BAHIR DAR UNIVERSITY

Faculty of Civil and Water Resource Engineering

Department of Hydraulics Engineering

Master Thesis

Evaluating Simple Irrigation Technologies to Improve Crop and Water Productivity of Onion in Dangishta Watershed

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Bahir Dar University

Bahir Dar, Ethiopia

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Evaluating Simple Irrigation Technologies to Improve Crop and Water Productivity of Onion in Dangishta Watershed

By

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THESIS

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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DECLARATION

I, Melaku Tesema Alemu, declare that this thesis is my own original work. In compliance with internationally accepted practices, I have duly acknowledged and referenced all materials used in this work. I understand that non-adherence to 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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This thesis is especially dedicated to my mother, Zewdachekole

and to all my family for their love and care.

Abstract

The development of irrigation and agricultural water management has significant potential to improve productivity and reduce climatic vulnerability. Although Ethiopia has abundant rainfall and water resources, its agricultural system does not yet fully benefit from the technologies of water lifting and optimal irrigation management. *Therefore, there is need to investigate the potential of manual irrigation water lifting technologies (pulley and rope &washer)and evaluate simple irrigation scheduling technologies for farmers. In this study two different irrigation scheduling methods were compared for each water lifting technology: irrigation scheduling by Wetting Front Detector (WFD) and soil water balance by measuring soil moisture using a Time Domain Reflectometr (TDR).*

The experimental plot size varied between $100 m^2$ *to* $230\ m^2$ *and plots were given the same onion seed, crop management and amount of fertilizer based on the recommendation. For each water lifting group (i.e. pulley, rope and washer) half of the farmers followed the WFD while the other half followed the TDR based soil water balance scheduling.*

Both irrigation water management tools, i.e. WFD and TDR, were found good to facilitate irrigation scheduling. Using the WFD seemed an appropriate simple scheduling technology for farmers. Applied irrigation depths between both scheduling methods were not found to be significantly different. On average the total irrigation depth in the WFD plots was found 20% lower than those applied in the TDR based soil water balance method.

Within the same water management group no significant differences were found between both water lifting technologies for the applied irrigation depth, crop and water productivity. Similar discharges ranging between 0.20 and 0.25 l/s were obtained for both water lifting technologies (i.e. pulley and rope & washer) irrespective if the technology was operated by men, women or youngsters (ages 14-15). The time taken to irrigate the plots by rope & washer was less as compared to Pulley.

Key words: *Wetting Front Detector(WFD), Time Domain Reflector (TDR), Irrigation productivity (IP),yield(y), Water use efficiency (WUE), soil moisture profiler reading (SMPR), Pulley (P) and rope & washer (RW)*

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

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List of Acronyms and abbreviations

AMD	Available Moisture Deficit
CWR	Crop Water Requirements
DA	Development Agent
DAP	Day after planting
ECe	Soli Exchangeable Cat ion
Etc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agricultural Organization
FC	Field Capacity
Ha	Hectares
ILSSI	Innovation laboratory for small scale irrigation
IR	Irrigation requirements
IWMI	International Water Management Institution
IWR	Irrigation Water Requirements
MoA	Ministry of Agriculture
MWR	Ministry of Water Resource
PWP	Permanent Wilting Point
SMPR	Soil moisture profiler reading
SSI	Small-Scale Irrigation
TAW	Total Available Moisture
TDR	Time domain reflectometr

WHC Water holding Capacity

WFD Wetting Front Detector

Y Yield

INTRODUCTION

1.1 Background and Justification

The development of irrigation and agricultural water management has significant potential to improve productivity and reduce climatic vulnerability. Although Ethiopia has abundant rainfall and water resources, its agricultural system does not yet fully benefit from the technologies of irrigation and water management**.** The majority of rural dwellers in Ethiopia are among the poorest in the country, with limited access to agricultural technology, limited possibilities to diversify agricultural production because of underdeveloped rural infrastructures, and little to no access to agricultural markets and technological innovations. These issues combined with increasing degradation of the natural resource base, especially in the highlands, aggravate the incidence of poverty and food insecurity in rural areas. Improved water management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity (MoA, 2002).

Ethiopia follows Agricultural Development Lead Industrialization (ADLI), and there is no readily identifiable yield increasing technology other than improved seed, irrigation, and fertilizer(Nigus, 2013).Irrigation will, therefore, play an increasingly important role now and in the future both to increase the yield from already cultivated land and also to bring marginal or unusable land due to moisture deficiency (FAO, 2002) under the cultivation.

Irrigation and improved agricultural water management practices could enhance productivity per unit of land, and increase the annual production volume significantly. Irrigated agriculture started in Ethiopia in 1960 with the objective of producing sugar and cotton on large-scale basis for industries. Local farmers however, had already been practicing traditional agriculture and irrigation by diverting water from rivers in the dry season for subsistence farming. The experience in modern small-scale irrigation (SSI) development and management started in the 1970s by the Ministry of Agriculture (Mo A, 2002).

In Ethiopia, small-scale traditional irrigation schemes constitute about 40% of the total irrigated land area. Despite this, the sector has largely been overlooked and is so far not supported by improved water management technologies. Due to land and water shortages and the need for food self-sufficiency in the region, it has become essential to improve the productivity of this sector (Geremew et al., 2008).

In Ethiopia, groundwater from underground aquifers can be used for irrigation using deep and shallow wells. Compared with other sources of irrigation, groundwater as a resource for agricultural production provides reliability, consistency and availability of water throughout the year. Despite these advantages, it is not widely exploited for agriculture in Ethiopia. Little information regarding groundwater recharge and extraction is available which makes estimations of groundwater consumption for irrigated agriculture in Sub Saharan Africa including Ethiopia challenging. The most traditional and widespread use of groundwater is for village 'garden-scale' irrigation of vegetables and seedlings, which helps to improve food and nutritional security at local scale. The groundwater irrigation potential of Ethiopia is estimated to be around 1.1 million ha (Awulachew, 2010).

Irrigation potential in Ethiopia is estimated as 3.7 million ha underconventional gravity irrigation. When rain water harvesting with supplementary irrigation, groundwater use, and water lifting technologies are considered, it is believed that the potential could be more significant. The irrigated area in year 2002 was 197,000 hectares with a coverage distribution of 38 % traditional, 20 % modern communal, 4 % modern private and 38 %public schemes (MoA, 2002). The revised figure according to the growth & transformation plan of the country agriculture land equipped with small scale irrigation will expand from 0.85 million ha during the base period 2010/2011 to 1.85 million ha at the end of the planning period 2014/2015 (Awulachew& Ayana, 2011)

The Federal and Regional Governments in Ethiopia have given due emphasis to irrigated agriculture to ensure food self-sufficiency. For instance, the Amhara Regional State has many irrigation development projects undergoing within the region. The Koga, Rib and Megech projects are among those in the region. In most irrigable lands, horticultural crops play an important role in contributing to the household food security. The horticultural crops such as garlic, onion, carrot being cash crop with nutritional value generate income for poor households. Higher profits can be achieved by increasing productivity and production throughout the year using efficient irrigation systems. With increasing municipal and industrial demands for water, its allocation for agriculture is decreasing steadily. The major agricultural use of water is for irrigation, which, thus, is affected by decreased supply (Nigus, 2013). Therefore, innovations are needed to increase water use efficiency. There are several possible approaches, however irrigation technologies and irrigation scheduling may be adapted for more-effective and rational uses of limited supplies of water. It is necessary to choose irrigation scheduling tools and irrigation water lifting technology based on full crop water requirement that are easy to use and save water.

1.2 Problem of statement

For agricultural intensification (such as improved input use), water is an entry point implying that irrigation development, especially irrigation technologies for smallholder farmers is very important. On the other hand, lack of simple and affordable irrigation technology to lift groundwater for the production of crops by the farmers is a serious limiting factor to achieve food security. While there is evidence that there is high small holder demand for different types of water lifting technologies (such as motorized and manual technologies), the level of adoption of the technologies is very low.

The farmers' irrigation application is most of the time either more or less than the crop water requirement. In some cases the soil may be naturally saturated with water or has more water than is required for healthy growth of the plant. This excess water is harmful to the growth of the plant which limits aeration of the root zone. On the other hand lack of water during critical stages of the plant life will hamper nutrient uptake, crop development and reduce yield. Therefore there are a lot of scientific methods developed to irrigate crops based on water requirement and soil moisture status. The scientific tools needed to schedule irrigation are well developed. More recently ranges of 'user friendly' capacitance devices, based on the measurement of the dielectric property of soil, have come into the market (Charlesworth, 2005). However, most of the farmers do not use these because of the complexity of the method and its cost. For example irrigation using the soil moisture control method does not yield direct information to the irrigator unless soil properties are known and the crop water requirement is calculated which is cumbersome for smallholder farmers in rural areas.

1.3 Research Questions

- Which water lifting technology is most suitable for irrigation and increases the productivity of onion during the dry season?
- Does a Wetting Front Detector help farmers to facilitate irrigation scheduling like scientific irrigation scheduling methods (TDR based soil moisture balance)?

1.4 Objective of the study

1.4.1 General objective

- To evaluate suitable water lifting technologies and irrigation scheduling methods for sustainable small scale onion production during February – May.

1.4.2 Specific objective

1. To evaluate the difference in water and onion productivity for two water management techniques:
   A) Irrigation based on the crop water requirement calculated from the measured soil moisture depletion using Time Domain Reflectometer (TDR)
   B) Irrigation based on signaling of the Wetting Front Detector (WFD)
2. To assess water and crop productivity of onion for both irrigation scheduling methods under two different manual water lifting technologies namely pulley and rope &washer.

2 LITERATURE REVIEW

2.1 Manual water lifting devices

Human Powered water lifting devices can be split into two categories, those designed to lift groundwater; and those designed to lift surface water. Groundwater is water that flows or seeps downward through the earth filling up the spaces between soil, sand and rock to form a saturated zone. The upper surface of this saturated zone is called the “water table.” The “water table” may be just below the surface like a spring. The only way to get access to this water is by digging or drilling. Surface Water is water present in depressions, lakes, rivers, reservoirs, and oceans.

There are a lot of manual water lifting device like open well pump, shallow well piston pump, rower, treadle pump Pulley and Rope & Washer (Karl,2005 and Henk et al., 2010).Treadle, Rower and Piston pump have the limitation of lifting water from depths of up to 7 meters while Pulley and Rope & Washer can lift water from the deeper wells (Robert, 1990).

2.1.1 Rope &Washer Pump

The rope and washer pump is a rotary pump which can lift water from 35 m depth. At this depth the average yield is calculated as 10 liters/min. However, these pumps more commonly operate at depths up to 10 m with a water yield of 40 liters/min. This type of pump is widely used for household irrigation and small community water supply. The main wheel is turned by hand and feeds the Rope & Washers down the well shaft, over the guide Pulley and through the riser pipe to the discharge point (Robert, 1990). The washers are an exact fit with the riser pipe and force water up towards the surface. Rope & Washer pumps design is simple and requires less maintenance than other equivalent pumps (Karl, 2005 and Henk et al., 2010).

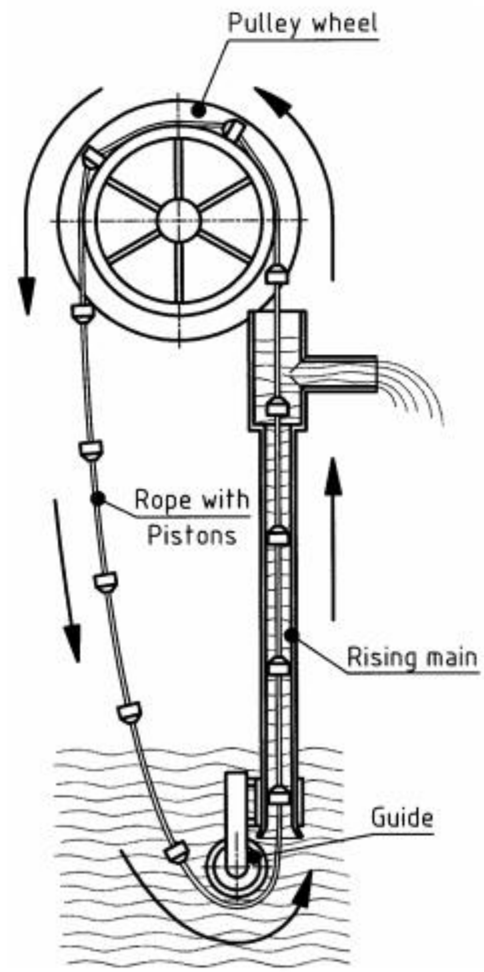

Figure 2-1: Rope & washer (source Karl 2005).

2.1.2 Pulley bucket

The Pulley and bucket water lifting technology lifts water from more than 20m depth. The amount of discharge depends on the bucket size and force required to pull it up. The advantages of Pulley are its durability and easy maintenance (WHO, 2003).

2.2 Soil moisture and crop water requirement

2.2.1 Soil Water Content

The gravimetric soil water content (GSWC) is expressed by weight as the ratio of the mass of water to the dry weight of the soil sample. To determine this ratio for a particular soil sample, the water weight is determined by drying the soil to constant weight and measuring the soil sample weight after and before drying (Black, 1965). The water weight is the difference between the weights of the wet and oven dry samples. The oven-drying technique is probably the most widely used of all gravimetric methods for measuring soil moisture and is the standard for the calibration of all other soil moisture determination techniques (Black, 1965). Volumetric soil water content (VSWC) relates volume of water in the sample to the total volume of soil and it is a more convenient way to express the soil moisture content for irrigation management. VSWC can be calculated by multiplying the gravimetric soil water content (GSWC) by the soil bulk density (Charlesworth, 2000).

Some terminology related with soil water content.

Available soil moisture: Is the difference between the amount of water in the soil at field capacity and the amount at the permanent wilting point.

Field capacity: The water content of the soil where all free water has been drained from the soil through gravity. Sandy soils may drain within a few hours but fine textured soils such as clay may take a few days to drain. Proper irrigation brings soil moisture up to filed capacity.

Permanent wilting point (PWP): The soil moisture content at which the plants will wilt and die. While there still may be water in the soil, the plant is not able to extract sufficient water from the soil to meet its needs.

Maximum soil water deficit (MSWD): Only a portion of the available water is easily used by the crop. The maximum soil water deficit is the amount of water stored in the plant's root zone that is readily available to the plant. To prevent plant water stress an allowable depletion factor is used to calculate the manageable allowable depletion.

Deep percolation: Water that drains beyond the plant root zone.

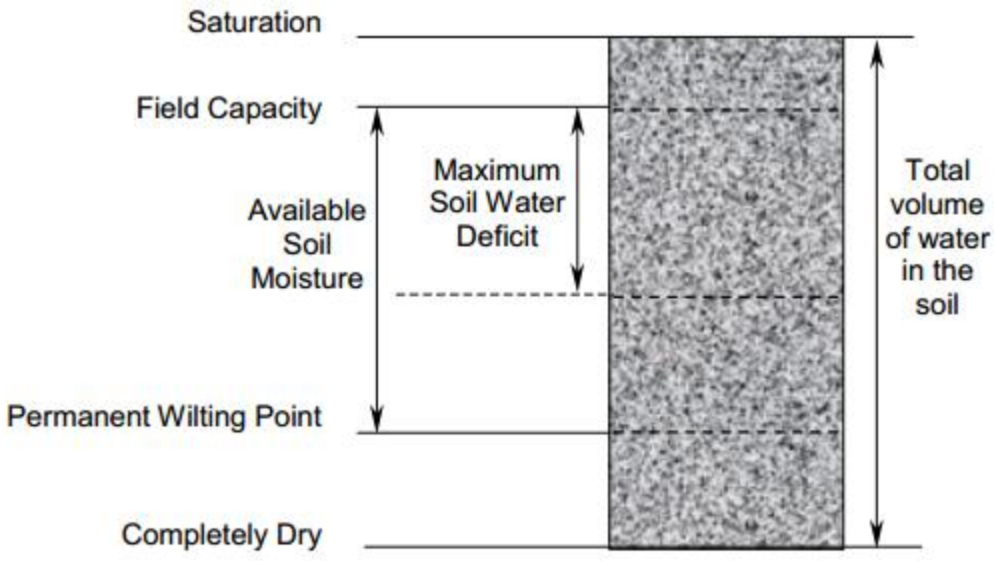

Figure 2-2:Soil water moisture term (source from Water conservation fact sheet).

2.2.2 Crop water requirement of onion

Onion requires 350 to 550 mm water for optimum yield. The crop coefficient (Kc) relating reference evapotranspiration (ETo) to water requirements (ETc) for different development stages after transplanting is, for the initial stage 0.4-0.6 (15 to 20 days), the crop development stage 0.7-0.8 (25 to 35 days), the mid-season stage 0.95-1. 1 (25 to 45 days), the late-season stage 0.85-0.9 (35 to 45 days), and at harvest 0.75-0.85 (Allen et al., 1998). Research conducted by Bekele and Tilahun, (2007) showed that to obtain maximum yield it is necessary to avoid water deficit, especially during the bulb development.

2.3 Irrigation scheduling

Irrigation scheduling may be accomplished by a number of different methods that strive to keep the soil moisture within proper limits. Proper irrigation scheduling is the application of water to crops only when needed and only in needed amounts. This requires the answer to two questions: when to irrigate and how much water to apply (Smajstrla, et al., 1997). According to Smajstrla et al. (1997) and Munoz et al. (2002) no irrigation system will apply water without some waste or losses, since the cost to prevent all losses is prohibitive. An excellent method to reduce water use consists of utilizing soil moisture monitoring devices in conjunction with rainfall records and knowledge of plant water needs (Muñoz-Carpenaet al., 2002).

2.3.1 Irrigation scheduling tools

The goal of irrigation management is to maintain the water level in the root zone within a range where crop yield and quality are not hampered due to either insufficient or excess water. For onion, soil water content in the root zone should not be allowed to drop below 25% of the available soil water storage between irrigations (King & Stark, 2002 &Doorenbos andKassam, 1979). Monitoring soil water in the crop root zone will allow better management of water applications to meet the requirements of the crop.

Irrigation scheduling can be done in various ways:1) visual observations of plant/soil status,2)measuring the soil moisture and calculating/modeling crop water requirement;3) automated/manual scheduling based on sensors.

Soil moisture measurement is an integral part of any irrigation scheduling program. Soil moisture readings can be used to schedule irrigations, but they are most useful when used in combination with other methods of scheduling such as a simple checkbook method or a computer model. Soil moisture readings can determine initial soil moisture balances and update those balances throughout the irrigation season. Where the soil moisture readings are the basis for scheduling irrigations, readings are taken at least once every two days. (http://agbiopubs.sdstate.edu/articles/FS876.pdf accessed January 5, 2015)

The soil moisture status requires periodic measurements in the field, from which one can project when the next irrigation should occur and what depth of water should be applied. Conversely, such data can indicate how much has been applied and its uniformity over the field.

There are numerous techniques for evaluating soil moisture. Perhaps the most useful are gravimetric sampling, tensiometers, the neutron probe the touch-and-feel method, and TDR. Through the volumetric soil moisture content, guidance on the quantity and timing of irrigation to sustain agricultural production and to improve water and energy use efficiency is feasible. Irrigation will only occur if the moisture sensor allows it, which in turn occurs only when substrate moisture dropped below acceptable level. To calculate the crop water requirement and the amount of irrigation needed, important soil characteristics in irrigated agriculture should be known: (1) the water-holding or storage capacity of the soil, field capacity and wilting point; (2) the permeability of the soil to the flow of water and air; (3) the physical features of the soil like the organic matter content, depth, texture and structure; and (4) the soil's chemical properties such as the concentration of soluble salts, nutrients and trace elements. For this study, the mechanical qualitative tool Wetting Front Detector was compared with the electronic quantitative TDR sensor and subsequent soil moisture balance calcuations.

2.3.1.1 Scheduling based on quantitative soil moisture readings: the time domain reflectometer.

A precise and relatively new technology to assess volumetric soil water content is the Time Domain Reflectometer (TDR). TDR voltage readings can be convertedin to volumetric soil water content (VSWC) which is a popular method to report the soil water status (Take et al., 2007)

A fully automatic irrigation system combines this kind of sensor with a data logger or computer to activate irrigation when moisture level have dropped below a set threshold and deactivate when the required soil moisture has been reached. TDR sensors give very accurate readings, however, they are still quite expensive (approximately $200 per sensor) and additional hardware and software is needed to control an irrigation system using TDR (Charlesworth, 2000). In this study the TDR was used to measure the volumetric water content and calculate the irrigation requirements manually.

2.3.1.2 Scheduling based on qualitative soil moisture measurements: the Wetting Front Detector

Direct measurement of soil water in the field is tedious and usually requires specialized equipment. Especially for small holder farmers the operation of soil moisture sensors and corresponding calculations are complicated. Wetting Front Detector (WFD) is simple and affordable irrigation-scheduling tool that monitors the physical movement of water down the soil profile (Stirzaker, 2003; Stirzaker et al., 2004).

Wetting Front Detectors are usually used in pairs. The first one is buried about one third of the way down the active root-zone. The second one is buried about two-thirds the depth of the active root-zone. The active root-zone depth of soil is the depth where the maximum roots are found in or the maximum depth of soil we aim to wet by irrigation. By observing shallow and deep detectors response through the season, the irrigator get an idea if they are applying too much or too little water (Geremew et al., 2007). The study of Geremew et al., (2007) explored the use of the WFD as a feedback to decide whether the irrigation amount recommended by the Soil Water Balance (SWB) needed to be adjusted. The study used a simple algorithm (Annandale et al., 2005) to decide when to adjust the recommended irrigation amount depending on the number of shallow and deep WFD responding after irrigation. Geremew et al., (2007) result shows when the WFD indicate under irrigation the recommended amount for the next irrigation based on the SWB increased by 20% and the other hand, when the detector show over irrigation the application was reduced by 20%. They attributed the low response of the WFD due to the deep installation of the shallow WFD (i.e. 30 cm).

If the detectors are rarely activated, the crop is likely to be under-irrigated (Figure 2-3, left). If both shallow and deep detectors regularly respond to irrigation, the crop is likely to be over-irrigated (Stirzaker,2003; Stirzaker et al., 2004) (Figure 2-3, right). The shallow detector has a yellow flag and the deep detector hasa red one. When the yellow detector pops up irrigation should be stopped to protect water loss under the active root depth (Figure 2-3, middle).

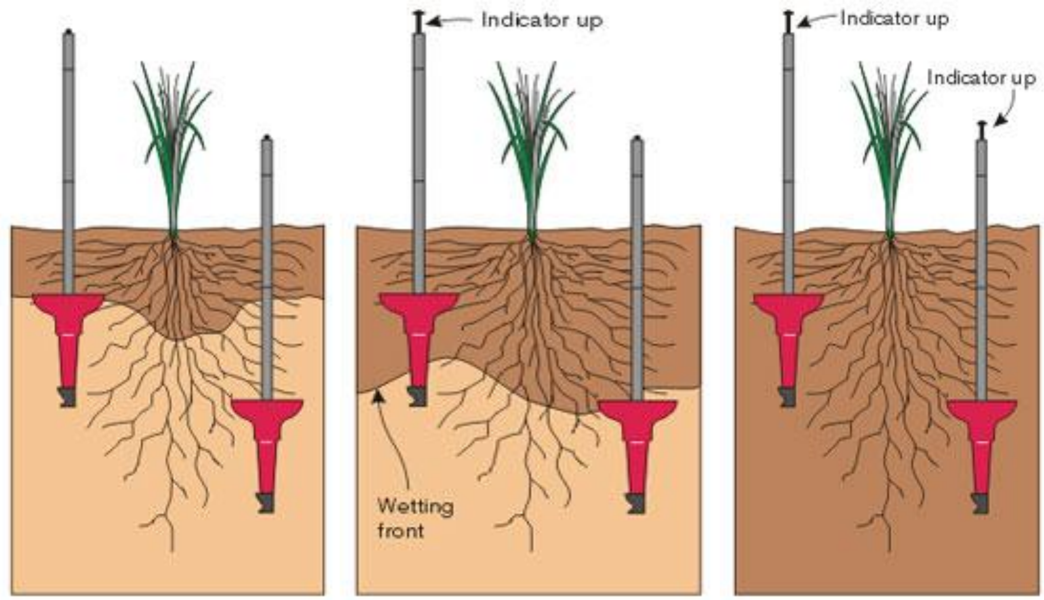

Figure 2-3: Water movement under the root zone and WFD. (Source from Stirzaker et al., 2004).

Many soil water content determination tools disturb the soil during installation and their sensitivity to the change in water content is greatest in the disturbed zone (Evett et al., 2002). Just like other methods, a potential drawback of the Wetting Front Detector is disturbance during installation. Even if soil is repacked to similar bulk density, disturbance changes the connectivity of soil pores, which impacts the saturated hydraulic conductivity. However, when the water is applied at rates less than the infiltration rate, as is typically for drip or sprinkler systems, the soil surface remains below saturation and the large pores do not conduct water (Whilte et al., 1979).

3 MATERIAL AND METHODS

3.1 Study area

Dangila woreda is located in Awi zone in the Amhara Region and is one of Agricultural Growth Program (AGP) and USAID feed the future Woredas in the Amhara Regional State. It is located about 80 km south west from Bahir Dar, 36.83° N and 11.25° E and on average 2000 m above sea level. In the woreda, there are 27 rural Kebeles among which 16 of them have access to a perennial river. Average annual rainfall is about 1600 mm, but varies between 1180-2000 mm. The mean annual potential evapotranspiration (PET) is 1250 mm. One of Dangila's kebeles selected for this study is Dangishta. The population of Dangishta is 5600.Dangishta has two major rivers; Branti river whose watershed covers 2291.49 ha and Kilti river whose watershed covers 1000 ha. Current status of groundwater use for domestic and irrigation is presented below. The study was conducted in the Brhanti watershed see (Table 3-1).

Table 3-1: Current status of groundwater in Dangila.

	Depth below surface (m)	Current Use	No. of Wells in Dangilaworeda	Remark
Shallow Hand dug wells	< 25	Irrigation and Domestic water supply	2281	Excavated by human labor
Shallow wells	25-75	Domestic water supply	3	Well drilling need machinery
Deep wells	>75	Domestic water supply	11 (includes non-functional)	Well drilling need machinery

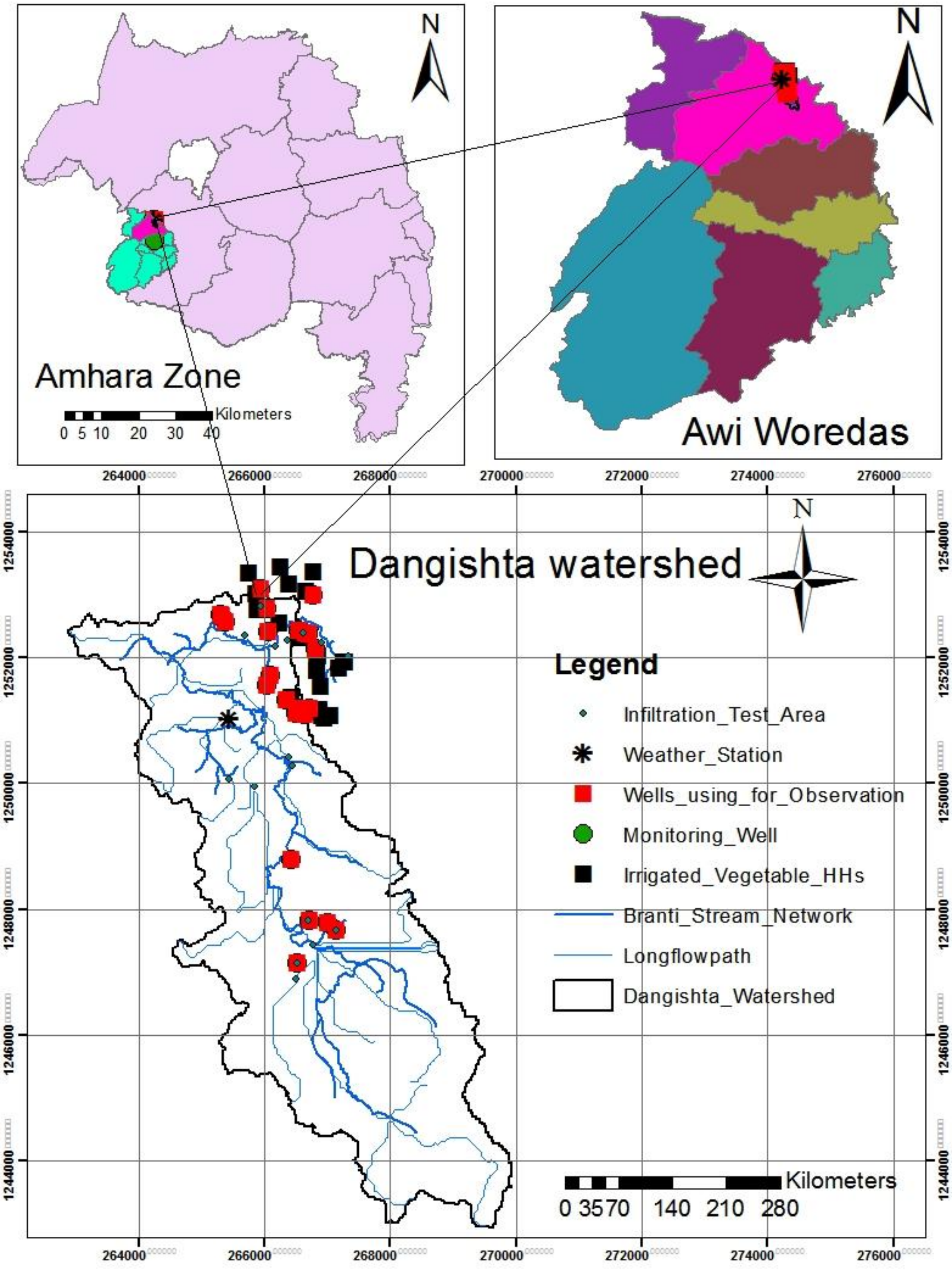

Figure3-1: Site description of the study area.

3.2 Experimental design

On October1, 2014, a focus group discussion was held with Agricultural office expert, Development agent and community leader of Dangiela woreda to explain the objective of the study. A meeting was then conducted with Dangeshita Keble farmers' and 18 smallholder farmers were selected who fulfill the experimental design criteria. The criteria were that the farmers should have two or more wells, and water availability in the wells throughout the season, from the mid of November to May-June.

The baseline survey was conducted where GPS coordinates of plots, slope of plots, size of experimental area, the well depth and soil samples for biophysical analysis were collected. At the end of January, the water lifting technologies and the Wetting Front Detector were installed. During the technology installation, training sessions were held on about the use of the water lifting technology and Wetting Front Detector. Irrigation training was given to all farmers depending on the irrigation scheduling treatment they belonged to. The WFD irrigation scheduling training was again conducted for the second time in April. Additionally, data collectors were trained to assist in data collection.

Important issues about the experimental design are listed as follows;

- Nine farmers irrigate onion using Rope & Washer the other 9 farmer use an improved Pulley with water tank connected to a delivery hose.
- The experimental plots varied between 100 m^2 to 230 m^2.
- Overhead irrigation was applied for onion in all plots using buckets.
- Local onion seed was sowed in all plots based on the farmer interest and appropriate fertilizer amounts, according to the local recommendation and the soil nutrient status were applied.
- The crop management systems in all plots were similar.
- The planting spacing for onion was the same for all plots: 20 cm spacing between rows and 30 cm spacing between plants. The bed width and length almost the same for all farmer that is 1.2 m width by 6 m length.

- In total nine Wetting Front Detectors were installed in the plots for both water lifting technology (i.e. 5 Rope & Washer and 4 Pulley users).
- Time Domain Reflector meter (TDR) was used for the remaining 9 plots to measure the soil moisture for (5 Pulley and 4 Rope & Washer plots) to guide the irrigation scheduling and quantity.
- Additional 6 Soil Moisture Profiler Probe (SPP) access tubes were installed, 3 for the Wetting Front Detector group and 3 for the TDR group to understand the effect of both scheduling methods on soil moisture changes throughout the soil profile.

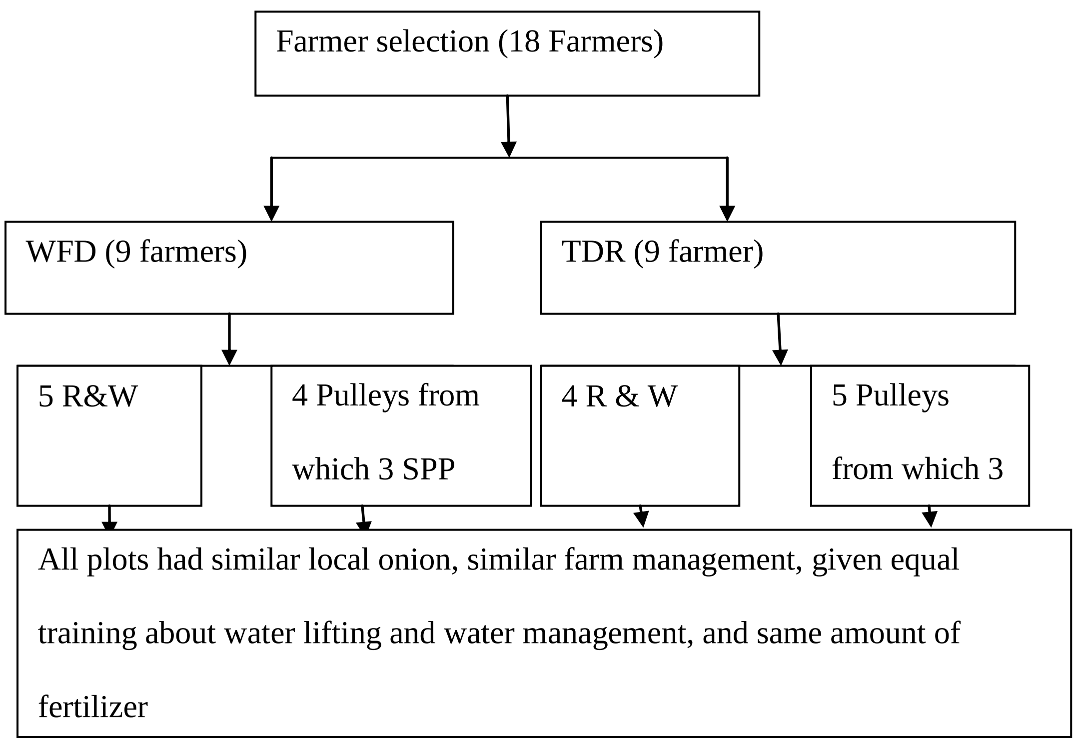

Figure3-2: flow chart of experimental design for the water management (i.e. TDR and WFD) and water lifting (i.e. R&W and Pulley) experiments. The SPP into WFD group and TDR group installed.

The experimental layout is classified based on water management method and the water lifting technology. Every plot was coded: the first letter represented the water lifting technology, the second letter the water management followed by the plot number. The letter used for water managements (WM) were TDR as T and WFD as W. For water lifting (WL), it was P for Pulley and RW for Rope & Washer. For example PT1 means

Pulley with TDR for plot one, RWT2 means Rope & Washer with TDR plot two, PW3means Pulley with WFD for plot 3 and RWW4 means Rope & Washer with WFD plot four, etc.

3.3 Installation of water lifting and management technologies

3.3.1 Installation of water lifting technologies: Pulley and Rope & Washer

The installation of Rope &Washer and Pulley with water tank and deliver hose was done in the experimental site by the manufacturers as show in Figure3-3. During the installation of the technology the farmers were given training regarding the operations and maintenance of the technologies. From the community two farmers got special training to maintain and service the water lifting technologies for all project farmers.

Rope & Washer Pulley

Figure3-3: Rope & Washer (left) and the improved Pulley with tanker and delivery hose (right).

3.3.2 Installation of the irrigation scheduling tool: Wetting Front Detector (WFD)

The Wetting Front Detector was installed in pairs in the middle of each plot, placed at 20cm and 40cm soil depths because the root zone depth of onion varies from 30 to 60 cm (FAO stat, 2004). The shallow WFD or yellow flag was buried one third of root zone depth i.e., 20 cm and the deep WFD or the red flag detector was buried at the 2/3rd of root zone depth i.e., 40cm (Strizaker et al., 2005). During installation a 20 cm diameter auger was used to excavate the hole as shown Figure 3-4. After placing WFD, the excavated hole was refilled and soil was compacted to represent the surrounding conditions as much as possible.

Figure3-4: Installation of Wetting Front Detector at the middle of the plot before starting (left) and changing of the broken WFD (Right).

3.4 Data collection and Methodology

3.4.1 Soil physico-chemical properties

The soil samples from 10 locations were collected from each plot at 0- 20cm depth using an auger. Soil samples collected from these 10 locations were mixed for observations and analysis (Figure3-5). Out of the above mixture 500-1000 gram of soil sample was analyzed at Amhara Design and Water Work Supervision Laboratory.

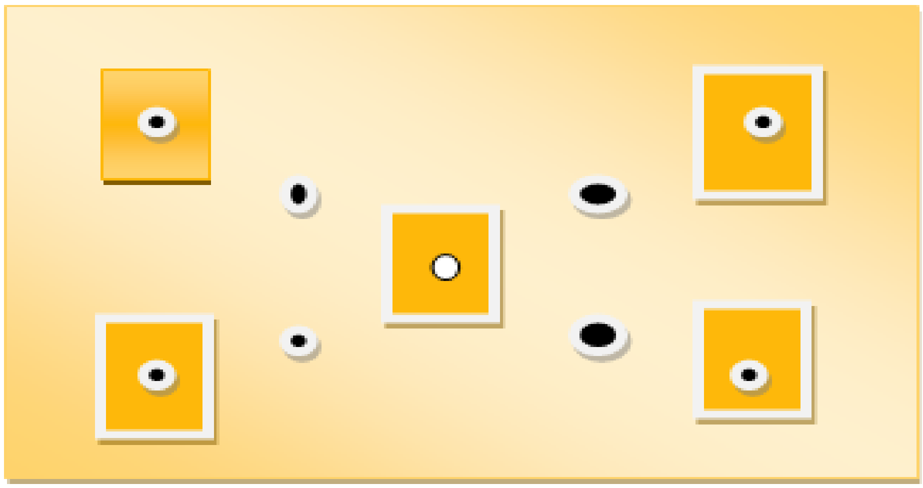

Figure3-5: Location of soil sample taken from each plot.

In the laboratory, soil samples were analyzed for field capacity, wilting point, soil texture, available organic matter, pH of soil sample, total exchange capacity, total nitrogen, nitrate and ammonia, available P and total P, available K, iron status, and anion (sulfur and phosphorus).

Soil texture of the field was determined in the laboratory using the Hydrometer method. The water content at field capacity was determined in the laboratory by using a pressure (porous) plate apparatus. Permanent wilting point was also determined by using pressure membrane apparatus by applying -15 bar to a saturated soil sample. When water is no longer leaving the soil sample, the soil moisture is taken as permanent wilting point. Electrometric method with the suspension of soil-water ratio of 1 to 2.5stirred for 30 minute was used to determine the pH of soil.): Kjeldahl method was used to determine total N (mg N g^{-1}).Plant available phosphorus P (mg P kg^{-1}soil) was obtained from extraction of acid-soluble and adsorbed phosphorus with fluoride-containing solution according Bray I test (acid soil).Electrical Conductivity Bridge was used to determine the EC (dS m-1)of the 60 min stirred suspended soil(1:5 H_2O ratio).

3.4.2 Discharge calibration and measuring well depth

The Rope & Washer discharge calibration depend on the well depth, pipe diameter and tire rotation speed (Karl, 2005 and Henk et al, 2010). The Pulley with tanker discharge calibration depends on the wheal diameter, depth of well and bucket size. The calibration of each water lifting technology was performed for male, female and youngsters (ages 14-15) for varying well depths. For the calibration of the rope and washer the timing to fill a 15 L bucket was recorded five times for each user group. For pulleys a similar calibration was performed but the bucket capacity was 5 L hanging from the rope and timing to fill 150 liter tanker was recorded. Well depths were measured using a tape measure.

3.4.3 Soil water balance

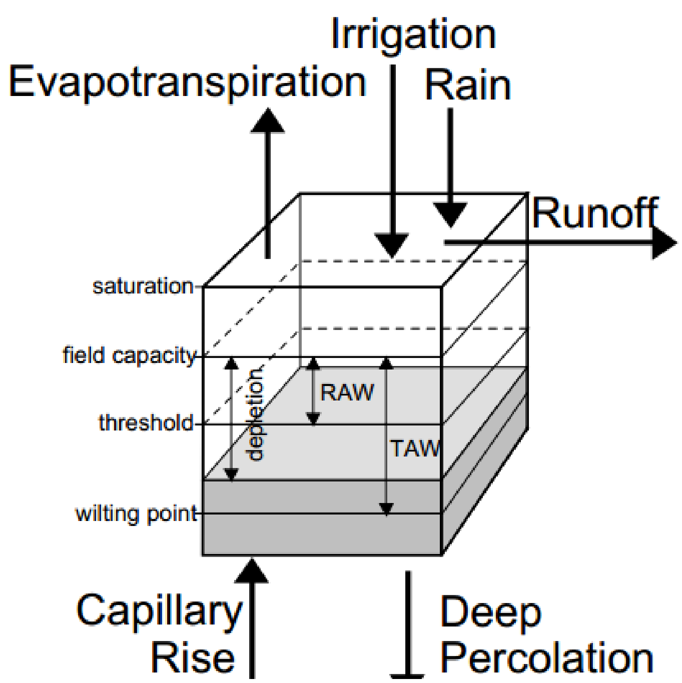

Figure3-6: Soil water balance in the root zone source from (FAO 56).

The irrigation method was overhead application using a bucket. Therefore, runoff, deep percolation and capillary rise were assumed to be negligible (see section 4.3.2).

$$\mathbf{ET = I + P - D - R - Cr \pm \Delta S} \text{ --------------------- } \textbf{Equation 3-1}$$

With ET = evapotranspiration (mm);

I = amount of irrigation (mm); P = precipitation (mm); R= Runoff (mm); D = drainage (mm); Cr= Capillary rise (mm) and ΔS= is the change in soil water storage (mm).

3.4.3.1 Rainfall

The rainfall data during irrigation season was collected from the meteorology department in Dangila gauge station, from the first week of February to the end of May.

3.4.3.2 Amount of irrigation water used in TDR group

The Time Domain Reflector meter was used at each irrigation event to obtain moisture readings in each plot before irrigation was started. The TDR had 20 cm rods giving average soil moisture content in the first 20cm of the soil profile. Soil moisture readings were taken from five places in each plot and the average was calculated. Based on the readings the calculation of irrigation quantity to be applied in the field was calculated for each farmer as shown in equations 2 to 6.

To know the total available water in the root zone of onion information on field capacity, permanent wilting point and root depth is required. The root depth of onion varies from 0.3 to 0.6 (Allen et al., 1998). Onion, as common with most vegetable crops, is sensitive to water deficit. For high yield, soil water depletion should not exceed 25 percent of available soil water(Allen et al., 1998).The total available water is the water holding capacity of the root zone. TAW is the difference between field capacity and wilting point moisture contents multiplied by the depth of the root zone.

$$\mathbf{TAW = (FC - WP) * RD} \text{ ------------------------- } \textbf{Equation 3-2}$$

$$\mathbf{WH = FC - WP} \text{ ------------------------------ } \textbf{Equation 3-3}$$

$$\mathbf{irrigation\ interval} = \frac{\mathbf{(AWA)}}{\mathbf{MAD}} \text{ -------------------------- } \textbf{Equation 3-4}$$

$$\mathbf{MAD = (WH * Ad)} \text{ ---------------------------- } \textbf{Equation 3-5}$$

$$\mathbf{AWA} = (\mathbf{FC} - \mathbf{I}) * \mathbf{Rd} ------------------------- \textbf{Equation 3-6})$$

where, FC=Field capacity (%);I =actual soil moisture content (this taken by TDR)(%); WP = wilting point (%); Ad=allowable depletion of onion (%); RD= effective root depth of the onion (cm); WH=water holding capacity (%)&AWA=Amount of water should be applied (mm/day).

3.4.3.3 Amount of irrigation water used in WFD group

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

The velocity of a wetting V front is given by

$$\boldsymbol{V} = \frac{(\boldsymbol{IR} - \boldsymbol{K\emptyset i})}{(\boldsymbol{\emptyset wf} - \boldsymbol{\emptyset i})} ------------------------ \textbf{Equation 3-7}$$

Where IR is the irrigation rate, $K\theta_i$ is the unsaturated conductivity at the initial water content, θ_{wf} is the water content behind the wetting front or field capacity and θ_i the initial water content or water content ahead of the front. For values of θ_i less than the upper drained limit, $K\theta_i$ is very low compared to the irrigation rate and can be omitted.

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

$$\boldsymbol{I} = \boldsymbol{d}(\boldsymbol{\emptyset wf} - \boldsymbol{\emptyset i}) ---- ------------------- \textbf{Equation 3-8}$$

θ_{wf} remains relatively constant for a given soil-irrigation rate combination, and since d is fixed depth of WFD, then for this study the yellow installed at 20cm and the red is 40cm.

$$\boldsymbol{I(mm)} \approx \mathbf{1}/\boldsymbol{\emptyset i} ------------------------ \textbf{Equation 3-9}$$

Thus the amount of irrigation applied on any day is linearly proportional to the initial water Content. Based on this the amount of irrigation is inversely related with the initially soil moisture content. When the initial soil is wet, it need the flag to response quickly and need small amount of water. When the soil is dry before irrigation, then the front will travel slowly and a long irrigation will be permitted before the front reaches the detector. And farmer applied water based on the detector response.

3.4.3.4 Soil moisture change throughout the soil profile (sp)

The Soil Moisture Profile Probe (SMPP) measures soil moisture content at different depths within the soil profile. It consists of a sealed polycarbonate rod, 25mm diameter, with electronic sensors attached at fixed intervals along its length. The tubes are specially constructed, thin-wall tubes which maximize the electromagnetic field into the surrounding soil. The probe is inserted into an access tube while taking a reading.

The installation of Soil Moisture Profiler access tube took place for both WFD and TDR. The cases of TDR installed in 1m deep hole, which was made with help of auger. For the WFD plot, it was installed in the middle of the TDR plot and between the shallow and the deep detector in the WFD plot (Figure 10).

Figure3-7: Soil moisture Profiler Probe (SPP) with WFD.

Measurements were taken regularly during each growth stages. Readings were taken at the onset of the irrigation and continued at 2, 5, 10, 15, 30, 60 and 180minutes interval. The data was collected for 3 farmers in each water management group (i.e. WFD and TDR) on the water movement within and below the root zone. The device records the volumetric water content at the depth of 10, 20, 30, 40, 60, and 100cm. The reading for the WFD group was additionally used to understand the signaling of the detector in relation to the moisture content throughout the profile.

3.4.4 Agronomic performance and yield.

The agronomic performance was collected from each plot during the growth stage: initial, development, mid-stage, and final stage. All parameters were determined and calculated from the average of five small 1 m^2sub plots (bold boxes in Figure 3-5). The following parameters were measured: plant height, number of stems, days to physiological maturity, and total tuber yield were recorded.

3.4.5 Irrigation productivity and water use efficiency

Irrigation productivity is the total yield per quantity of irrigation water used. Several factors affect water productivity such as: crop management, soil preparation, soil type, irrigation scheduling, crop variety and climate (Stanhill et al., 1960 & Zwart and Bastiaanssen, 2004). The irrigation experiment was conducted using similar local onion seed variety, similar crop management, and similar climate condition and irrigation application method (i.e. overhead) for all treatments. The irrigation was given by the responds of the flag of WFD (WFD group) or the soil water balance calculation (TDR-group). The water productivity is calculated by dividing the yield (kg ha^{-1}) by the amount of irrigation water (mm) so water productivity is expressed by kg ha^{-1} mm^{-1}or we can expressed by kgm^{-3} because 1mm=10m^3ha^{-1}(Stanhill, 1986).

As such the irrigation productivity based on the water management was calculated according to:

$$\boldsymbol{IP} = \frac{\boldsymbol{Yield}}{\boldsymbol{I}} ------------------------------ \textbf{Equation 3-10}$$

Where IP= irrigation productivity (kg m^{-3} or kg ha^{-1} mm^{-1}), yield is (kg ha^{-1}) and I=irrigation water applied (mm or m^3ha^{-1}).

The water use efficiency was calculated based on:

WUE was obtained as crop yield per unit seasonal Etc

$$WUE = \frac{Y}{Etc} \text{------------------------} \quad \textbf{Equation 3-11}$$

$$ET_c = (Iw + P - D - R - \Delta s) \text{----------------} \quad \textbf{Equation 3-12}$$

where ETc, is the crop evapotranspiration, Iw irrigation water, P the precipitation, D deep percolation, R the runoff and ΔS is the change in soil water storage between the start and the end of the irrigation season (computed from TDR data). All terms are expressed in mm of water in the onion root zone. The change in soil water storage from 0 to 20cm depths was measured. Run-off and deep percolation was assumed to be negligible as overhead irrigation was performed (as can be seen in section 3.4.2).

3.5 Data analysis

At the end of cropping season, onion yield and its parameters for all irrigation treatments were determined. Firstly, the collected data such as irrigation amount, crop water use, crop yield and water use efficiency was checked by Q-Q plot normality test (Appendix M).Afterwards a two-way analysis of variance (ANOVA) using the Least Significant Differences (LSD) test at the 5% probability level ($P < 0.05$) was performed. All statistical procedures involved in this study were done using SPSS 16.0 version software.

4 RESULT AND DISCUSSION

4.1 Soil physic-chemical property

The average standard deviation of pH, EC, OM, Av P FC and PWP is shown in Table4-1, and details can be found in appendix A. There is no significant difference between the four treatment groups (i.e. pulley-TDR, pulley WFD, rope & washer-TDR and rope & washer WFD) for all parameters as shown in Appendix Table N.

Table 4-1: Soil physio-chemical property of all plots.

Water lifting Technology	Parameter	Water Management			
		WFD		TDR	
		Average	SD	Average	SD
Pulley	pH (1:2.5)	5.72	0.27	5.93	0.35
	ECE(ds/m)	0.12	0.15	0.17	0.188
	OM (%)	3.76	0.95	4.27	0.8
	TN (%)	0.19	0.046	0.21	0.04
	Av P (ppm)	11.32	6.76	11.42	4.71
	Fe (ppm)	18.01	4.96	17.70	3.60
	FC(%)	31.50	1.86	31.14	3.04
	PWP (%)	19.8	1.39	20.67	0.25
Rope & Washer	PH (1:2.5)	6.06	0.15	5.95	0.84
	ECE(ds/m)	0.15	0.19	0.22	0.2
	OM (%)	5.13	0.82	5.28	1.71
	TN (%)	0.26	0.04	0.26	0.09
	Av P (ppm)	18.34	10.73	22.59	30.22
	Fe (ppm)	18.6	2.83	16.72	5.24
	FC(%)	33.4	0.93	33.55	3.06
	PWP(%)	21.48	0.35	21.28	1.53

The soil pH of the experimental field did not vary from plot to plot. The average pH of 6 showed that the soil of the site was suitable for onion crop production with regard to soil pH. The soil texture of most of the experimental plots is clay and clay loam (Appendix A), which medium textured soil suitable for onion is growing (FAOSTAT, 2001).

The water content at field capacity (FC) and permanent wilting point (PWP) of the soil were determined and there average values were 31-33% and 20-22% respectively. The maximum and the minimum value of EC in this study is 0.12dS/m to 0.26dS/m respectively and the average value is 0.17dS/m. The onion crop is sensitive to soil salinity and yield decrease at varying levels of EC is: 0% at EC 1.2dSm^{-1}, 10% at EC1.8dSm^{-1}, 25% at EC2.8dSm^{-1}, 50% at EC4.3dSm^{-1} and 100% at EC 7.5dSm^{-1}. As the soil salinity values in the study area were below 1.2dSm^{-1} it will not affect crop performance.

4.2 Discharge from the various water lifting devices

4.2.1 Discharge of Rope &Washer and well depth

The average discharge obtained from Rope & Washer is shown in Table 4-2 and the detailed observations are shown in Appendix C. The average discharge of the Rope & Washer is calculated according to the various user groups (i.e. men, women and youngsters (ages 14-15)) and Appendix C shows relatively similar results between the various irrigators. Within the user group very little difference was observed i.e. less than 0.03ls^{-1} from the mean. No significant difference was found between the different plots although there is a variation of well depth ranging between 4.5m and 11m.

Table 4-2: Discharge obtained from the Rope & Washer.

Plot code	Well depth(m)	Repetition	Bucket size (l)	Time (s)	Average discharge (l s^{-1})
RWW5	7	3	15	59	0.25
RWW6	4.6	3	15	60	0.25
RWW10	11	3	15	60	0.25
RWW13	10.2	3	15	60	0.25
RWW14	5	3	15	59	0.25
RWW15	4.5	3	15	59	0.25
RWW17	5	3	15	59	0.25
RWW20	8.3	3	15	59	0.25
RWW22	4.5	3	15	59	0.25
Average	**6.6**	**3**	**15**	**60**	**0.25**

The discharge of Rope & Washerwas0.25 l $s^{-1}$the same for all farmers because it depends on the pipe diameter and the diameter of pipe varies based on the well depth. All farmers in the study had a well depth above 11 m and the average well depth was 6.6 m. According to Henk.H et al.,(2010) the well depth from 4to 11m, requires a 30mm or 1 inch diameter pipe and the discharge at 10m depth is 40 l/minute (0.67 l s^{-1}). The difference in discharge obtained in this study and Henk.H et al., (2010) may be because of a different calibration method and manpower during the calibration. The discharge is dependent on the speed of rotation but at discharges above 0.25l s^{-1} there is water spillage from the pipe. Hence, farmers rotate at a lower speed.

4.2.2 Discharge of Pulley with tank and well depth

The average discharge of Pulley with tank was 0.2 l $s^{-1}$for the bucket size of 5 liter bucket hanging by rope and fetch water from the well depth of 5 m to fill 150 liter of water tank (Appendix Table C).Discharge depends on the size of bucket and the well depth. The average discharge of pulley was calculated using the main irrigator (i.e. men, women and youth (ages 14-15)) and Table 4-3 show relatively similar results between the users.

Table 4-3: Average discharge calibration of pulley and rope & washer based on different user level.

Water Lifting Technology	User group	Well depth (m)	Repetition	Bucket size (l)	Time taken (s)	Average Discharge (l/s)
Pulley	Men	5	3	150	720	0.21
	Women	5	3	150	756	0.20
	Kid	5	3	150	780	0.19
	Average	**5**	**3**	**150**	**752**	**0.20**
Rope & Washer	Men	6.6	3	15	58	0.26
	Women	6.6	3	15	60	0.25
	Kid	6.6	3	15	62	0.24
	Average	**6.6**	**3**	**15**	**60**	**0.25**

4.3 Soil Water balance in the root zoon of onion

4.3.1 Irrigation water used

The irrigation water applied based on the WFD and TDR method is shown in Table 4-4. The detailed observation of each WFD & TDR user is shown in Appendix B and Appendix D respectively and summary is shown in Appendix G.

Table 4-4 : Irrigation water applied based on water management.

No	WFD	TDR
1	335	547
2	452	409
3	320	585
4	376	267
5	311	300
6	439	537
7	389	614
8	453	370
9	273	525
Average	**372**	**462**
SD	**66**	**128**

Table 4-5: The effect of WFD and TDR on irrigation (mm).

	Average irrigation (mm)
WFD	372[a]
TDR	462[a]
$LSD_{0.05}$	120
CV(%)	17.7

Key: Means followed by the same letter for the same factor are not significantly different, WFD=Wetting Front Detector, TDR (Time domain reflectometer), CV= Coefficient of variance and LSD= list significant difference

The result of variance analysis for the irrigation water used does not show significant difference (P>0.05) (Appendix O and Table 4-5). There is a non-significant 20% reduction of irrigation water application in WFD plots. The variation between the various farmers within the WFD group is half of the standard deviation obtained within the TDR group.

The reason of water saving is the installation of the Wetting Front Detector at 20 cm compared to the full root zone calculations in the TDR group. In the WFD group the devices is triggered when the moisture is reached at 20 cm of the root depth and the other portion of the root zone is slowly wetted and wetted without water loss by percolation, while for the TDR group the calculations are based on the assumed root zone of 40 cm.

4.3.2 Change of soil moisture in the soil profile

4.3.2.1 Change of soil moisture throughout the soil profile in the WFD group.

The temporal evaluation of the soil moisture allows for the understanding of soil moisture increases during and after irrigation along the entire profile as function of the water management. In order to understand the functioning of the Wetting Front Detector specific attention was paid to the soil moisture change at 20cm (depth of the yellow WFD) and at 40 cm (depth of the red WFD).

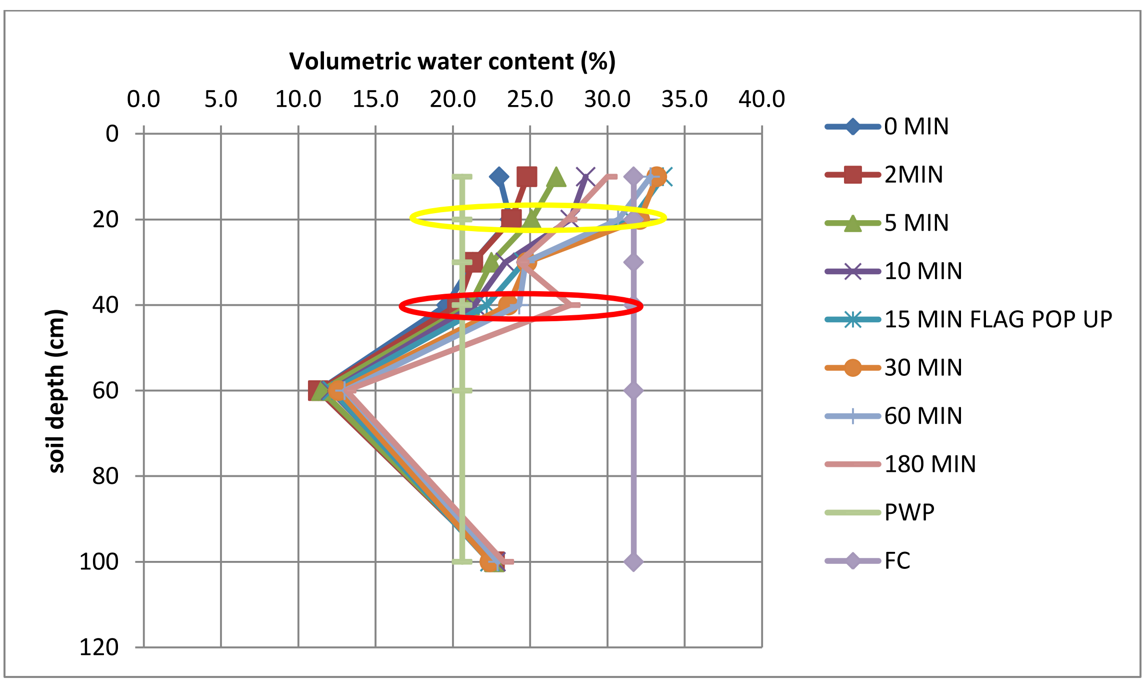

Figure4-1: Soil moisture reading by the soil profiler probe.

Figure 4-2 shows soil moisture reading with wetting front response from individual plot. The measured field capacity of the top soil (0-20cm) was 31.7% while the permanent wilting point was 20.6%.Similar texture and soil conditions for the entire 1m profile was assumed for evaluating the changes during irrigation. The shallow (yellow) detector at 20cm responded 15min after irrigation started. During that the soil moisture reading was 31.6% which are close to field capacity or available soil moisture in the root zone.

At 40cm depth, the soil moisture was maximum at 27.6% after3 hours of irrigation which is lower than the field capacity. Hence the detector at 40cm did not react and there is no deep percolation beyond 60 cm.

4.3.2.2 Change of soil moisture throughout the soil profile in the TDR group

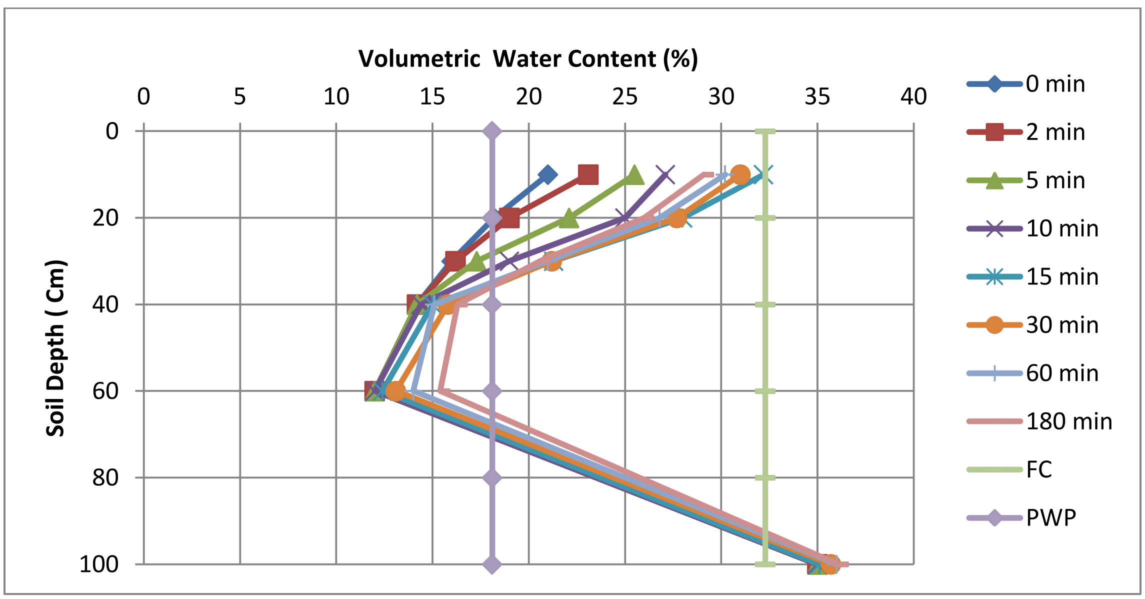

Figure 4-2: soil moisture reading with TDR plot.

Figure 4-3 shows soil moisture reading from single plot of TDR group. The measured field capacity of the top soil (0-20cm) was 33.67% while the permanent wilting point was 20.6%. Similar texture and soil conditions for the entire 1m profile was assumed for evaluating the changes during irrigation. The required soil moisture (32.7%) was achieved during 15 minute at the depth of 20cm which is between field capacity and permanent wilting point. Beyond 60 cm depth the volumetric water content between 0 minute and 3 hour looks similar and therefore deep percolation is assumed negligible in the TDR plots.

4.3.3 Crop water used

The water used by onion in each plot based on the water management and water lifting technology is shown in Table 4-6which was calculated by equation 3-12 and the details are given in Appendix P. The result of variance analysis for the crop water used is not significant difference (P>0.05) as show in appendix table L.

Table 4-6:Overview of the various water balance components, i.e. crop water used (ET_c), irrigation amount (I), Rainfall (R) and changes in the soil moisture balance (ΔS) based on water management and water lifting technology.

Water Lifting Technology	WFD					TDR				
		I (mm)	R (mm)	ΔS (mm)	ET_c (mm)		I (mm)	R (mm)	ΔS (mm)	ET_c (mm)
Pulley	Max	452	240	-17	709	Max	547	240	2.8	784
	Min	320	240	22	538	Min	268	240	9	499
	Average	**371**	**240**	**4.8**	**616**	**Average**	**452**	**240**	**-27.4**	**645**
	SD	**59.1**	**0**	**24.3**	**70.1**	**SD**	**142.2**	**0**	**15.4**	**142**
Rope & Washer	Max	439	240	-12	691	Max	614	240	9	845
	Min	273	240	-16	529	Min	370	240	19	591
	Average	**373**	**240**	**-0.3**	**612**	**Average**	**512**	**240**	**-26**	**718**
	SD	**66**	**0**	**18.8**	**78.6**	**SD**	**128**	**0**	**1.6**	**97.1**

From table 4-6 it can be seen that10% of water was saved by WFD and there is no significant difference between the two water management methods. Schmitter et al., (2015) showed for Koga irrigation scheme that the irrigation depth was reduced by 34% and 39 % in potato and wheat for furrow irrigation, respectively. This can be explained by the lower efficiency of furrow irrigation compared to overhead irrigation.

The averaged ET_c value ranged between 612 to718 mm and is higher than the ET values obtained by other researchers in different agro-ecological places. For example seasonal

ET_c of 337.8 mm for onions irrigated with micro sprinklers between April and July in an arid Bulgarian environment was reported by Meranzova and Babrikov (2002). Pelter et al.,2004) recorded an onion ET_cf 597 mm hen irrigated by drip-irrigation estimate Columbia Basin, Washington state, USA. In Oregon, an average ET_c of 791 mm was measured(Shock et al., 2004,Olalla et al., 2004).It is interesting to note that the variation in the TDR group is larger than that of the WFD group due to the larger differences in irrigation depth.

The detailed table of change in soil moisture is shown in the Appendix F. The TDR treatment of Δs was positive (Table 4-6), indicating that the soil become moist at the end of the growing season and some of the WFD treatment was negative, suggesting that the soil become dry. Dry soil can absorb more water, so the wetting front may not go all that deep, even with a heavy irrigation. However, if the soil is already wet light irrigation can penetrate deeply into the soil.

4.4 Agronomic Performance of onion

4.4.1 Plant height

The height of onion at various days after planting (DAP) was measured and shown in Table 4-7.The statistically analysis of the plant height did not show a significant difference between water management method and water lifting technologies at P >0.05 may be seen in Appendix J.

Table 4-7: The average height of onion on each crop development stage, i.e. initial (15 DAP), development (45 DAP), mid (85 DAP) and end (95 DAP) stage.

Water lifting technology	Day after planting (Day)	TDR	WFD
		Height (cm)	Height (cm)
Pulley	15	4.5	3.7
	45	19.1	19.9
	85	24.6	25.6
	95	2.5	2.8
Rope & Washer	15	4.1	4.1
	45	19.8	19.1
	85	24.3	25.3
	95	2.5	2.7

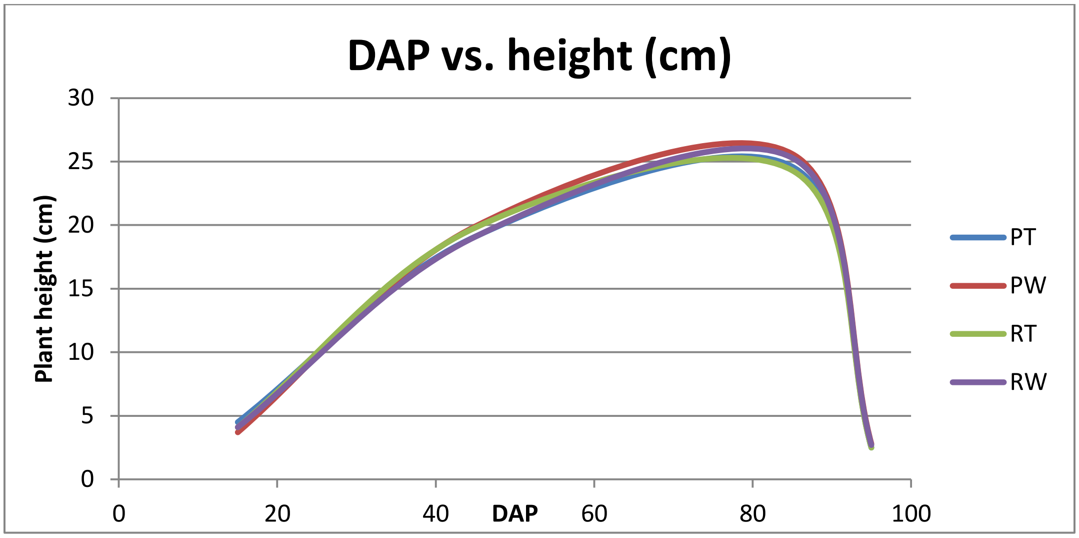

Figure4-3:Change in onion plant height in function of the days after planting for the various treatment groups, i.e. pulley +TDR (PT), pulley + WFD (PW), R&W +TDR (RT) and R&W +WFD (RW).

4.4.2 Yield

The mean yield obtained (kgha^{-1}) is presented in Table4-8 (details are shown in Appendix M). Figure 15 shows that the highest yield obtained was 4010 kgha^{-1}forRope & Washer with WFD treatment combination and the lowest yield was 3139 kgha^{-1}observed for Pulley with TDR treatment combination. The analysis of variance (Appendix Q) showed that water management (WFD &TDR) and water lifting (Pulley and Rope& Washer)and their interaction do not significantly ($p > 0.05$) influence the onion bulb yield (Table 4-9).A 25 % larger yield variation was obtained in the TDR group compared to the WFD group.

Table 4-8: Yield based on water management.

Water lifting technology	WFD			TDR		
		Plot Code	Yield (kgha^{-1})		Plot Code	Yield (kgha^{-1})
pulley	Max	PW16	5800	Max	PT2	5500
	Min	PW18	2500	Min	PT8	1500
	Average		**3444**	**Average**		**3139**
	SD		**1576**	**SD**		**2030**
Rope & Washer	Max	RWW6	5674	Max	RWT22	7087
	Min	RWW5	1786	Min	RWT15	2364
	Average		**4010**	**Average**		**3795**
	SD		**1592**	**SD**		**2247**

Table 4-9: Interaction effect of water lifting and water management on yield (Kg/ha).

	Water management	
Water lifting	WFD	TDR
Pulley	3444^{a}	3139^{a}
R& W	4010^{a}	3795^{a}
LSD $_{0.05}$	2378.8	
CV(%)	**181.1**	

Key: Means followed by the same letter for the same factor are not significantly different, WFD=Wetting Front Detector, TDR (Time domain reflectometr), CV= Coefficient of variance and LSD= list significant difference

4.5 The effect of water management and water lifting technology on onion production

4.5.1 Irrigation productivity

Based on equation 3-10 the average irrigation productivity (kgm^{-3}) is presented in Table4-10. The highest irrigation productivity was observed in Rope & Washer with TDR treatment and the lowest is observed from Pulley with TDR the value is 1.3and 0.4 respectively. The analysis of variance (Appendix R) showed that water management (WFD & TDR) and water lifting (Pulley and Rope& Washer) and their interaction do not significantly ($p > 0.05$) influence the irrigation productivity. Comparing the two water lifting devices showed that the rope and washer with WFD is 33% more irrigation productivity compared to the pulley with TDR.

Table 4-10: Average and standard deviation of irrigation productivity based on water management.

	WFD					TDR				
Water Lifting Technology		Plot Code	I (m^3 ha^{-1})	Yield (kg ha^{-1})	IP (kg m^{-3})		Plot Code	I (m^3 ha^{-1})	Yield (kg ha^{-1})	IP (kg m^{-3})
Pulley	Max	PW16	4520	5800	1.3	Max	PT2	5470	5500	1
	Min	PW18	3200	2500	0.7	Min	PT8	2680	1500	0.4
	Average		3710	**3444**	**0.9**	**Average**		4520	**3139**	**0.7**
	SD		591	**1576**	**2.6**	**SD**		1422	**2030**	**2.7**
Rope & Washer	Max	RWW6	4520	5674	13.1	Max	RWT22	6140	7087	13.5
	Min	RWW5	2730	1786	5.8	Min	RWT15	3700	2364	6.4
	Average		3730	**4010**	**1.1**	**Average**		5120	**3795**	**0.8**
	SD		660	**1592**	**3**	**SD**		1280	**2247**	**4.1**

The regressions between WFD and TDR are shown in Figure4-6.The R^2 value of TDR is 0.85 and the R^2 value of WFD is 0.84, which shows the trend between the TDR groups is slightly better than the WFD. The slop of WFD shows twice than the TDR group.

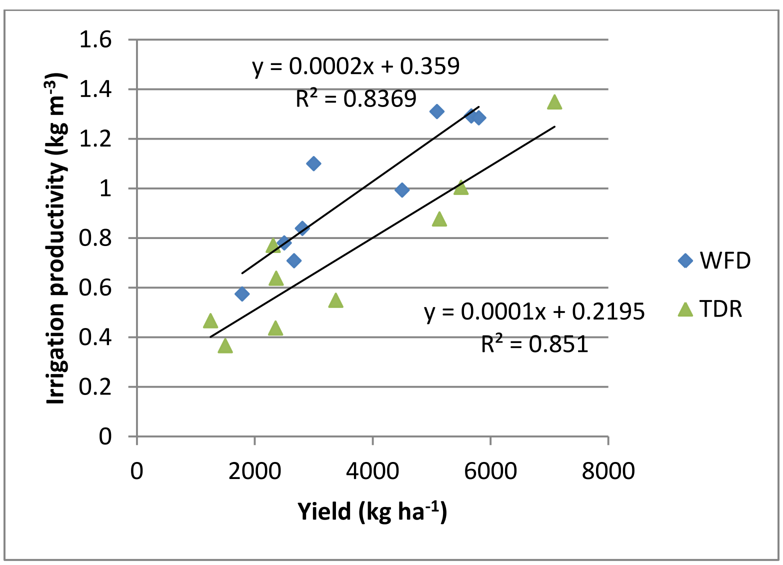

Figure4-4:Yield (kg m^{-3}) vs. irrigation productivity (kg ha^{-1}) for the two irrigation scheduling groups.

4.5.2 Water use efficiency

The average irrigation water use efficiency (kgm^{-3}) was obtained using equation 11 and is presented in Table4-11. The highest water use efficiency was $1kgm^{-3}$for Rope & Washer with TDR treatment combination and the lowest water use efficiency was observed 0.3kg m^{-3} observed from Pulley with TDR treatment combination. Analysis of variance (Appendix Table S) showed that water management (WFD & TDR) and water lifting (pulley and rope & washer) with their interaction do not significantly ($p > 0.05$) influence water use efficiency. Comparing the two water lifting devices showed that the rope and washer with WFD uses the water 28% more efficient compared to the pulley with TDR.

Table 4-11:Water use efficiency based on water management and water lifting technology.

Water lifting Technology	WFD					TDR				
		Plot Code	**ET_c (m^3 ha^{-1})**	**Yield (kg ha^{-1})**	**WUE (kg m^{-3})**		**Plot Code**	**ET_c (m^3 ha^{-1})**	**Yield (kg ha^{-1})**	**WUE (kg m^{-3})**
Pulley	Max	PW16	7090	5800	0.8	Max	PT2	7840	5500	0.7
	Min	PW18	5380	2500	0.5	Min	PT8	6060	1500	0.3
	Average		6160	**3444**	**0.5**	**Average**		6650	**3139**	**0.5**
	SD		704	**1576**	**0.2**	**SD**		1496	**2030**	**0.2**
Rope & Washer	Max	RWW6	6910	5674	0.8	Max	RWT22	7500	7087	1
	Min	RWW5	5270	1786	0.3	Min	RWT15	5910	2364	0.4
	Average		6120	**4010**	0.6	**Average**		7260	**3795**	**0.5**
	SD		703	**1592**	0.2	**SD**		1330	**2247**	**0.3**

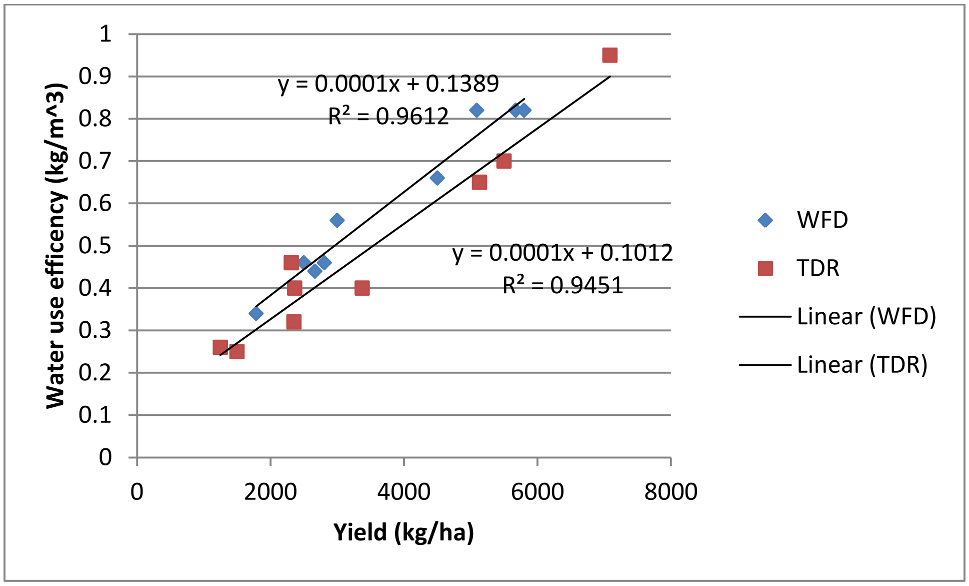

Figure4-: Yield vs. water use efficiency.

The regressions between WFD and TDR are shown in the above Figure4-7. The R^2 value of TDR is 0.95 and the R^2 value of WFD is 0.96 which shows that the trend between the WFD groups is slightly better than the TDR. The slope for both regression functions is the same and indicates that the water management has not altered the water usage by the crop.

4.6 Limitation of the study

Due to the large variation between farmers within one treatment group as function of farmer management and the small sample group results were not found to be significantly different. A larger sample group would help in validating the results of this study.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Both water lifting technologies are helping the farmer to improve irrigation productivity. However, Rope & Washer saves time because of slightly higher discharges, thus requiring less labor compared to the pulley. When we compare onion productivity statistically there is no significant deference between Rope & Washer and Pulley. Because both lifting technologies were subjected and managed by a specific irrigation method. However, given the slight differences in discharge observed and the difference in manpower needed for both lifting devices, differences in irrigation application, water and crop productivity are expected to occur in small holder farms when no irrigation scheduling tool or method is followed.

The water management technologies namely WFD and TDR have been found suitable. However, irrigation water used by WFD is 20% less compared to the TDR. However, the irrigation applied, onion yield as well as the irrigation productivity and water use efficiency were not found to be statistically significant between both water management treatments. Both water management methods led to negligible deep percolation losses beyond 60 cm. WFD seems to be a good and easy farmer scheduling tool alternative to TDR in improving crop productivity and water use efficiency in Ethiopia. The TDR methods are a solid scientific method but it is cumbersome and difficult for rural small holder farmers. Hence, the WFD is a good alternative as no significant decreases in yield were obtained.

5.2 Recommendation

Water lifting technologies are good to improve irrigation productivity as found in this study. Rope & Washer is good for irrigation but need further investigation. However, the spare parts and training on maintenance to the farmers will be necessary. The farmers are recommended to use WFD for irrigation scheduling in both the water lifting technologies, because only by seeing the signal of WFD they can irrigate the crop. Furthermore, the cost of WFD is relatively cheap ($60) compared with scientifically electronically sensors like TDR $ 800.

However, a large scale investigation is needed to validate these findings as high variability was found between farmers was found due to local management variations. These variations in combination with the small sample size partly explain the non-significance found in this study. A larger sample size as well as its replicable for different soil types and crops will yield valuable information to improve crop and water productivity for high value irrigated crops in Ethiopia.

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APPENDICES

Appendix-A: Physical and chemical propertiesof the soil.

PLOT CODE	pH (H_2O) 1:2.5	EC dS/m	Texture % sand	% clay	% silt	Class	CEC	OM %	TN	Av. P ppm	Fe	FC %	PWP
PW1	5.43	0.137	26	51	23	Clay	12.4	2.36	0.12	7.65	16.8068	32.63	20.50
PT2	5.76	0.176	28	47	25	Clay	23.4	4.29	0.21	6.53	13.3148	32.90	21.05
RT3	5.13	0.14	30	41	29	Clay	24.8	4.45	0.22	12.07	20.1408	32.32	20.11
PW4	6.03	0.09	26	51	23	Clay	25.8	3.43	0.17	20.28	10.8728	32.66	21.19
RW5	5.86	0.221	40	29	31	clay loam	27.6	5.22	0.26	25.12	15.0668	34.61	21.58
RWW6	6.11	0.083	34	37	29	clay loam	25	3.95	0.20	10.67	17.3068	32.82	20.99
RT7	6.2	0.287	52	23	25	sandy clay loam	28	4.79	0.24	16.07	17.6788	33.52	21.69
PT8	5.4	0.056	16	53	31	Clay	21.2	3.03	0.15	7.44	14.2808	30.92	20.34
RWW9	5.47	0.127	36	37	27	clay loam	27.4	4.97	0.25	12.56	21.5808	34.36	21.49
RW10	6.03	0.341	50	25	25	Clay	29.000	6.14	0.31	13.68	22.2408	34.13	21.87
PT11	6.3	0.106	32	37	31	clay loam	29.400	5.29	0.26	12.42	20.9208	32.21	20.70
PT12	6.1	0.132	38	33	29	clay loam	24.600	4.45	0.22	12.49	20.0808	33.67	20.66
RT13	7.11	0.596	68	9	23	heavy clay	34.200	8.068	0.403	76.14	19.44	38.49	23.75
RW14	6.02	0.115	28	43	29	Clay	26.800	4.793	0.240	8.49	17.96	32.39	21.69
RT15	6.53	0.142	32	43	25	Clay	22.000	3.534	0.177	10.10	13.08	30.64	21.12
PW16	5.96	0.104	20	51	29	Clay	18.400	3.862	0.193	9.82	22.12	32.29	18.70
PT17	6.1	0.113	28	45	27	Clay	22.200	4.293	0.215	18.24	19.98	26.00	20.61
PW18	5.48	0.124	30	45	25	Clay	21.000	4.293	0.215	4	16.96	31.70	20.68
PW19	5.68	0.147	32	47	21	Clay	19	4.88	0.24	14.88	23.3208	28.24	17.96
RW20	6.28	0.177	42	29	29	clay loam	27.8	5.55	0.28	33.75	20.6808	33.05	21.28

Appendix-B: Wetting Front Detector individual data sheet.

They have 9 farmer using WFD. For example one of those farmers PW4is irrigate during16-Feb-2015

- During yellow flag pop-up number of irrigated water by tanker is 7
- The storage capacity of tanker is 150liter this means 7*150=1050liter or 1.05M^3
- Area of plot is 130 M^2
- Amount of water applied is = (1.05M^3)/ (130M^2)$^=$ 0.008m or 8mm

Name of the Farmer **PW4 (Pulley)**				Type of Crop **Onion**		
Soil Type **Clay**				Date of planting **16-Feb-15G.C**		
Irrigation interval **Based WFD(one)**				Depth of yellow WFD **20CM**		
Storage Capacity of Tank **150liter**				Depth of red WFD **40CM**		
Date	Flag before start irrigation				which flag pop up	
	Yellow	Red	Amount of water apply		Yellow	Red
	1= pop up	1= pop up	By TANKER	(MM)		
	0= pop down	0= pop down				
16-feb-15	0	0	7	8	1	
18-feb-15	0	0	6	7	1	
20-feb-15	0	0	4	5	1	
22-feb-15	0	0	6	7	1	
24-feb-15	0	0	6	7	1	
26-Feb-15	0	0	6	7	1	

28-Feb-15	0	0	6	7	1	
1-Mar-15	0	0	6	7	1	
3-Mar-15	0	0	6	7	1	
5-Mar-15	0	0	6	7	1	
7-Mar-15	0	0	7	8	1	
9-Mar-15	0	0	7	8	1	
11-Mar-15	0	0	7	8	1	
13-Mar-15	0	0	7	8	1	
15-Mar-15	0	0	7	8	1	
17-Mar-15	0	0	7	8	1	
19-Mar-15	0	0	7	8	1	
21-Mar-15	0	0	6	7	1	
23-Mar-15	0	0	6	7	1	
25-Mar-15	0	0	6	7	1	
27-Mar-15	0	0	6	7	1	
29-Mar-15	0	0	6	7	1	
31-Mar-15	0	0	6	7	1	
2-Apr-15	0	0	6	7	1	
4-Apr-15	0	0	6	7	1	
6-Apr-15	0	0	6	7	1	
8-Apr-15	0	0	6	7	1	
10-Apr-15	0	0	6	7	1	
12-Apr-15	0	0	6	7	1	
14-Apr-15	0	0	6	7	1	
16-Apr-15	0	0	6	7	1	

18-Apr-15	0	0	6	7	1	
20-Apr-15	0	0	6	7	1	
22-Apr-15	0	0	6	7	1	
24-Apr-15	0	0	6	7	1	
27-Apr-15	0	0	6	7	1	
29-Apr-15	0	0	6	7	1	1
2-May-15	0	0	7	8	1	
4-May-15	0	0	5	6	1	1
6-May-15	0	0	5	6	1	1
8-May-15	0	0	5	6	1	1
10-May-15	0	0	5	6	1	1
12-May-15	0	0	5	6	1	1
14-May-15	0	0	5	6	1	1
16-May-15	0	0	5	6	1	1
18-May-15	0	0	5	6	1	1
20-May-15	0	0	5	6	1	1
22-May-15	0	0	5	6	1	1
24-May-15	0	0	5	6	1	1
6-Jun-15				335		

Amount of irrigation water used from each WFD user.

Date	Pw4 (mm)	Rww5 (mm)	Rww6 (mm)	Rww10 (mm)	Rww14 (mm)	Pw16 (mm)	Pw18 (mm)	Pw19 (mm)	Rww20 (mm)
16-feb-15	8	8	10	8	11	11	8	9	10
18-feb-15	7	6	8	8	9	9	6	8	8
20-feb-15	5	4	5	7	6	6	4	5	5
22-feb-15	7	6	8	7	9	9	6	8	8
24-feb-15	7	6	8	7	9	9	6	8	8
16-feb-15	7	6	8	7	9	9	6	8	8
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	--	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
6-Jun-15	335	331	439	389	453	452	320	376	273


Training about WFD before start irrigation and evaluating the farmer after starting there was no runoff during irrigation.

Appendix-C: Discharge calibration for both water lifting technology

Farmer code	Repetition	Well Depth (m)	Bucket volume	Time started	Time stopped(min)	Time total	Discharge
PT2	3	9	150	0:00	0:00	12:22	0.000202262
	1		150	0:00	11:30	11:30	0.000217391
	1		150	0:00	12:35	12:35	0.0002
	1		150	0:00	13:02	13:02	0.000189394
PW4	3	3.5	150	0:00	0:00	12:38	0.000196436
	1		150	0:00	12:30	12:30	0.0002
	1		150	0:00	12:42	12:42	0.000197
	1		150	0:00	12:44	12:44	0.000192308
PT8	3	3.8	150	0:00	0:00	12:32	0.000199784
	1		150	0:00	12:00	12:00	0.000208333
	1		150	0:00	12:33	12:33	0.000199203
	1		150	0:00	13:03	13:03	0.000191816
PT12	3	4	150	0:00	0:00	12:32	0.000199784
	1		150	0:00	12:00	12:00	0.000208333
	1		150	0:00	12:33	12:33	0.000199203
	1		150	0:00	13:03	13:03	0.000191816
PW16	3	3.4	150	0:00	0:00	12:22	0.000202262
	1		150	0:00	11:30	11:30	0.000217391
	1		150	0:00	12:35	12:35	0.0002
	1		150	0:00	13:02	13:02	0.000189394
PT17	3	5.2	150	0:00	0:00	12:38	0.000196436
	1		150	0:00	12:30	12:30	0.0002
	1		150	0:00	12:42	12:42	0.000197
	1		150	0:00	12:44	12:44	0.000192308
PW18	3	4.2	150	0:00	0:00	12:32	0.000199784
	1		150	0:00	12:00	12:00	0.000208333
	1		150	0:00	12:33	12:33	0.000199203
	1		150	0:00	13:03	13:03	0.000191816
PW19	3	6	150	0:00	0:00	12:38	0.000196436
	1		150	0:00	12:30	12:30	0.0002
	1		150	0:00	12:42	12:42	0.000197
	1		150	0:00	12:44	12:44	0.000192308
PT21	3	6	150	0:00	0:00	12:32	0.000199784
	1		150	0:00	12:00	12:00	0.000208333

	1		150	0:00	12:33	12:33	0.000199203
	1		150	0:00	13:03	13:03	0.000191816
Average	**3**	**6**	**150**	**0:00**			**0.0002**
RWW6	3	4.6	15	0:00	0:00	1:00	0.000248869
	1		15	0:00	1:07	1:07	0.000223881
	1		15	0:00	0:55	0:55	0.000272727
	1		15	0:00	1:00	1:00	0.00025
RWW10	3	11	15	0:00	0:00	1:00	0.000248869
	1		15	0:00	1:07	1:07	0.000223881
	1		15	0:00	0:55	0:55	0.000272727
	1		15	0:00	1:00	1:00	0.00025
RW5	3	7	15	0:00	0:00	1:03	0.000249388
	1		15	0:00	1:05	1:05	0.000230769
	1		15	0:00	1:07	1:07	0.000263158
	1		15	0:00	0:59	0:59	0.000254237
RWT13	3	10.2	15	0:00	0:00	1:00	0.0002502
	1		15	0:00	1:02	1:02	0.0002419
	1		15	0:00	0:58	0:58	0.0002586
	1		15	0:00	1:00	1:00	0.0002500
RWW20	3	8.3	15	0:00	0:00	1:03	0.000249388
	1		15	0:00	1:05	1:05	0.000230769
	1		15	0:00	1:07	1:07	0.000263158
	1		15	0:00	0:59	0:59	0.000254237
RWW14	3	5	15	0:00	0:00	1:03	0.000249388
	1		15	0:00	1:05	1:05	0.000230769
	1		15	0:00	1:07	1:07	0.000263158
	1		15	0:00	0:59	0:59	0.000254237
RWT22	3	4.5	15	0:00	0:00	0:00	0.000249388
	1		15	0:00	1:05	1:05	0.000230769
	1		15	0:00	1:07	1:07	0.000263158
	1		15	0:00	0:59	0:59	0.000254237
RWT15	3	4.2	15	0:00	0:00	1:03	0.000249388
	1		15	0:00	1:05	1:05	0.000230769
	1		15	0:00	1:07	1:07	0.000263158
	1		15	0:00	0:59	0:59	0.000254237
RWT7	3		15	0:00	0:00	1:03	0.000249388
	1		15	0:00	1:05	1:05	0.000230769
	1		15	0:00	1:07	1:07	0.000263158
	1		15	0:00	0:59	0:59	0.000254237
Aver	**3**	**6.6**	**15**	**0:00**			**0.00025**

Appendix-D: Time domain reflectometer individual data sheet

For example farmer PT2 irrigate 13 mm of water during 24-Feb-15

- The field capacity of PT2 is 32.9% and the permanent wilting point is 21.05%
- Effective root depth (Rd) of onion is 0.4m or 40cm
- Water holding capacity in the root zone is = (FC-PWP)*Rd=(32.9-21.05)/100*0.4= 4.7cm
- Soil moisture reading (SMR) by TDR is 29.6%
- Amount of water should be applied = (FC-SMR)*Rd=(32.9-29.6)*0.4=1.32CM or 0.0132m
- Plot area of farmer PT2 is $220M^2$
- Therefore $=220M^2$ *0.0132M=**$2.90M^3$**
- Allowable deficit of onion is **25%**
- So Maximum Allowable Deficit is =(water holding capacity)*25%=**1.185cm**
- To know irrigation interval= Amount of water should be applied/ Maximum Allowable Deficit

  = 1.32cm/1.185cm/day=1.1=**1day**

= Amount of water should be applied/ irrigation interval

= 1.32cm/1day=**13mm** water for that day.

Measuring initial soil moisture reading by TDR onion root depth(CM) 0.4-0.6   effective root depth (M) 0.4

Maximum Allowable deficit (MAD) 25%

Soil type **Clay**

Name of the HH **PT2**

date	F.c	Pwp	TDR reding	Area	water holding	amount of water applied			MAD	irrigation interval	IWU
	%	%	%	M^2	cm	cm	m	M^3		(day)	cm/d
24-Feb-15	32.90	21.05	29.6	220	4.74	1.32	0.013	2.91	1.18	1	**1.3**
26-Feb-15	32.90	21.05	26.62	220	4.74	2.52	0.025	5.53	1.18	2	1.3
28-Feb-15	32.90	21.05	25.8	220	4.74	2.84	0.028	6.25	1.18	2	1.42
30-Feb-15	32.90	21.05	22.7	220	4.74	4.08	0.040	8.98	1.18	3	1.36
1-Mar-15	32.90	21.05	28.1	220	4.74	1.92	0.019	4.23	1.18	2	0.96
3-Mar-15	32.90	21.05	26.28	220	4.74	2.65	0.026	5.83	1.18	2	1.32
5-Mar-15	32.90	21.05	25.7	220	4.74	2.88	0.028	6.34	1.18	2	1.44
7-Mar-15	32.90	21.05	24.5	220	4.74	3.36	0.033	7.39	1.18	3	1.12
9-Mar-15	32.90	21.05	28	220	4.74	1.96	0.019	4.31	1.18	2	0.98
11-Mar-15	32.90	21.05	25.28	220	4.74	3.05	0.030	6.70	1.18	3	1.01
13-Mar-15	32.90	21.05	22.2	220	4.74	4.28	0.042	9.41	1.18	4	1.07

15-Mar-15	32.90	21.05	26.28	220	4.74	2.64	0.026	5.82	1.18	2	1.32	
17-Mar-15	32.90	21.05	26.62	220	4.74	2.51	0.025	5.52	1.18	2	1.25	
19-Mar-15	32.90	21.05	22.7	220	4.74	4.08	0.040	8.97	1.18	3	1.36	
21-Mar-15	32.90	21.05	25.28	220	4.74	3.04	0.030	6.70	1.18	3	1.01	
23-Mar-15	32.90	21.05	26.1	220	4.74	2.72	0.027	5.98	1.18	2	1.36	
25-Mar-15	32.90	21.05	28.84	220	4.74	1.62	0.016	3.57	1.18	1	1.62	
27-Mar-15	32.90	21.05	28.64	220	4.74	1.70	0.017	3.75	1.18	1	1.70	
29-Mar-15	32.90	21.05	26.6	220	4.74	2.52	0.025	5.54	1.18	2	1.26	
31-Mar-15	32.90	21.05	28	220	4.74	1.96	0.019	4.31	1.18	2	0.98	
2-Apr-15	32.90	21.05	28.64	220	4.74	1.70	0.017	3.75	1.18	1	1.70	
4-Apr-15	32.90	21.05	25.66	220	4.74	2.89	0.028	6.37	1.18	2	1.44	
6-Apr-15	32.90	21.05	27.68	220	4.74	2.08	0.020	4.59	1.18	2	1.04	
8-Apr-15	32.90	21.05	25.6	220	4.74	2.92	0.029	6.42	1.18	2	1.46	
10-Apr-15	32.90	21.05	29	220	4.74	1.56	0.015	3.43	1.18	1	1.56	
12-Apr-15	32.90	21.05	26.62	220	4.74	2.51	0.025	5.52	1.18	2	1.25	
14-Apr-15	32.90	21.05	29.6	220	4.74	1.32	0.013	2.90	1.18	1	1.32	
16-Apr-15	32.90	21.05	24.5	220	4.74	3.36	0.033	7.39	1.18	3	1.12	
18-Apr-15	32.90	21.05	28.64	220	4.74	1.70	0.017	3.75	1.18	1	1.70	
20-Apr-15	32.90	21.05	26.86	220	4.74	2.41	0.024	5.31	1.18	2	1.20	

22-Apr-15	32.90	21.05	29.64	220	4.74	1.30	0.013	2.87	1.18	1	1.30	
24-Apr-15	32.90	21.05	26.6	220	4.74	2.52	0.025	5.54	1.18	2	1.26	
27-Apr-15	32.90	21.05	27.96	220	4.74	1.97	0.019	4.34	1.18	2	0.98	
29-Apr-15	32.90	21.05	28.1	220	4.74	1.92	0.019	4.22	1.18	2	0.96	
2-May-15	32.90	21.05	30	220	4.74	1.16	0.011	2.55	1.18	1	1.16	
4-May-15	32.90	21.05	30.1	220	4.74	1.12	0.011	2.46	1.18	1	1.12	
6-May-15	32.90	21.05	29.3	220	4.74	1.44	0.014	3.16	1.18	1	1.44	
8-May-15	32.90	21.05	31	220	4.74	0.76	0.007	1.67	1.18	1	0.76	
10-May-15	32.90	21.05	30.7	220	4.74	0.88	0.008	1.93	1.18	1	0.88	
12-May-15	32.90	21.05	28.9	220	4.74	1.60	0.016	3.52	1.18	1	1.60	
14-May-15	32.90	21.05	30.9	220	4.74	0.80	0.008	1.76	1.18	1	0.80	
16-May-15	32.90	21.05	30.5	220	4.74	0.96	0.009	2.11	1.18	1	0.96	
18-May-15	32.90	21.05	30.3	220	4.74	1.04	0.010	2.28	1.18	1	1.04	
20-May-15	32.90	21.05	29.2	220	4.74	1.48	0.014	3.25	1.18	1	1.48	
2-Jun-15	32.90	21.05									54.7	

Appendix-E: amount of irrigation water used of TDR group of all plot based individual data sheet

Time dominreflector mater (TDR) total irrigation water use based on the above individual data sheet.

Date	PT2 (mm)	RT3 (mm)	PT8 (mm)	PT12 (mm)	RWT13 (mm)	RWT15 (mm)	PT17 (mm)	PT21 (mm)	RwT22 (mm)
24-Feb-15	13	11	11	11	13	10	7	9	10
26-Feb-15	12	9	9	18	15	11	-	-	-
28-Feb-15	14	14	9	13	12	8	-	-	-
30-Feb-15	13	11	15	15	16	10	-	-	-
1-Mar-15	9	15	5	10	16	10	-	-	-
3-Mar-15		9	9	18	12	9	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
15/9/07	6	5	10	7	-	-	-	-	-
2 Jun 15	**547.4**	**537.6**	**409.2**	**585**	**614.2**	**370.3**	**267.3**	**300**	**525.3**

Appendix-F: All (18) plots soil moisture was measured by TDR

For example PT2 plot soil moisture measured by TDR the sum of Δs become 0.7 % and to change in mm = (0.7*0.4m)/100 it gives 0.0028m or 2.8mm

change of soil moisture (Δs)		
	PT2	
date	soil moisture by TDR(%)	Δs=si+1-Si
24/02/2015	29.6	
26-Feb-15	26.62	-2.98
28-Feb-15	25.8	-0.82
30-Feb-15	22.7	-3.1
1-Mar-15	28.1	5.4
3-Mar-15	26.28	-1.82
5-Mar-15	25.7	-0.58
7-Mar-15	24.5	-1.2
9-Mar-15	28	3.5
11-Mar-15	25.28	-2.72
13-Mar-15	22.2	-3.08
15-Mar-15	26.28	4.08
17-Mar-15	26.62	0.34
19-Mar-15	22.7	-3.92
21-Mar-15	25.28	2.58
23-Mar-15	26.1	0.82
25-Mar-15	28.84	2.74
27-Mar-15	28.64	-0.2
29-Mar-15	26.6	-2.04
31-Mar-15	28	1.4
2-Apr-15	28.64	0.64
4-Apr-15	25.66	-2.98
6-Apr-15	27.68	2.02
8-Apr-15	25.6	-2.08
10-Apr-15	29	3.4
12-Apr-15	26.62	-2.38
14-Apr-15	29.6	2.98
16-Apr-15	24.5	-5.1
18-Apr-15	28.64	4.14
20-Apr-15	26.86	-1.78
22-Apr-15	29.64	2.78

24-Apr-15	26.6	-3.04
27-Apr-15	27.96	1.36
29-Apr-15	28.1	0.14
2-May-15	30	1.9
4-May-15	30.1	0.1
6-May-15	29.3	-0.8
8-May-15	31	1.7
10-May-15	30.7	-0.3
12-May-15	28.9	-1.8
14-May-15	30.9	2
16-May-15	30.5	-0.4
18-May-15	30.3	-0.2
sum		0.7

soil moisture			
TDR		WFD	
plot code	Δs (mm)	plot code	Δs (mm)
PT2	2.8	PW4	-32
RT3	47	RW5	24
RWT13	43	RWW6	-12
RWT15	29	RWW10	10
PT17	9	RWW14	16
RWT22	19	PW16	-17
PT12	25	PW18	22
PT8	37	PW19	8
PT21	15	RWW20	-16

Appendix-G: Average Soil moisture profiler reading of the growing stage of 3 hour reading

Time (Minute)	Depth (CM)	PW4 SPR(%)	PW16 SPR(%)	PW18 SPR(%)	PT12 SPR(%)
0	10	**28.3**	**25.4**	**23.0**	23.7
	20	**27.3**	**23.7**	**23.7**	22.2
	30	**23.5**	**17.2**	**21.3**	20.5
	40	**19.4**	**20.0**	**19.6**	20
	60	**30.1**	**19.2**	**11.3**	9.8
	100	**38.8**	**34.1**	**22.7**	35.2
2	10	**30.6**	**27.4**	**24.8**	27.8
	20	**27.8**	**25.4**	**23.8**	25.3
	30	**24.4**	**19.0**	**21.3**	23
	40	**19.6**	**20.0**	**20.3**	22.7
	60	**30.1**	**19.2**	**11.3**	11
5	100	**38.8**	**34.1**	**22.7**	35.2
	10	**31.2**	**29.0**	**26.7**	30.7
	20	**28.3**	**26.6**	**25.1**	27.5
	30	**24.7**	**20.9**	**22.5**	23.5
	40	**19.8**	**20.9**	**21.1**	23
	60	**30.1**	**19.2**	**11.5**	11.7

	100	**38.8**	**34.1**	**22.7**	35.3
10	10	**32.7**	**30.5**	**28.6**	35.8
	20	**29.4**	**27.5**	**27.6**	31.8
	30	**25.6**	**22.2**	**23.4**	23.2
	40	**20.4**	**21.3**	**21.4**	22.5
	60	**30.4**	**20.5**	**12.1**	11.8
	100	**38.8**	**34.3**	**22.8**	36.6
15	10	**31.8**	**31.3**	**33.6**	34.9
	20	**28.6**	**28.8**	**31.6**	32.6
	30	**25.1**	**23.1**	**24.6**	23.1
	40	**20.4**	**22.0**	**22.2**	22
	60	**31.6**	**21.0**	**12.2**	11.8
	100	**40.0**	**34.6**	**22.4**	37
30	10	**30.3**	**29.8**	**33.2**	33.4
	20	**28.0**	**28.6**	**32.1**	30.5
	30	**24.7**	**23.0**	**24.8**	21.6
	40	**20.0**	**22.3**	**23.6**	20.6
	60	**31.9**	**21.9**	**12.6**	12
	100	**40.4**	**35.0**	**22.4**	37.3
60	10	**29.9**	**29.0**	**32.8**	30.3
	20	**27.5**	**27.9**	**30.7**	27.6
	30	**25.2**	**22.7**	**24.7**	20.1
	40	**22.0**	**22.7**	**24.3**	20.2

	60	**32.2**	**22.1**	**13.0**	12.1
	100	**40.5**	**35.1**	**22.9**	37.9
180	10	**29.7**	**27.2**	**30.0**	26.3
	20	**28.0**	**26.1**	**27.4**	23.7
	30	**24.7**	**22.0**	**24.3**	17.4
	40	**20.0**	**22.8**	**27.6**	18.0
	60	**31.0**	**22.9**	**13.1**	12.5
	100	**39.1**	**35.3**	**23.3**	37.1

Appendix-H: irrigation water used and crop water used of onion

Farmer code	volume of water (m3)	irrigation water I(m3/ha)	ETc (mm)	ETc (m3/ha)
PT2	120.4	5474.5	785.5	7855
PT8	81.8	4092.0	613	6130
PT12	87.8	5852.0	801	8010
PT17	32.1	2676.0	499	4990
PT21	48.0	3000.0	525.8	5258
AVERAGE	**74.0**	**4218.9**	**644.9**	**6449**
STANDARD DIV	**34.8**	**1425.3**	**141.8**	**1418**
PW16	45.2	4515.0	709.3	7093
PW4	43.5	3346.2	607.5	6075
PW18	44.9	3203.6	539.1	5391
PW19	45.15	3762.5	609	6090
AVERAGE	**44.7**	**3706.8**	**616.2**	**6162**
STANDARD DIV	**0.8**	**588.7**	**70.1**	**7010**
RWT13	98.3	6142.3	812	8120
RWT15	40.7	3703.0	582.1	5821
RT3	91.4	5376.8	731.5	7315
RWT22	120.8	5253.8	747.1	7471
AVERAGE	**87.8**	**5119.0**	**718.2**	**7182**
STANDARD DIV	**33.8**	**1022.6**	**97.2**	**9720**
RWW6	48.3	4390.9	691.9	6919
RWW10	42.8	3886.4	619.6	6196
RW5	43.5	3107.1	527.5	5275
RWW14	45.3	4530.0	677.8	6778
RWW20	27.3	2727.3	529	5290
AVERAGE	**41.4**	**3728.3**	**609**	**6090**
STANDARD DIVAT	**8.2**	**789.7**	**78.6**	**786**

Appendix-I: crop water used based on water management

plot code	irrigation (mm)	precipitation (mm)	Change in storage (mm	crop water used (mm) Etc
PW4	334.6	240.8	-32.1	607.5
RW5	310.7	240.8	24	527.5
RWW6	439.1	240.8	-12	691.9
RWW10	388.8	240.8	10	619.0
RWW14	453.0	240.8	16	677.8
PW16	451.5	240.8	-17	709.3
PW18	320.3	240.8	22	539.1
PW19	376.2	240.8	8	609
RWW20	272.7	240.8	-16	529.5
AVERAGE	**371.9**	**240.8**	**0.3**	**612.4**
St.DIVATI	**66**	**0**	**1**	**70.2**
PT2	547.5	240.8	2.8	785.5
RT3	537.7	240.8	47	731.5
PT8	409.2	240.8	37	613
PT12	585.2	240.8	25	801
RWT13	614.2	240.8	43	812
RWT15	370.3	240.8	29	582
PT17	267.6	240.8	9	499.4
PT21	300.0	240.8	15	525.8
RWT22	525.3	240.8	19	747.1
AVERAGE	**461.9**	**240.8**	**25.2**	**677.5**
St.DIVATI	**127.7841881**	**3.01458E-14**	**1.54**	**122.8**

Appendix-J: Day after planting and plant height

	day after planting	PT2	PT8	PT12	PT17	average
	15	4.7	2.6	5.8	4.7	4.5
	45	19.1	15.4	21.1	20.7	19.1
	85	24.5	23.9	25.5	24.6	24.6
PT	95	2	2.9	3	2	2.5
		PW16	PW18	PW19	PW4	average
	15	4.7	3.3	3	3.7	3.7
	45	19.1	18.1	20.5	21.9	19.9
	85	26.3	24.7	25.4	25.9	25.6
PW	95	3	3	2	3	2.8
		RWT13	RWT15	RWT3	RWT22	average
	15	3.2	3.7	4.7	4.7	4.1
	45	15.3	21.9	21.1	20.7	19.8
	85	21.5	24.7	26.3	24.6	24.3
RT	95	3	3	2	2	2.5
		RWW5	RWW6	RWW10	RWW14	average
	15	3.2	2.7	4.7	5.9	4.1
	45	21.1	16.9	19.1	19.1	19.1
	85	25.7	23.3	26.26	25.9	25.3
RW	95	2.3	2.3	3	3	2.7

Appendix-K: Onion harvest data sheet

Danghista: Onion Harvest

Date: ……………………………… **Farmer Name: …………………………**

Crop: … …………………………..Plot Code: ………………………………

			Plants/Bed	
	Total plants originally planted	**Total plants died**	**Good onion (number)**	**Bad onion (number)**
Full field				
Bed 1				
Bed 2				
Bed 3				

1 m2 plot	**Good onion (number)**	**Bad onion (number)**	**Total weight good plants (kg)**	**Total weight bad plants (kg)**
Sub-plot 1				
Sub-plot 2				
Sub-plot 3				
Sub-plot 4				
Sub-plot 5				

* Mark the plot that had the WFD installed. Bad onion is the onion that farmers cannot sell on the market.

Total harvest of the entire field (kg): ______________________

Take 5 sub-sample of the field (1 representative per sub-plot). Cut the onion in two and count the number of pills (rings), measure the diameter

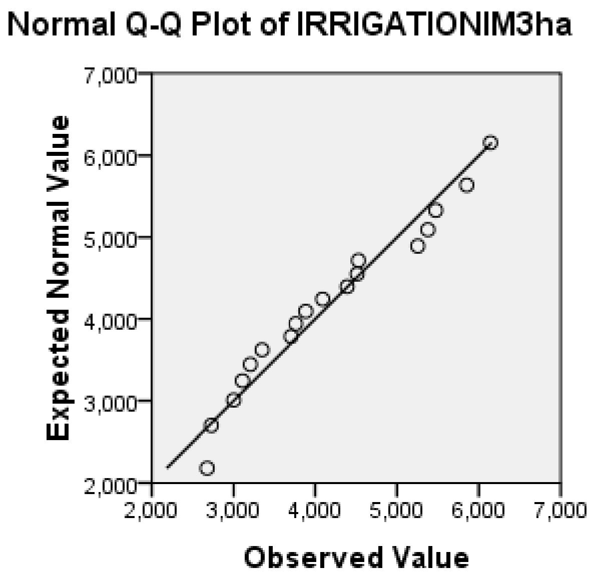
Plot	Onion	Diameter (cm)	Number of rings
Sub-plot 1	Onion 1		
Sub-plot 2	Onion 2		
Sub-plot 3	Onion 3		
Sub-plot 4	Onion 4		
Sub-plot 5	Onion 5		

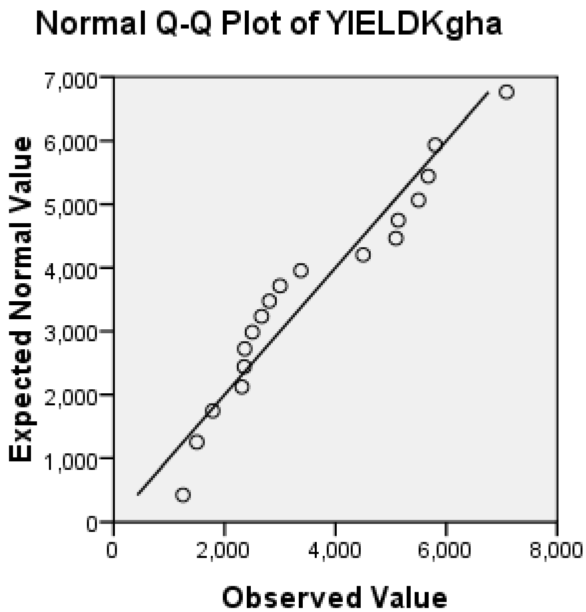
Table5. onion yield harvesting data sheet.

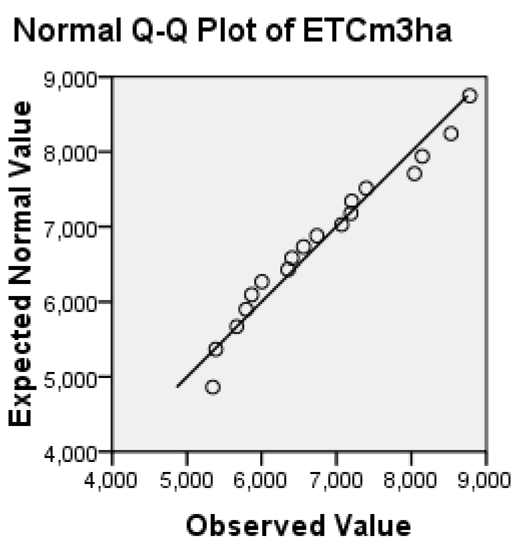
Appendix-L: Yield from each plot

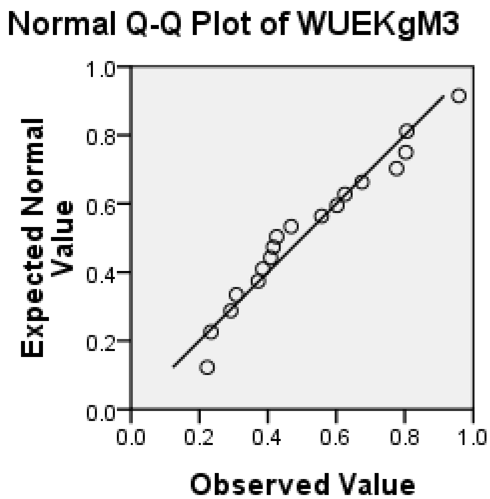
Farmer code	water lifting	Irrigation scheduling method	Total yield (kg/ha)
PT2	**pully**	**TDR**	5500
PT8	**pully**	**TDR**	1500
PT12	**pully**	**TDR**	5133
PT17	**pully**	**TDR**	1250
PT21	**pully**	**TDR**	2313
AVERAGE	**pully**	**TDR**	**3139**
STANDARD DIVATION	**pully**	**TDR**	**2030**
PW16	**pully**	**WFD**	5800
PW4	**pully**	**WFD**	2808
PW18	**pully**	**WFD**	2500
PW19	**pully**	**WFD**	2667
AVERAGE	**pully**	**WFD**	**3444**
STANDARD DIVATION	**pully**	**WFD**	**1576**
RWT13	**RW**	**TDR**	3375
RWT15	**RW**	**TDR**	2364
RT3	**Rw**	**TDR**	2353
RWT22	**RW**	**TDR**	7087
AVERAGE	**RW**	**TDR**	**3795**
STANDARD DIVATION	**RW**	**TDR**	**2247**
RWW6	**RW**	**WFD**	5674
RWW10	**RW**	**WFD**	5091
RW5	**Rw**	**WFD**	1786
RWW14	**RW**	**WFD**	4500
RWW20	**RW**	**WFD**	3000
AVERAGE	**RW**	**WFD**	**4010**
STANDARD DIVATION	**RW**	**WFD**	**1592**

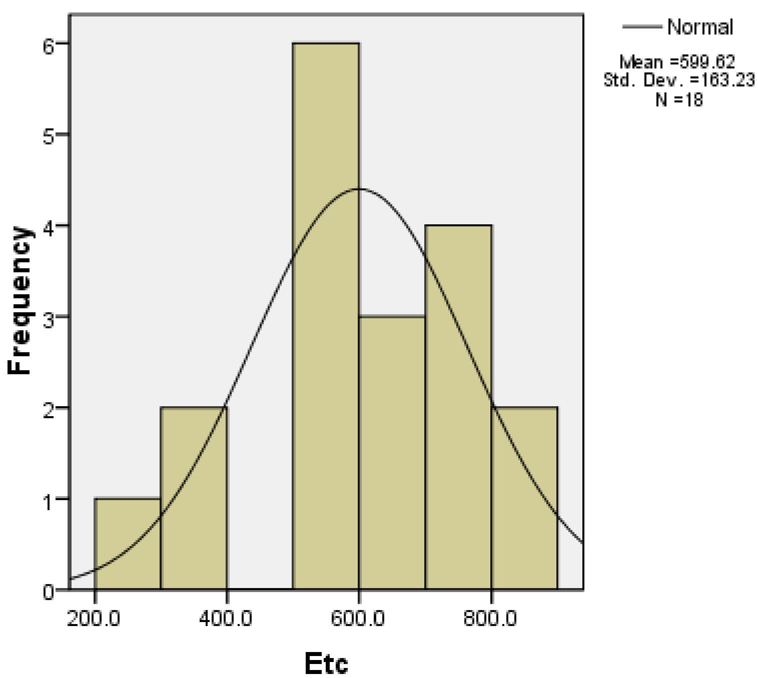
Appendix-M: Normality test by Q-Q plot and Histogram with normal curve

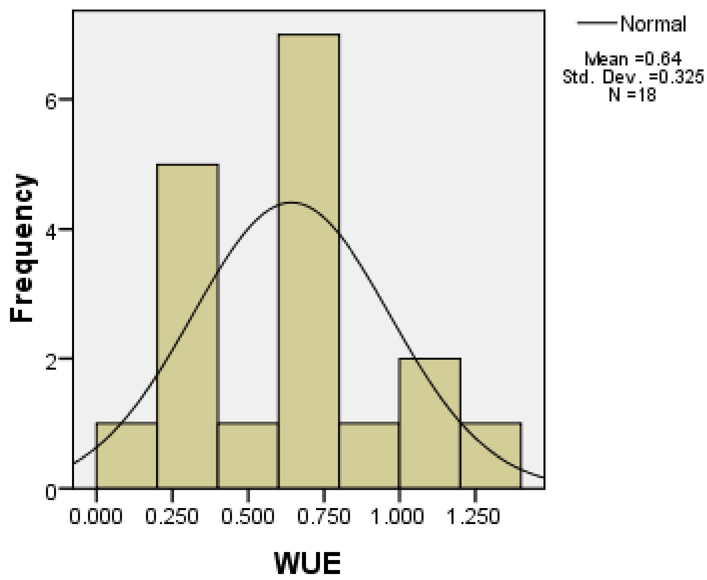


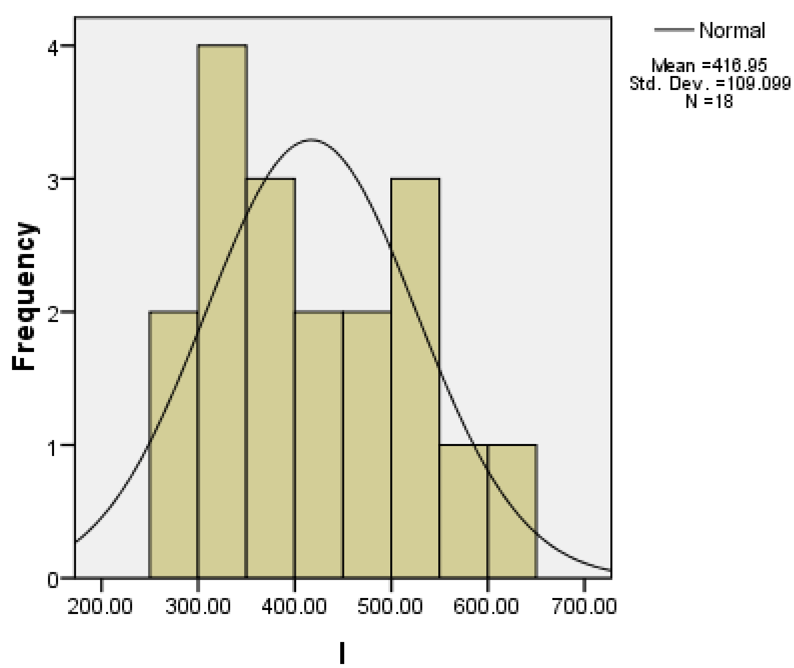

Normal Q-Q Plot of YIELDKgha
Expected Normal Value
Observed Value
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
0
2,000
4,000
6,000
8,000


Normal Q-Q Plot of ETCm3ha
Expected Normal Value
Observed Value
4,000
5,000
6,000
7,000
8,000
9,000
4,000
5,000
6,000
7,000
8,000
9,000


Normal Q-Q Plot of WUEKgM3
Expected Normal Value
Observed Value
0.0
0.2
0.4
0.6
0.8
1.0


Normal
Mean =599.62
Std. Dev. =163.23
N =18
Frequency
Etc
200.0
400.0
600.0
800.0


Normal
Mean =0.64
Std. Dev. =0.325
N =18
Frequency
0
2
4
6
0.000
0.250
0.500
0.750
1.000
1.250
WUE


Normal
Mean =416.95
Std. Dev. =109.099
N =18
Frequency
0
1
2
3
4
200.00
300.00
400.00
500.00
600.00
700.00
I

Summary Based On WaterManagement

				I (mm)	R (mm)	Etc(mm)	Y(kg/ha)	IP(kg/ha*mm^{-1})	IWUE(kg/ha*mm^{-1})
WM	WFD	1		311	240	527	1786	5.7	3.4
		2		439	240	691	5674	13.0	8.2
		3		389	240	619	5091	13.1	8.2
		4		453	240	677	4500	10.0	6.6
		5		273	240	529	3000	11.0	5.6
		6		335	240	607	2808	8.4	4.6
		7		452	240	709	5800	12.8	8.2
		8		320	240	538	2500	7.8	4.6
		9		376	240	608	2667	7.1	4.4
		Total	N	9	9	9	9	9	9
			Minimum	273	240	527	1786	5.7	3.4
			Maximum	453	240	709	5800	13.1	8.2
			Mean	372.00	240.00	611.67	3758.44	9.878	5.978
	TDR	1		547	240	784	5500	10.1	7.0
		2		585	240	796	5133	8.8	6.5
		3		268	240	483	1250	4.7	2.6
		4		409	240	606	1500	3.7	2.5
		5		300	240	503	2313	7.7	4.6
		6		614	240	845	3375	5.5	4.0
		7		370	240	591	2364	6.4	4.0
		8		538	240	731	2353	4.4	3.2
		9		525	240	750	7087	13.5	9.5
		Total	N	9	9	9	9	9	9
			Minimum	268	240	483	1250	3.7	2.5
			Maximum	614	240	845	7087	13.5	9.5
			Mean	461.78	240.00	676.56	3430.56	7.200	4.878
Total	N			18	18	18	18	18	18

Summaries Based water lifting [a]

				I(mm)	R(mm)	Etc(mm)	Y(kg/ha)	IP(kg/ha*mm^{-1})	IWUE(kg/ha*mm^{-1})
WL	R & W	1		311	240	527	1786	5.7	3.4
		2		439	240	691	5674	13.0	8.2
		3		389	240	619	5091	13.1	8.2
		4		453	240	677	4500	10.0	6.6
		5		273	240	529	3000	11.0	5.6
		6		614	240	845	3375	5.5	4.0
		7		370	240	591	2364	6.4	4.0
		8		538	240	731	2353	4.4	3.2
		9		525	240	750	7087	13.5	9.5
		Total	N	9	9	9	9	9	9
			Minimum	273	240	527	1786	4.4	3.2
			Maximum	614	240	845	7087	13.5	9.5
			Mean	434.67	240.00	662.22	3914.44	9.178	5.856
	P	1		335	240	607	2808	8.4	4.6
		2		452	240	709	5800	12.8	8.2
		3		320	240	538	2500	7.8	4.6
		4		376	240	608	2667	7.1	4.4
		5		547	240	784	5500	10.1	7.0
		6		585	240	796	5133	8.8	6.5
		7		268	240	483	1250	4.7	2.6
		8		409	240	606	1500	3.7	2.5
		9		300	240	503	2313	7.7	4.6
		Total	N	9	9	9	9	9	9
			Minimum	268	240	483	1250	3.7	2.5
			Maximum	585	240	796	5800	12.8	8.2
			Mean	399.11	240.00	626.00	3274.56	7.900	5.000
	Total	N		18	18	18	18	18	18
		Minimum		268	240	483	1250	3.7	2.5
		Maximum		614	240	845	7087	13.5	9.5
		Mean		416.89	240.00	644.11	3594.50	8.539	5.428

a. Limited to first 100 cases.

Appendix-N: ANOVAs single factor of FC (field capacity) and PWP (permanent wilting point)

Anova: Single Factor
of **Field Capacity**

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
WFD	10	324.52	32.452	2.930796
TDR	10	323.46	32.346	9.917382

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.05618	1	0.05618	0.008745	0.926527	4.413873
Within Groups	115.6336	18	6.424089			
Total	115.6898	19				

Anova: Single Factor
of **Wilting Point**

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
WFD	10	206.44	20.644	1.700071
TDR	10	209.75	20.975	1.173894

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.547805	1	0.547805	0.381219	0.544684	4.413873
Within Groups	25.86569	18	1.436983			
Total	26.4135	19				

Statically analysis by SPSS

Appendix-O: The Interaction of water management and water lifting technology based on irrigation amount (mm)

Dependent Variable: I (mm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
WM	40026.711	1	40026.711	3.794	.072
WL	9445.378	1	9445.378	.895	.360
WM * WL	8545.878	1	8545.878	.810	.383
Error	147714.300	14	10551.021		
Total	3330310.000	18			
Corrected Total	201975.778	17			

Appendix-P: The Interaction of water management and water lifting technology based on crop water used (mm)

Dependent Variable:Etc (mm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
WM	21638.003	1	21638.003	1.871	.193
WL	8594.669	1	8594.669	.743	.403
WM * WL	11503.403	1	11503.403	.995	.335
Error	161882.150	14	11563.011		
Total	7668752.000	18			
Corrected Total	200927.778	17			

Appendix-Q: The Interaction of water management and water lifting technology based on Yield (kg/ha)

Dependent Variable:- Y(kg/ha)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
WM	300444.444	1	300444.444	.085	.774
WL	1659204.444	1	1659204.444	.472	.503
WM * WL	8820.900	1	8820.900	.003	.961
Error	4.922E7	14	3515856.650		
Total	2.839E8	18			
Corrected Total	5.137E7	17			

Appendix-R: The Interaction of water management and water lifting technology based on irrigation productivity IP (kg $ha^{-1}mm^{-1}$)

Dependent Variable:-IP(kg/ha*mm^{-1})

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
WM	29.298	1	29.298	3.000	.105
WL	4.378	1	4.378	.448	.514
WM * WL	1.308	1	1.308	.134	.720
Error	136.710	14	9.765		
Total	1487.090	18			
Corrected Total	174.663	17			

Appendix-S: The Interaction of water management and water lifting technology based on water used efficiency IP (kg ha^{-1}mm^{-1})

Dependent Variable:-WUE(kg/ha*mm^{-1})

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
WM	4.601	1	4.601	.928	.352
WL	2.450	1	2.450	.494	.494
WM * WL	.191	1	.191	.039	.847
Error	69.409	14	4.958		
Total	607.790	18			
Corrected Total	77.496	17			

Appendix-T: Onion harvesting, weight measuring and quality of onion measuring.



Soil moisture profiler reading on WFD plot

Training about water lifting technology and water management after farmer selection and before start irrigation