Bahir Dar University

Faculty of Civil and Water Resource Engineering

Department of Hydraulics Engineering

MASTER THESIS

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.

By: Tesfaye Ewnetie

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Bahir Dar, Ethiopia

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Submitted to the Faculty of Civil and Water Resource Engineering in partial fulfillment of the requirements for the Degree of Master of Science in Hydraulics Engineering

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October, 2015

DECLARATION

I, Tesfaye Ewnetie, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have dually acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the university and can also evoke penal action from the sources which have not been properly cited or acknowledged.

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Date

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ABSTRACT

Agriculture is the main economic activity in Ethiopia and its primary source of water is rain. However, the erratic nature of the rainfall influences the amount of production as it is sometimes low and even absent when needed by the crop. Most of the rivers in the Amhara region dry up during the dry season starting from January onwards. Therefore, the source of water for irrigation in these areas is groundwater. However, there is also a problem of farmers not having access to appropriate water lifting technologies to lift water from wells. The water management system of farmers is also not efficient to use the water resource efficiently. Many farmers irrigate two times in a day at the early stage of the crop, then once in a day and then once in three days by their traditional knowledge of irrigation scheduling. The amount of water added is not calculated but rather, is estimated by simply observing the excess water when the soil is saturated.

The aim of the research is to contribute to the country's development program by enabling the stakeholders select appropriate lifting technologies which can fit with the sites' situation, and water management system so that farmers can use the available water resources more efficiently.

To achieve the research aim, primary data were collected from field by conducting an experiment on selected plots, plot's soils were analyzed in the laboratory for nutrients' concentrations and water holding capacity. Data like moisture content of the soil, amount of water added to the soil and yield were collected; and, secondary data from government offices like meteorological office, and agricultural office was collected.

After analysis was done using different statistical tools, the results were interpreted and they showed that pulley performed better than RWP. The analysis also showed that more water was applied to the tomato with pulley than the RWP yet the yield was not significantly different, which implies that less water could be applied without affecting yield. The analysis done to compare the Thornthwaite-mather method with TDR soil moisture measurements has shown that the Thornthwaite-Mather model can be used for planning purpose to quantify the total amount of water required for one irrigation season.

Key words – water lifting technologies, irrigation water management, yield and water productivity, water use efficiency.

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The contents of the paper are the responsibility of the author and do not necessarily reflect the views of USAID or the United States government.

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ACRONYMS

AWC – Available water content

Av – Average

BMC – Billion Meter Cube

CSA – Central Statistical Agency

ETo – Potential evapotranspiration

EC – Electric conductivity

ETc – amount of irrigation water used by tomato plant

Ex - Example

FC – Filed capacity of the soil

FY – Fiscal Year

GDP – Gross Domestic Product

GW – Ground water

Ha – Hectare

IrrWpro – Irrigation water Productivity

IWMI – International water management institute

LAI – Leaf Area Index

MAX – Maximum

Min–Minimum

MCB – meter cube

MOWR – Ministry of Water Resources

MWI&E – Ministry of water, Irrigation and Energy

No.– Number

NTd group – farmers grouped under none TDR (who use their traditional knowledge) of irrigation scheduling method.

PWP – Permanent wilting capacity of the soil.

RH – Relative humidity

RWP – Rope and washer pump.

SW – Surface water

TDR – Time domain reflectometer

Td group – farmers grouped under measured soil moisture using TDR

TWMM – Thornthwaite-Mather method

VWC – Volumetric water content of the soil.

WUE –Water Use Efficiency

WL tech – Water lifting technology

WM – Water management system

IWUE – Irrigation Water Use Efficiency

TWUE - Total Water Use Efficiency

Q – discharge of water in l/min

1. INTRODUCTION

1.1. Background and Justification

Ethiopia is home to 96.5 million people (IFAD, 2014), of which over 60 million (66%) live on less than US$2 per day; approximately 28 million (31%) live on less than US$1.25 per day (World Bank, 2013).

Irrigation is an age-old art–perhaps as old as civilization. As reported by FAO (2001), irrigation in Ethiopia dates back to several centuries, if not millennia. However, commercial irrigated sugar estate farms, the first modern and large scale farms in the country, started in the early 1950s by the Imperial Government of Ethiopia and the Dutch company known as HVA-Ethiopia. The increasing need for crop production due to the growing population in the world is necessitating a rapid expansion of irrigated agriculture throughout the world. The situation is not any different in Ethiopia. It has been clearly and loudly stated that if Ethiopia is to feed its ever increasing population, lessen risk of catastrophes caused by drought, and increase population density in the arid and sparsely populated areas, continuous and extensive efforts need to be made towards developing irrigated agriculture and intensifying agricultural production. A reliable and suitable irrigation water supply can result in vast improvements in agricultural production and assure the economic vitality of the region. Many developed countries have been dependent on irrigated agriculture to provide the basis of their society and enhance the food security of their people (FAO, 2001).

Ethiopia has both surface and groundwater sources; the surface water resources being the predominant ones**.** The country has 12 river basins. The total mean annual flow from all the 12 river basins is estimated to be 122 BMC (MoWI&E, 2010). Ethiopia also has 11 fresh and 9 saline lakes, 4 crater lakes and over 12 major swamps or wetlands. One of the 11 fresh water lakes is Tana which is located near the study area and near Bahir Dar, the capital city of Amhara region. Ethiopia has also a groundwater potential, which, based on the scanty knowledge, is estimated to be about 2.6 BMC annually rechargeable resource (MoWR, 2002). This figure appears to be extremely underestimated. However, Tadesse (2004) estimated that at least 13.2 BMC infiltrates into the groundwater system of which 50% could be extractable, which means, the total extractable groundwater source is 6.6 BMC.

Though the country possesses a substantial amount of water resources, little has been developed for agriculture and other purposes. Based on the present indicative information sources, the potential irrigable land is about 3.7 million hectares (Awulachew et al., 2005). This figure is believed to be on a lower side, and could change as more reliable data emerges particularly on small-scale irrigation potential. Estimates of the irrigated area presently vary, but range between 150,000 and 250,000 hectares less than 5% of potentially irrigable land (Werfring, 2004; Awulachew et al., 2005).

The above figures clearly indicate the extent and magnitude of the need for accelerated development and management of the available water resources of the country. Hence, given the rapidly growing population in the foreseeable future, these resources will have to be tapped and harvested in order to attain food security, overcome the effects of climate change and variability, maintain sustainable industrial growth and improve the overall standard of living of the people of Ethiopia.

Expanding small scale irrigation technologies will enable farmers to practice irrigation since;

- Family labor for irrigation and other agricultural activities is available if the farmers can be supported technically and financially,
- They have experience on manual shallow well digging,
- They have small land holding size (on average 0.75ha) and even less for newly emerging households (2014 woreda agricultural office quarterly report,).
- There is abundant water source in the area due to the flat topography in a big portion of the area and the presence of Lake Tana which is close to the site.

Having assessed and identified the needs and gaps on agricultural production, there are efforts made by the Ethiopian government and partners to boost agricultural food production. The Agricultural Growth Program, Agribusiness and Marketing Development (AGP – AMD) a flagship project under USAID's Feed the Future program (FtF) strategy for Ethiopia is one of the projects working to fight poverty among various similar food security projects. The program uses a value chain approach to strengthen the agriculture, enhance access to finance which mostly targets women headed households, and stimulate innovation and private sector investment. Although the crops identified in the program are coffee, sesame, chickpea, honey, wheat, and maize, vegetables like tomato can be also included if one can show their potential for food security and income generation.

Farmers' efforts to extract and use of groundwater source for agricultural production need to be supported. There is need to assist them with information on appropriate water lifting technologies, facilitate credit for startup investment particularly for women headed households who faces shortage of startup capital, and link them to markets so that they can earn an income from their produce.

1.2. Problem Statement

Food insecurity remains a common issue in Ethiopia, and yet the agriculture sector has great potential to play a stronger role in development, food security and poverty reduction, as the government has set out to do through its strategy of Agriculture Development Led Industrialization (FAO, 2010).Tesfaye (2008) also emphasized that food insecurity is a major concern in Ethiopia due to the unpredictability and unreliability nature of the main source of water which is rainfall.

In rainfed agriculture, water is the key constraint for improving agricultural productivity owing to the extreme variability of rainfall, long dry seasons, recurrent droughts, and floods. In spite of being important for food security, the investments in irrigated agriculture, particularly in water management, have been neglected for a long period of time (SIWI, 2000; Wani etal., 2003). Efforts to use groundwater sources by using efficient water lifting technologies are minimal except farmers' traditional practices of excavating wells and lifting water using bucket and rope. Scientific methods of irrigation scheduling are also not practiced so far in most parts of Ethiopia, particularly in Amhara. Farmers simply use their skill of irrigation scheduling and also estimate the amount of irrigation water by simple observations. During irrigation, farmers stop applying water when they observe excess water flowing to the neighboring fields and water courses. This has brought about losses of irrigation water and reductions in yields. Therefore, it is important to use appropriate irrigation scheduling methods to better utilize the available surface and groundwater resources. Soil moisture monitoring and the Thornthwaite-Mather model are some of the ways of knowing the temporal soil moisture status which is essential in helping farmers know how much water to apply to the fields.

1.3. Hypotheses

Some types of water lifting technologies could be more effective than others. Some existing water lifting technologies can be modified and improved to enhance their performance. Hence, investigating various lifting technologies and comparing them on ease of operation and maintenance, and the effort required to withdraw water from wells of various depths will enable coming up with recommendations on the appropriateness of the technologies depending on the yield of the wells and tomato crop water demand.

In addition, the applied water from these technologies in the Ethiopian highlands needs improvement in terms of being able to use water resources sustainably, efficiently and effectively. Hence, attempting to predict the irrigation water requirement through soil moisture monitoring and other estimation methods such as Thornthwaite-Mather method will lead to efficient utilization of the technologies and the water resources.

1.3. Research Questions

- Which lifting technology is better in terms of crop productivity, water use efficiency, and irrigation productivity?
- Is Thornthwaite-Mather method able to predict the soil moisture depletion in agricultural plots for vegetables?

1.5. Objective of the research

1.5.1. General Objective;

- To evaluate water lifting technologies for groundwater irrigation of tomato, and evaluate the accuracy of the Thornthwaite-Mather method in predicting soil moisture content.

1.5.2. Specific objectives

1. To compare the manual lifting technologies (pulley/tank/hose system and rope & washer pump) in terms of irrigation water applied, yield, water use efficiency, and irrigation productivity, for small scale groundwater irrigation of tomato.

2. To evaluate the capacity of Thornthwaite-Mather method to predict soil moisture at plot level for tomato production in Robit kebele of BahirdarZuria woreda and Dangishta kebele of Dangila woreda.

2. LITERATURE REVIEW

2.1. Irrigation Water Requirement and Evapotranspiration

Evapotranspiration (ET) is an important component of the hydrological cycle and is essential for understanding land surface processes in climatology. In ecosystem and agriculture studies, productivity is closely linked to actual ET. In practice, estimation of actual ET is often made by using information about potential ET. Formally defined as wet-surface evaporation is the ET governed by available energy and atmospheric conditions, as the water availability is not a limiting factor. Thus, potential ET is a function of atmospheric forcing and surface types (Chen, et al, 2005).

There exists a multitude of methods for estimation of potential evapotranspiration and free water evaporation E, which can be grouped in to five categories: (1) water budget (Guitjens, 1982), (2) mass transfer (Harbeck, 1962), (3) Combination (Penman, 1948), (4) Radiation (Priestley and Taylor, 1972), (5) Temperature based (Thornthwaite, 1948, Blaney-Criddle, 1950). The availability of many equations for determining evapotranspiration, the wide range of data types needed, and the wide range of expertise to use the various equations correctly make it difficult to select the most appropriate evaporation method for a given study(Xu and Singh, 2002).

Although various methods are available to estimate reference evapotranspiration (ETo) from standard meteorological observations, the Penman-Monteith method is considered to be the most physical and reliable method and is often used as a standard to verify other empirical methods (Cheng et al, 2005).

The fruit yield of tomato is directly related with the irrigation depth. Eddossa et al., (2013), has stated that the amount of water added to the soil has direct relation (impact) on the growth and yield of tomato crop. Irrigation levels brought highly significant effect on the stand of the plant (plant height, canopy width, leaf chlorophyll content, stomatal conductance), and total yield. Halil et al., (2004) also found that as applied irrigation water decreased, tomato yield also decreased.

The study of irrigation water requirement requires a thorough understanding of the reference evapotranspiration, consumptive water use and soil properties like the field capacity and permanent wilting point. Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the ground area, plant transpiration becomes the main process. At sowing, nearly 100% of ET comes from evaporation, while at full crop cover more than 90% of ET comes from transpiration (FAO, 2000).

2.2. Water lifting Technologies

Water lifting technologies allow users to lift water from depths that users cannot access easily. They can be used to lift water from groundwater (wells), water harvesting structures, and lakes/rivers/streams. There are different water lifting technologies available in the market for farmers in Amhara region. Some of the technologies like rope and washer (RWP), pedal (treadle) pumps, wing pumps and motor pumps are distributed by the woreda agricultural office (governmental office) and other NGOs. There are also other technologies supplied by business makers like pulley (also classified by suppliers as local or imported) and various types and brands of motor pumps. The motor pumps are fuel operated pumps whereas the remaining pumps are operated manually. For example, pedal pumps are operated by feet, pulley and rope and washer pumps are operated by hand. Pulley cannot lift water alone unless it is combined with rope and bucket. The bucket may be any size based on the physical strength (power) of the person who lifts water. On the other hand, rope and washer pumps use a riser pipe, inside which a rope with rubber washers are inserted (Woreda Agricultural office irrigation team quarter report, 2014).

Figure 2-1 RWP (left) and Pulley (right).

Figure 2-2 Motor pump (to the left), Wing pump (to the right)

Makonnnen et al., (2012) indicated that agricultural water management technologies are successful in low rainfall areas to agricultural production. Particular characteristics of each technology, which environment they are suitable for, conditions for their suitability for a given environment, and the conditions for their successful adoption and scaling up were identified. Some of the researcher’s conclusions and recommendations were: 1) Agricultural water management technologies are successful in low rainfall areas to increase agricultural production, 2) adoption of small motorized pumps by farmers is increasing at an alarming rate which contribute to assuring food security, 3) in areas where there is a potential for shallow well development it has preference over water lifting technologies and found to be more sustainable if supported with watershed conservation activities, as watershed conservation has contribution to ensure the sustainability of groundwater source. In areas where the water source is less than 6 meters, treadle pumps offer potentially suitable technology to adopt in conjunction with storage structures. However, treadle pumps are not useful in Robit kebele since almost all of the wells have a depth of greater than 6m. Farmers have also complained about the treadle pump because of its high labor demand.

2.3 Soil Moisture and Irrigation Scheduling

2.3.1. Irrigation Scheduling

A well-managed irrigation system is one that optimizes the spatial and temporal distribution of water, not necessarily to obtain the highest yields or to use the lowest amount of water possible but to attain the highest amount of yield per unit amount of water which could maximize the benefit to cost ratio (Daniel, 1982). Irrigation scheduling can be done using various methods which can be; by soil moisture measurement which is probably the oldest method in existence and, by estimating the consumptive water use of the crop/vegetables at its different growth stages (Daniel, 1982).

2.3.2. Thornthwaite-mather method

Water balance models have been developed at various time scales (for example: hourly, daily, monthly and yearly) and to varying degrees of complexity. Monthly water balance models were first developed in the 1940's by Thornthwaite and later revised by Thornthwaite-Mather (1955, 1957). These models have since been adopted, modified and applied to a wide spectrum of hydrological problems. Recently they have been employed to explore the impact of climate change, and, long range stream flow forecasting (Xu and Sigh, 1998).

The Thornthwaite-Mather procedure calculates the water balance for the root zone. It has been successfully applied to water balance for whole watersheds and in calculations of recharge to ground water. Below is a schematic explanation of how the different conceptual portions of a watershed are combined in the Thornthwaite-Mather model.

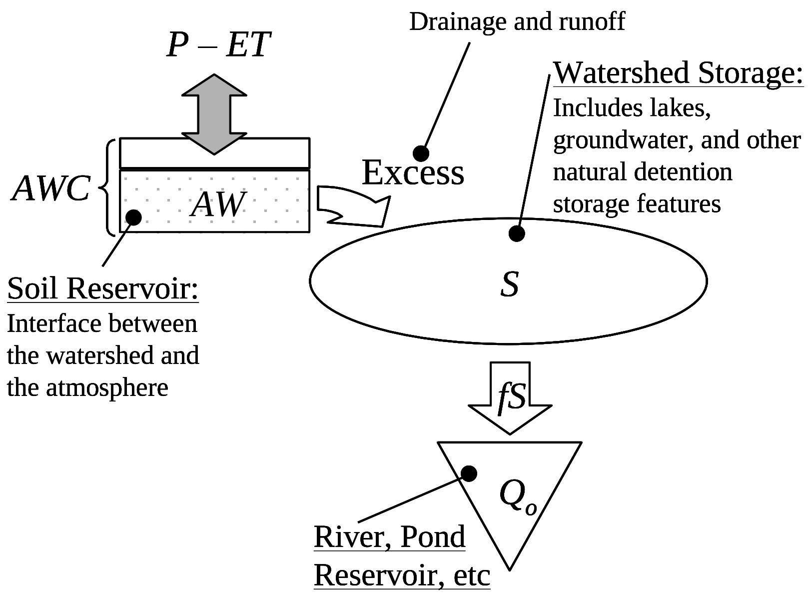

Figure 2-3 The Soil reservoir

Where;

AWC = Available Water Capacity [mm]

= (soil depth) ×(FC-PWP) --(2.1)

AW = Available Soil Water [mm]

= (soil depth)*(AR-PWP) -- (2.2)

P – PET is Net Precipitation [mm]

Where:

P = Precipitation plus added water via irrigation [mm]

PET = Potential Evapotranspiration [mm]

The Thornthwaite-Mather model ---Equation 2.3

Situation in the watershed	AW_t	Excess
Soil is drying – A		
$\Delta P < 0$	$AW_t = AW_{t-1}\exp(-\Delta P/AWC)$	= 0
Soil is wetting		
$\Delta P > 0$ but, $AW_{t-1} + \Delta P \leq AWC$	$AW_t = AW_{t-1} + \Delta P$	= 0
Soil is wetting above capacity $\Delta P > 0$ but, $AW_{t-1} + \Delta P > AWC$	$AW_t = AWC$	$E_{xs} = AW_{t-1} + \Delta P - AWC$

The drainage portion of the excess water is all the water above field capacity but below saturation and the overland flow is all water that exceeds soil saturation (i.e. saturation excess overland flow). Adapting the Thornthwaite-Mather soil-water budget to a daily time step require keeping track of one extra water reservoir, i.e., the soil water above field capacity and below saturation, which we usually assume drains out of the root zone in a day. The simplest assumption is that it drains to the groundwater the same day.

2.3.3. TDR

TDR is a relatively new technology which is used to assess the volumetric water content of the soil. TDR voltage readings can be converted into volumetric water content of the soil (VWC) which is a popular method to report the soil water status. TDR sensors give very accurate readings, however, they are still quite expensive (approximately $200 per sensor) (Charlesworth, 2000). In a TDR probe, the speed of an electromagnetic signal passing through a material varies with the dielectric material. A signal is sent down through steel probes buried in the media. When it reaches the end of the probes, it is reflected back to the TDR receptor unit. The difference in time that takes the signal to return is caused by the dielectric constant that is affected by the water content of the substrate that surrounds the probes. The levels of voltage received by a TDR probe are converted into volumetric soil water content (VWC). The lengths of TDR rods which are commercially available in the market are 12cm and 20cm.

2.3.4. Soil moisture profiler

The soil moisture profiler is built around newly patented sensing technology which provides a good performance in all soil types, with minimal influence from either salinity or temperature. First, an access tubes is installed into the soil. The access tube is manufactured to strict tolerances and is exceptionally strong and durable in the soil but correct installation is essential, thus it is recommended to use an auger for digging, allowing easy installation and minimal soil disturbance. The soil profiler reads a soil moisture up to the depth of 100cm (User Manual of soil profiler).

3. MATERIALS AND METHODS

3.1. Description of study area.

The study was conducted in Yigashu watershed of Robitkebele, an experimental watershed of 911 ha, located at the south eastern edge of Lake Tana, BahirdarZuriaw Woreda of Amhara National Regional State, Ethiopia. Figure 3.1 shows the map of study area. The kebele has a total population of 9707 people (5000 male and 4707 female). This community has 3736 hand dug individually owned wells. The 157 motor pumps that the community members own lift water from streams, stream diversions. Other water lifting techniques include rope fitted with bucket, and pulley plus rope fitted with bucket. The lifting technologies are used to irrigate 1824.65 hectares of land (Woreda Agricultural office irrigation team 2014 report).

A baseline survey was conducted on the selected 18 farmers to determine if farmers had experience with irrigation, irrigation application methods used, water sources, the type of water lifting technologies the farmers were using, the type of crops/vegetables they produce with irrigation, annual income, and access to credit services.

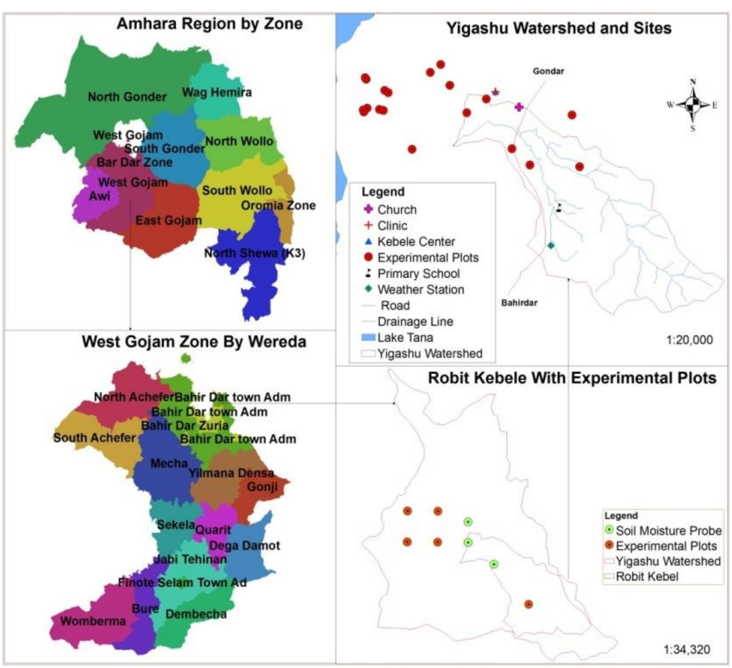

Figure 3-1 Map of the Study Area

3.2. Experimental design

Two water lifting technologies (rope and washer pump and pulley/tank/hose system) were field tested for one dry season of irrigated tomato production. The experimental design was as follows;

For each of the water lifting technologies, 6 female headed and 6 male headed households, resulting in a total of 24 households were selected. However, farmers' expected to receive the water lifting technologies for free, which wasn't the case, hence 6 farmers dropped out. This study was therefore conducted with 18 farmers (13 male headed households and 5 female headed households). Out of the 18 farmers, 11 received pulley and 7 received RWP. 3 of the RWP farmers totally lost their tomato seedlings almost immediately after transplanting; one of these farmers did not water his tomato for three days(Friday to Sunday) as his hired laborer works only on working days, the other two plots of tomato were totally grazed by animals. Therefore, with this limitation, it was only possible to compare the two technologies using the 11 pulleys and 4 RWPs.

The experimental plots had a minimum size of 100m² for each water lifting technology, but, the experimental plot size varied up to the available irrigated household land size in order to test the capacity of the various technologies. The actual area of each plot is shown in table 3.1.The same variety of tomato and similar land management practices (i.e. field preparation, fertilizer application, and planting density) were used for each water lifting technology.

Irrigation scheduling for tomato crop was done either through soil moisture measurement using the TDR or through farmers' practice (traditional way). Out of 11 pulley farmers, five were TDR users and the remaining 6 non TDR users (control or used farmers' practice). And, out of the 7 RWP farmers, five were TDR users and 2 were non TDR users. However, from RWP TDR users, 3 more farmers lost their tomato the 2 farmers by overgrazing and 1 farmer poor survival of the tomato seedlings. Therefore, 2 RWP farmers were TDR users and the other 2 RWP farmers were non

TDR users. The group who use TDR was named as Td group and the non TDR NTd group. The irrigation scheduling was based on calculating the soil water deficit from the TDR reading and converting it to liters of water, and advising farmers on how many liters to apply. The method of computation to change VWC (%) to liters of water is stated in section 3.3.4. the control group (or non TDR users) irrigated their land based on their traditional knowledge of irrigation scheduling system. They also quantify the amount of water to irrigate by their own knowledge. This group was named as NTd group.

Comparison of the Thornthwaite-Mather method with measured soil moisture content using TDR was done in 10 TDR plots in Robit kebele of BahirdarZuria Woreda and 9 TDR plots in Dangishta kebele of Dangila woreda. As a tomato (hybrid variety called shanty) was grown in Robit plots, and onion (local variety) was grown in Dangishta plots. And, like the Robit plots, the Dangishta plots were using irrigation water lifted by pulley and RWP.

3.2.1. Codes assigned for farm plots

Codes were assigned for each plot to identify the plot by its code. The code was given by the type of water lifting technology and water management system the plot owner is using. Accordingly, PTd was assigned for pulley water lifting technology owners who use TDR for irrigation scheduling where as PNTd was assigned for pulley water lifting technology owners who use traditional irrigation scheduling system. Similarly, RTd was assigned for RWP water lifting technology users who use TDR for irrigation scheduling where as RNTd was assigned for RWP water lifting technology users who use traditional irrigation scheduling system.

Table 3-1 ***Codes assigned for plots in Robit kebele with their respective areas***

S/N	Assigned Codes	Area planted in m^2
1	PTd1	150
2	PTd2	200
3	PTd3	105.8
4	PTd4	150
5	RTd5	222
6	RTd6	102
7	PNTd7	200
8	PNTd8	200
9	PNTd9	150
10	PNTd10	156.3
11	PNTd11	200
12	PNTd12	160
13	RNTd13	103.9
14	RNTd14	108.5
15	RTd15	125
16	RTd16	125
17	RTd17	200
18	PTd18	150

For Dangeshta kebele, codes were also assigned for each farm based on the technology they are using and type of moisture measuring instrument. For example: PT2 stands for a farmer who uses pulley water lifting technology and TDR measurements for irrigation scheduling.

Table 3-2 Codes assigned for plots in Dangishta kebele

S/N	Farmer code
1	PT2
2	RWT3
3	PT8
4	PT12
5	RWT13
6	RWT14
7	RWT15
8	PT17
9	RWT22

3.3 Data collection and Methodology

The tomato was planted in the Robit nursery site, a communal nursery site for the kebele community to get better management of the tomato seedlings. A tomato hybrid variety called Shanty PM was sowed on 22/01/2015 on the well prepared and leveled beds. The seedlings started to germinate on 26/01/2015 and monitoring of the seedlings started from that time. Transplanting of the seedlings was started on 05/03/2015 when the average height of the seedlings had reached to 10cm. The seedlings were planted at distances of 0.4m between plants and 1m between rows. Field observation and measurement of data like amount of water applied per unit time by each technology, soil moisture content, irrigation duration, plant height and area. The plant height and leaf area were measured at the 15th, 44th and 77th days of the transplanting date.

3.3 Data collected

3.3.1. Discharging capacity of technologies

Discharging capacity of technologies is the volume of water a lifting technology can draw in a certain period of time. Water was drawn using each lifting technology into a tank of known volume and time to fill the tank was recorded. The discharging capacity of technologies was measured from the wells of each farmer once every month for three consecutive months; March, April and May. At every measurement of discharging capacities, the measurement was conducted three times (replications) and the average value was taken for that specific month. The average of the three month value was taken as the discharging capacity of the technology. The same process of measuring discharging capacity goes to both pulley and RWP water lifting technologies.

$$Q = \frac{V}{T} ------------------------------------ 3.1$$

Where;

Q is the discharge of water (l/min);

V is the total volume of water withdrawn by technologies (liter).

T is time taken to withdraw volume of water V (minute).

3.3.2. Soil samples collection

Soil samples were collected from the18 plots. The soil sample collection procedure was such that the soil surface was cleared of leaves and branches of previously harvested crops and each sample from a plot was taken using auger at depths of 0 to 20cm, from ten different locations in each plot and mixed together to get a composite mix of soil for each plot. Soil samples were given to Amhara design enterprise laboratory for chemical and physical properties analysis. This included measuring of field capacity, wilting point, soil texture, available organic matter, pH, total exchange capacity, total nitrogen, nitrate and ammonia, available phosphorus, and iron status.

3.3.3. Soil Moisture Measurement

Soil moisture, measured for two purposes;

1) TDR: TDR measurements were used to schedule irrigation. Initial soil moisture content (measured at transplanting time) was measured using TDR. Throughout the growing season, TDR measurements were taken every 3days except on the days were there was rainfall. At the rainy days, TDR measurement was not conducted as it was thought that there was no need of adding additional water.
2) Soil profiler: soil profile measurements were conducted to check for percolation of water below the root zone during the irrigation period. Throughout the growing season, Soil profiler measurements were conducted once in a week.

3.3.3.1. **TDR**

As mentioned earlier, the TDR was used for irrigation scheduling purposes; to decide the amount of water to be added to the soil on days readings were taken. It was used to measure the amount of water available in the soil (VWC in %). The amount of water to be added to the soil in VWC (%) was then calculated by subtracting the VWC read using TDR from FC (%). Then the value was multiplied by the root depth of tomato to change the VWC of the soil in %age to depth of water in mm. This depth of water was then multiplied by the area of the plot to estimate the total amount of water to be added. Therefore, soil moisture measurement using TDR was done regularly every three days before the next irrigation except at the days there was rain as during rainy days there was no irrigation.

The TDR was also used to test the accuracy of Thornthwaite-Mather Method (model) for use for irrigation scheduling in areas where there is no access to use TDR and other soil moisture measurement methods.

3.3.3.2. ***Soil Profiler***

Although TDR was used for irrigation scheduling, it was not possible to monitor the movement of water at depth of soil greater than 12cm, and quantify the percolation of water below root depth of tomato plant using the TDR as the length of its rods used were only 12cm. Therefore, soil profiler was used to monitor movement of water up to 1 m depth in order to be able to quantify percolation below the root zone. Accordingly, soil moisture was measured using soil profiler in four plots (2 from pulley and TDR users and, 2 from RWP and TDR users). The measurement was conducted on weekly basis and the readings were collected from the depths of 10cm, 20cm, 30cm, 40cm, 60cm and 100cm. The average value of VWC of the moisture content was computed from the weekly measurements.

The soil moisture data at 100cm was measured once in a week like the other depth data but two times in a day when measurement was conducted at a minimum difference of four hours to check percolation.

3.3.4 Irrigation scheduling (water management system)

Irrigation scheduling is the decision of when and how much water to apply to a field in order to maximize irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level. Therefore, one can definitely say that Irrigation scheduling saves water and energy. And, all irrigation scheduling procedures consist of monitoring indicators that determine the need for irrigation (Borner, 2005).

Two soil moisture measuring instruments mentioned in 3.3.3.1 1and 3.3.3.2, namely TDR and soil moisture profiler were used to measure the soil moisture. And, basically TDR was used to estimate soil moisture at 12cm soil depth whereas soil profiler was used to estimate soil moisture up to 100cm soil depth.

Irrigation was scheduled based on the actual moisture content of the soil which shows how much the soil is wet or dry.

On the non TDR plots, farmers used their traditional knowledge of irrigation scheduling system. At the days immediately after transplanting, some of these farmers were irrigating their land twice in a day and the rest farmers once in a day. As the seedlings developed, the farmers changed their irrigation schedule. They were irrigating every three to four days. The amount of water irrigated per day was estimated by their observation of the soil. Whenever they saw excess water on the surface of the soil, they would stop irrigating their land.

3.3.5. Estimation of irrigation water (I)

In the plots where TDR was used for irrigation scheduling, the amount of irrigation water to be added to the soil was estimated by measuring the volumetric water content of the soil using the TDR and then changing to volume of water (m^3).

$$S = FC - VWC \qquad 3.2$$

$$NIR = S * D \qquad 3.3$$

$$GIR = \frac{NIR}{ح} ----------------------------- 3.4$$

$$V = GIR * A ------------------------------ 3.5$$

Where;

S is the available soil moisture in %

FC is the field capacity of the soil in %

VWC is the actual water content of the soil read using TDR in %

NIR is the net irrigation depth required in m

D is the root depth of tomato in m

GIR is gross irrigation requirement in m

ح is efficiency of hose irrigation which is estimated to be 0.85.

V is the volume of water which is required to be added to the plot (m^3)

A is the plot area (m^2)

3.3.6. Amount of water applied

After estimating the amount of water to be added to the soil (V) using the method explained in 3.3.5, the volume was converted to liters. The volume was further changed to the number of containers to inform farmers who use TDR easily. For example, if V was calculated to be 0.75 m^3, then this value is changed to liters and equal to 750 liters. This volume was then divided by the volume of bucket that the farmers use to draw water or the volume of the tank in which they store the water. For example, if the volume of the tank is 150 liters, the number of tanks is equal to 750litres/150litre/tank = 5 tanks. Therefore, the farmer was informed to apply 5 tanks of water in one irrigation application to the whole plot. This was done for both the pulley and RWP water lifting technologies, as farmers using both technologies stored the water from the wells using tankers and transported it to plots using buckets.

On the other hand, farmers who use traditional irrigation scheduling system were irrigating their land on the interval they believe is the best from their experience.

Amount of irrigation water applied in either of the measured or traditional methods was recorded at every irrigation application.

For this purpose, the volume of buckets or tanks that the farmers use was measured at the beginning of the study and farmers were always counting the number of full buckets or tanks when they were applying irrigation water. Finally, the number of buckets added was multiplied by the volume of bucket to get the total amount of water applied in one irrigation application for the control (non TDR farmers).

3.3.7. Nature and frequency of water lifting technologies' failure

The frequency of water lifting technology failure is the number of occurrences where the pulley or rope washer pumps failed to function.

To minimize the failure rate and give services at local level, four farmers were trained on RWP maintenance and maintenance tools were provided for those trained farmers to maintain all RWPs. The farmers maintain their own RWPs, but to other farmers' RWP they negotiate on the fee which should be fair. If the training was not provided, the failure of RWPs could have been more than once which is mentioned in table 4.3 of the result section.

The functionality status of technologies was monitored once in a week for the whole study time. The status observed during the visit including whether the irrigation technology was functional or not, the parts failed and reasons for non-functionality were carefully inspected and recorded.

3.3.8. Productivity of technologies

The productivity of technologies was recorded in terms of yield and other yield parameters including plant height and leaf area. The plant height and leaf area were measured three times during the growing period, at initial stage (15^{th} day of transplanting), mid stage (44^{th} day of transplanting) and maturity (77^{th} day of transplanting). The data collected at the 77^{Th} day was the maximum height and leaf area, after which leaf area started to deteriorate due to the shrinkage and falling off of the leaves. The tomato height was measured by erecting a ruler perpendicularly starting from the ground level to the tip of the plant. The length of each branch and its respective width was also measured using ruler. Following this procedure, the height and leaf area of five tomato plants were measured in each plot per measuring day. Then the area computation was done using the following procedure;

- Area covered by one leaf = length * width of a leaf
- Total leaf area of the tomato plant = average area of one leaf * average number of leaves on a plant

The yield of tomato was recorded whenever it was harvested. Farmers were harvesting the tomato frequently and using the tomato for the following purposes;

i. Market
ii. Household consumption
iii. Gift for relatives and friends

Tomato yield harvested at different time for all of the above purposes were recorded and, the total amount of yield was computed for each plot. The yield calculated at each plot was converted to yield per hectare.

3.3.9. Irrigation water productivity computation

Irrigation water productivity is a measure of performance generally defined as the physical quantity or economic value generated from the use of a given quantity of water (Molden et al., 2003). Increasing water productivity to obtain higher output or value for each drop of water applied is key to the efficient use of water in the sub-basin and therefore a very important factor in the comparative analysis of irrigation technologies.

$$\mathrm{IWP} = \frac{\mathrm{Y}}{\mathrm{I}} \quad \text{--------------------------------} \quad 3.6$$

Where;

IWP - is irrigation water productivity in kg/m^3,

Y - is the amount of production in kg/ha;

I - is the amount irrigation water applied in m^3/ha;

Therefore, the yield and irrigation water applied were converted to hectare.

3.3.10. Water Use Efficiency

Water use efficiency was computed to understand the yield produced from each plot with a certain amount of water used by the tomato crop. Efficiency as defined by L.S Perera, 1996 is the ratio of outputs to inputs. Therefore;

$$TWUE = \frac{Y}{ETc} ---------------------------------- 3.7$$

Where;

TWUE – total water use efficiency (kg/m^3),

Y is the yield of tomato (Kg/ha),

ETc - is the total volume of water used by the tomato (m^3). Its unit is in a hectare of land is (ha*mm). Therefore, multiply the depth of water (mm) by 10 to get the volume of water in m^3/ha; since 1ha*1mm = 10000m^2 * 0.001m = 10m^3.

ETc was calculated using the soil water balance method:

$$ETc = P + I - R \pm \Delta S - D -- 3.8$$

Where;

P - is total amount of precipitation in the production season (mm),

I - is the total amount of irrigation water used (added) in the production season (mm),

R – is the total amount of runoff recorded during the production season (mm),

ΔS – is the change in moisture content of the soil (storage) (mm)

D – is the total amount of water percolated in to ground water (mm).

And;

$$\Delta S = Si - Sn ----------------------- 3.9$$

Where;

S_i– is the moisture content of the soil measured with the TDR at transplanting time (mm),

S_n is the moisture content of the soil measured with the TDR at harvest time (mm).

The computation of change in available moisture content of the soil was done to be able to predict the crop water use. Therefore, if moisture content is increased increased from the initial moisture content of the soil, then it was deducted as this moisture is not used by the plant and rather is stored in the soil.

Percolation was checked by measuring the soil moisture using soil profiler to 1m depth.

3.4. Computation of soil available water using Thornthwaite-Mather Method.

The Thornthwaite-Mather method calculates water balance for the crop root zone. It has been successfully applied to water balance for whole watersheds and in calculation of recharge to ground water (Steenhuis and Van der Molen, 1986). The author added, instead of a monthly time step, the Thornthwaite-Mather model can be used on a daily time step; examples of daily time step were included in the original 1957 publication of the Thornthwaite-Mather. The advantage of a smaller time step is that a better resolution in the recharge time series can be obtained (Steenhuis and Van der Molen, 1986).

In this study, Thornthwaite-Mather method was used to estimate the soil available water. Soil moisture was computed in mm depth using this method for each of the plots by the following formulae.

3.4.1 Soil moisture estimation using Thornthwaite-Mather Method

Soil moisture estimation was done using Thornthwaite-Mather method to compare the value with the measured soil moisture using TDR. The formula indicated in equation 2.3 of literature review section was used for the computation of available water in the soil.

$$AWC = (FC - PWP) * D ----------------------------(3.10)$$

Where;

D is root depth in mm

AWC is available water content (mm)

FC is field capacity (%).

PWP is permanent wilting point (%).

The soil moisture content was estimated at 12cm since the length of TDR rods was 12cm.

AW_{t-1} is the initial moisture content of the soil. This was measured at the beginning before applying any irrigation water. AW_t is the water content of the soil at time t. It was computed using the formula given in section 3.4.1.

The amount of water added to the soil was calculated using the following formula;

$$P = J + I ----------------------------------3.11$$

Where;
P = total amount of water added to the soil (mm)
J = amount of water added to the soil in the form of precipitation (mm).
I = amount of irrigation water added to the soil (mm).

3.4.2. Reference Evapotranspiration

The reference evapotranspiration was calculated to be used in the Thornthwaite-mather method for computing available water at any time, t, as stated in section 3.4.1. The ETo was calculated using FAO Penman-Monteith equation (Monteith, 1973).

The equation requires solar radiation, maximum and minimum air temperature, humidity and wind speed data.

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

------------------------------ (3.12)

Where;

ET_o– reference evapotranspiration (mm/day);

R_n–is the net radiation at the crop surface (MJm^{-2});

G - is the soil heat flux density (MJm^{-2} day^{-1});

T – is the mean daily air temperature at 2 m height (^oC)

U_2 – the wind speed at 2m height (m/s),

e_s– the saturation vapor pressure (kpa);

e_a– the actual vapor pressure (kpa).

(e_s- e_a) – the saturation vapor pressure deficit (kpa);

Δ – the slope of vapor pressure curve ($KPaC^{-1}$); and;

γ – psychrometric constant ($KPaC^{-1}$).

The data collected from Bahirdar Meteorological Station (wind speed, sunshine hour, minimum and maximum daily temperature, precipitation, relative humidity) was used for the computation of Reference evapotranspiration. The total amount of water added to the soil which was used for this computation calculated as the sum of precipitation and irrigation water. Then, the available water was computed using the formula indicated in section 3.4.1. A sample calculation of soil moisture is shown in appendix 17.

3.5. Method of Analysis

3.5.1. Normality test

Normality test was conducted before the analysis work to select the appropriate tools to analyze the data.

The normality test was done for comparison of tomato height, leaf area index, yield, irrigation productivity, crop water use and water use efficiency due to effects of water lifting technologies and water management systems. For all of the above parameters, the distributions were found to be normal as the data fall close to the straight lines in the graphs.

3.5.2. Analysis

3.5.2.1 Method of Analysis for comparison of technologies and water management systems.

Analysis was done using SPSS to compare the two water lifting technologies and irrigation scheduling systems. Therefore, the combined effects of water lifting technologies (pulley and RWP) and water management systems (using irrigation scheduling by measuring with TDR and using farmers' traditional knowledge of scheduling) were analyzed and the results were interpreted.

All data collected for the comparison of technologies and water management systems like tomato height, leaf area index, irrigation water, crop water use, yield, water use efficiency, irrigation productivity were analyzed using SPSS.

3.5.2.2 Method of analysis to compare the Thornthwaite-Mather method with measured soil moisture using TDR

The Thornthwaite-Mather model was tested for use for irrigation scheduling by comparing it with the TDR readings. Then the mean soil moisture measured using TDR of each plot and the mean soil moisture of each plot computed using the Thornthwaite-Mather method were compared. The number of plots used for comparison was 9 and 10 in Robit and Dangishta respectively.

The data collected for the comparison of Thonthwaite-Mather method vs. measured soil moisture using TDR was analyzed using F-test and students T-Test. The F-test was used to check whether the variances in the values of soil moisture estimated by the two methods are equal or different. And, knowing this relation between the variances, an appropriate statistical tool was selected.

4. RESULTS AND DISCUSSION

4.1. Baseline survey

The baseline survey conducted on the 18 selected farmers showed that all the farmers have groundwater sources and among them, four have surface water sources (streams). 17 farmers out of 18 (94.4%) said their water source stays for the whole year, whereas one farmer mentioned that his well dries up in February. All of the farmers who said to have a surface water source stated the stream water is used only until January, and then the stream will dry up. All of the 18 farmers use the ground water sources for domestic purposes. Besides, 15 farmers out of 18 (83.3%) were using irrigation before the start of the irrigation project.

Out of the 18 farmers, 11 farmers said they own at least one water lifting technology while the other 7 do not own any. 7 farmers own only pulley, 4 farmers own motor pump. One of motor pump farmers also has a pulley and a RWP. But the RWP was not functioning at the interviewing time as its rope was broken.

Out of the 15 previously irrigation users interviewed, 7 farmers said they use flood irrigation; including all the motor pump users.8 farmers said they convey water by buckets and add it directly to the plant.

11 farmers out of 15 (73.3%) farmers who irrigate their land select the crop to produce based on market information whereas four (26.7%) farmers select the crop/vegetable to produce based on their families consumption demand. Out of 15 farmers who used irrigation previously, 11 farmers plant Khat; 7 farmers of these farmers also produce vegetables and 4 them also produce mango, coffee, and other cash crops like ‘’Gesho’’ (ingredient for preparing local brew, called tella). Non-Khat farmers produce vegetables, mango, coffee and Gesho using groundwater.50% of the farmers (9 out of 18) have the experience of producing tomato either in Meher (main rainy season) or irrigation previously while the other 50% didn’t have. The farmers’ wells ranged from 6 to13.5m in depth (Appendices1&2). The summary of the baseline results is shown in Appendix 35 and 36.

4.2 Soil physiochemical results

Soil samples were taken by auger at depths of 0 to 20cm from each plot. The plots' soil texture varied from clay to clay loam to loam and to sandy loam. Seven of the plots are with clay soils, five plots with clay loam, six plots loam and one plot sandy loam.

The pH of the soil varied from plot to plot, the minimum and maximum pH of the soil being 5.4 and 7.16 respectively and, the average was 6.4.The field capacity and permanent wilting point of the soils was also determined. The average field capacity was VWC 37.27% (223.63mm) and average wilting point was VWC 22.60% (135.59mm) at 600 mm effective root depth of tomato. Therefore, the average available water content of the soil was 88.04mm. The average EC and CEC were 0.11dS/m and 18.43% respectively. The plots had an average organic matter of 3.58%, total nitrogen of 0.179%, phosphorus of 32.9 ppm, and iron of 12.83 ppm. The detailed results of soil physiochemical properties' analysis are shown in Appendix 4. All the physiochemical properties were not significantly different across fields allocated to pulley and RWP (Table 4.1).

Table 4-1 Average soil laboratory results.

	pH (H_2O)	**EC**	**CEC**	**OM**	**TN**	**Av. P**	**Fe**	**FC**	**PWP**
	1:2.5	**dS/m**		**%**		**Ppm**		**%**	
Pulley	6.50	0.12	17.49	3.63	0.18	37.02	13.31	37.22	22.19
RWP	6.19	0.10	20.43	3.48	0.17	24.18	11.79	37.39	23.48
p-value	0.122	0.682	0.152	0.870	0.873	0.407	0.571	0.924	0.243

4.3. Performance of technologies

4.3.1**.** Discharging capacity of technologies

The discharging capacity of technologies at each well depth is shown in Table 4.2. However, since the depth of wells is not equal for all of the plots, the plot owners have differences in sex, age and physical strength; it is difficult to conclude that the difference in discharge among wells is due to the performance of technologies.

Table 4-2 Discharging Capacity of Water Lifting Technologies

S/N	Plot ID	Technology type	Well depth (m)	Sex of House owner	Discharge (l/min)
1	RTd 5	RWP	6	M	13.1
2	RTd 6	RWP	8	M	4.4
3	RNTd13	RWP	8	M	9.0
4	RNTd 14	RWP	13	M	2.1
5	RTd15	RWP	6	F	13.3
6	RTd 16	RWP	6	M	6.7
	Mean				**8.1**
	SD				**4.57**
7	PTd1	Pulley	6	M	6.1
8	PTd2	Pulley	12	F	5.2
9	PTd3	Pulley	10	M	6.8
10	PTd4	Pulley	15	F	9.8
11	PTd7	Pulley	11	F	15.8
12	PNTd8	Pulley	13.5	M	16.6
13	PNTd 9	Pulley	15	M	13.8
14	PNTd 10	Pulley	14	M	20.3
15	PNTd 11	Pulley	10	M	12.7
16	PNTd 12	Pulley	13	M	13.55
	Mean				**13.42**
	SD				**6.9**

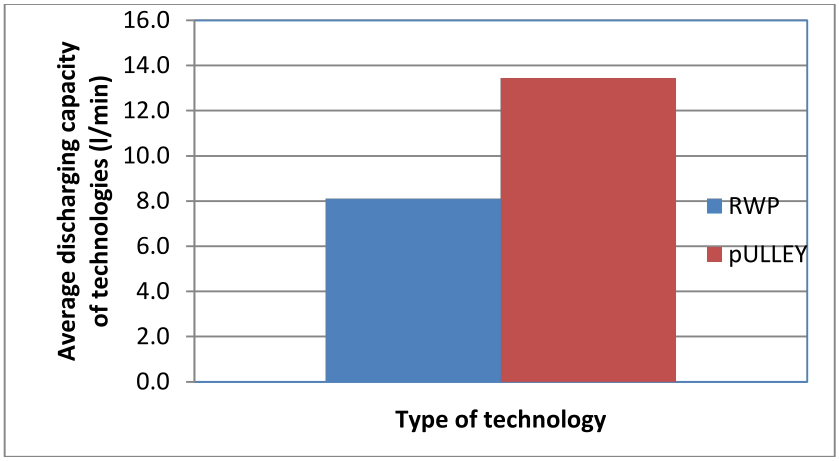

Figure 4-1 Discharging capacity of Water Lifting Technologies

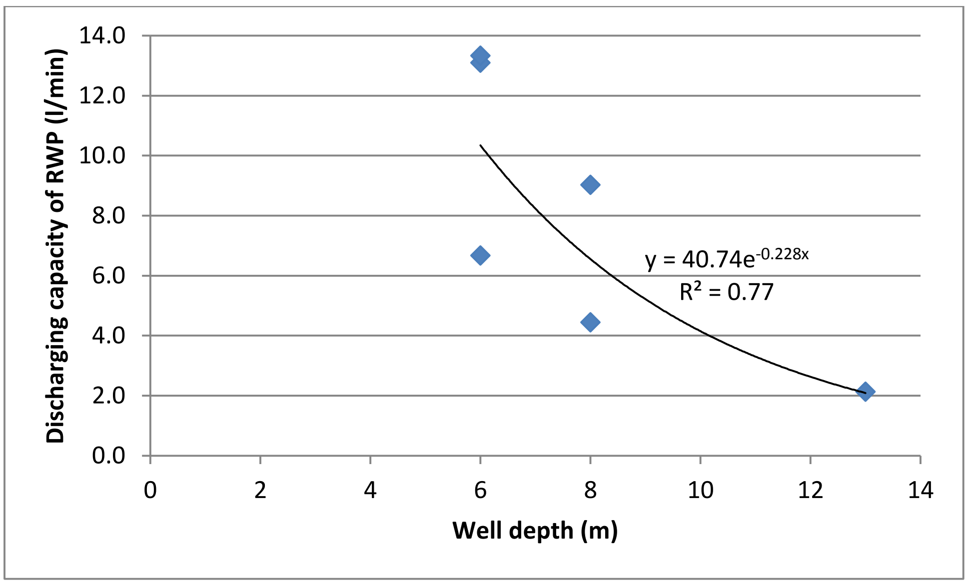

Figure 4-2 Discharging capacity of RWP with depth

The discharge from RWP decreases as the well depth increases and, the relationship between discharging capacity of the RWP and well depth is exponential as shown in Figure 4.2. This is because the weight of water increases with increasing well depth. Therefore, it is easier and faster to lift less weight than when the weight increases. Therefore, RWP is found to be easier to lift water on shallow depth wells than on deeper wells.

There was no direct relation observed on discharging capacity of pulley with depth. The following are the justifications for the no relationship between depth and discharging capacity of pulley.

- Plot ID 8, 11 and 12 were relatively at the lower part of the watershed near Lake Tana. Therefore, the well yield was reliable throughout the season.
- All of the farmers working on Plot ID 8, 9, 10, 11, 12 were male, healthy and with ages between 20 – 45 years. Therefore, the reason for drawing more water is the energy difference due to sex difference.
- In plot ID1, most of the family members engaged in lifting water from the well were his son (at age of around 15) and his daughter (at age of around 18). Therefore, the low discharge at shallower well depth may be due to energy difference due sex and age differences.
- In plot ID7, the farmer is a woman. She was sick during the course of the study (she has broken her hand) and it was her daughter who was working throughout the tomato production season. Her daughter just graduated from grade 12 and is physically strong. Therefore, the reason for higher discharge compared to others may be due to the energy of the woman working in the farm.
- In plot ID2, the well is 12m deep and the discharge is relatively low. The well is at the upper hill of the water shed. The plot owner who does the irrigation activities was breastfeeding at the time of the study. Therefore, the reason could be; the discharge of well since the well is deeper, low energy compared to males and other women since she was breastfeeding.

4.3.2. Nature and frequency of Irrigation technologies failure.

On average, RWP failed once for every farmer in one tomato production season whereas pulley did not fail at all. Table 4.3 shows the number of failures occurred in the whole production season by each technology.

Table 4-3 Frequency of irrigation technology failure

Plot ID	Type of technology	Frequency of technology failure	The average number of days the failure lasted
RTd5	RWP	3	6
RTd6	RWP	0	
RTd17	RWP	1	8
RNTd13	RWP	1	7
RNTd14	RWP	1	8
RTd15	RWP	1	5
RTd16	RWP	0	
Sub Total		**7**	
Average		**1**	
PTd1	Pulley	0	
PTd2	Pulley	0	
PTd3	Pulley	0	
PTd4	Pulley	0	
PTd7	Pulley	0	
PNTd8	Pulley	0	
PNTd9	Pulley	0	
PNTd10	Pulley	0	
PNTd11	Pulley	0	
PNTd12	Pulley	0	
Sub Total		**0**	
Average		**0**	

Most of the problems seen on RWP were: loose joints, breaking of the nylon rope, poor installation of technology (delivery PVC not erected perpendicularly). The technologies were maintained immediately since farmers were trained on pump maintenance.

4.3.3. Performance of lifting technologies and irrigation scheduling methods

Results of the Normality test shown in Appendix 7 indicate that the data distribution to compare the mean yield, plant height, leaf area, irrigation water productivity, ETc, and WUE due to the combined effects water lifting technologies and water management system is normal. Appendix7 shows the Q –Q plots of the data distributions around the means. The data are close to the straight line indicating that the distribution is normal for all of the parameters.

Table 4-4 WUE and Irrigation Productivity of all plots

Code	Yield in kg/ha	Irrigation water applied (mm)	Rain (mm)	Soil moisture at transplanting (mm)	Soil moisture at harvest (mm)	ETc	WUE (Kg/m^3)	Irrigation productivity (kg/m^3)
PTd1	18185	962	272	8.8	30.2	1212	1.50	1.89
PTd2	42504	1054	272	6.8	29.6	1304	3.26	4.03
PTd3	52891	1260	272	6.5	38.0	1501	3.52	4.20
PTd4	74880	674	272	8.9	31.6	924	8.11	11.11
RTd5	20694	742	272	10.2	30.3	994	2.08	2.79
Rtd6	60966	687	272	8.2	36.8	931	6.55	8.87
PNTd7	17911	661	272	14.5	33.4	915	1.96	2.71
PNTd8	95391	585	272	7.6	32.4	833	11.46	16.30
PNTd9	63595	1044	272	6.8	30.2	1293	4.92	6.09
PNTd10	94110	1082	272	7.1	30.9	1330	7.07	8.70
PNTd11	74800	997	272	8.2	29.8	1247	6.00	7.50
PNTd12	78360	955	272	7.5	31.5	1203	6.51	8.21
RNTd13	5295	635	272	10.1	28.8	889	0.60	0.83
RNTd14	12156	372	272	7.2	34.0	617	1.97	3.27

Table 4-5 Summary of Comparison of Water lifting technologies and water management systems

	Irrigation applied (mm)	ETc (mm)	Yield (kg/ha)	WUE (kg/m^3)	Irrigation productivity (kg/m^3)
Lifting technology					
RWP	609	858	24778	2.89	4.1
Pulley	927	1176	61263	5.21	6.6
Irrigation scheduling					
TDR	897	1144	45020	3.93	5.02
Control	791	1041	55202	5.3	6.98

Table 4-6 Summary of Significance on differences of different parameters with respect to water lifting technologies (WL) and water management (WM) systems

Comparisons	**p-value at 5% significance level**		
Parameter	**WL×WM**	**WL**	**WM**
Irrigation water (mm)	0.665	0.025	0.239
Crop water use (ETc) (mm)	0.664	0.024	0.242
Yield (kg/ha)	0.098	0.049	0.786
WUE (kg/m^3)	0.156	0.190	0.818
Irrigation productivity (kg/m^3)	0.296	0.388	0.747

4.3.3.1. Amount of irrigation applied

The amount of water applied by each farmer is shown in Table 4.4. The interaction between lifting technology and irrigation scheduling method was not significant for the amount of irrigation applied (Table 4.6). The difference in the irrigation water applied using the pulley and rope washer pump technologies was significant; more water was applied with the pulley (927 mm) when compared to the 609 mm applied using RWP (Table 4.5).This was due to: 1) RWP has lower discharging capacity than pulley which also decreases with increase in well depth (figure 4.2) and 2) RWP had more failures than pulley as shown in table 4.3.

The irrigation interval was such TDR farmers irrigate their land usually every three days but decided on the value of the TDR reading. In the presence of rainfall, there was no irrigation unless the soil moisture was measured to be less than required. Farmers who used traditional irrigation system also irrigated their land once in three days, sometimes once in four days. Although plots whose irrigations were scheduled using TDR had more applied water (897 mm) than the 791 mm applied based on farmers' practice, the difference in irrigation amounts was not significant (Table 4.6).

4.3.3.2 ETc

ETc was determined using the soil moisture balance equation 3.7, and the results of ETc is shown in table 4.4.

The data showed that almost of the moisture readings were less than field capacity, which means there was no excess water observed. The application method was also by adding using cans on the plant. Therefore, there was no run off created. This was checked by observing the plots to see if there is exess water coming out of the plots. But there was no run off observed to flow out of the plots. Therefore, runoff was considered to be zero. That is;

R = 0.

Percolation was checked by measuring the soil moisture using soil profiler to 1m depth. Figure 4.7 indicates soil moisture contents up to 1m depth throughout the tomato growing season for one of the plots where soil profiler readings was taken. There were minimal changes in soil moisture below 60 cm, the effective rooting depth of the tomato. Also, soil moisture below 60 cm was always below field capacity indicating that deep percolation was negligible and hence taken as zero (D=0).

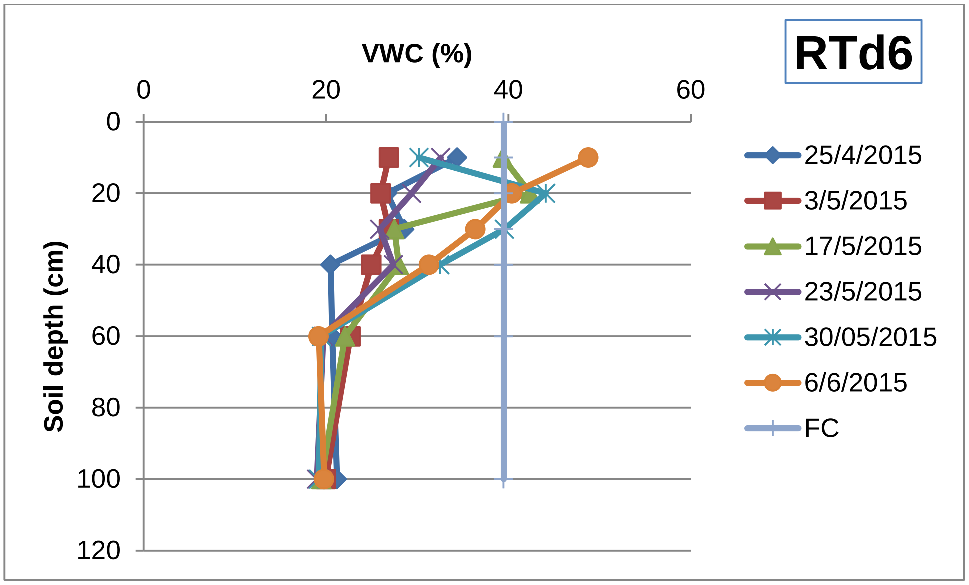

Figure 4-3 Average Soil Moisture with Depth of Water of plot RTd6

The summary of crop water use (ETc) is shown in table 4.5. A two factorial analysis was conducted, type of lifting technology and irrigation scheduling method. The interaction between lifting technology and irrigation scheduling was not significant for the cop water use (p = 0.664) (table 4.6). The difference in crop water use between pulley and RWP was significant (p = 0.024). This was because more water was lifted and irrigated by pulley when compared to RWP as mentioned in 4.3.3.1. And, although the crop water use was higher with TDR users (1144mm) when compared to the crop water use in traditional irrigation scheduling user farmers (1041mm), the difference was not significant as indicated in table 4.6 (p=0.242).

4.3.3.3. Plant height

The plant height measured at 3 growth stages as shown in Table 4.7.A two factorial analysis was conducted: type of technology and irrigation scheduling method. There was no interaction between type technology and irrigation scheduling method for plant height (p-value = 0.061).There was no significant difference on the average height of tomato using the irrigation technologies of RWP and pulley (p-value = 0.076) and water management systems (p = 0.457) (Table 4.9 and Appendix 8).

Table 4-7 Plant height of tomato at different growth stages due to using different technologies and water management systems.

	Plant Height (cm)- Pulley			
Code	15th day of transplanting	44th day of transplanting	77th day of transplanting	Average of the growing stages
PTd1	11	31	61.5	34.5
PTd2	15	32	67.5	38.2
PTd3	11	29	52	30.7
PTd4	13	26	42	27.0
Average ptd	12.5	29.5	55.8	32.6
STDV PTd	1.9	2.6	11.2	4.8
PNTd7	13	25	45	27.7
PNTd8	18	40	95	51.0
PNTd9	21	37	87	48.3
PNTd10	18	36	89	47.7
PNTd11	18	35	87	46.7
PNTd12	17	28	82	42.3

Average PNtd	17.5	33.5	80.8	43.9
STDV PNtd	2.6	5.8	18.0	8.5
Average Pulley	15.5	31.9	70.8	39.4
STDV Pulley	3.3	5.0	19.8	9.3

Plant Height (cm)- RWP

Code	15th day of transplanting	44th day of transplanting	77th day of transplanting	Average of the growing stages
RTd5	15	28	50	31.0
RTd6	14.5	30	61	35.2
Average RTd	14.8	29.0	55.5	33.1
STDV RTD	0.4	1.4	7.8	2.9
RNTd13	15	28	44	29.0
RNTd14	12	26	42	26.7
Average RNTd	13.5	27.0	43.0	27.8
stdv RNTD	2.1	1.4	1.4	1.6
Average RWP	14.1	28.0	49.3	30.5
STDV RWP	1.4	1.6	8.5	3.6

4.3.3.4 Leaf area

The tomato at the 15th day of transplanting was at initial stage, and therefore, the area coverage of the land by leaves (leaf area index) was small. At the later stages both height and leaf area increased, of which the maximum height and leaf area index was attained at the 77th day of transplanting. And, the days after the 77th day of transplanting, the leaf area index started to reduce due to the shrinkage and falling off leaves.

The leaf area calculated in %age of land is shown in Table 4.8.A two factorial analysis was conducted: type of technology and irrigation scheduling method. There was no interaction between type technology and irrigation scheduling method for LAI (p-value =

0.207). There was no significant difference on the LAI using the irrigation technologies of RWP and pulley (p-value = 0.17) and water management systems (p = 0.495) (Table 4.9, Appendix 8).

Table 4-8 Leaf Area Index (LAI) at different growth stages of tomato

	Pulley Leaf Area Index (%)			
Code	15th day of transplanting	44th day of transplanting	77th day of transplanting	Average of the growing stages
PTd1	2.4	42.5	80.1	41.7
PTd2	5.3	56.9	78.9	47.0
PTd3	2.4	39.2	76.7	39.4
PTd4	3.2	20.0	70.1	31.1
Average ptd	3.3	39.7	76.5	39.8
STDV PTd	1.4	15.2	4.5	6.6
PNTd7	3.2	17.4	72.3	31.0
PNTd8	14.7	84.7	92.8	64.1
PNTd9	21.2	75.6	89.5	62.1
PNTd10	14.7	67.0	89.5	57.1
PNTd11	14.7	64.2	84.7	54.5
PNTd12	6.5	38.7	81.6	42.3
Average PNtd	12.5	57.9	85.1	51.8
STDV PNtd	6.5	25.2	7.4	12.8
Average Pulley	8.8	50.6	81.6	47.0
STDV Pulley	6.7	22.7	7.5	12.4

	RWP Leaf Area Index (%)			
Code	15th day of transplanting	44th day of transplanting	77th day of transplanting	Average of the growing stages
RTd5	5.3	30.2	78.3	37.9
RTd6	4.2	37.6	78.9	40.2
Average RTd	4.8	33.9	78.6	39.1
STDV RTD	0.8	5.2	0.4	1.6
RNTd13	6.5	30.9	78	38.5
RNTd14	2.3	28.1	65.9	32.1
Average	4.4	29.5	72.0	35.3

RNTd				
stdv RNTD	3.0	2.0	8.6	4.5
Average RWP	4.6	31.7	75.3	37.2
STDV RWP	1.8	4.1	6.3	3.5

Table 4-9 Summery of differences (p) on the comparison of H and LAI on pulley and RWP lifting technologies on TDR and traditional irrigation scheduling systems

Parameter	WM*WL	WL	WM
H	0.061	0.076	0.457
LAI	0.207	0.17	0.495

4.3.3.5 Yield

The productivity of water lifting technologies which was measured in terms of yield is shown in table 4.4.

A two factorial analysis was conducted; type of technology and irrigation scheduling method. There was no interaction between type of technology and irrigation scheduling method for yield (p-value = 0.098). The yield comparison of the two technologies in Table 4.5 shows that farmers who used pulley produced more than farmers who used RWP. The average yield from plots irrigated using pulley was 61,263kg/ha and that of the RWP plots was 24,778kg/ha. This is because more water was applied with pulley as seen above than the RWP which facilitated better yields. There was no significant difference on the mean yield produced using the irrigation technologies of RWP and pulley (p-value = 0.049).Yield for both lifting technologies generally increased with increase in the amount of water applied (Figure 4.4)

Table 4.5 shows that plots where the farmers' practice was used yielded more tomato(55,202kg/ha) than those whose irrigations were scheduled using the TDR (45,020kg/ha).The difference between the mean yield of plots which used traditional irrigation scheduling and those where TDR was used were not significant (p-value = 0.78).The reason can be, most of the farmers in Robit kebele have irrigation experience, and since they irrigate several crops other than the tomato from the same sources, even with the farmers' traditional practice, they try to ration water appropriately to prevent wastage of the scarce resource.

There were a number of occurrences of tomato diseases and pests which affected the yield in some plots. There were diseases and pests in plots of PTd2, RTd5, and PNTd9. Particularly before the first harvest, these plots were affected by a disease called Blosom-Endrot. There was also a cut worm on plots PTd2, RTd5, and PTd7. The tomato diseases and pests were prevented by spraying with chemicals like Ethiodemetrin and Unizeb. Moreover, all of the plots were sprayed once in a week with a fungicide called Ridomel to prevent the tomato from diseases. The tomato of PTd1, PTd3 and RTd6, RNTd13 and RNTd14 plots were also grazed by a wild animal called Porcupine (local name Jart).The wild animal was prevented by reinforcing the fence of each plot. The plots of PTd1, PTd3 and RNTd14 were also affected by hail during the harvest period.

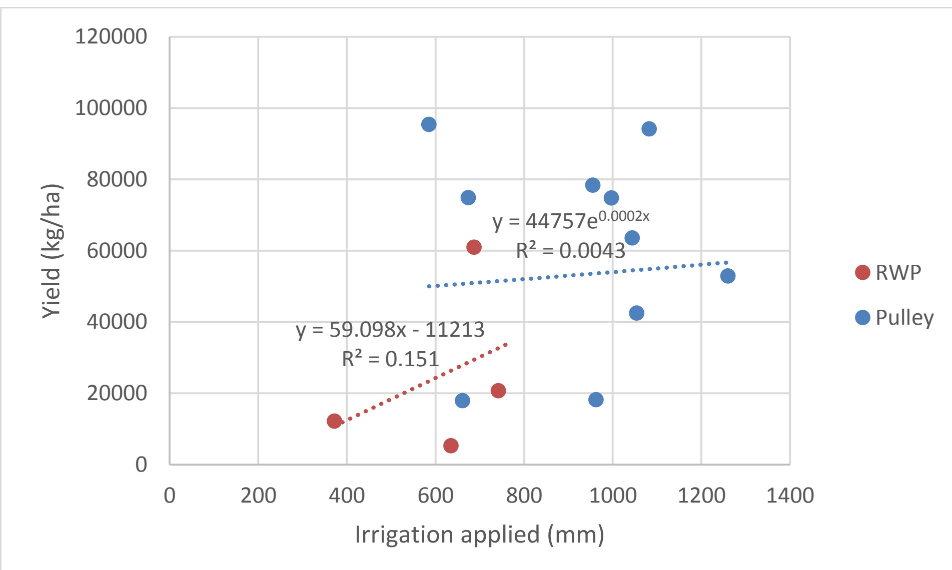

Figure 4-4 Yield (kg/ha vs. amount of irrigation water applied (mm)

As shown in figure 4.4, the amount of yield increases with increasing irrigation water applied for the tomato on both pulley and RWP technologies. However, the slope is higher on RWP than pulley, suggesting that more yield can be gained by adding small amount of water on RWP technology. The slope of the line on pulley is small suggesting that small amount of yield increase can be gained by adding irrigation water applied for the tomato.

4.3.3.6. Water use efficiency

A two factorial analysis was conducted; type of lifting technology and irrigation scheduling method. There was no interaction between the type of lifting technology and irrigation scheduling method for WUE ($p = 0.156$).The WUE comparison in table 4.5 shows that, farmers who produced using pulley have higher WUE than farmers who produced using RWP. The average WUE in plots irrigated using pulley was 5.21kg/m^3 and that of RWP plots was 2.89kg/m^3. However, as indicated in table 4.6, the difference in average WUE due the difference in lifting technology was not significant ($p = 0.19$).

As indicated in figure 4.5, WUE increased with increasing the amount of irrigation water applied, whereas for pulley (where the amount of irrigation water was significantly higher than the RWP), the WUE decreased with increasing irrigation water applied. The implication here is that water applied with pulley can be reduced without affecting tomato production and thus saving on water.

Table 4.5 shows that plots where the farmers used traditional irrigation scheduling systems have higher WUE (5.3kg/m^3) than those whose irrigations were scheduled using the TDR (3.93kg/m^3). However, the difference between the mean WUE of plots which used traditional irrigation scheduling and those where TDR was used were not significant ($p = 0.818$). This could be because higher yield was recorded on plots which used traditional irrigation methods than plots which used TDR for irrigation scheduling.

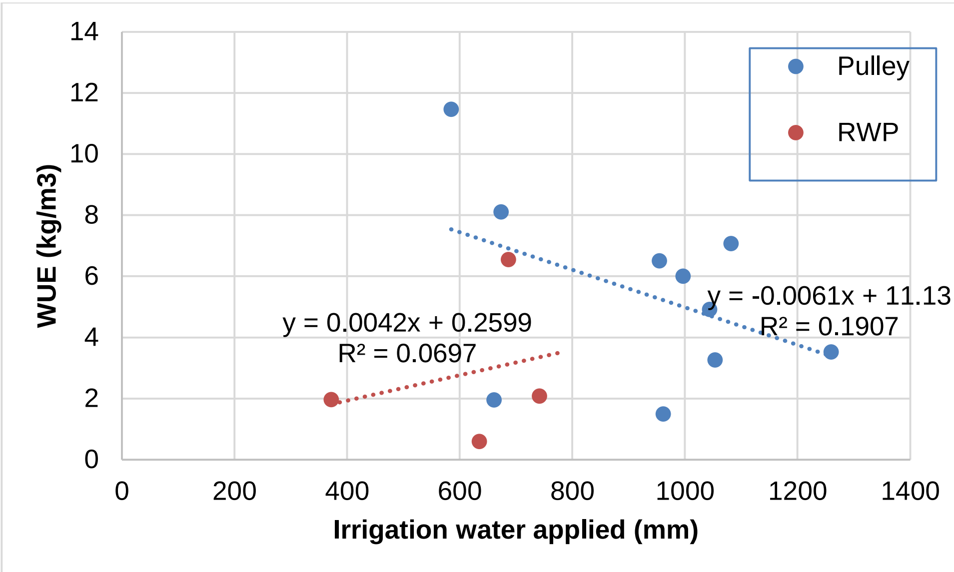

Figure 4-5 WUE (kg/m^3) vs. amount of irrigation water applied (mm)

As shown in figure 4.5, for RWP, WUE increases with increasing irrigation water, whereas for pulley irrigation productivity decreases with increasing irrigation water. This shows that the amount of water added using pulley can be reduced without affecting yield and the water can be used to irrigate extra land.

4.3.3.7. Irrigation productivity

A two factorial analysis was conducted; type of lifting technology and irrigation scheduling method. There was no interaction between the type of lifting technology and irrigation scheduling method for irrigation productivity ($p = 0.296$).The irrigation productivity comparison in table 4.5 shows that, farmers who used pulley have higher irrigation productivity than farmers who produced using RWP. The average irrigation productivity in plots irrigated using pulley was 6.6kg/m^3 and that of RWP plots was 4.1kg/m^3. However, as indicated in table 4.6, the difference in average irrigation productivity due the difference in lifting technology was not significant ($p = 0.388$).

Table 4.5 shows that plots where the farmers used traditional irrigation scheduling systems have higher irrigation productivity (6.98kg/m^3) than those whose irrigations were scheduled using the TDR (5.02kg/m^3). However, the difference between the mean irrigation productivity of plots which used traditional irrigation scheduling and those where TDR was used were not significant (p = 0.747). This was because higher yield was recorded on plots which used traditional irrigation methods than plots which used TDR for irrigation scheduling.

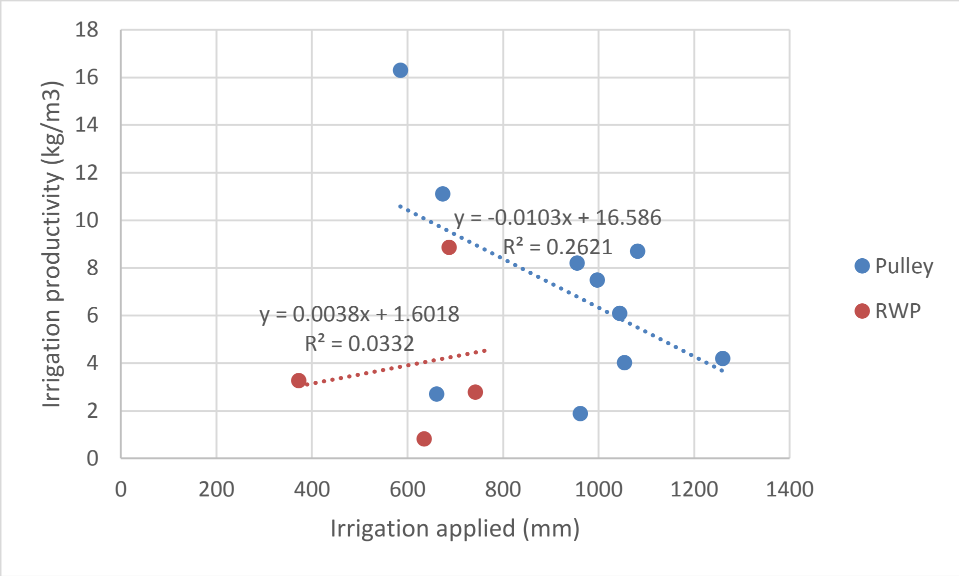

Figure 4-6 ***Irrigation Productivity (kg/m3) vs Irrigation water applied (mm)***

As shown in figure 4.6, for RWP, irrigation productivity increases with increasing irrigation water, whereas for pulley irrigation productivity decreases with increasing irrigation water. This shows that the amount of water added using pulley can reduced without affecting yield and used to irrigate extra land.

4.4 Comparison of available soil water estimation - computed using Thornthwaite-Mather Method versus measured soil moisture using TDR.

This study was conducted by computing the available water content of the soil on daily basis using Thornthwaite-Mather method to test the model if it can be used for irrigation scheduling. The study used the combination of Penman-Montheith and Thornthwaite--Mather methods; the Penman-Montheith method to calculate reference evapotranspiration and the Thornthwaite-mather method to calculate available water in the soil. Appendix 18 shows the detail computed values of plot RT3 of Dangishta kebele. The graph of the computed soil moisture using TWMM method vs. measured soil moisture using TDR of this plot is shown in figure 4.9.The mean values of the computed soil moisture using TWMM and measured soil moisture using TDR are shown in Appendices 27 (for Dangishta) and 28 (for Robit) kebele plots.

The relationship between the available water computed using TWMM Model and measured soil moisture using TDR was analyzed using F – test, Students T – test, and R- square. The analysis results of F test and T test are shown in Appendices 14 -16.

4.4.1 Results of the Analysis in Dangishta kebele.

The analysis was done first on data collected from 9 plots.

F test was conducted as the first step to do the T – test to choose the analysis tool of either equal variance or unequal variance in the T - test. The analysis of the F – test shows, the variances of the two variables are different (7.5 and 2.6).

The value F- statistic is also less than Fcrit (2.9 < 3.4). P-value = 0.08which shows there is significant difference between the two means and, the null hypothesis which says that the two means are equal is rejected.

The T test analysis shows that, $t_{stat}<t_{critical}$, that is 1.4 < 1.8. In other words, $-t_{crit}<t_{stat}<t_{crit}$ is fulfilled since -1.8<1.4<1.8is true. And the value of p = 0.09, which means there is no significant difference at 5% significant level. Therefore, the null hypothesissaying that the two means are equal is accepted.

4.4.1.2 Results of the Analysis in Robit kebele.

F–test was conducted first to understand whether the variances of the two variables are equal or different in order to analyze the data using T – test. The variances of the two variables are 4.47 and 2.06 (different). The value of F was also less than F_{crit} (1.34 < 3.18), and the value of p is 0.34, which also shows the null hypothesis is accepted.

The data was also analyzed using T – test. The value of t_{stat} is 1.2, the value of t_{cirt} is 1.73 which shows that the condition $- t_{cirt} < t_{stat} < t_{cirt}$ is fullied since: -1.73 <1.2 < 1.73 which shows that the null hypothesis saying that the values of the two means is equal is fulfilled. The value of p is also 0.12 which shows that the variation between the two means is not significant.

<u>R – Square</u>

The R^2 value of the comparison of TWMM vs. measured using TDR as indicated in figure 4.7 is 0.837 which is acceptable to say the two variables (the soil moisture computed using TWMM and Measured using TDR) have linear relationship. The value of R^2 of the analysis of the data collected from Robit watershed as shown in figure 4.8 is 0.913. Therefore, in all cases (inDangishta and Robit), R^2 is high which shows that there is strong relationship between the two variables.

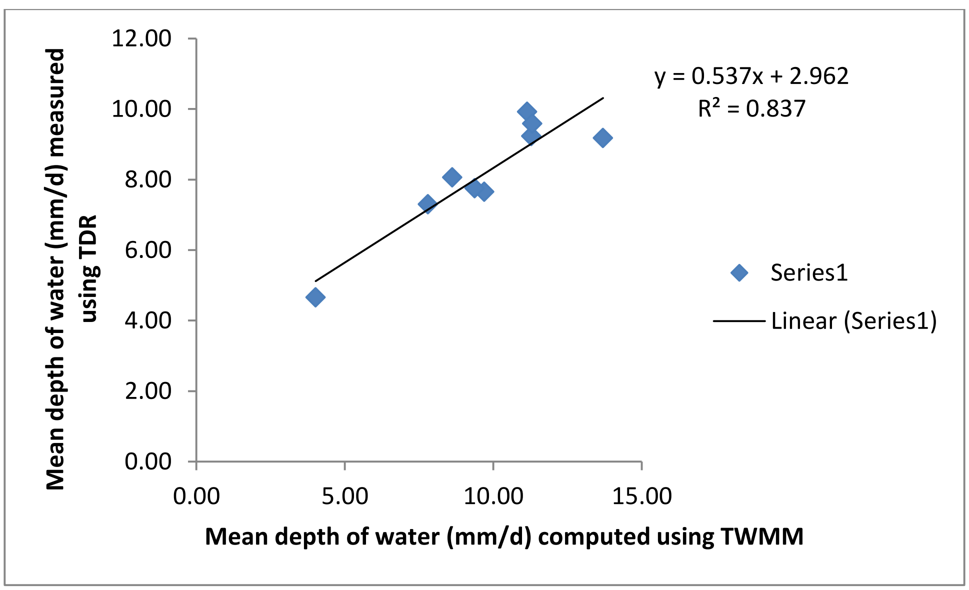

Figure 4-7 Soil Moisture computed using TWMM VS Measured using TDR for Dangishta kebele.

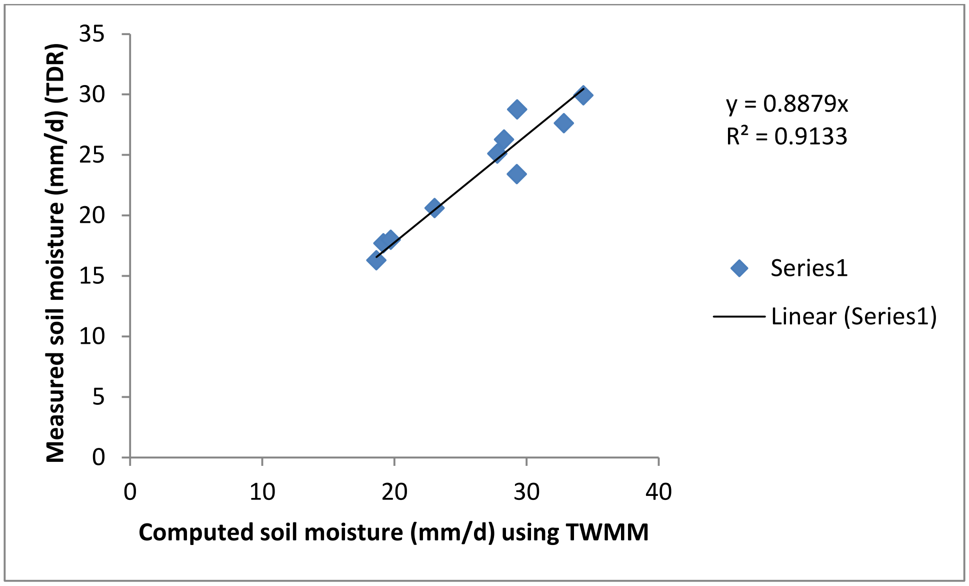

Figure 4-8 Comparison of mean values of soil moisture computed using TWMM vs. measured using TDR in Robit kebele.

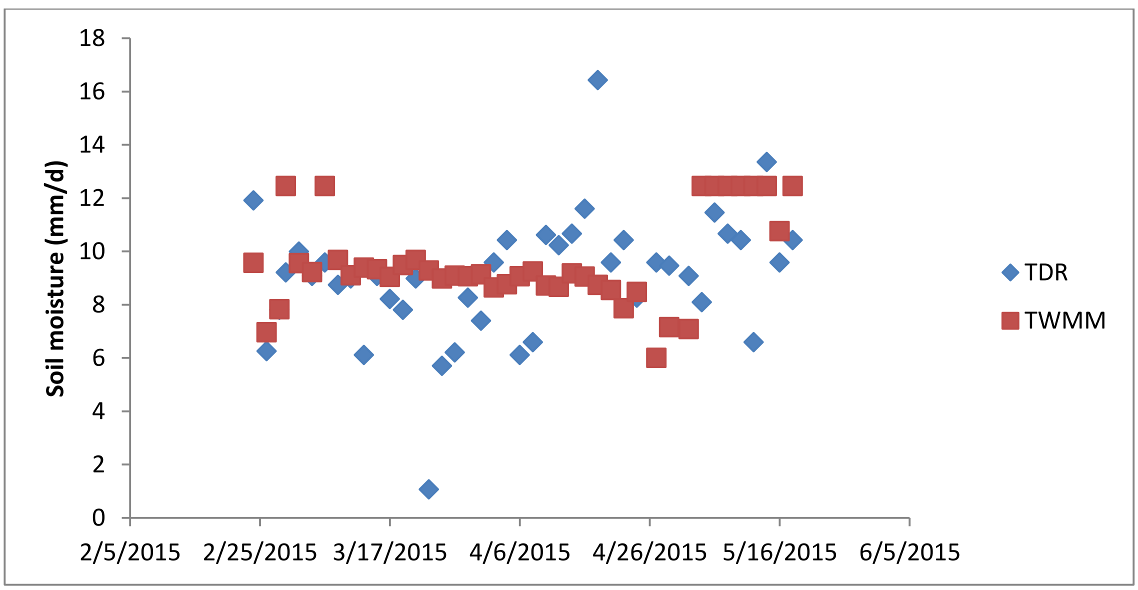

Figure 4-9 Comparison of TWMM VS TDR in plot RT3 of Dangishta kebele (red TDR and blue TWMM)

Table 4-10 Summary of significance (P) and R^2

Site	P	R^2
Dangishta-(number of plots = 9)	0.09	0.837
Robit – (number of plots =10)	0.12	0.91

The result in this study is the mean of the Thornthwaite-Mather method and measured (using TDR) are almost the same so that TWMM method can be used in place of TDR to estimate the amount of water required for irrigation for the whole irrigation season at any type of soil. When the measured soil moisture increase, the total computed soil moisture using TWMM increase and vice versa.

Steenhuiset al. (1986) applied the TWMM to water balance for the whole watershed and in calculations of recharge to ground water. However, this study has shown that the model can also be used to predict irrigation scheduling at plot level.

5 Conclusion

The analysis done using SPSS has shown that there was no interaction between lifting technologies and the irrigation scheduling methods for tomato height, leaf area index, amount of irrigation water applied, ETc, yield, WUE and irrigation productivity. Single factor analysis for only lifting technology of irrigation water, crop water use and yield shows significant differences between the pulley and the RWP in which the pulley had better results. Tomato yield generally increased with increase in the amount of irrigation water applied. The irrigation productivity and the WUE though were not significantly different across the two lifting technologies. Both WUE and irrigation productivity decreased with increasing amount of water applied using the pulley suggesting that there is potential to decrease the amount of water applied to the tomato crop and still be able to maintain the yield. This means, there was a potential to expand the irrigation area to some extent and get higher yield than actually harvested. Due to the good performance of the pulley, its low cost, and it having no maintenance and repair issues, the farmers in Robit prefer it to the RWP. The performance of the RWP in Robit kebele has been poor since its introduction a few years ago due to its frequent failures.

Single factor analysis of only the irrigation scheduling methods; using TDR measurements vs. farmers' practice showed no significant differences in irrigation water applied, crop water use, yield, WUE and irrigation productivity.

The study was constrained by the prevalence of tomato pests and diseases during the growing season. Also in some plots, due to poor fencing, wild animals would graze of the tomato crop. Hail also affected yields in some plots.

The significance tests done using F-test, T-test and linear regression showed that the daily soil moisture content computed with the TWMM closely matched the soil moisture measurements taken with the TDR. The TWMM can therefore be used to predict the total amount of water for irrigation required for the whole season.

6. Recommendations

The pulley has lower initial investment cost (on average 1350 Birr per pulley plus tank) than RWP which goes for 4075 Birr per RWP, and lower maintenance requirement. Therefore, taking all of the above mentioned factors in to account, the author recommends Pulley for Robit community instead of RWP.

The author also recommends the use of the tomato hybrid variety (called Shanty PM) with close monitoring of vegetable protection experts as its productivity is high in spite of its vulnerability to diseases and pests. The seedlings preparation should be done in the farmers plots instead of in communal land so that the seedlings will adapt the general conditions around the plots, farmers will experience producing the seedlings, and to get better accountability as farmers who produce their seedlings will be accountable than nursery workers who produce the seedlings of other farmers.

The analysis result shows that there is strong relationship between the means of the available water in the soil computed using Thornthwaite-Mather method and measured by the TDR. Therefore, it is concluded that Thornthwaite-Mather method can be used to quantify the total amount of irrigation water required for the whole irrigation season.

The author recommend that further researches should be conducted the ability of TWMM to use for irrigation scheduling.

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8. APPENDICES

Appendix 1 – Summary Baseline results

S/N	Description	No. of respondents	No. of respondents who said yes	No. of respondents who said No.	% who said Yes	GW only	Surface water only	Both GW and SW
1	Does the HH currently have a source of water for irrigation?	18	18	0	100			
2	Is the HH currently practicing any irrigation?	18	15	3	83.33			
4	Does the well you want to use irrigation stay the whole year	18	17	1	94.44			
5	Have you the experience of producing tomato in Meher or Irrigation	18	9	9	50			
6	Do you have water lifting technologies?	18	11	7	61.11			
7	If yes, what are the current sources of water for irrigation?	18				14		4

Appendix 2 – Summary of the baseline results

S/N	Description	Market information	Consumption demand	N/A	Vegetables	Chat	Fruits and Gesho	Motor Pump	Pulley	RWP
1	How do you decide which crops to favor for irrigation? (only if the household is already doing irrigation)	11	4	3						
2	What types of crops you produce using irrigation?				7	11	5			
3	Which water lifting technology do you own?							4	7	1

Appendix 3 - Available Water Content of Soils at each Plot

Farmer code	pH (H2O) 1:2.5	FC	PWP	AWC in %	AWC in mm	Length of TDR rod, m	AWC in mm
PT2	5.76	32.90	21.05	11.85	11.85	0.12	14.22
RT3	5.13	32.32	20.11	12.21	12.21	0.12	14.65
PT8	5.4	30.92	20.34	10.58	10.58	0.12	12.69
PT11	6.3	32.21	20.70	11.51	11.51	0.12	13.812
PT12	6.1	33.67	20.66	13.01	13.01	0.12	15.61
RWT13	7.11	38.49	23.75	14.74	14.74	0.12	17.68
RWT15	6.53	30.64	21.12	9.52	9.52	0.12	11.42
PT17	6.1	26.00	20.61	5.38	5.38	0.12	6.46
RWT22	5.5	31.95	19.92	12.03	12.03	0.12	14.44

Appendix4 - Soil Physiochemical properties

		pH (H_2O)	EC	Texture	CEC	OM	TN	Av. P	Fe	FC	PWP
Sr.No	Code	1:2.5	dS/m	Class		%		ppm		%	
1	RTd5	5.57	0.04	clay	23.2	3.12	0.16	6.09	11.35	37.24	22.62
2	RTd6	6.08	0.06	clay loam	25.8	1.69	0.08	3.44	7.991	39.49	28.56
3	PTd3	6.27	0.05	clay loam	22.4	2.28	0.11	16.64	8.097	35.13	21.23
4	RTd16	6.5	0.03	clay	21	1.76	0.09	2.03	8.539	33.39	21.62
5	RTd17	5.82	0.05	clay	14	2.86	0.14	5.00	4.999	32.36	19.73
6	PTd18	5.96	0.05	clay	16	2.28	0.11	6.25	8.237	32.92	21.75
7	PNTd11	6.62	0.16	Loam	21.6	4.03	0.20	71.41	17.94	35.19	22.19
8	PNTd19	6.37	0.15	Loam	14.6	4.79	0.24	66.80	18.6	36.16	22.30
9	RTd13	6.45	0.18	Loam	16.2	3.95	0.20	70.31	19.16	37.24	22.57
10	PTd20	6.71	0.13	loam	19.8	4.12	0.21	25.63	12.11	42.09	23.57
11	PNTd8	6.71	0.48	sandy	18.4	7.05	0.35	92.03	22.04	44.08	23.37

				loam							
12	PNTd9	7.16	0.08	clay loam	10.8	3.78	0.19	16.02	11.15	38.57	25.99
13	PNTd21	6.6	0.19	loam	20.4	4.97	0.25	78.13	21.08	41.62	26.08
14	PTd22	7.05	0.13	loam	16.6	6.07	0.30	84.56	19.36	41.15	20.27
15	RTd15	6.71	0.05	clay	17.2	2.36	0.12	4.49	7.143	39.04	23.63
16	PTd7	6.6	0.04	clay loam	20.4	2.52	0.13	6.04	10.14	41.52	23.78
17	PTd1	6.54	0.07	clay loam	16.2	3.71	0.19	4.35	13.97	34.37	18.89
18	PTd2	6.6	0.04	Loam	24.6	0.93	0.05	20.07	6.969	34.88	21.26
19	PTd23	6.66	0.14	heavy clay	16.8	1.78	0.09	47.79	12.42	35.25	21.52
20	PTd7	6.24	0.05	clay	11	2.69	0.13	8.49	8.493	31.18	19.72
21	PTd24	5.4	0.07	sandy loam	12.8	3.43	0.17	11.16	8.989	34.15	20.90
22	RTd14	6.2	0.3	clay	25.6	8.65	0.43	77.89	23.38	42.96	25.62

Appendix 5- Yield on using WM system of soil moisture Using TDR

S/N	Plot ID	No. of plants	Actual yield in kg	Yield per plant	No. of plants in 1 ha	Yield converted to kg/ha
1	PTd1	175	153	0.87	20800	18185
2	PTd2	92	188	2.04	20800	42504
3	PTd3	35	89	2.54	20800	52891
4	PTd4	10	36	3.6	20800	74880
5	RTd5	197	196	0.99	20800	20694
6	RTd6	29	85	2.93	20800	60966
	Sum		747	12.98	124800	270121
	Average		124.5	2.16	20800	45020
	SD		64.2	1.08	0	22477

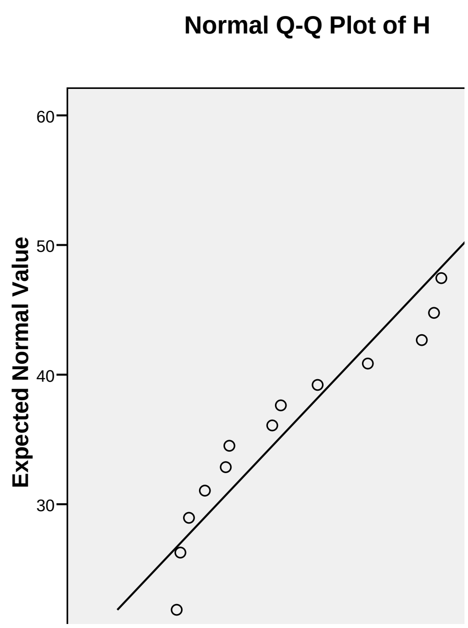
Appendix 6- Yield on WM system of Soil Moisture Using Traditional Irrigation Scheduling System

S/N	Plot ID	No. of plants	Actual yield in kg	Yield per plant	No. of plants in 1 ha	Yield converted to kg/ha
1	PTd7	36	31	0.86	20800	17911
2	PNTd8	180	825.5	4.59	20800	95391
3	PNTd9	87	266	3.06	20800	63595
4	PNTd10	102	461.5	4.52	20800	94110
5	PNTd11	104	374	3.60	20800	74800
6	PNTd12	101	380.5	3.77	20800	78360
7	RNTd13	110	28	0.25	20800	5295
8	RNTd14	77	45	0.58	20800	12156
	Sum		2411.5	21.23	166400	441618
	Average		301.44	2.65	20800	55202

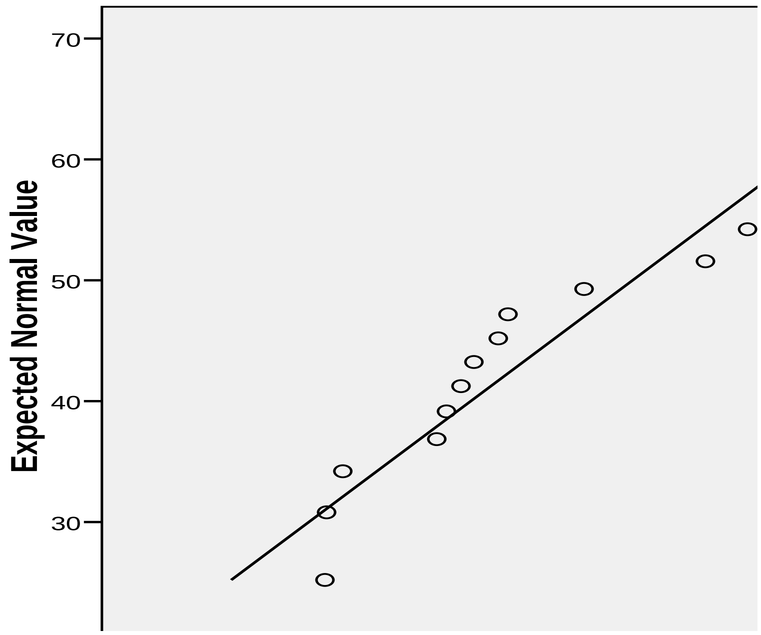
Appendix 7- Comparison of Irrigation Water Productivity Due to Using TDR and Traditional Irrigation Scheduling Systems

Codes	Irrigation Water Productivity- kg/m^3 - TDR	Codes	Irrigation Water Productivity- kg/m^3 -Non TDR
PTd1	1.89	PNTd7	2.71
PTd2	4.03	PNTd8	16.3
PTd3	4.2	PNTd9	6.09
PTd4	11.1	PNTd10	8.7
RTd5	2.79	PNTd11	7.5
RTd6	8.87	PNTd12	8.21
		RNTd13	0.83
		RNTd14	3.27

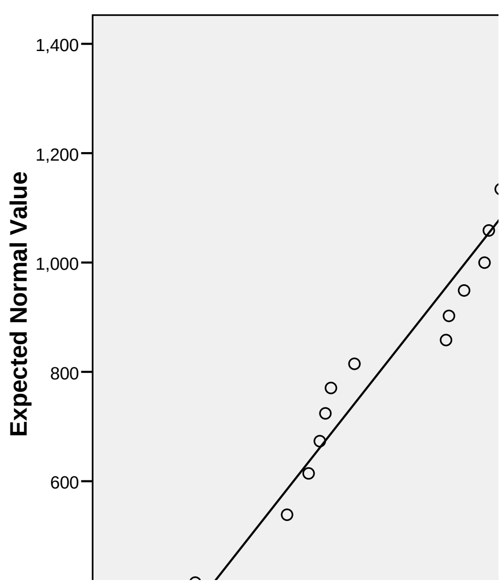
Appendix 7 - Normality test for the comparison of height, leaf area, yield, irrigation productivity, ETc and WUE on pulley and RWP lifting technologies and TDR and traditional Irrigation scheduling systems.



Normal Q-Q Plot of LAI



Normal Q-Q Plot of IW



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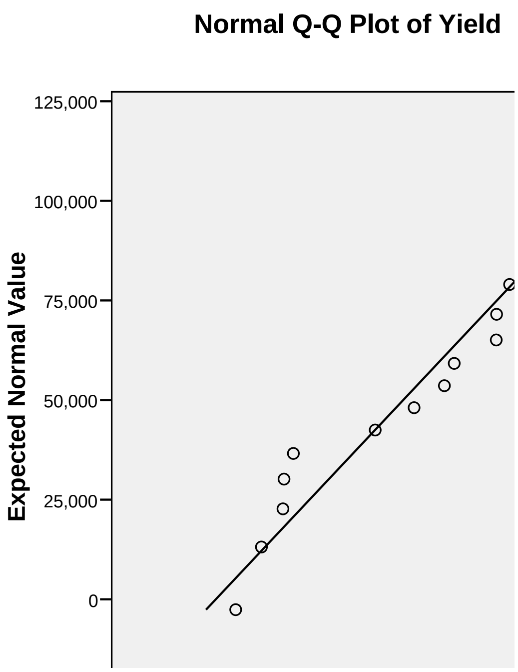
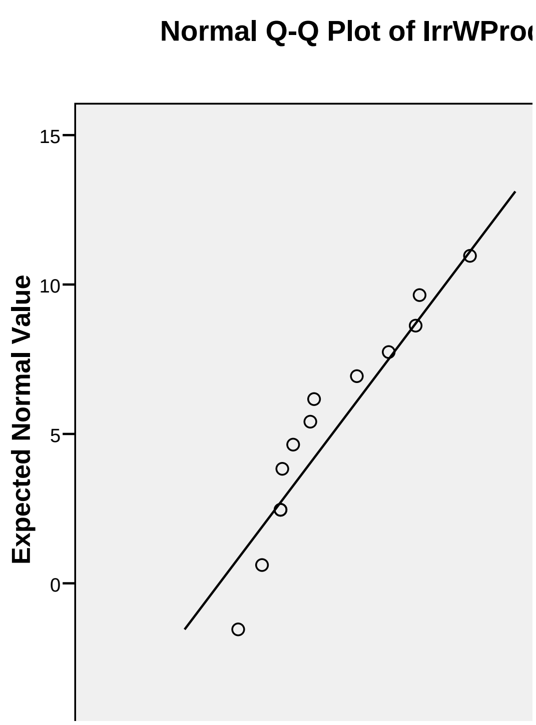
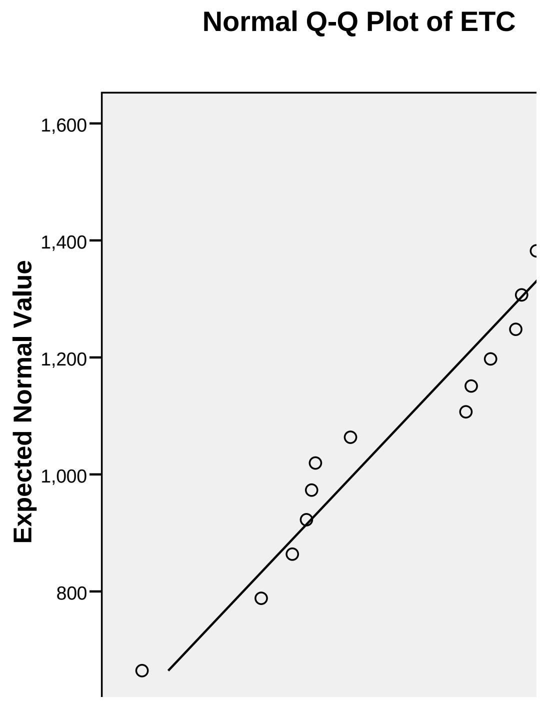
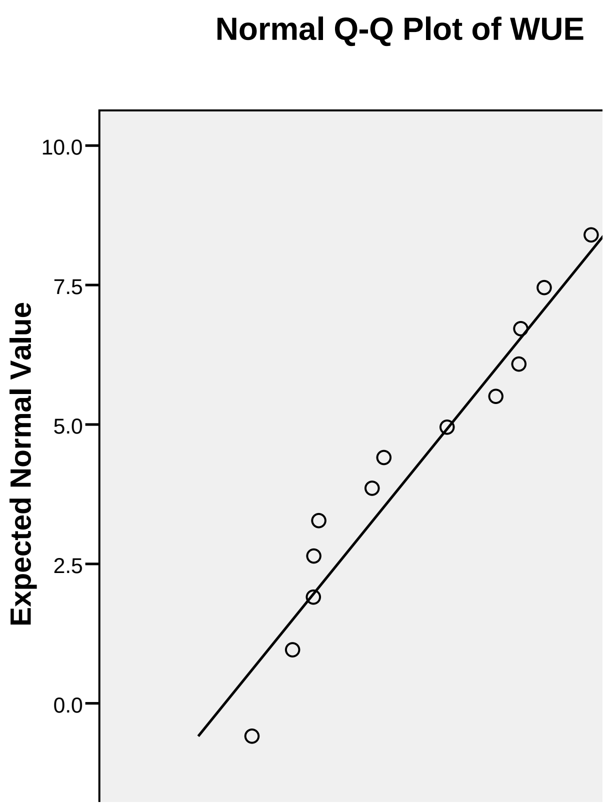

Normal Q-Q Plot of Yield
Expected Normal Value
125,000
100,000
75,000
50,000
25,000
0


Normal Q-Q Plot of IrrWProd
Expected Normal Value
15
10
5
0


Normal Q-Q Plot of ETC
Expected Normal Value
1,600
1,400
1,200
1,000
800


Normal Q-Q Plot of WUE
Expected Normal Value
10.0
7.5
5.0
2.5
0.0

Appendix 8 - Two factorial analysis of plant height and leaf area index on pulley and RWP lifting technologies and TDR and traditional irrigation scheduling systems.

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Height	564.834(a)	3	188.278	4.294	.034
	Leaf area	640.037(b)	3	213.346	2.199	.151
Intercept	Height	13345.588	1	13345.588	304.388	.000
	Leaf area	19451.294	1	19451.294	200.516	.000
WM	Height	26.266	1	26.266	.599	.457
	Leaf area	48.628	1	48.628	.501	.495
WL	Height	171.784	1	171.784	3.918	.076
	Leaf area	211.264	1	211.264	2.178	.171
WM * WL	Height	194.513	1	194.513	4.436	.061
	Leaf area	176.216	1	176.216	1.817	.207
Error	Height	438.440	10	43.844		
	Leaf area	970.060	10	97.006		
Total	Height	20021.560	14			
	Leaf area	28978.740	14			
Corrected Total	Height	1003.274	13			
	Leaf area	1610.097	13			

a R Squared = .563 (Adjusted R Squared = .432)
b R Squared = .398 (Adjusted R Squared = .217)

Appendix 9- Analysis of yield differences due to using different water lifting technologies and water management systems.

Between-Subjects Factors

		N
WM	1	6
	2	8
WL	1	10
	2	4

Tests of Between-Subjects Effects

Dependent Variable: Yield

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
WM	51300441.176	1	51300441.176	.078	.786
WL	3288525900.000	1	3288525900.000	5.007	.049
WM * WL	2188734957.176	1	2188734957.176	3.333	.098
Error	6567202410.000	10	656720241.000		
Total	48919116682.000	14			
Corrected Total	12735678560.857	13			

a R Squared = .484 (Adjusted R Squared = .330)

Appendix 10- Analysis of Irrigation water productivity difference between due to using different water lifting technologies and water management systems.

Between-Subjects Factors

		N
WM	1	6
	2	8
WL	1	10
	2	4

Tests of Between-Subjects Effects

Dependent Variable: IrrWProd

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
WM	2.163	1	2.163	.110	.747
WL	15.989	1	15.989	.815	.388
WM * WL	23.815	1	23.815	1.214	.296
Error	196.246	10	19.625		
Total	708.129	14			
Corrected Total	239.466	13			

a R Squared = .180 (Adjusted R Squared = -.065)

Appendix 11 - Comparison of different WL technologies and WMsystemson total amount Irrigation water delivered.

Between-Subjects Factors

		N
WM	1	6
	2	8
WL	1	10
	2	4

Tests of Between-Subjects Effects

Dependent Variable: IW

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
WM	68350.138	1	68350.138	1.570	.239
WL	304499.434	1	304499.434	6.996	.025
WM * WL	8640.203	1	8640.203	.199	.665
Error	435261.830	10	43526.183		
Total	10588749.026	14			
Corrected Total	793467.842	13			

a R Squared = .451 (Adjusted R Squared = .287)

Appendix 12 - Comparison of different WL technologies and WM systems on crop water use (ETc).

Between-Subjects Factors

		N
WM	1	6
	2	8
WL	1	10
	2	4

Tests of Between-Subjects Effects

Dependent Variable: ETC

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
WM	66846.921	1	66846.921	1.547	.242
WL	304291.615	1	304291.615	7.042	.024
WM * WL	8676.295	1	8676.295	.201	.664
Error	432115.863	10	43211.586		
Total	17277864.980	14			
Corrected Total	788902.054	13			

a R Squared = .452 (Adjusted R Squared = .288)

Appendix 13 - Comparison of different WL technologies and WM systems based on parameter of water use efficiency.

Between-Subjects Factors

		N
WM	1	6
	2	8
WL	1	10
	2	4

Tests of Between-Subjects Effects

Dependent Variable: WUE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
WM	.460	1	.460	.056	.818
WL	16.382	1	16.382	1.976	.190
WM * WL	19.474	1	19.474	2.349	.156
Error	82.901	10	8.290		
Total	430.254	14			
Corrected Total	123.714	13			

a R Squared = .330 (Adjusted R Squared = .129)

Appendix 14- Comparison of the TWMM and TDR soil moisture values (mm) using inDangishtakebele. (Number of plots = 9) F test and T - test

F – test

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	9.660026559	8.14920055
Variance	7.530607491	2.59414563
Observations	9	9
df	8	8
F	2.90292396	
P(F<=f) one-tail	0.076438182	
F Critical one-tail	3.438101233	

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	9.6600266	8.149201
Variance	7.5306075	2.594146
Observations	9	9
Hypothesized Mean Difference	0	
df	13	
t Stat	1.4244378	
P(T<=t) one-tail	0.0889404	
t Critical one-tail	1.7709334	
P(T<=t) two-tail	0.1778807	
t Critical two-tail	2.1603687	

Appendix 15 comparison of the TWMM and TDR soil moisture values (mm) using F test in Robit.

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	26.25	23.37
Variance	32.69	24.47
Observations	10.00	10.00
df	9.00	9.00
F	1.34	
P(F<=f) one-tail	0.34	
F Critical one-tail	3.18	

Appendix 16comparison of the TWMM and TDR soil moisture values (mm) using t - test in Robit.

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	26.245	23.37
Variance	32.68745	24.47024444
Observations	10	10
Hypothesized Mean Difference	0	
Df	18	
t Stat	1.202542677	
P(T<=t) one-tail	0.12236706	
t Critical one-tail	1.734063592	
P(T<=t) two-tail	0.244734119	
t Critical two-tail	2.100922037	

Appendix 17 - Sample soil available water computation using Thornthwaite-Mother Method.

Code - RT3

				AWC	14.65	mm					
Date	Irrigation	Prec (mm)	Irrigation + pptn	PET (mm)	P-PET	AW	AW_{i+1} mm	AET	Excess	TDR	TWMM
							4.08				
2/24/2015	11.176	0	11.18	4.00	7.17	11.25	11.25	4.00	0.00	11.92	11.25
2/26/2015	8.824	0	8.82	4.32	4.51	12.71	12.71	4.32	0.00	6.252	8.20
2/28/2015	13.529	0	13.53	4.03	9.50	18.72	14.65	4.03	4.07	7.812	9.21
3/1/2015	11.176	0	11.18	3.96	7.21	21.86	14.65	3.96	7.21	9.21	14.65
3/3/2015	15.294	0	15.29	4.29	11.00	22.24	14.65	4.29	7.60	9.996	11.24
3/5/2015	8.824	0	8.82	4.48	4.35	15.20	14.65	4.48	0.55	9.084	10.85
3/7/2015	8.824	8.2	17.02	3.80	13.22	27.87	14.65	3.80	13.22	9.588	14.65
3/9/2015	16.471	0	16.47	4.43	12.04	23.42	14.65	4.43	8.78	8.748	11.38
3/11/2015	9.412	0	9.41	4.67	4.75	15.46	14.65	4.67	0.81	8.988	10.72
3/13/2015	9.412	0	9.41	4.77	4.64	15.69	14.65	4.77	1.04	6.108	11.05
3/15/2015	14.118	0	14.12	4.70	9.42	20.39	14.65	4.70	5.74	9.084	10.97
3/17/2015	8.824	0	8.82	3.61	5.21	15.85	14.65	3.61	1.20	8.22	10.63
3/19/2015	10.588	25.5	36.09	3.63	32.46	43.62	14.65	3.63	28.97	7.812	11.16
3/21/2015	11.176	0	11.18	4.73	6.45	17.83	14.65	4.73	3.18	8.988	11.38
3/23/2015	9.412	0	9.41	4.64	4.77	15.69	14.65	4.64	1.04	1.068	10.92
3/25/2015	11.176	0	11.18	4.60	6.58	17.15	14.65	4.60	2.50	5.7	10.57
3/27/2015	14.706	0	14.71	5.00	9.71	20.41	14.65	5.00	5.76	6.204	10.70
3/29/2015	14.118	0	14.12	4.58	9.54	20.21	14.65	4.58	5.56	8.268	10.67
3/31/2015	10.588	0	10.59	4.89	5.70	16.44	14.65	4.89	1.80	7.404	10.75
4/2/2015	11.765	0	11.76	4.95	6.82	16.99	14.65	4.95	2.34	9.588	10.17
4/4/2015	16.471	0	16.47	5.25	11.22	21.54	14.65	5.25	6.90	10.43	10.32
4/6/2015	14.118	0	14.12	4.60	9.52	20.19	14.65	4.60	5.54	6.108	10.67
4/8/2015	14.118	0	14.12	5.13	8.99	19.88	14.65	5.13	5.23	6.588	10.89
4/10/2015	12.941	0	12.94	5.26	7.68	17.94	14.65	5.26	3.30	10.62	10.27

4/12/2015	12.941	0	12.94	4.99	7.95	18.15	14.65	4.99	3.50	10.24	10.20
4/14/2015	14.706	0	14.71	4.54	10.17	20.97	14.65	4.54	6.32	10.67	10.80
4/16/2015	12.941	0	12.94	5.33	7.61	18.26	14.65	5.33	3.61	11.6	10.65
4/18/2015	10.000	0	10.00	5.71	4.29	14.58	14.58	5.71	0.00	16.43	10.29
4/20/2015	8.824	0	8.82	5.46	3.36	13.42	13.42	5.46	0.00	9.588	10.06
4/22/2015	16.471	0	16.47	5.48	10.99	20.25	14.65	5.48	5.60	10.43	9.26
4/24/2015	13.529	0	13.53	5.56	7.97	17.94	14.65	5.56	3.29	8.268	9.97
4/27/2015	10.588	0	10.59	5.53	5.06	12.13	12.13	5.53	0.00	9.588	7.06
4/29/2015	16.471	0	16.47	5.01	11.46	19.88	14.65	5.01	5.24	9.468	8.42
5/2/2015	17.059	0	17.06	4.48	12.58	20.91	14.65	4.48	6.26	9.084	8.33
5/4/2015	8.824	0.1	8.92	3.32	5.60	20.25	14.65	3.32	5.60	8.1	14.65
5/6/2015	10.588	0.2	10.79	3.60	7.19	21.84	14.65	3.60	7.19	11.46	14.65
5/8/2015	10.588	0	10.59	4.33	6.26	20.91	14.65	4.33	6.26	10.67	14.65
5/10/2015	12.941	1.1	14.04	2.47	11.57	26.22	14.65	2.47	11.57	10.43	14.65
5/12/2015	14.118	1.6	15.72	3.93	11.79	26.44	14.65	3.93	11.79	6.588	14.65
5/14/2015	12.941	5.5	18.44	4.96	13.48	28.13	14.65	4.96	13.48	13.36	14.65
5/16/2015	4.118	1	5.12	4.81	0.30	12.96	12.96	4.81	0.00	9.588	12.65
5/18/2015	16.471	10.5	26.97	4.76	22.21	36.85	14.65	4.76	22.21	10.43	14.65

Appendix 18- Daily Precipitation Data used for TWMM computation.

Date	Jan	Feb	Mar	Apr	May	Jun
1	0	0	0	0	0	10.5
2	0	0	0	0	0	3.5
3	0	0	0	0	18.9	38
4	0	0	0	0	0.1	0
5	0	0	0	0	36.8	0
6	0	0	7	1	0.2	1.2
7	0	0	8.2	0	4.8	0
8	0	0	0	0	0	8
9	0	0	0	0	6.9	45
10	0	0	0	0	1.1	11.3
11	0	0	0	0	11	6.3
12	0	0	0	0	1.6	1.6
13	0	0	0	0	0	1.5
14	0	0	0.1	0	5.5	0
15	0	0	0	0	2.5	0.4
16	0	0	0.3	0	1	47
17	0	0	0	0	11	0
18	0	0	0	0	10.5	15.5
19	0	0	25.5	0	1.7	3.2
20	0	0	0	0	0	17.2
21	0	0	0	0	3.2	0.6
22	0	0	0	0	3.1	0
23	0	0	0	0	2.3	3.2
24	0	0	0	0	32.2	3.2
25	0	0	0	0	8.4	15.4
26	0	0	0	0	5	24.8
27	0	0	0	0	34.9	1.2

28	0	0	0	0	7.1	9.6
29	0		0	0	19	0
30	0		0	0	15.2	0.9
31	0		0		28	

Appendix 19 – Daily MAX Temp (year 2015) used for TWMM Computation

Date	Jan	Feb	Mar	Apr	May	Jun
1	26.5	28.2	29	29.5	27	24
2	26	29	29.5	28	28.6	24.5
3	26.2	29.2	30	29.6	26.5	25.2
4	25	29.6	30.2	28.5	25.6	27
5	25.5	29.8	30	28.5	24.5	27
6	26	28.5	29.5	30.2	24.6	26.5
7	25.5	29.5	28.5	28.2	25.4	25.7
8	26.2	29.5	29	29.4	25.6	25.5
9	23.8	28.5	29.8	29.5	25.4	26
10	23.5	29.6	30	28.6	23.5	25.2
11	24	29	30.5	28.5	25.5	23.5
12	24.6	28.5	29.2	28.2	28	24.5
13	24.2	28.5	30.5	28.5	27.5	23.5
14	25.2	28	30.6	27.5	29	23
15	25.5	26.5	30.2	27.5	28.6	25.5
16	26.2	27.5	31	30	30	22.5
17	25.5	28	29.5	29	27	22.5
18	25.5	28.6	29.5	29.5	26.5	23.5
19	25	29.8	28	29.2	27	25
20	25.5	29.8	27	29.6	27	25.2
21	26.5	28.6	29	30.2	26.5	23.2
22	27.5	29.2	28.5	29.6	25.6	19.6

23	28	29	28.6	30	25.5	21
24	27.6	29.5	28.6	30.5	24	24
25	27.2	29.6	29	29.2	26.5	23.5
26	28	30	29.5	30	25	24.5
27	27.6	30.5	30	29	24.8	21.2
28	27.5	30	29.6	30	23.5	20.2
29	27.8		28	30	25.5	24
30	28.5		28.5	30.5	26	25
31	28.5		29.2		26	

Appendix 20 -Daily Minimum Temp (year 2015) used for TWMM computation

Date	Jan	Feb	Mar	Apr	May	Jun
1	3.5	2.2	10.0	10.5	16.0	13.4
2	1.5	3.5	11.0	11.2	12.0	13.5
3	2.0	3.3	12.5	8.8	14.0	14.0
4	3.0	5.0	7.0	13.5	12.0	11.0
5	2.5	5.5	12.0	11.0	14.0	11.3
6	3.5	6.5	11.0	12.5	11.6	12.2
7	5.0	6.6	10.0	9.0	14.0	12.0
8	4.8	6.8	12.0	9.5	14.5	12.3
9	6.0	6.3	8.0	11.0	14.0	13.0
10	5.0	6.6	8.2	11.0	14.5	12.5
11	5.0	6.8	9.5	13.0	14.2	12.5
12	3.0	7.0	10.8	9.0	13.0	12.0
13	5.0	7.4	11.5	9.0	12.5	13.0
14	6.5	7.8	14.0	13.0	13.5	13.5
15	7.0	9.5	13.8	10.5	14.0	13.0
16	6.5	10.5	14.0	9.0	14.5	15.0
17	5.0	10.0	15.0	11.0	13.5	12.4
18	5.0	13.5	15.0	10.5	13.0	13.5
19	5.5	13.0	14.0	11.0	12.5	12.5
20	4.5	9.0	11.0	13.5	12.0	13.5
21	7.0	8.5	12.0	11.0	11.8	13.0
22	7.0	8.5	11.5	13.0	12.6	13.8
23	8.0	9.5	10.0	10.0	11.2	13.6
24	6.5	7.4	9.5	10.5	13.0	13.5
25	7.0	9.5	8.0	14.0	12.2	10.0
26	7.5	8.4	9.0	13.5	13.0	13.0
27	7.5	11.0	9.0	15.0	12.8	12.5
28	6.0	11.0	12.0	11.0	13.0	13.4

29	5.5		14.5	13.5	13.5	12.0
30	5.5		11.0	14.5	12.5	11.5
31	4.0		11.0		12.0	

Appendix 21 - Average Relative Humidity (2015) for TWMM computation

Date	Jan	Feb	Mar	Apr	May	Jun
1	41.6	32.6	40.2	50.2	43.2	84
2	42.8	33	47.2	46.8	41.8	69
3	38	37	36.4	40.8	77.8	88
4	42	30.8	34	40.2	67	61
5	49.2	29.2	44	47.8	82.2	71
6	49.8	35	40.8	43.8	67.2	70
7	57.6	33.2	60.8	48.4	60.2	69
8	60.2	33.2	42.8	31.8	61.8	74
9	66.6	34.8	38.6	27	70.4	73
10	61.4	28.4	37	26.2	78.2	76
11	59.2	31	35.8	35	72.6	77
12	59	38.4	31.2	29.2	67.2	74
13	57.6	41.8	35.6	40	62.4	82
14	60.4	48.4	35.4	39.2	59.2	78
15	52.4	52.4	34	28.8	60.4	69
16	53.8	42	35.4	28.8	62.2	87
17	51.8	50.2	48.2	31.6	63.8	85
18	53.8	49.4	49.4	38	66.2	86
19	52.4	42	56.2	37.2	70.2	76
20	49.8	39.8	54	32.6	59	75
21	46.4	42	48.6	29.2	57	80
22	50.4	40.8	46.6	26	66.2	86
23	48	42.4	44.8	29.8	62.6	74
24	46.2	35.6	40.4	30.8	78.4	74

25	46.6	34.2	44.6	25.6	69.8	75
26	43.4	33	34.8	30.2	73.6	79
27	47.2	32.2	42.2	27	78.4	86
28	44.2	40.4	38.4	23	88.8	84
29	34		48.4	25.4	76.6	67
30	33.6		57.2	33.6	67.2	77
31	34.8		59.6		76	

Appendix 22- Daily Sun Shine Duration (SS) used for TWMM computation

1	10	10.1	7.9	10.5	4.3	4.1
2	10.2	10.6	7.4	10.2	6.8	9.9
3	10.1	10.7	9.1	9.7	4.4	6.4
4	10.1	10.5	9.8	9.5	4.1	8.6
5	9.7	10.5	9	8.8	0.9	7.6
6	8.9	10.6	9.5	7.3	5.5	6.8
7	9.1	10.5	7.4	7.6	3.8	9.1
8	9.4	10.2	6.7	9.8	7.5	5.5
9	7.3	10.1	9.9	10.4	4.9	6.4
10	9	10.4	11	10.1	1.1	6.8
11	4.9	10.2	10.5	10.1	3.3	7.5
12	6.8	9.7	8	9	5.8	7.6
13	3.5	9.5	10.5	6.7	9.8	7.3
14	8	8.1	7.7	6.6	10.1	5.7
15	7.9	4	9.8	8.4	8.4	5.8
16	9.7	7.3	9.7	10.4	8.5	2.7
17	10.1	4.5	4	9.2	5.8	0.6
18	9.8	4.2	5.6	10.2	9.7	2.2
19	9.5	9.3	5.3	10.6	6.3	5.3
20	9	10.8	6.2	10.5	9.5	6

21	7.4	7.6	10	9.5	7.5	3.2
22	7.9	9.1	8.4	10.3	5.8	0
23	9.1	7.5	9 .3	10.9	8.3	0.6
24	9.9	8	10.5	9.2	4.6	4.2
25	9.9	10.6	10	6	7.4	9.3
26	10	9	10	8.6	5.5	2.5
27	10.3	9.6	11	10.8	5.7	0.9
28	10	8.7	8	10.6	1	2.2
29	10.4		8.2	8	6.4	7.9
30	10.5		8.4	5.8	8.3	5.4
31	10.6		9.6		7.1	

Appendix 23 – Wind Speed (m/s) at 2m (2015) Used for TWMM computation

Date	Jan	Feb	Mar	Apr	May	Jun
1	0.49	0.63	0.68	1.54	1.07	0.88
2	0.50	0.51	0.62	1.06	1.06	0.93
3	0.45	0.51	0.66	1.28	1.00	0.75
4	0.74	0.52	0.73	1.41	0.80	0.73
5	0.68	0.63	0.87	0.95	1.03	0.77
6	0.71	0.68	0.89	1.03	0.91	0.8
7	0.83	0.64	0.61	0.99	1.05	0.96
8	0.77	0.59	0.48	1.12	1.17	0.78
9	1.05	0.77	0.69	1.02	0.75	0.79
10	1.06	0.64	0.61	1.19	0.58	1.15
11	0.47	0.85	0.71	1.24	0.79	0.73
12	0.75	0.92	0.66	1.20	1.03	0.95
13	0.45	1.06	0.74	1.18	1.13	1.02
14	0.77	0.83	0.74	1.24	0.80	0.95
15	1.03	0.52	0.73	0.98	0.99	0.82
16	0.84	0.45	0.97	1.13	1.12	0.62

17	0.88	0.54	0.84	1.23	0.90	0.38
18	0.82	0.65	0.90	1.73	1.30	0.91
19	0.66	0.65	0.68	1.28	0.74	0.71
20	0.52	0.86	0.67	1.16	0.84	1.02
21	0.50	0.98	0.80	1.31	1.33	0.88
22	0.50	0.88	0.70	1.20	0.79	0.42
23	0.62	0.65	0.76	1.31	0.94	0.52
24	0.61	0.78	0.82	1.48	0.51	0.63
25	0.66	0.93	0.72	1.70	1.36	1.03
26	0.63	0.85	0.65	1.42	0.89	0.6
27	0.52	1.03	0.83	1.14	0.66	0.83
28	0.56	0.52	1.00	1.02	0.70	0.46
29	0.45		1.00	1.09	0.77	0.74
30	0.54		1.14	0.80	0.79	0.72
31	0.51		1.31		1.11	

Appendix 24 - Amount of irrigation water added each day (Liter).

Date	RTd 5	Rtd1 6	Rtd1 5	RTd1 3	PTd 3	PTd 2	RTd 6	PTd 1	PNTd 7	RTd1 4	Ptd 4
3/13/15	600	150	150	70	150	150	140	280	140	140	140
3/14/15		150	300	70	150	150	140	280	140	140	140
3/15/15	600	150	300	70	150	150	140	280	140	140	140
5/16/15		150	300	70	150	150	140	280	140	140	140
3/17/15	600	150	300	70	150	150	140	280	140	140	140
5/18/15		150	300	70	150	150	140	280	140	140	140
3/19/15	600	150	300	70	150	150	140	280	140	140	140
3/20/15		150	300	70	150	150	140	280	140	140	140
3/21/15	600	150	300	70	150	150	140	280	140	140	140
3/22/15		150	300	70	150	150	140	280	140	140	140
3/23/15	600	150	300	70	150	150	140	280	140	140	140
3/24/15		150	300	70	150	150	140	280	140	140	140
3/25/15	600	150	300	70	150	150	140	280	140	140	140
3/26/15		150	300	70	150	150	140	280	140	140	140
3/27/15	600	150	300	70	150	150	140	280	140	140	140

3/28/15		150	300	70	150	150	140	280	140	140	140
3/29/15	600	150	300	70	150	150	140	280	140	140	140
3/30/15		150	300	70	150	150	140	280	140	140	140
3/31/15	600	150	300	70	150	150	140	280	140	140	140
4/1/15		150	300	70	150	150	140	280	140	140	140
4/2/15	600	150	300	70	150	150	140	280	140	140	140
4/3/15		150	300	70	150	150	140	280	140	140	140
4/4/15	600	150	300	70	150	150	140	280	140	140	140
4/5/15		150	300	70	150	150	140	280	140	140	140
4/6/15	600	150	300	70	150	150	140	280	140	140	140
4/7/15		150	300	70	150	150	140	280	140	140	140
4/8/15	600	150	300	70	150	150	140	280	140	140	140
4/9/15		150	300	70	150	150	140	280	140	140	140
4/10/15	600	150	300	70	150	150	140	280	140	140	140
4/11/15		150	300	70	150	150	140	280	140	140	140
4/12/15	600	150	300	70	150	150	140	280	140	140	140
4/13/15		150	300	70	150	150	140	280	140	140	140

Date	RTD 5	RT d16	RTd 15	RNT d13	PTd 3	PTd 2	RTd 6	PTd 1	PNTd 7	RNT d14	PTd 4
14/4/15	300	20	120	70	280	210	140	280	140	72	280
16/4/15	500	40	70	100	280	140	60	420	210	72	280
18/4/15	1000	50	60	130	350	210	50	280	210	84	140
20/4/15	700	80	70	90	280	140	70	420	200	96	280
22/4/15	1100	60	80	60	410	175	80	350	210	84	420
24/4/15	700	80	60	80	350	210	70	420	180	108	420
27/4/15	700	60	70	70	420	280	90	280	210	84	420
29/4/15	900	70	90	90	280	210	90	560	210	108	420
1/5/2015	1000			80	560	280	80	560	210	96	420
3/5/2015	1000			90	245	280	100	490	233	96	390
5/5/2015	1100			30	210	280	120	560	280	120	420

7/5/2015	500			35	245	280	110	420	280	108	280
9/5/2015	450			40		280	90	560	326	131	420
11/5/2015	500			50	280	350	80	490	373	96	700
17/5/2015	0			45	245	350	100			42	0
19/5/2015	0				315	385	120	700	280	48	630
22/5/2015	600				280	420	100	770		42	700
24/5/2015				30	350			840	373	54	630
27/5/2015	500						0			48	0
29/5/2015				40		420		630	326	48	560
31/5/2015	400				280		0			0	0
2/6/2015					330	460		560		0	490

Appendix 25 - Amount of irrigation water added each day (Liter)

Date	PNTd8	PNTd12	PNTd11	PNTd9	PNTd9
13/3/15	560	420	420	280	560
15/3/15	560	420	490	420	840
17/3/15	560	490	490	420	560
19/3/15	560	420	490	420	560
21/3/15	560	560	560	560	560
24/3/15	560	420	560	560	560
27/3/15	560	560	560	560	560
30/3/15	560	560	560	560	560
2/4/2015	560	560	560	560	560
14/4/15	560	420	420	140	560
16/4/15	560	420	490	140	840
18/4/15	560	490	490	420	560
20/4/15	560	420	490	420	560
22/4/15	560	560	560	560	560
25/4/2015	560	420	560	560	560

28/4/2015	560	560	560	560	560
1/5/2015	560	560	560	560	560
3/5/2015	560	560	560	560	560
16/5/15	560	560	560	560	560
19/5/15	560	560	560	560	560
22/5/15	560	490	980	560	560
7/6/2015	490	560	490	490	490
9/6/2015	560	560	560	420	560
12/6/2015	420	560	490	560	490

Appendix 26- Data of soil moisture in mm computed using TWMM and measured using TDR – Dangishta.

Code	TWMM	TDR	Code	TWMM	TDR
PT2	2.45	2.70	RT3	11.25	13.74
	1.77	3.94		8.20	7.21
	10.63	7.71		9.21	9.01
	7.63	6.57		14.65	10.62
	14.22	9.75		11.24	11.52
	10.83	7.24		10.85	10.47
	10.44	6.43		14.65	11.05
	14.22	4.77		11.38	10.09
	10.97	9.62		10.72	10.36
	10.31	5.85		11.05	7.04
	10.64	1.59		10.97	10.47
	10.56	7.24		10.63	9.48
	10.23	7.71		11.16	9.01
	10.75	2.28		11.38	10.36
	10.97	5.85		10.92	1.23
	10.51	6.99		10.57	6.57
	10.16	6.43		10.70	7.15
	10.29	10.78		10.67	9.53
	10.26	10.50		10.75	8.54
	10.34	7.68		10.17	11.05
	9.77	9.62		10.32	12.02
	9.92	10.50		10.67	7.04
	10.26	6.38		10.89	7.60

	10.48	9.17		10.27	12.24
	9.86	6.29		10.20	11.80
	9.80	11.00		10.80	12.30
	10.39	7.71		10.65	13.38
	10.24	11.83		10.29	18.94
	9.89	4.77		10.06	11.05
	9.70	10.50		9.26	12.02
	9.71	8.04		9.97	9.53
	9.57	11.88		7.06	11.05
	6.71	7.68		8.42	10.92
	9.56	9.56		8.33	10.47
	7.95	9.75		14.65	9.34
				14.65	13.21
				14.65	12.30
				14.65	12.02
				14.65	7.60
				14.65	15.40
				12.65	11.05
				14.65	12.02

Code	TWMM	TDR	Code	TWMM	TDR
PT8	6.10	7.97	PT12	8.66	11.76
	4.24	7.97		6.44	8.58
	3.64	4.23		11.43	12.81
	4.97	12.81		14.07	11.04
	9.36	12.26		12.18	11.54
	6.20	7.83		10.98	12.98
	7.71	5.34		15.61	8.49
	9.49	12.81		12.32	7.66
	7.05	10.60		10.86	8.77
	4.44	7.97		9.87	10.15
	4.41	7.75		8.98	11.54
	3.50	4.23		8.10	8.58
	3.97	12.81		12.10	12.81
	9.49	8.22		12.33	8.77
	5.87	8.66		11.85	11.54
	4.38	10.60		10.22	11.04
	3.19	10.74		11.63	12.62

	3.25	12.40		9.88	12.40
	3.45	11.90		11.68	11.54
	2.04	13.25		11.09	12.81
	1.29	9.91		11.24	8.77
	0.71	9.16		11.60	8.58
	2.63	11.98		10.35	9.71
	1.66	11.76		8.52	11.32
	1.01	10.04		7.06	9.60
	0.69	11.15		11.57	8.58
	0.75	13.25		10.16	9.71
	0.68	9.16		8.26	12.45
	0.38	11.98		6.50	8.25
	0.23	9.21		10.15	10.29
	0.13	11.68		7.90	12.70
	1.42	11.76		4.54	8.58
	0.89	12.12		8.77	11.54
	0.45	11.98		6.14	14.31
	12.69	11.68		15.61	15.97
	12.69	12.26		15.61	15.00
	12.69	9.63		15.61	15.55
	12.69	11.76		15.61	15.69
	12.69	10.74		15.61	14.17
	12.69	11.01		15.61	14.03
	10.72	10.46		15.61	13.48
	12.69	11.76		15.61	14.86

Code	TWMM	TDR	Code	TWMM	TDR	Code	TWMM	TDR
RWT13	14.76	8.18	RWT14	11.54	5.96	RWT15	11.35	2.19
	11.36	7.54		9.12	10.11		7.56	5.04
	13.55	8.79		9.29	12.88		7.56	4.81
	17.68	5.71		7.89	8.73		10.81	5.64
	14.20	7.95		9.45	12.88		8.13	3.15
	13.79	8.79		8.96	8.73		7.77	9.66
	17.68	7.60		8.90	11.77		11.42	4.12
	14.35	2.01		12.85	8.73		8.26	8.69
	13.65	7.21		9.50	10.11		7.65	7.14
	14.00	8.09		9.12	11.50		7.95	10.68
	13.92	4.44		9.01	8.73		7.85	11.98
	13.56	7.54		9.64	12.88		7.57	4.84

	14.12	5.71		8.99	4.16		8.06	5.64
	14.35	4.50		9.32	5.96		8.26	8.13
	13.86	6.71		9.17	1.81		7.84	8.69
	13.49	6.02		8.71	10.80		6.89	9.52
	13.63	5.44		9.42	11.64		7.63	11.73
	13.60	7.21		9.64	7.35		7.61	8.13
	13.68	7.26		9.19	8.73		5.10	9.52
	13.07	3.64		8.85	10.11		4.68	5.76
	13.60	12.63		8.98	4.58		6.80	8.96
	13.83	7.10		8.95	8.73		7.61	9.08
	13.17	7.10		9.02	10.11		7.80	11.79
	13.10	20.93		8.47	1.81		7.24	12.06
	13.74	15.40		8.41	8.73		3.95	7.61
	13.58	20.93		8.47	10.11		2.37	9.52
	13.20	12.63		9.16	12.88		4.00	4.68
	13.00	7.10		8.57	8.73		6.09	8.13
	13.00	1.56		9.38	4.58		5.31	6.20
	12.86	20.93		10.90	8.73		4.43	9.52
	9.66	11.25		11.99	11.77		5.46	10.63
	17.68	7.10		11.74	8.73		6.82	9.66
	8.35	4.05		11.09	10.11		5.99	8.13
	17.68	14.01		10.81	1.81		4.24	9.80
	17.68	10.56		10.42	8.73		11.42	12.06
	17.68	6.27		6.88	10.11		11.42	7.94
	17.68	8.48		6.84	12.88		11.42	7.58
	17.68	12.63		5.69	8.73		11.42	9.46
	17.68	11.25		9.36	4.58		11.42	11.73
	15.66	8.48		10.61	8.73		11.42	10.90
	17.68	8.48		9.79	11.77		9.46	10.85
	15.66	6.27		9.78	10.80		11.42	12.06
				10.06	6.52			
				8.81	8.73			
				8.95	12.88			
				9.50	11.50			

Code	TWMM	TDR	Code	TWMM	TDR

PT17	4.72	7.43	RWT22	14.44	11.23
	2.30	2.20		10.48	9.74
	2.65	6.90		10.42	13.39
	3.62	5.27		14.44	12.29
	1.39	4.14		11.04	10.35
	1.91	3.86		10.65	11.01
	4.88	4.69		14.44	8.36
	3.65	3.03		11.18	11.18
	3.18	7.18		10.52	14.22
	2.30	6.90		10.85	9.52
	1.31	4.14		10.77	10.35
	4.11	2.20		10.44	9.74
	1.83	5.27		10.96	12.29
	3.65	6.90		11.18	13.39
	3.32	5.24		10.72	8.55
	1.00	6.46		10.37	9.24
	3.17	5.38		10.50	8.55
	3.15	6.35		10.47	12.06
	2.60	3.86		10.55	10.74
	0.78	4.69		9.97	12.56
	0.76	4.14		10.12	13.39
	1.21	6.90		10.47	12.78
	2.62	5.27		10.69	11.01
	2.99	5.38		10.07	11.32
	2.08	6.35		10.00	10.74
	0.53	6.90		10.60	12.51
	0.64	5.27		10.45	12.56
	6.46	4.69		10.10	8.96
	6.46	5.27		9.91	7.86
	6.46	6.90		9.91	11.18
	6.46	5.38		9.77	9.24
	6.46	4.14		6.89	11.12
	6.46	6.90		9.98	12.56
	4.64	4.69		8.15	13.72
	6.46	7.45		14.44	7.89
				14.44	7.86
				14.44	12.51
				14.44	13.39
				14.44	9.74
				14.44	12.84
				12.45	10.74

				14.44	11.46
			Mean	9.37	9.37
			SD	3.84	3.60

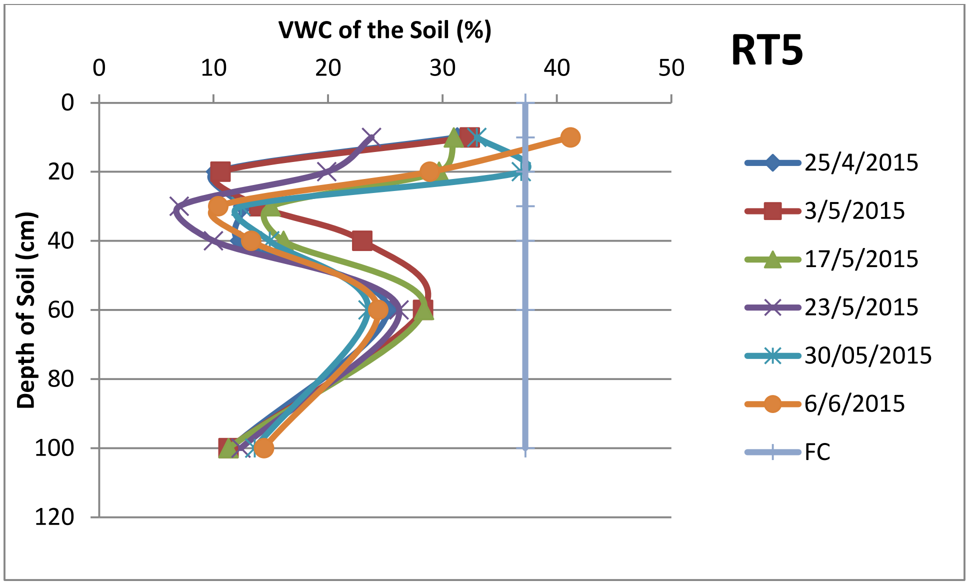
Appendix 27- Data of soil moisture in mm computed using TWMM and measured using TDR – Robit.

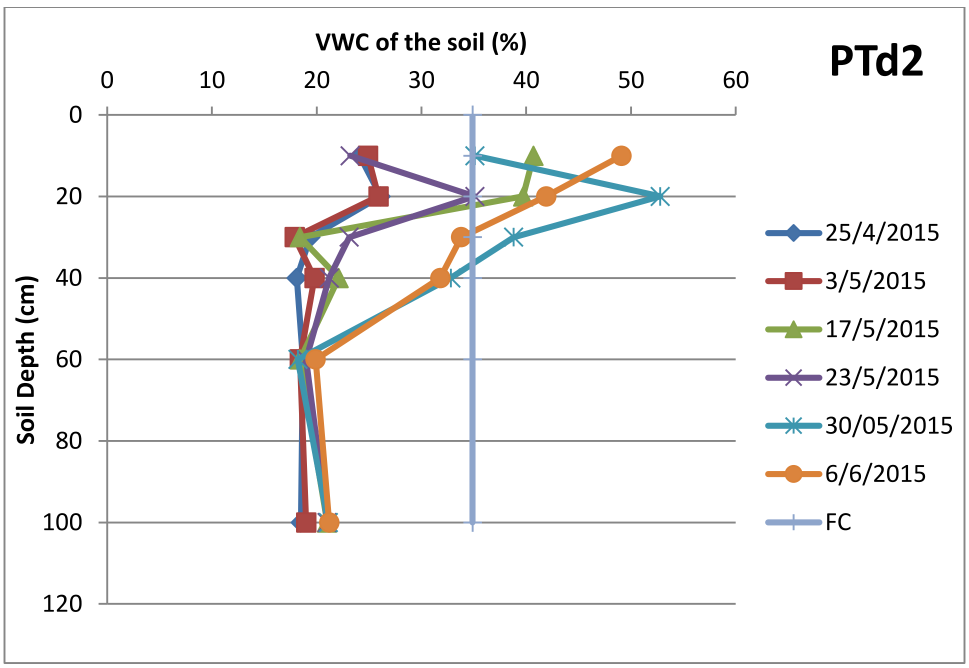
Code	TWMM	TDR	Code	TWMM	TDR	Code	TWMM	TDR
RTd5	17.08	21.23	PTd1	18.55	25.27	RTd6	12.162	29.182
	31.12	25.07		29.91	27.43		23.192	30.862
	31.12	39.83		29.91	40.75		26.814	40.702
	31.12	33.83		29.91	16.75		33.865	31.342
	31.12	28.19		29.91	12.67		39.35	22.342
	31.12	19.91		29.91	15.19		40.462	22.342
	31.12	20.39		29.91	16.27		40.462	16.222
	31.12	32.03		29.91	13.51		40.462	36.262
	31.12	17.27		28.22	20.83		40.462	8.9023
	31.12	23.27		29.91	16.75		40.462	12.382
	31.12	13.19		29.91	13.75		40.462	20.662
	31.12	38.87		29.91	15.79		40.462	26.302
	31.12	19.19		29.91	16.51		40.462	26.302
	31.12	36.71		29.91	38.11		40.462	37.342
	12.04	24.35		29.91	39.19		40.462	36.022
	8.57	13.79		29.91	32.95		40.462	40.342
	31.12	12.47		29.91	18.19		25.192	43.222
	22.66	17.03		29.91	15.19		40.462	37.102
	31.12	20.75		28.95	16.03		40.462	26.782
	30.88	33.83		29.91	43.39		40.462	36.862
	31.12	35.03		29.91	22.15		31.6	42.142
	23.30	26.51		29.91	38.59		17.126	26.902
RNTd13	24.01	23.66	RTd15	32.68	24.94		13.466	37.582
	30.53	22.82		32.68	35.86	PTd3	29.42	30.22
	16.76	15.62		26.78	14.62		29.42	27.10
	21.53	14.54		21.40	12.34		29.42	17.74
	21.53	14.78		17.45	19.18		29.42	36.34
	18.75	19.82		14.59	14.02		29.42	37.66
	14.54	17.30		11.62	16.30		29.42	29.86
	16.18	10.70		8.14	10.54		29.42	24.58
	16.21	14.54		7.42	11.38		28.46	21.22

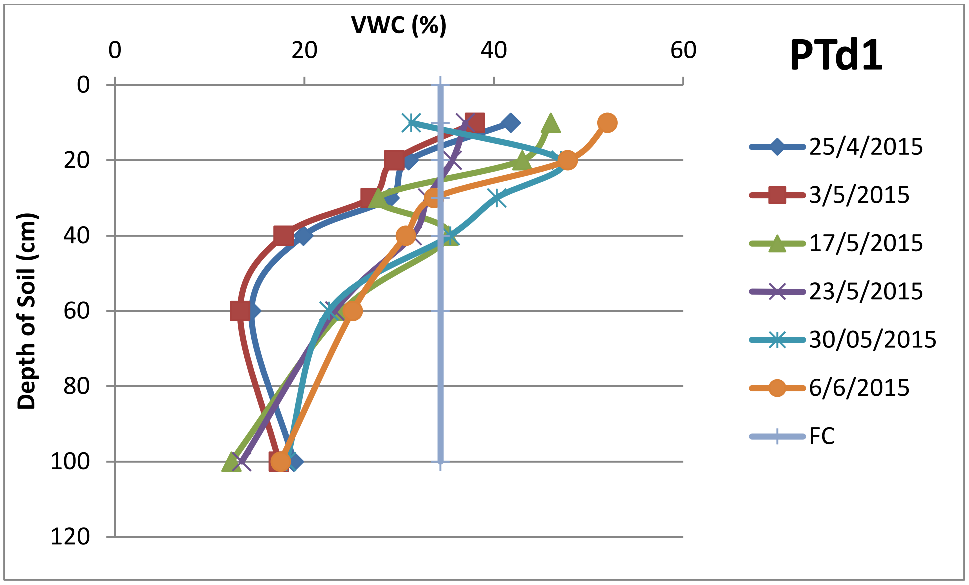
	13.69	12.98					29.18	34.18
	12.35	11.30					29.42	28.78
	22.82	19.46						
	14.41	14.30						
	11.02	19.22						
	19.49	16.94						
	24.46	12.98						

Code	TWMM	TDR	Code	TWMM	TDR	Code	TWMM	TDR
PTd4	14.88	25.25	PTd7	18.23	20.53	PTd2	19.726	22.166
	25.59	37.37		35.56	40.21		29.096	29.246
	24.05	14.33		35.56	9.73		29.096	26.726
	18.53	12.17		35.56	14.05		29.096	18.086
	18.22	13.49		35.56	19.09		29.096	20.726
	22.69	12.53		35.56	31.57		29.096	29.006
	25.59	13.85		35.56	30.97		29.096	23.846
	24.79	17.33		35.56	21.73		29.096	18.686
	25.59	22.97		35.56	30.85		29.096	34.646
	25.59	19.37		35.56	20.53		29.096	29.726
	25.59	23.33		35.56	20.53		29.096	28.646
	25.59	11.33		35.56	37.21		29.096	33.686
	25.59	19.01		35.56	30.49	RNTd14	21.941	16.991
	25.59	20.33		35.56	42.73		18.753	14.711
	8.06	29.09		15.49	41.89		17.12	16.271
	21.53	17.09		30.52	36.97		15.13	11.951
	25.59	18.53		32.84	34.33		15.051	18.431
	24.63	25.49		34.59	16.57		12.449	17.111
	25.59	21.17		35.56	18.73		12.944	13.391
	25.59	31.61		27.60	33.73		26.789	27.431
	25.59	27.29					26.789	20.351
							26.789	18.071
							9.2777	15.431
							18.145	14.591
							14.688	20.351
							26.553	18.551
							26.789	16.751
							26.789	27.551

Appendix 28 Graph showing change in water content (VWC) of the soil with depth







Appendix 29 – Soil profiler, tomato seedlings and plants

Appendix 30 – Technology distribution