:40	11:00	20	0.0075	0.000125
PR14CW_NUT	16	2	1	200	0.15	11:00	11:15	15	0.01	0.00017
	17		1		0.15	11:00	11:20	20	0.0075	0.000125
PR17CW_NUT	16	2	1	200	0.2	11:00	11:15	15	0.013	0.00022
			1	.	0.2	10:40	11:00	20	0.01	0.00017
PR15CW	17	2	1	200	0.2	10:40	11:00	20	0.01	0.00016
PR12FR	15	2	1	150	0.15	11:20	11:35	15	0.01	0.00016
PR23CW_NUT	17	2	1	.	0.2	10:40	11:00	20	0.01	0.00016
PR22_NUT	17	2	1	200	0.2	10:30	10:20	20	0.01	0.00016
PR21_NUT	15	2	1	200	0.2	10:40	11:00	20	0.01	0.00016
PR19FR	16	2	1	150	0.15	11:00	11:20	20	0.0075	0.000125
			1		0.15	11:00	11:20	20	0.0075	0.000125

Appendix G; crop water used per each irrigation plot

plot code	Water management methods	Area in ha	IRR(mm)
PR23CW_NUT	CWR	0.010	461
PR4CW	CWR	0.006	591
PR9CW	CWR	0.003	522
PR24CW	CWR	0.004	523
PR10CW	CWR	0.006	607
PR14CW_NUT	CWR	0.008	474
PR17CW_NUT	CWR	0.006	492
PR15CW	CWR	0.006	489
PR3T	TDR	0.005	603
PR8T_NUT	TDR	0.008	545
PR5T_NUT	TDR	0.004	655

PR11T	TDR	0.008	583
PR16T_NUT	TDR	0.006	571
lPR18T	TDR	0.005	566
PR6FR_NUT	FARM	0.005	796
PR12FR	FARM	0.004	618
PR22_NUT	FARM	0.005	419
PR21_NUT	FARM	0.005	511
PR19FR	FARM	0.004	362

Comparison of Water consumption in each development stage of the crop in WM'S

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
initial stage	3	334.11	111.37	263.74
development stage	3	432.26	144.08	708.67
Mid stage	3	409	136.33	1760.3
maturity stage	3	468	156	973

ANOVA

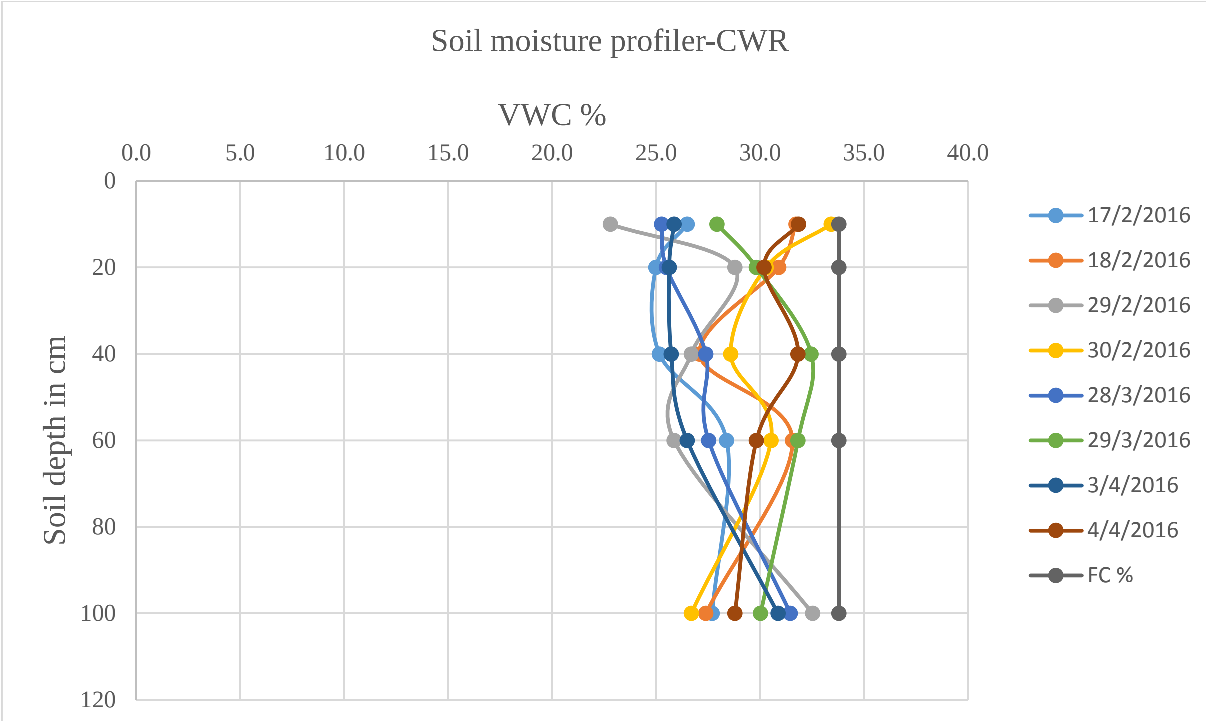
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3205.284	3	1068.428	1.153266	0.385377	4.066181
Within Groups	7411.496	8	926.4369			
Total	10616.78	11				

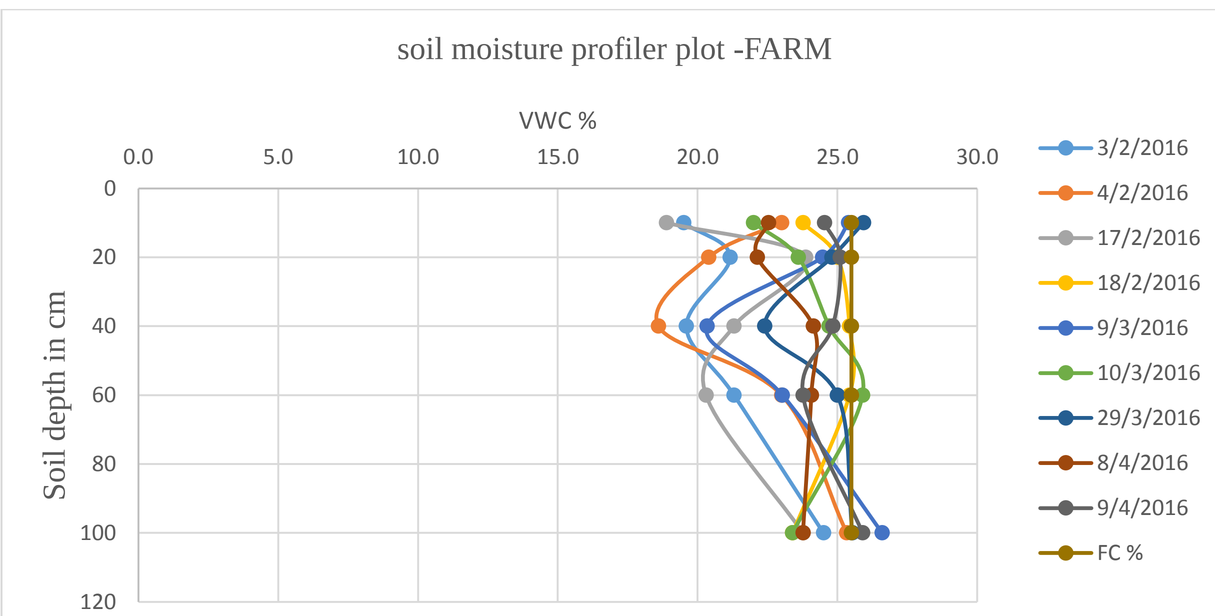
Appendix H; soil moisture reading through PR2 Moisture profiler Delta T-device.

plot coded by PR8T_NUT soil moisture measurement by moisture profiler					
Date reading	AvSMP10	AvSMP20	AvSMP40	AvSMP60	AvSMP100
3/2/2016	26.8	19.3	24.8	23.4	37.4
4/2/2016	25.7	25.9	28.4	24.7	34.8
7/2/2016	24.4	19.3	18.3	19.1	36.1
8/2/2016	24.1	23.9	26.6	26.6	30.2
11/2/2016	17.6	17.2	21.5	18.7	31.4
12/2/2016	23.5	27.2	24.3	23.7	30.3
17/2/2016	18.2	14.6	25.8	23.1	27.1

18/2/2016	25.9	27.0	27.5	23.0	26.0
21/2/2016	20.9	24.6	23.4	25.5	28.2
22/2/2016	27.5	27.6	25.4	25.6	26.8
25/2/2016	19.1	25.9	22.5	24.8	25.9
26/2/2016	25.8	27.9	24.8	25.7	25.5
29/2/2016	15.4	22.4	20.8	26.1	27.6
30/2/2016	26.2	26.8	25.2	27.2	28.2
5/3/2016	17.1	24.7	22.0	26.3	28.0
6/3/2016	25.5	26.5	25.0	27.5	28.8
9/3/2016	21.3	14.8	25.2	21.3	26.2
10/3/2016	26.5	25.1	26.9	26.2	27.5
13/3/2016	15.7	22.5	21.2	23.4	24.4
14/3/2016	25.2	25.9	26.2	26.8	26.8
17/3/2016	21.3	24.3	24.7	24.1	24.4
18/3/2016	25.8	26.5	26.8	27.2	26.9
23/3/2016	20.6	20.8	20.1	21.7	21.6
24/3/2016	25.5	26.9	26.5	25.5	25.5
28/3/2016	20.9	21.0	22.7	23.3	23.1
30/3/2016	25.5	26.2	26.0	26.2	26.8
3/4/2016	23.4	18.8	21.6	24.2	24.2
4/4/2016	26.8	26.2	26.2	26.2	26.2
8/4/2016	20.1	23.1	22.7	21.6	23.7
9/5/2016	25.5	25.9	26.5	25.8	25.5

Appendix I; Sample plots from CWR and FARM soil moisture profiling group





Appendix J; crop water used during the irrigation period (ETc -2016 irrigation season)

plot code	water management methods	Area in ha	Total water used by the plot in m^3	Total water used in m^3/ha	ETC (mm)
PR23CW_NUT	CWR	0.0096	53	5546	428
PR4CW	CWR	0.0056	38	6846	413
PR9CW	CWR	0.0028	17	6163	384
PR24CW	CWR	0.0044	27	6169	433
PR10CW	CWR	0.0056	39	7006	390
PR14CW_NUT	CWR	0.0081	46	5678	441
PR17CW_NUT	CWR	0.0060	35	5862	406
PR15CW	CWR	0.0056	33	5827	428
average		0.0060	**36**	**6137**	**415**
standard deviation		0.002	**10**	**499**	**20**
PR3T	TDR	0.005	33	6973	411
PR8T_NUT	TDR	0.008	50	6391	373
PR5T_NUT	TDR	0.004	27	7488	391
PR11T	TDR	0.008	51	6772	
PR16T_NUT	TDR	0.006	40	6649	429
PR18T	TDR	0.005	33	6602	413
average		0.006	**39**	**6812**	**404**
standard deviation		0.002	**10**	**383**	**19**
PR6FR_NUT	FARM	0.0046	41	8896	413
PR12FR	FARM	0.0036	26	7115	338
PR22_NUT	FARM	0.0048	25	5128	407
PR21_NUT	FARM	0.0049	29	6048	335
PR19FR	FARM	0.0036	16	4558	363
average		0.0043	**27**	**6349**	**371**
standard deviation		0.0006	**9**	**1722**	**37**

Appendix K; Water productivity of the three group water managements by both fresh and dry yield

Plot code	Area in ha	Moisture content of tomato fruit	Dry Yield in kg	fresh Yield in kg	Actual irrigation water used(in mm)	Rain fall in mm	Total water consumed by the plot in m^3	water productivity in kg/m3 by dry yield	water productivity in kg/m3 by fresh yield
climate based irrigators	0.0096	81	81	350	461	94	53	1.5	8.1
	0.0056	85	36	207	591	94	38	0.9	6.3
	0.0028	75	8	26	522	94	17	0.5	2.0
	0.0044	79	14	51	523	94	27	0.5	2.4
	0.0056	82	37	169	607	94	39	0.9	5.3
	0.0081	80	42	170	474	94	46	0.9	4.6
	0.0060	82	51	237	492	94	35	1.5	8.2
	0.0056	83	38	183	489	94	33	1.2	6.8
	0.005	78	8	28	603	94	33	0.2	1.1
TDR groups	0.008	82	59	268	545	94	50	1.2	6.6
	0.004	81	19	86	655	94	27	0.7	3.9
	0.008	79	48	186	583	94	51	0.9	4.5
	0.006	65	140	263	571	94	40	3.5	10.1
	0.005	82	12	55	566	94	33	0.4	2.0
Farmers practice	0.0046	82	31	136	796	94	41	0.7	4.1
	0.0036	86	5	33	618	94	26	0.2	1.5
	0.0048	93	2	35	419	94	25	0.1	1.5
	0.0049	79	7	29	511	94	29	0.3	1.2
	0.0036	79	32	120	362	94	16	2.0	9.3

Appendix L; average Nutrient balance comparison in each plot of the three water management strategies.

Farmer code	Irrigation method	Depletion of N balance (kg)/ha per season	Depletion balance of p (kg)/**ha** per season	Depletion balance of K **(kg)/ha** per season
PR3T	TDR	-19.2	-0.07	-277.2
PR8T_NUT	TDR	-134.0	-0.1	-420.7
PR5T_NUT	TDR	-302.3	-0.7	-360.7
PR6FR_NUT	FARM	-98.3	-0.12	-262.8
PR11T	TDR	-296.5	-1.1	-198.4
PR16T_NUT	TDR	-264.8	-2.6	-604.7
PR18T	TDR	77.2	0.2	-111.4
PR4CW	CWR	-423.2	-2.0	-397.3
PR24CW	CWR	23.1	-0.06	-157.8
PR10CW	CWR	-170.5	-0.07	-106.4
PR14CW_NUT	CWR	-188.1	-0.27	-320.6
PR17CW_NUT	CWR	-5.8	-0.26	-482.4
PR15CW	CWR	-120.6	-1.26	-374.8
PR12FR	FARM	163.2	0.4	5.4
PR23CW_NUT	CWR	-236.6	-1.052	-354.4
PR22_NUT	FARM	104.8	0.07	-54.5
PR21_NUT	FARM	160.9	0.5	-56.2
PR19FR	FARM	-236.7	-1.6	-117.9

Partial NPK balance in the three water management strategies; Comparison of Partial NPK in depletion balance in mg/ha.

Appendix M; average plant height of tomato days after planting in each development stage.

Water management methods of the three groups	Days after planting	plant height in m for each plot							
GRP^T		PR3T	PR8T_NUT	PR5T_NUT	PR7T	PR11T	PR16T_NUT	PR18T	Average
	25	0.26	0.26	0.27	0.24	0.51	0.52	0.33	0.34
	55	0.57	0.65	0.48	0.55	0.83	0.72	0.55	0.62
	95	0.64	0.84	0.64	0.73	1.14	0.89	0.69	0.80
	125	0.55	0.68	0.55	0.68	0.87	0.76	0.56	0.66
GRP^{Cw}		PR23CW_NUT	PR24CW	PR10CW	PR14CW_NUT	PR17CW_NUT	PR15CW	PR4CW	Average
	25	0.30	0.23	0.24	0.35	0.28	0.26	0.24	0.27
	55	0.72	0.61	0.55	0.62	0.74	0.66	0.64	0.65
	95	0.80	0.69	0.98	1.10	0.67	0.68	0.73	0.81
	125	0.75	0.58	0.79	0.80	0.54	0.59	0.59	0.66
		PR22FR_NUT	PR21FR_NUT	PR19FR	PR12FR	PR6FR_NUT			Average
	25	0.22	0.20	0.19	0.29	0.25			0.23
	55	0.37	0.34	0.41	0.45	0.42			0.40
	95	0.67	0.71	0.74	1.03	0.63			0.75

		12 5	0.46	0.65	0.63	0.55	0.53			0.56

Appendix N; Tomato Harvest data sheet at Robit

Project + site of collection ……………… Farmer Name …………

Crop … …… Date ………………

Plot Code: ………………

Treatments (Specify the treatment)	Sample plant	Number of fruits /plant						Total number of fruits/plant	Average length of the fruit* (cm)	Average fruit diameter* (cm)
		Marketable fruits/plant			Un marketable fruits/plant					
		Bed 1	Bed 2	Bed 3	Bed 1	Bed 2	Bed 3			
	Plant 1									
	Plant 2									
	Plant 3									
		Bed 1	Bed 2	Bed 3	Bed 1	Bed 2	Bed 3			
	Plant 1									
	Plant 2									
	Plant 3									
		Bed 1	Bed 2	Bed 3	Bed 1	Bed 2	Bed 3			
	Plant 1									
	Plant 2									
	Plant 3									

* Average is only measured for the marketable fruits. The average is based on 6 randomly taken fruits. Specify if the treatment is WFD, control, or any other treatment

Treatments (Specify the treatment)	**Sample beds**	**Number of fruits /bed**		**Total number of plants/bed**	**Total number of fruit/bed**
		Marketable fruit/bed	**Un marketable fruit/bed**		
	Bed 1				
	Bed 2				

	Bed 3				
	Bed 1				
	Bed 2				
	Bed 3				
	Bed 1				
	Bed 2				
	Bed 3				

* Specify if the treatment is WFD, control, or any other treatment

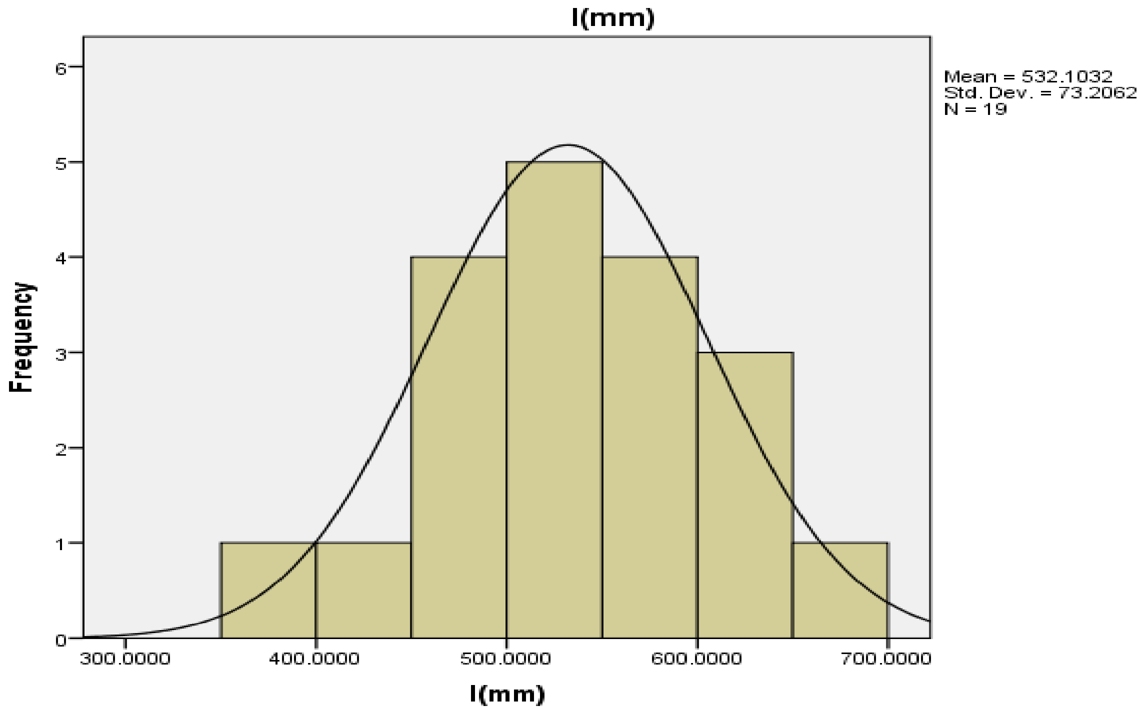
Farmers Preference	
Farmer choice	**Reason**

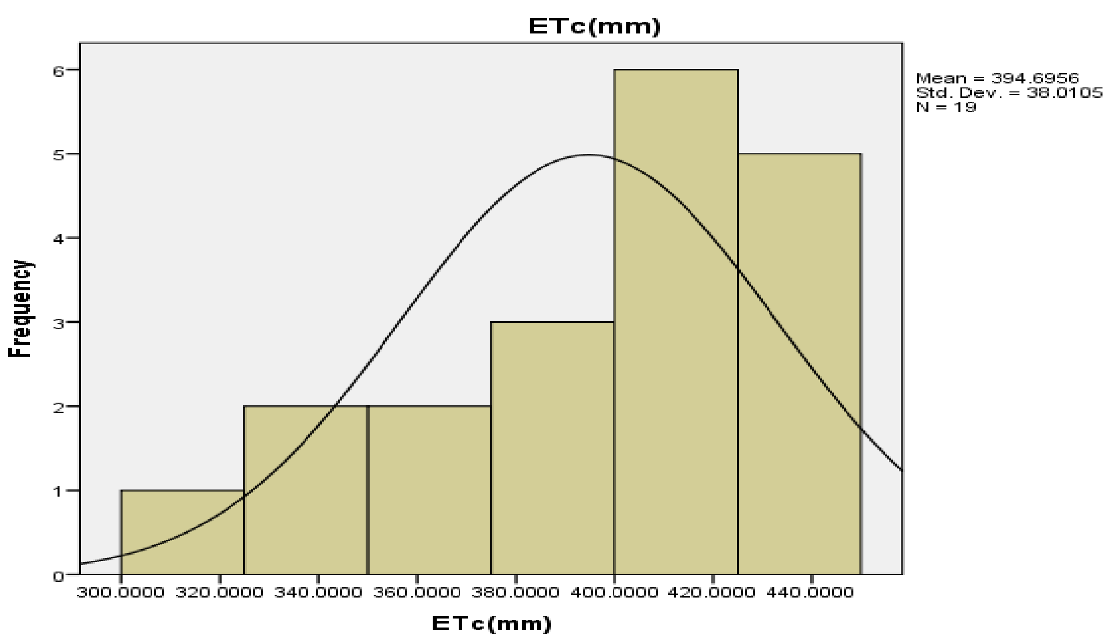
Let the farmer choose if he likes the fruit better from the control or the TDR plot, but don't let him know which fruit comes from which experimental plot (i.e. control plot or TDR plot). Write **"1"** if the farmer chooses the sample taken from the **WFD plot** and write **"0"** if the farmer chooses the sample taken from the **Control plot**. Also, specify why he made this choice.

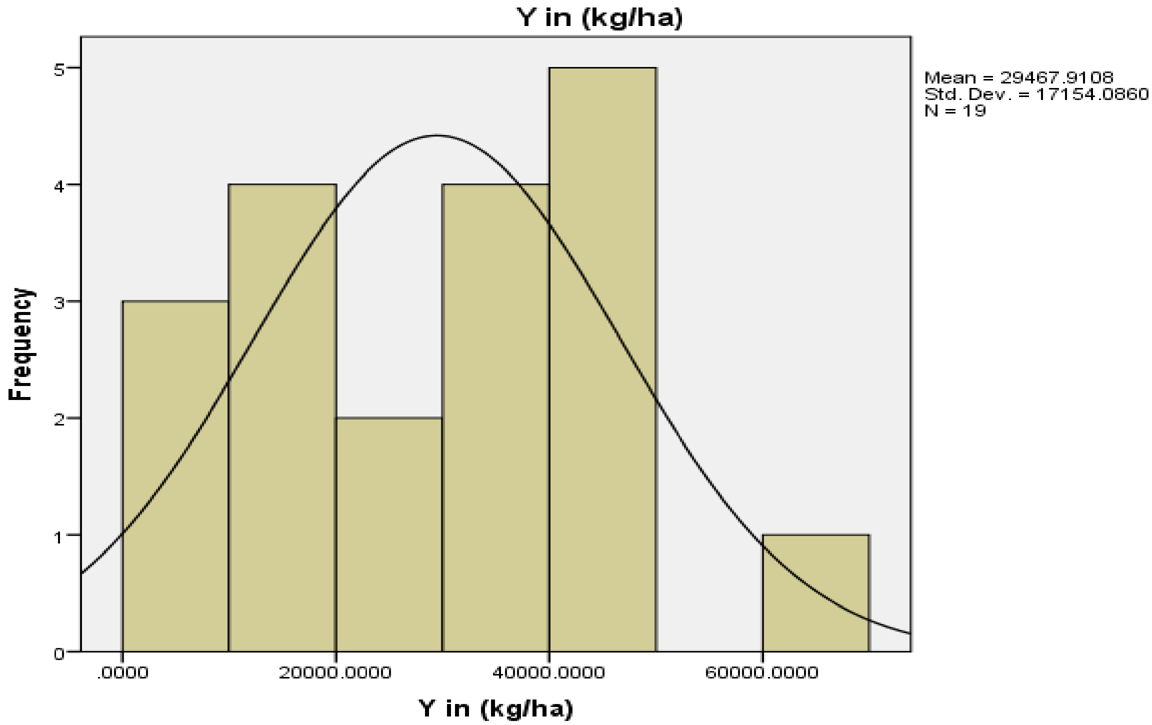
Treatments (Specify the treatment)	**Harvest**	**Date**	**Harvested yield (Kg/bed)**					
			Bed 1		**Bed 2**		**Bed 3**	
			Marketable	**Unmarketable**	**Marketable**	**Unmarketable**	**Marketable**	**Unmarketable**
	Harvest 1							
	Harvest 2							
	Harvest 3							
	Harvest 4							
	Harvest 5							
	Harvest 6							
	Harvest 7							
	Harvest 8							
	Harvest 9							
	Harvest 10							

SPSS 20 analysis outputs

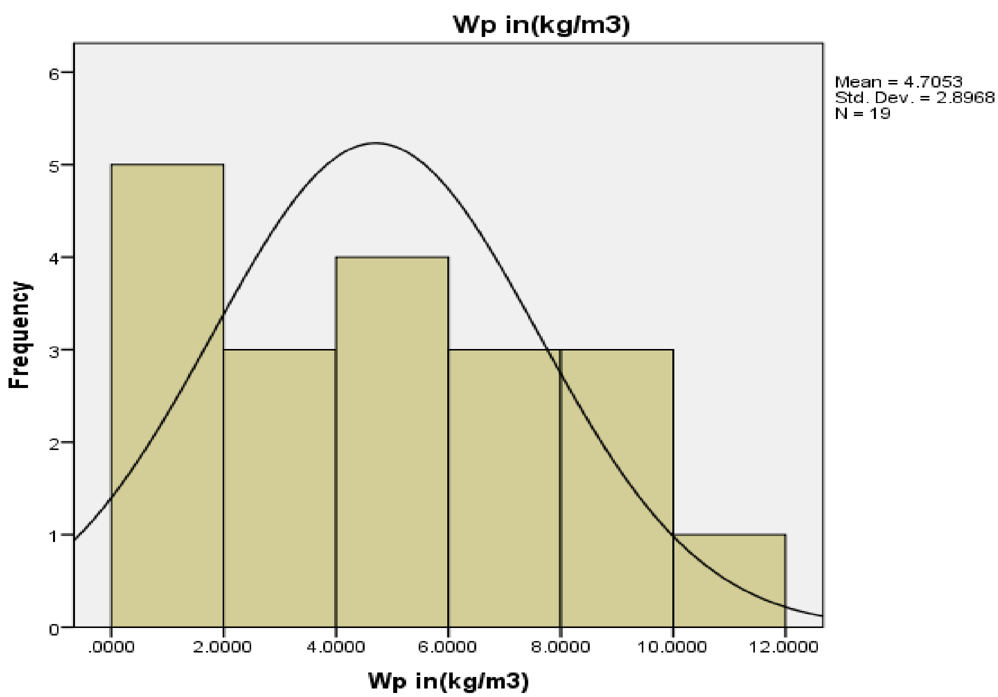
Appendix O; Normal distribution plot of irrigation I(mm), ETc-2016 (mm) , yeild(kg/ha) ,WP(kg/m3),WUE (kg/m3)



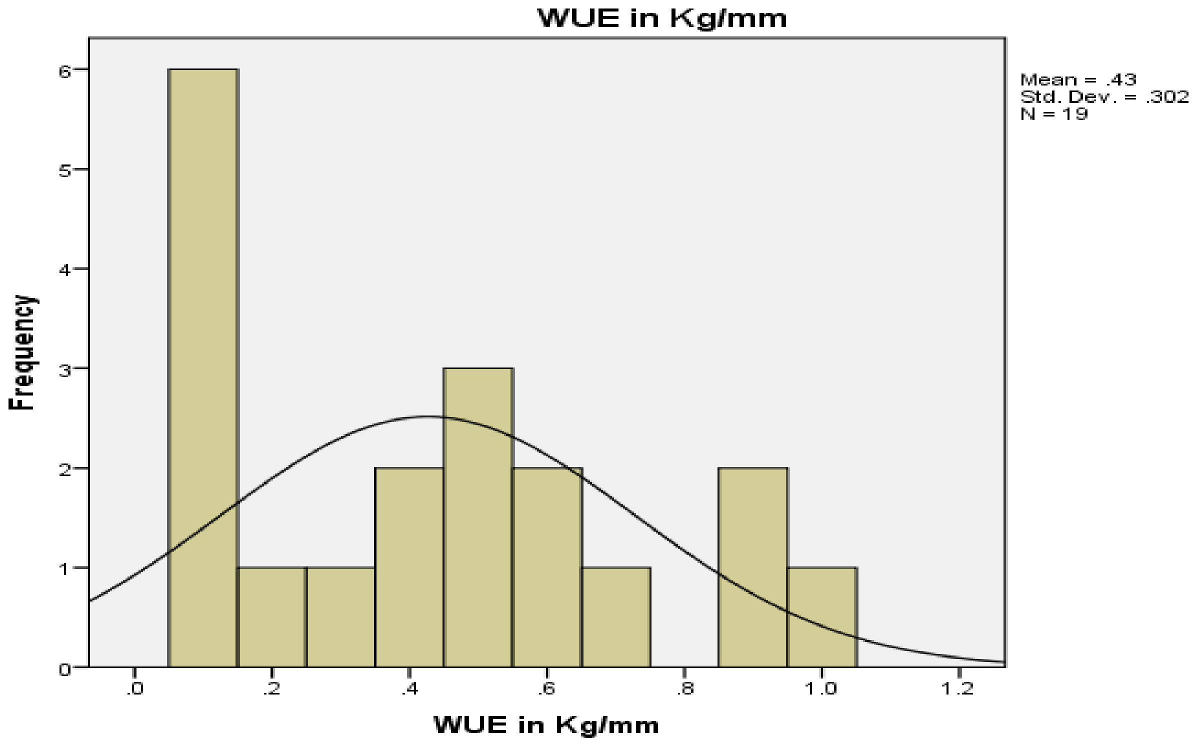




Yield normality check for the whole plots production



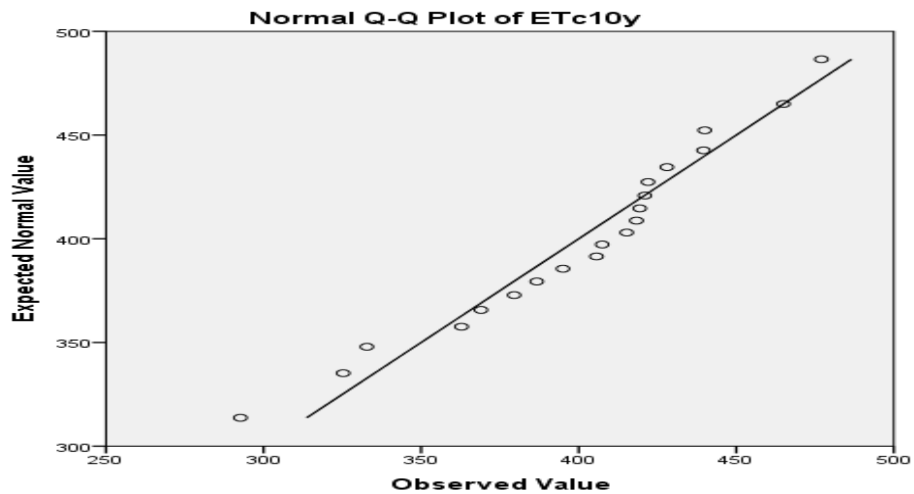
Normal distribution of water productivity

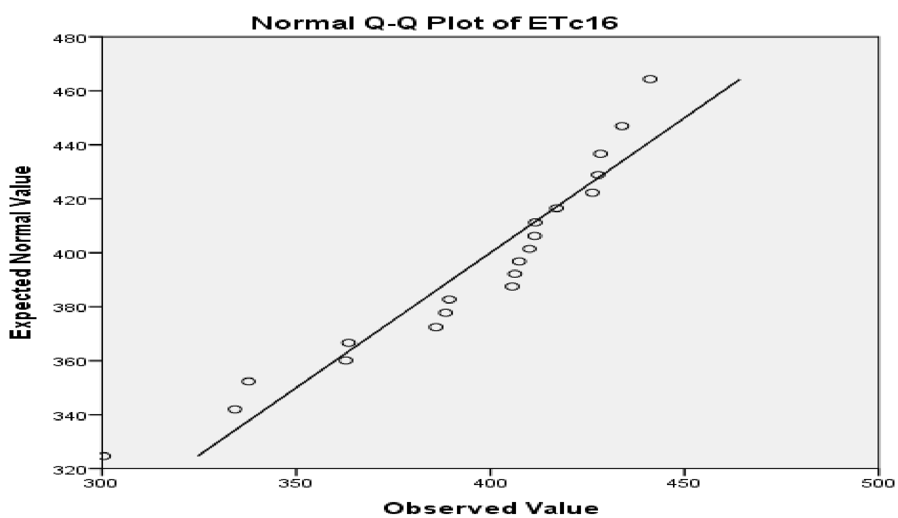


Normality check for the parameters of the three water management's methods

Appendix P; normality plot and comparison between the 10 years based ETc computed value and the ETc value of 2016 (irrigation period).

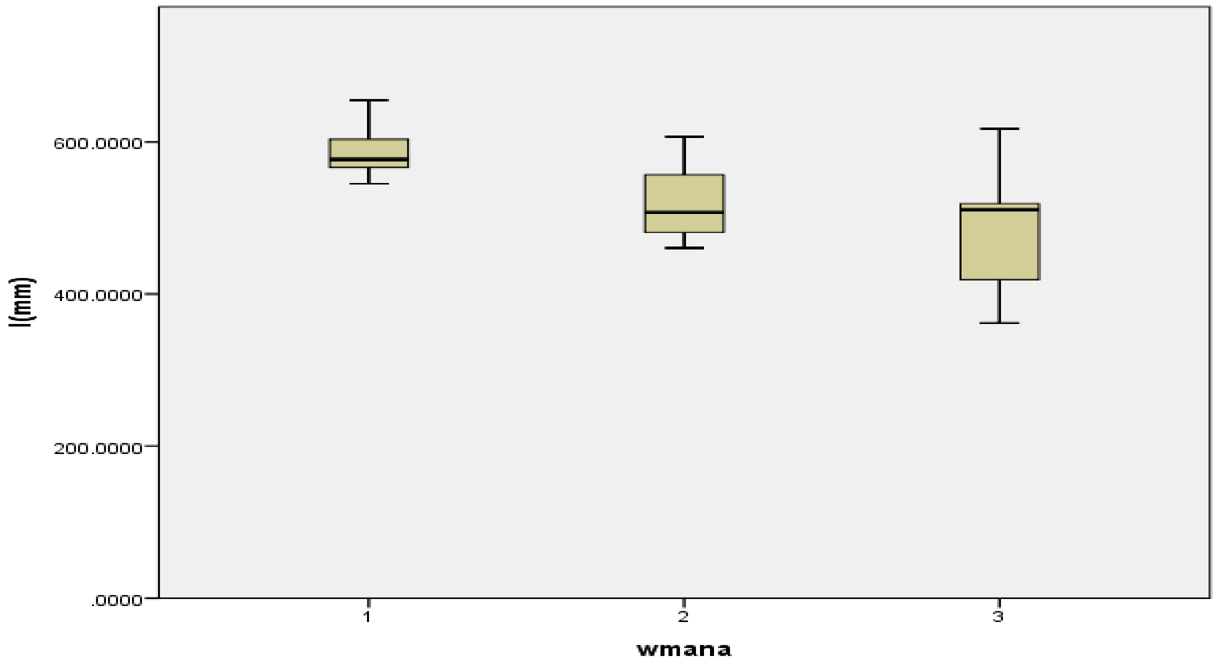
Statistics			
		ETc-2016	ETc10 years
N	Valid	20	20
	Missing	0	0
Mean		394.5	400.1
Median		406.8	411.3
Std. Deviation		37.4	46.3
Minimum		300.4	292.7
Maximum		441.2	477.0



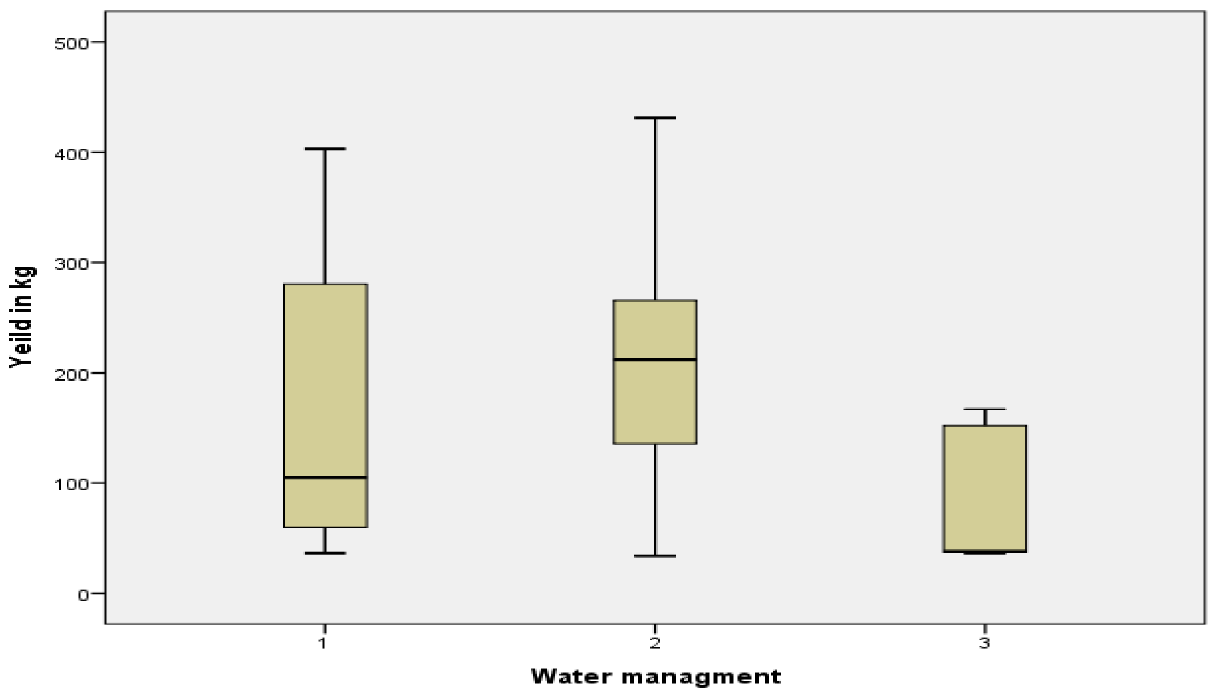


Appendix Q; box plot comparison of irrigation, water productivity, yield, water use efficiency & ETc-2016.

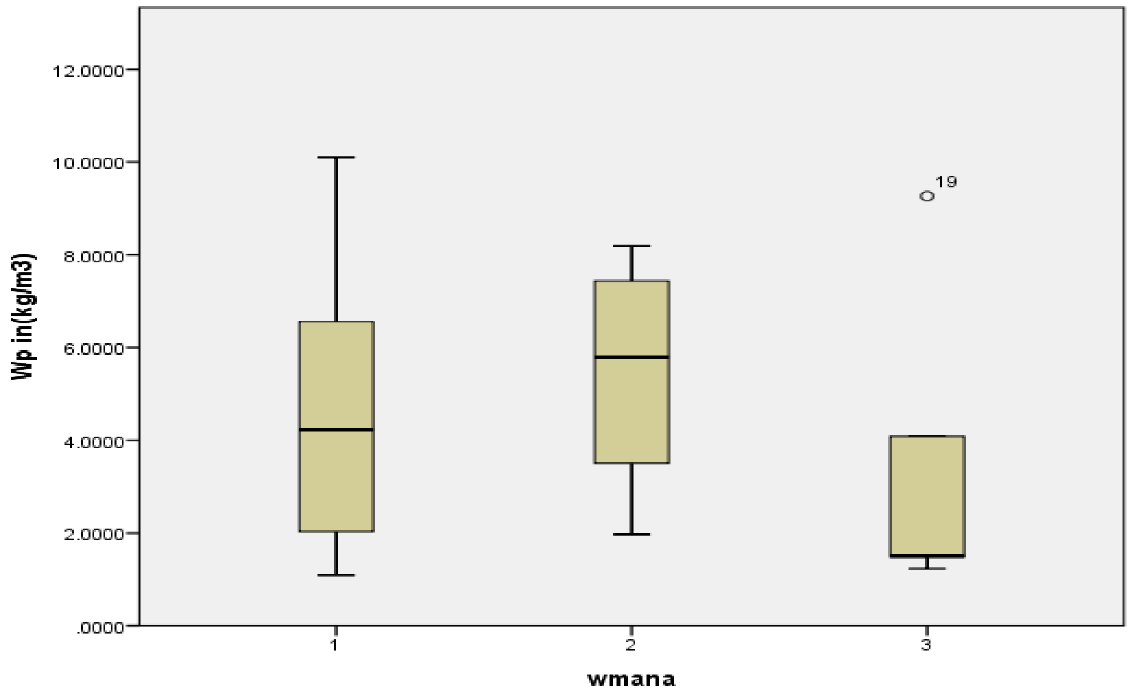
Irrigation of water management’s comparison box plot (WM=water management’s)



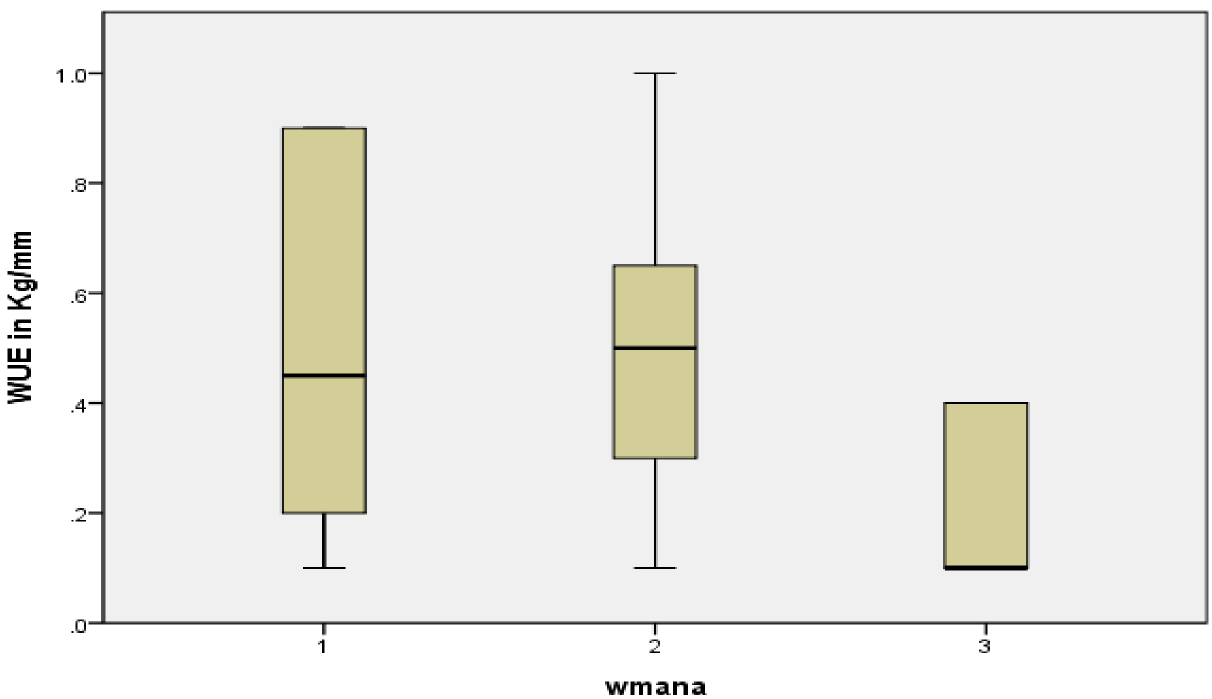
Yield comparison box plot of water managements (WM = water management's)



Comparison box plot of water management's in terms of water productivity (WM = water management's) [1, 2, 3] for mentioned WM (water management) is TDR, CWR and FARM practice respectively.



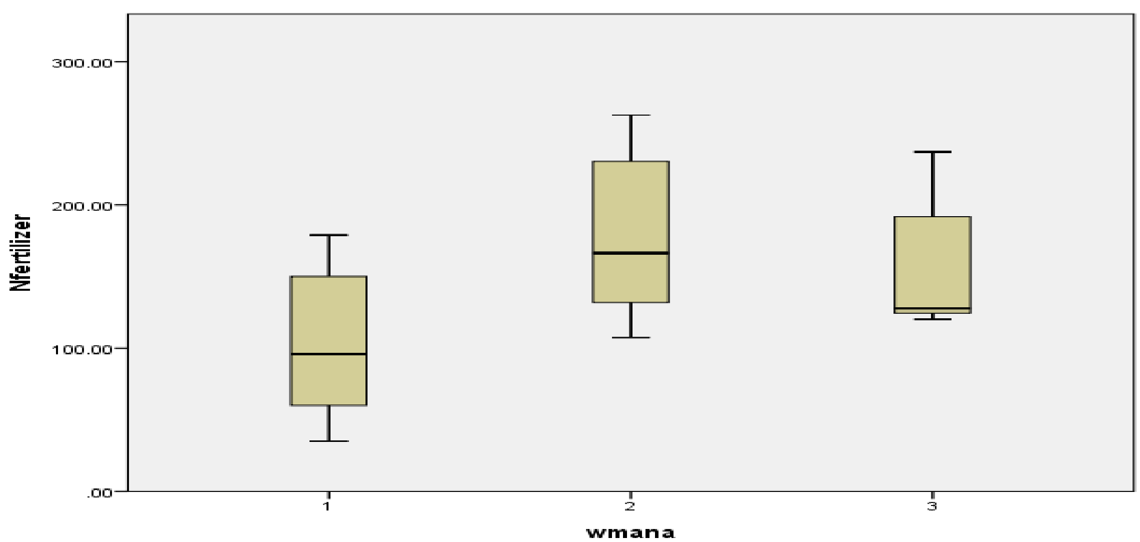
Water use efficiency of the water management groups (WM = water management's)

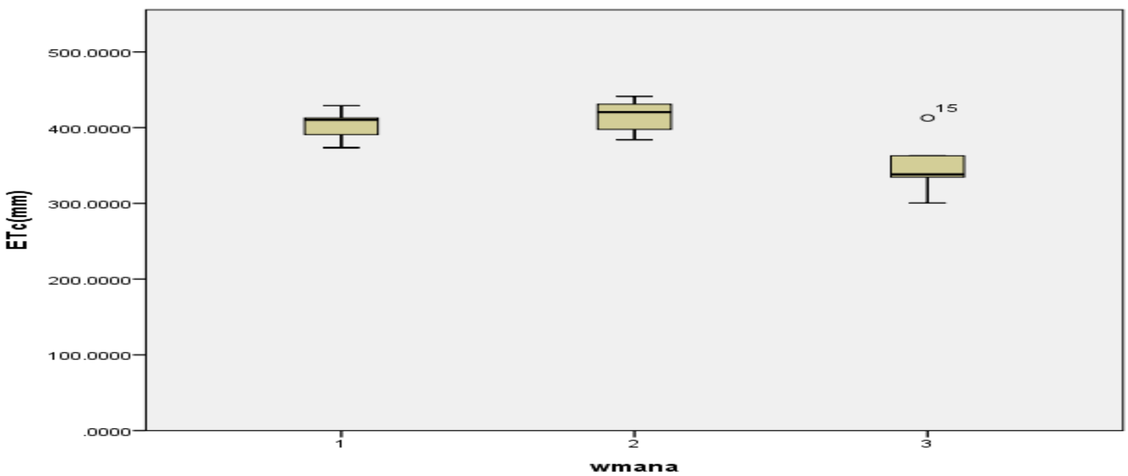


Appendix R; comparison of Fertilizer and ETc-2016 among water management's

Tests of Between-Subjects Effects					
Dependent Variable: N - fertilizer					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	20455.5[a]	2	10227.8	3.3	.065
Intercept	396125.5	1	396125.5	125.9	.000
Water management's	20455.5	2	10227.8	3.3	.065
Error	50312.5	16	3144.5		
Total	496619.6	19			
Corrected Total	70768.0	18			
a. R Squared = .289 (Adjusted R Squared = .200)					

Fertilizer comparison box plot of each water management's.





Normality check through Q-Q Normality test for various parameters

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	water management method	1.89	19	.809	.186
	Yield in kg	164.97	19	129.6	29.8
Pair 2	Yield in kg	164.97	19	129.6	29.8
	Water consumption in mm	661.58	19	129.2	29.6
Pair 3	water management method	1.9	19	0.8	0.18
	Water consumption in mm	661.6	19	129.2	29.6

Paired Samples Correlations				
		N	Correlation	Sig.
Pair 1	water management method & Yield in kg	19	-0.247	0.309
Pair 2	Yield in kg & Water consumption in mm	19	-0.341	0.153
Pair 3	water management method & Water consumption in mm	19	-0.083	0.736

Appendix S: ANOVA single factor analysis comparison of three irrigation treatments.

CWR	TDR	FARM
462	601	796
385	529	618
492	645	419
430	423	511
426	535	362
464	613	-
403	-	-

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
CWR	7	3060.823	437.2604	1394.52
TDR	6	3346.654	557.7757	6399.384
FARM	5	2704.706	540.9412	29665.49

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	55263.75	2	27631.88	2.606355	0.106783	3.68232
Within Groups	159026	15	10601.73			
Total	214289.7	17				

Appendix T: ANOVA: single factor for the comparative analysis between cropwat, manual computation and field actual applied irrigation.

plot code	Cropwat automatic computed (mm)	Recommended irrigation water used in mm	Actual irrigation water used(in mm)
PR14CW_NUT	502	426	474
PR23CW_NUT	486	422	461

PR4CW	511	462	591
PR17CW_NUT	512	464	492
PR15CW	498	403	489
PR24CW	511	492	523
PR10CW	505	430	607
PR9CW	483	385	522

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
CROPWAT	8	4008	501	128
Recommended	8	3483.03	435.4	1223.626
Actual applied	8	4158.174	519.7	2844.425

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	31415.17	2	15707.58	11.23026	0.000482	3.4668
Within Groups	29372.36	21	1398.684			
Total	60787.52	23				

Anova: Single Factor

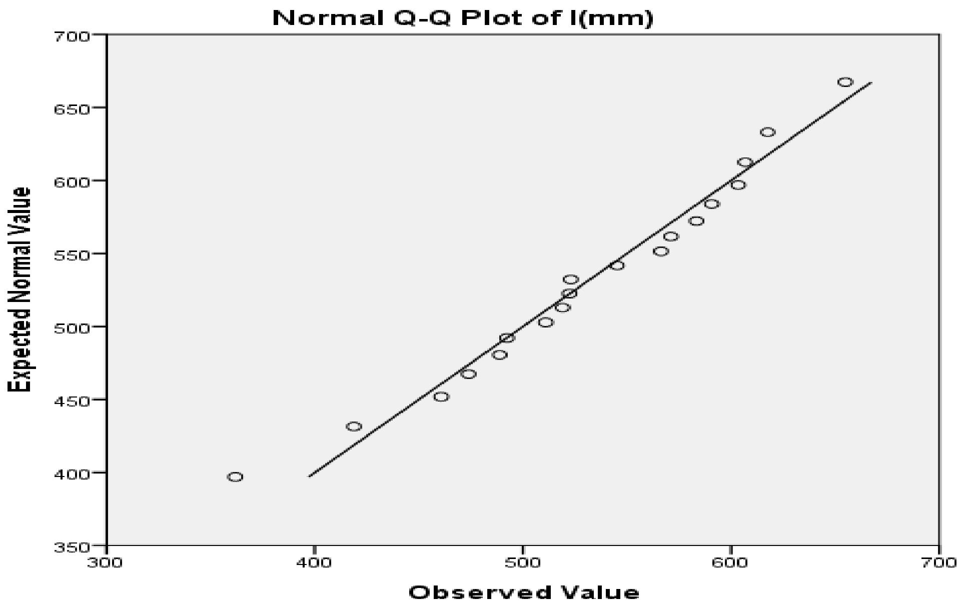
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
ETc-water balance method	3	1941	647	4579
ETc-Climate based	3	1167.233	389.0778	1534.085

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	99785.81	1	99785.81	32.64663	0.004641	7.708647
Within Groups	12226.17	4	3056.542			
Total	112012	5				

Appendix U ;Parameters Q-Q normality test plots of irrigation ,10 years ETc ,2016 G.C ETc, yield ,water productivity , water use efficiency and fertilizer.



Normality Q-Q test for 10 years historical weather data based ETc value.

Appendix V: The ten years ETc calculated and irrigation season (November to march -2016 ETc) comparison

Irrigation method	ETc10y's	I(mm)	R(mm)	ETc 16(mm)	Y in (kg/ha)	WP (kg/m3)	WUE in Kg/mm
CWR	439	461	94	428	44896	8	1.0
CWR	405	591	94	413	43393	6	0.6
CWR	386	522	94	384	12143	2	0.1
CWR	442	523	94	433	14773	2	0.1
CWR	388	607	94	390	36786	5	0.5
CWR	402	474	94	406	26173	5	0.5
CWR	445	492	94	441	48000	8	0.7
CWR	433	489	94	428	39464	7	0.5
TDR	419	603	94	411	7604	1	0.1
TDR	380	545	94	373	41923	7	0.9
TDR	372	655	94	391	29167	4	0.3
TDR	406	583	94	410	30789	5	0.6
TDR	440	571	94	429	67167	10	0.9
TDR	415	566	94	413	13400	2	0.2
FARM	418	519	94	413	36304	4	0.4

FARM	315	618	94	338	10556	1	0.1
FARM	293	419	94	300	7708	2	0.1
FARM	333	511	94	335	7423	1	0.1
FARM	363	362	94	363	42222	9	0.4

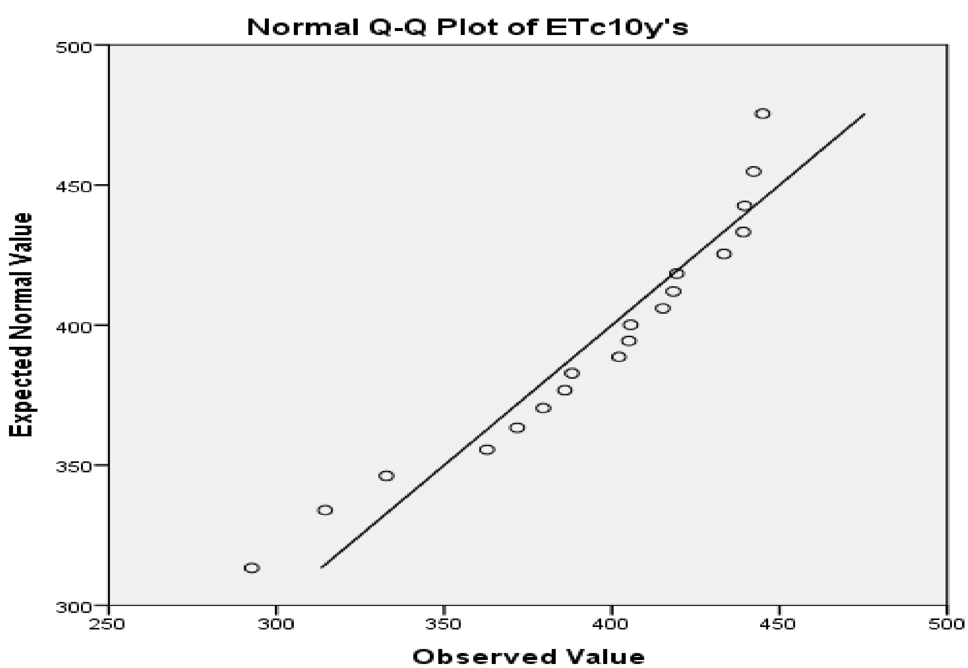
Anova: Single Factor

SUMMARY

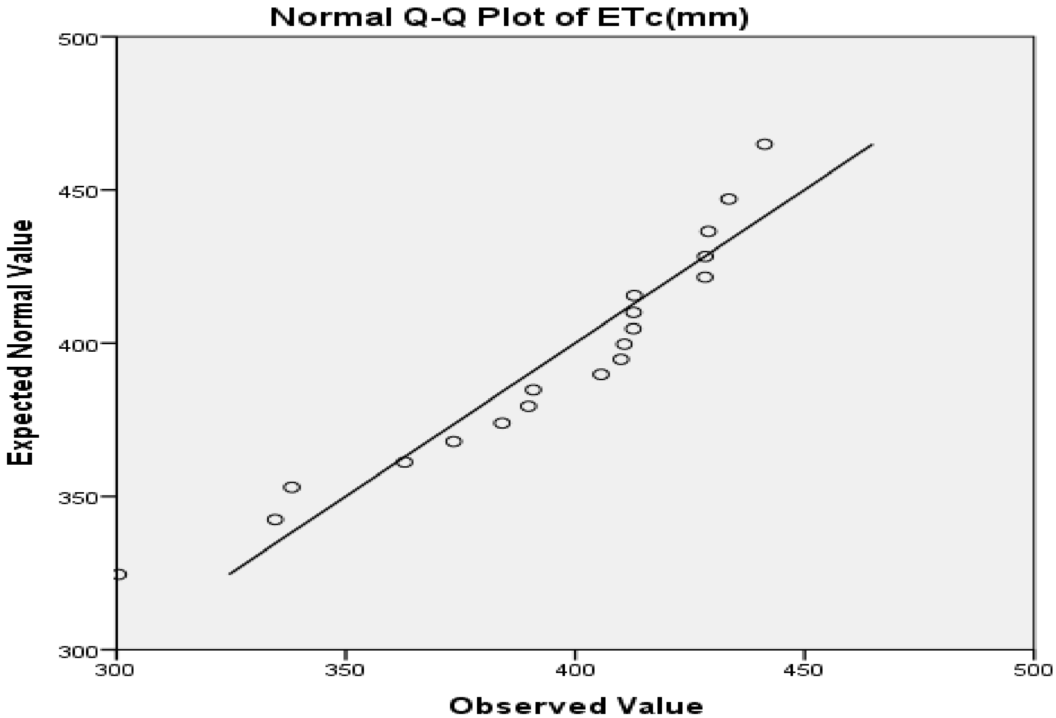
Groups	*Count*	*Sum*	*Average*	*Variance*
ETc10y's	19	7493.577	394.3988	1929.328
ETc(mm)-2016	19	7499.217	394.6956	1444.798

ANOVA

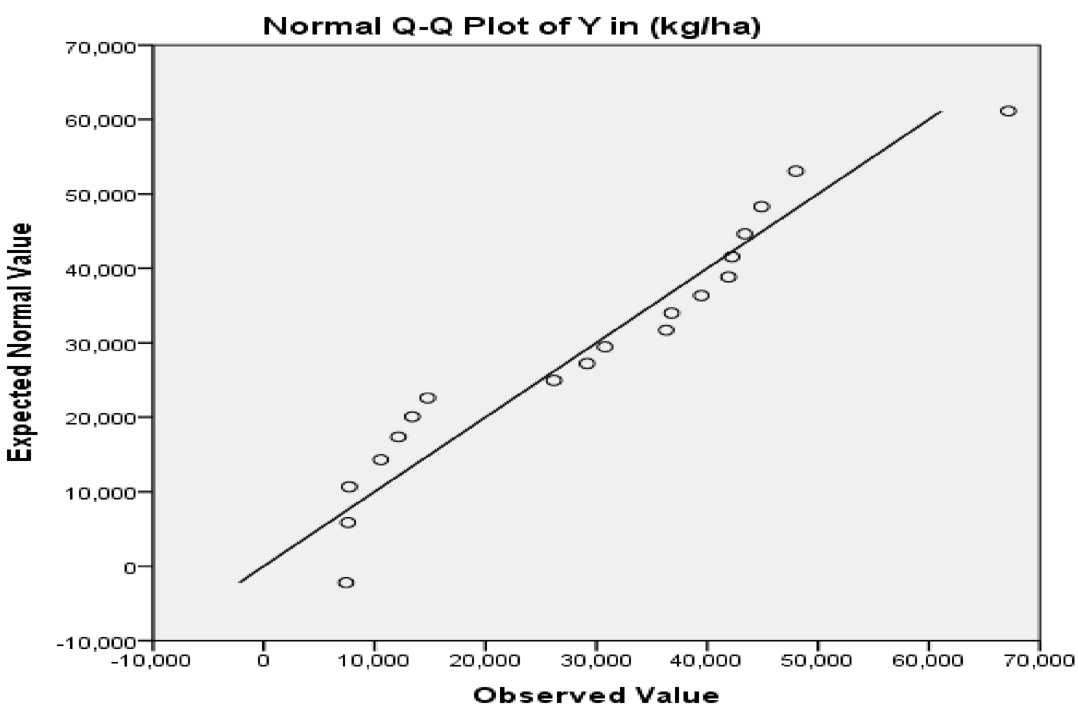
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.836941	1	0.836941	0.000496	0.982353	4.113165
Within Groups	60734.26	36	1687.063			
Total	60735.1	37				



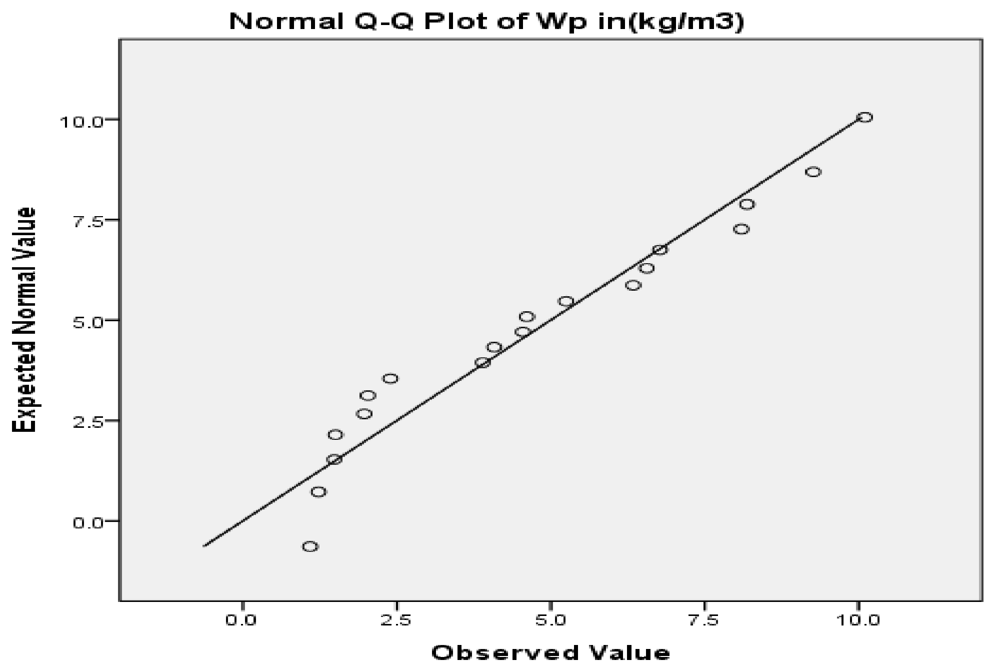
Normality Q-Q test of 2016 ETc (mm)



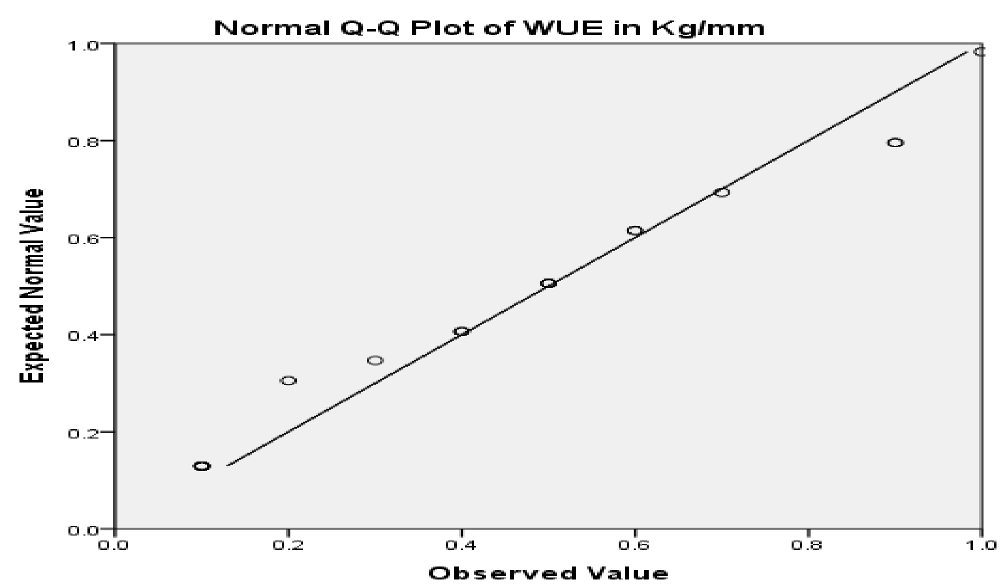
Normality Q-Q test plot of Yield



Q-Q Normality test plot of water productivity.



Q-Q Normality test plot of water use efficiency.



Q-Q Normality test plot of fertilizer used

Appendix V; soil physic –chemical statistical analysis result before irrigation

(Test at p =0.05 / at 95 %significance level)

1=TDR group, 2 =CWR group and 3 = farmers practice are labels & WM = water management

Multiple Comparisons

Dependent Variable		WM(a)	WM(b)	Mean Difference (a-b)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
pH	Scheffe	1	2	0.36	0.23	0.31	-0.25	0.97
			3	0.18	0.26	0.80	-0.51	0.87
		2	1	-0.36	0.23	0.31	-0.97	0.25
			3	-0.19	0.25	0.76	-0.86	0.48
		3	1	-0.18	0.26	0.80	-0.87	0.51
			2	0.19	0.25	0.76	-0.48	0.86
EC	Scheffe	1	2	0.02	0.05	0.91	-0.11	0.16
			3	-0.01	0.06	0.99	-0.16	0.15
		2	1	-0.02	0.05	0.91	-0.16	0.11
			3	-0.03	0.06	0.86	-0.18	0.12
		3	1	0.01	0.06	0.99	-0.15	0.16
			2	0.03	0.06	0.86	-0.12	0.18
Sand	Scheffe	1	2	9.96	7.19	0.40	-9.31	29.24
			3	0.91	8.14	0.99	-20.90	22.73
		2	1	-9.96	7.19	0.40	-29.24	9.31
			3	-9.05	7.92	0.53	-30.29	12.19
		3	1	-0.91	8.14	0.99	-22.73	20.90
			2	9.05	7.92	0.53	-12.19	30.29
Silt	Scheffe	1	2	2.39	2.57	0.65	-4.48	9.27
			3	3.54	2.90	0.49	-4.23	11.32
		2	1	-2.39	2.57	0.65	-9.27	4.48
			3	1.15	2.83	0.92	-6.42	8.72
		3	1	-3.54	2.90	0.49	-11.32	4.23
			2	-1.15	2.83	0.92	-8.72	6.42
Clay	Scheffe	1	2	-12.36	9.01	0.41	-36.50	11.79

			3	-4.46	10.19	0.91	-31.78	22.86
		2	1	12.36	9.01	0.41	-11.79	36.50
			3	7.90	9.92	0.73	-18.70	34.50
		3	1	4.46	10.19	0.91	-22.86	31.78
			2	-7.90	9.92	0.73	-34.50	18.70
CEC	Scheffe	1	2	-0.99	5.02	0.98	-14.44	12.47
			3	-0.93	5.68	0.99	-16.14	14.29
		2	1	0.99	5.02	0.98	-12.47	14.44
			3	0.06	5.53	1.00	-14.76	14.88
		3	1	0.93	5.68	0.99	-14.29	16.14
			2	-0.06	5.53	1.00	-14.88	14.76
OM	Scheffe	1	2	0.74	0.69	0.57	-1.10	2.58
			3	-0.59	0.78	0.75	-2.67	1.49
		2	1	-0.74	0.69	0.57	-2.58	1.10
			3	-1.33	0.75	0.24	-3.36	0.69
		3	1	0.59	0.78	0.75	-1.49	2.67
			2	1.33	0.75	0.24	-0.69	3.36
TN	Scheffe	1	2	0.04	0.03	0.55	-0.05	0.13
			3	-0.03	0.04	0.78	-0.13	0.08
		2	1	-0.04	0.03	0.55	-0.13	0.05
			3	-0.07	0.04	0.25	-0.17	0.04
		3	1	0.03	0.04	0.78	-0.08	0.13
			2	0.07	0.04	0.25	-0.04	0.17
Av. P	Scheffe	1	2	-2.87	6.33	0.90	-19.83	14.08
			3	2.24	7.16	0.95	-16.94	21.42
		2	1	2.87	6.33	0.90	-14.08	19.83
			3	5.12	6.97	0.77	-13.56	23.79
		3	1	-2.24	7.16	0.95	-21.42	16.94
			2	-5.12	6.97	0.77	-23.79	13.56
Fe	Scheffe	1	2	3.12	3.48	0.68	-6.20	12.43
			3	0.07	3.93	1.00	-10.48	10.61
		2	1	-3.12	3.48	0.68	-12.43	6.20
			3	-3.05	3.83	0.73	-13.31	7.22
		3	1	-0.07	3.93	1.00	-10.61	10.48

			2	3.05	3.83	0.73	-7.22	13.31
FC	Scheffe	1	2	0.68	2.71	0.97	-6.59	7.95
			3	2.19	3.07	0.78	-6.03	10.42
		2	1	-0.68	2.71	0.97	-7.95	6.59
			3	1.51	2.99	0.88	-6.50	9.52
		3	1	-2.19	3.07	0.78	-10.42	6.03
			2	-1.51	2.99	0.88	-9.52	6.50
PWP	Scheffe	1	2	1.05	1.13	0.66	-1.98	4.08
			3	1.41	1.28	0.56	-2.02	4.84
		2	1	-1.05	1.13	0.66	-4.08	1.98
			3	0.36	1.25	0.96	-2.97	3.70
		3	1	-1.41	1.28	0.56	-4.84	2.02
			2	-0.36	1.25	0.96	-3.70	2.97
K	Scheffe	1	2	521.75	323.99	0.30	-346.57	1390.07
			3	-160.87	366.55	0.91	-1143.26	821.52
		2	1	-521.75	323.99	0.30	-1390.07	346.57
			3	-682.62	356.87	0.19	-1639.08	273.85
		3	1	160.87	366.55	0.91	-821.52	1143.26
			2	682.62	356.87	0.19	-273.85	1639.08

Appendix W: the comparison of before and after NPK and OM with in treatment groups.

Analysis of variance for the OM % before planting and after harvest.

		Sum of Squares	df	Mean Square	F	Sig.
Before planting	Between Groups	4.641	2	2.321	1.300	.298
	Within Groups	30.357	17	1.786		
	Total	34.998	19			
After harvest	Between Groups	.703	2	.351	.432	.656
	Within Groups	13.845	17	.814		
	Total	14.548	19			

Analysis of variance for the AV.p % before planting and after harvest.

Analysis of variance for the TN % before planting and after harvest.						
		Sum of Squares	df	Mean Square	F	Sig.
TN % before planting	Between Groups	.012	2	.006	1.308	.296
	Within Groups	.076	17	.004		
	Total	.087	19			
TN % after harvest	Between Groups	.002	2	.001	.421	.663
	Within Groups	.037	17	.002		
	Total	.039	19			

		Sum of Squares	df	Mean Square	F	Sig.
Before planting AV.P	Between Groups	139.848	2	69.924	.478	.628
	Within Groups	2484.584	17	146.152		
	Total	2624.432	19			
After harvest av.p	Between Groups	364.032	2	182.016	.991	.392
	Within Groups	3122.398	17	183.670		
	Total	3486.430	19			

Analysis of variance for the AV.p % before planting and after harvest.						
		Sum of Squares	df	Mean Square	F	Sig.
K before planting	Between Groups	1744730.458	2	872365.229	2.228	.138
	Within Groups	6656559.980	17	391562.352		
	Total	8401290.438	19			
P after harvesting	Between Groups	120280.351	2	60140.176	.375	.693
	Within Groups	2729122.206	17	160536.600		
	Total	2849402.558	19			

Appendix Y: nutrient (NPK) depletion balance single factor statistical test for the treatments

Anova: Single Factor (nitrogenDepletion)

SUMMARY

Groups	Count	Sum	Average	Variance
FARM_Nitrogen	5	93.98611	18.79722	31875.05
TDR_Nitrogen	7	-634.301	-90.6145	53114.7
CWR_Nitrogen	8	-1213.03	-151.629	19861.45

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	89462.86	2	44731.43	1.299402	0.298445	3.5915
Within Groups	585218.5	17	34424.62			
Total	674681.4	19				

Anova: Single Factor (phosphorus Depletion)

SUMMARY

Groups	Count	Sum	Average	Variance
FARM_phosphorus	5	-0.84021	-0.16804	0.726225
TDR_Phosphorus	7	-4.41703	-0.631	1.007819
CWR_phosphorus	8	-4.25887	-0.53236	0.743925

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.667782	2	0.333891	0.400878	0.675899	3.591531
Within Groups	14.15928	17	0.832899			
Total	14.82707	19				

Anova: Single Factor (Potasium Depletion)

SUMMARY

Groups	Count	Sum	Average	Variance
FARM_potasium	5	-486.001	-97.2003	10472.65
TDR_Potasium	7	-1988.02	-284.002	39502.11
CWR_potasium	8	-2158.86	-269.858	30194.76

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	121247.7	2	60623.86	2.102133	0.152833	3.591531
Within Groups	490266.6	17	28839.21			
Total	611514.3	19				

Appendix X; Mahalanobis multivariate outlier identification through SPSS with variable combination with in the group

ID	WMG	IRR(mm)	pH	EC	Sand	Clay	Silt	CEC	OM	TN	Av.P	Fe	FC	PWP	K	Yield	MAH_1	Pro-MD2	outlier
1	TDR	583	6	0.3	57	12	31	51	7	0.4	31	32	39	25	1996	30790	17	1	0
3	FARM	618	7	0.3	53	12	35	51	7	0.3	15	22	44	23	1590	12667	17	1	0
2	CWR	607	6	0.2	35	32	33	51	3	0.2	11	10	34	19	392	36786	16	1	0
3	FARM	511	6	0.1	9	72	19	22	3	0.1	8	5	24	16	57	10000	16	1	0
1	TDR	603	6	0.0	27	40	33	33	2	0.1	7	6	35	21	103	15208	15	1	0
1	TDR	655	7	0.3	43	22	35	25	4	0.2	22	6	39	24	805	29167	15	1	0
1	TDR	571	6	0.2	41	18	41	42	4	0.2	15	12	32	22	1991	67167	14	1	0
2	CWR	461	7	0.2	35	28	37	35	5	0.2	54	13	34	23	518	37560	14	1	0
1	TDR	566	6	0.1	27	36	37	31	5	0.2	26	10	30	21	544	18611	14	1	0
3	FARM	796	7	0.2	33	36	31	35	5	0.2	13	7	32	23	1100	36304	14	1	0
3	FARM	362	7	0.3	47	16	37	40	6	0.3	26	18	32	22	1766	42222	12	1	0
2	CWR	522	6	0.2	27	36	37	49	2	0.1	10	8	42	24	117	20278	12	1	0
1	TDR	545	7	0.1	13	56	31	39	3	0.1	9	10	29	20	165	32564	11	1	0
2	CWR	474	6	0.1	19	46	35	31	3	0.2	17	10	29	19	562	26173	11	1	0
3	CWR	419	6	0.1	17	52	31	34	4	0.2	9	8	26	18	398	10278	9	1	0
2	CWR	523	6	0.2	17	54	29	42	3	0.1	9	9	35	21	112	14773	9	1	0
2	CWR	492	5	0.1	13	62	25	26	4	0.2	11	6	30	20	94	47167	8	1	0
2	CWR	591	6	0.1	17	54	29	26	3	0.2	13	6	31	20	281	43393	7	1	0
2	CWR	489	6	0.1	19	52	29	32	4	0.2	30	10	30	22	322	39464	6	1	0

Appendix Z: Input-output measurements and depletion balance for Nitrogen from all experimental plots

		Inputs			outputs		
Farmer	Irrigation method	Total N atmospheric wet deposition kg	N fertilizer applied kg/ha	N in irrigation water kg/ha	Total N harvested kg	Total N residual biomass kg	Depletion balance (kg)/ha per season
PR3T	TDR	2.4	179	14	107	108	-19
PR8T_NUT	TDR	2.4	150	8	140	155	-134
PR5T_NUT	TDR	2.4	77	26	284	124	-302
PR6FR_NUT	FARM	2.4	60	23	123	60	-98
PR7T	TDR	2.4	544	27	201	60	313
PR11T	TDR	2.4	28	10	218	127	-304
PR16T_NUT	TDR	2.4	115	8	234	156	-265
PR18T	TDR	2.4	184	15	76	47	77
PR9CW	CWR	2.4	128	18	155	84	-91
PR4CW	CWR	2.4	123	22	482	88	-423
PR24CW	CWR	2.4	141	41	93	67	23
PR10CW	CWR	2.4	107	15	146	149	-171
PR14CW_NUT	CWR	2.4	149	11	210	140	-188
PR17CW_NUT	CWR	2.4	263	33	149	155	-6
PR15CW	CWR	2.4	205	12	169	171	-121
PR12FR	FARM	2.4	256	15	68	42	163
PR23CW_NUT	CWR	2.4	120	10	230	140	-237
PR22_NUT	FARM	2.4	192	10	91	7	105
PR21_NUT	FARM	2.4	237	12	32	59	161
PR19FR	FARM	2.4	128	9	246	130	-237

Appendix AA: Input-output measurements and depletion balance for phosphorus from all experimental plots

Farmer	Irrigation method	inputs		outputs		Depletion balance of p kg **ha^{-1}** per season
		P fertilizer applied kg ha^{-1}	P in irrigation water kg ha^{-1}	Total p harvested kg ha^{-1}	Total P residual biomass kgha^{-1}	
PR3T	TDR	0.0172	0.8418	0.404	0.525	-0.070
PR8T_NUT	TDR	0.0369	1.2538	0.811	0.589	-0.108
PR5T_NUT	TDR	0.0000	0.7836	1.049	0.468	-0.734
PR6FR_NUT	FARM	0.0000	0.8298	0.743	0.265	-0.178
PR7T	TDR	0.2455	0.4657	0.502	0.163	0.047
PR11T	TDR	0.0000	0.5927	1.181	0.511	-1.099
PR16T_NUT	TDR	0.0000	0.3142	1.997	0.969	-2.652
PR18T	TDR	0.0000	0.8585	0.449	0.212	0.198
PR4CW	CWR	0.0000	0.8269	2.548	0.303	-2.023
PR9CW	CWR	0.0070	0.7313	0.000	0.000	0.738
PR24CW	CWR	0.5083	0.7321	0.598	0.706	-0.064
PR10CW	CWR	0.4675	0.8494	0.827	0.564	-0.074
PR14CW_NUT	CWR	0.0025	1.2183	0.949	0.540	-0.268
PR17CW_NUT	CWR	0.0230	1.1503	0.920	0.512	-0.259
PR15CW	CWR	0.0000	0.6843	1.053	0.888	-1.257
PR12FR	FARM	0.0000	0.8645	0.344	0.147	0.374
PR23CW_NUT	CWR	0.0000	0.5391	1.097	0.495	-1.052
PR22_NUT	FARM	0.0000	0.5740	0.478	0.027	0.069
PR21_NUT	FARM	0.0000	0.9616	0.234	0.218	0.510
PR19FR	FARM	0.0000	0.5066	0.820	1.302	-1.615

Appendix AB: Input-output measurements and depletion balance for Nitrogen from all experimental plots

		Inputs		outputs		
Farmer	Irrigation method	K in fertilizer applied kg ha^{-1}	K in irrigation water kg ha^{-1}	Total k harvested kg ha^{-1}	Total K IN residual biomass kg ha^{-1}	Partial Potassium balance kg ha^{-1} per season
PR3T	TDR	8.84	27.65	134.34	179.35	350.19
PR8T_NUT	TDR	7.99	41.40	201.03	269.05	519.47
PR5T_NUT	TDR	0.00	45.13	218.48	187.35	450.96
PR6FR_NUT	FARM	0.00	15.56	160.38	118.01	293.96
PR7T	TDR	3.52	15.30	12.01	21.66	52.50
PR11T	TDR	0.00	19.47	144.68	73.25	237.41
PR16T_NUT	TDR	0.00	16.22	402.14	218.78	637.15
PR18T	TDR	0.00	28.20	78.65	60.95	167.81
PR4CW	CWR	0.00	27.16	329.51	94.96	451.63
PR9CW	CWR	7.80	24.02	0.00	0.00	31.82
PR24CW	CWR	5.63	24.05	97.38	89.01	216.06
PR10CW	CWR	2.88	27.90	88.20	49.05	168.03
PR14CW_NUT	CWR	2.80	31.42	158.74	197.49	390.45
PR17CW_NUT	CWR	10.36	43.35	248.01	284.66	586.38
PR15CW	CWR	0.00	22.48	198.99	198.29	419.75
PR12FR	FARM	0.00	28.40	9.95	13.07	51.42
PR23CW_NUT	CWR	0.00	18.91	203.26	170.09	392.26
PR22_NUT	FARM	0.00	25.64	70.42	9.73	105.78
PR21_NUT	FARM	0.00	24.44	42.44	38.17	105.05
PR19FR	FARM	0.00	16.64	100.45	34.07	151.15

Appendix AC: Tomato photo t different development stage.


a)


b)


c)


d)

Initial, development, flowering and maturity/harvesting stage (yield of tomato)