BahirDar University

Faculty of Civil and Water Resource Engineering

Department of Hydraulic Engineering

Development of crop coefficients and evaluating the productivity and water use for Napier grass under small- scale irrigation: the case of Robit Kebele

By: Hanibal Mulugeta Woldemeskel

Bahir Dar University

Bahir Dar, Ethiopia

November, 2015

Development of crop coefficients and evaluating the productivity and water use for Napier grass under small- scale irrigation: the case of Robit Kebele

Hanibal Mulugeta Woldemeskel

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

Supervised by: Seifu A. Tilahun (PhD)
Co-Supervised by: Prossie Nakawuka (PhD)
Petra Schmitter (PhD)

Bahir Dar University

Bahir Dar, Ethiopia

November, 2015

DECLARATION

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

Hanibal Mulugeta Woldemeskel

Date

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By: Hanibal Mulugeta Woldemeskel

Approved by Board of Examiners **Name/Signature**

School Director (Dr. Seifu A.)

ሰይፉ አድማሱ ጥላሁን (ዶ/ር)
Seifu Admasu Tilahun (PhD)
የፋኩልቲ ዲን
Faculty Dean

Advisor (Dr. Seifu A.)

Seifu Admasu Tilahun (PhD)
የፋኩልቲ ዲን
Faculty Dean

Co-Advisor (Dr. Prossie N.)

Prossie Nakawuka

External Examiner (Dr. Mekonen A.)

Mekonen A

Internal Examiner (Dr. Mekete D.)

Mekete D.

Chairperson (Teshale T.)

Teshale T.

November, 2015
Bahir Dar

DEDICATED

This paper is dedicated to my beloved family Mr. Mulugeta Woldemeskel, Ms. Ehite Gashu, Ms. Sosina Mulugeta and her family. You all played a great role for my success and nothing was possible without your support, I truly thank you all.

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ABSTRACT

The manual water lifting technologies are very important to low income small holder farmers using groundwater as a water source and these technologies have to be studied in detail based on their efficiency of use of energy, simplicity of operation and maintenance and productivity, compared to traditional methods. Furthermore, due to the forage shortage for livestock in the dry season, an assessment is needed to determine whether lifting technologies and overall irrigation of fodder using groundwater wells are feasible. This study was conducted with the main objectives of assessing the potential of manual water lifting technologies for irrigation of Napier grass (*Pennisetum purpureum*) from groundwater, determining the water requirement of Napier grass through scientific irrigation scheduling, and developing its crop coefficients at the different development stages. The study site was Robit kebele in Bahir-dar Zuria Woreda of Amhara regional state. The water lifting technologies used in this study were pulley/tank/hose system and rope and washer pumps. Using this lifting technologies' in the season irrigation water applied, yield, irrigation productivity, water use efficiency were compared. In addition, ease of use of the technologies and their operation and maintenance were measured by the failure history during the dry season and the area of land that can be adequately irrigated by each technology. Results show that the pulley technology had a better performance giving the highest average yield of 1598 kg/ha while the rope and washer yielded 1110 kg/ha. The pulley also had higher average water use efficiency of 0.351 kg/m^3 compared to 0.152 kg/m^3 for the rope and washer. In terms of irrigation productivity, pulley had 0.511 kg/m^3 whereas the rope and washer had 0.203 kg/m^3. The pulley therefore had better potential for irrigation of Napier grass and even a better discharge; it can discharge 0.346 lit/sec while the rope and washer discharges only 0.207 lit/sec. In addition, the pulley has no failure issues during the growing season whereas four rope and washers farmers experienced problems with the technology including wheel getting hard to rotate and rope breaking. In the development of crop coefficients, the reference evapotranspiration (ETo) was calculated by the Penman-Monteith equation and had an average value of 4.34 mm/day. The actual evapotranspiration (ETc) was calculated using the soil water balance method. The average evapotranspiration for Napier grass was found to be 562 mm. The developed crop coefficients for the various development stages include: 0.821 (28 days), 1.351 (35 days) and 1.453 (42 days) for the initial, mid- and maturity stages respectively. The study faced some limitations including water shortages, and in some plots the Napier grass was eaten by livestock a number of times during the growing season. The results presented in this study represent only one irrigation season and one cutting of Napier grass. Effects of season to season variability and year to year variability are not represented in the results of this study.

Key words - Napier grass, pulley, rope and washer, yield, irrigation productivity, water use efficiency, crop coefficient (Kc)

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LIST OF ACRONYMS

Kc – Crop coefficient

ETo - Reference evapotranspiration

ETc - Crop evapotranspiration

SSI - Small scale-irrigation

FAO - Food and Agricultural Organization

FC - Field capacity

PWP - Permanent wilting point

GDP - Gross domestic product

ETB – Ethiopian birr; 1 ETB = 0.048 USD

TDR - Time domain reflectometry

R&W – Rope and washer pump

GPS - Global positioning system

SMP - Soil moisture profiler

WUE - Water use efficiency

IP - Irrigation productivity

CWD - Crop water demand

ANOVA - Analysis of variance

IWMI - International water management institute

ILRI - International livestock research institute

ILSSI - Innovation Lab for Small Scale Irrigation

ARARI- Amhara Regional Agricultural Research Institute

USAID - United States Agency for International Development

FtF - Feed the Future

FGD – Focus group discussion

1. INTRODUCTION

1.1 Back ground

Agriculture is the core driver for Ethiopia's growth and long-term food security. Agriculture directly supports 85 % of the population's livelihoods, 43 % of gross domestic product (GDP) and over 80 percent of export value (Awulachew, 2010). Ethiopia comprises 112 million hectares (Mha) of land. Cultivable land area estimates vary between 30 to 70 Mha. High estimates show that only 15 Mha of land is under cultivation. From the existing cultivated area, only about 4% to 5% is irrigated, with existing equipped irrigation schemes covering about 640,000 ha (Awulachew, 2010). This means that a significant portion of cultivated land in Ethiopia is currently not irrigated. Over the next two decades, Ethiopia could irrigate over 5 Mha with existing water sources, contributing around 140 billion ETB per annum to the economy and ensuring food security for up to six million households (Awulachew, 2010).

From the current irrigation scheme coverage which is about 640,000 ha across the country, small scale-irrigation (SSI) cover less than 200 ha (Awulachew, 2010). SSI is often community-based and uses traditional methods. Examples of SSIs include household based rain water harvesting, hand-dug wells, and shallow wells, flooding (spate), individual household-based river diversions and other traditional methods (Awulachew, 2010).

The small scale irrigation contribution to livestock production is almost nil. Ethiopia holds the largest livestock population in Africa. The contribution of livestock to cash income of the smallholders accounts for to 87 % (Duguma et al., 2012). The livelihood of some pastoral communities is entirely based on livestock and livestock products. Despite these roles, the productivity of livestock in general is low and compared to its huge resources, its contribution to the national economy is also low. Feed shortage, poor feed quality, poor genetic potential for productive traits, poor health care and management practices are the major contributions to the low productivity (Duguma et al., 2012)

Two main drivers are leading to changes in feeding practices in the Ethiopian livestock sector. Firstly, growing urban populations and rising incomes are fueling increased demand for livestock products such as milk and meat. Dairy value chains to supply urban markets with milk have long existed but are showing signs of more serious development (Duncan & Teufel, 2010). More intensive production demands higher quality feeds and a more reliable source of year-round nutrients leading to increased demand for agro-industrial by-products, planted forages and pasture hay. Secondly, rising human populations are placing increased pressures on grazing lands with pasture lands being increasingly cultivated for cereal production to satisfy the increasing demands for food production. This has led to even greater scarcity of livestock feed, an increased use of crop residues for livestock feed and increasing reliance on purchased feed (which includes crop residues as well as more refined concentrates and supplements) to support livestock production, (ILRI, 2012).

With the increasing demand of fodder, the production is not enough to meet all the demand as it increases in the future. Ethiopian agricultural production is mostly dependent on rain (Fig. 1.1). Production in the dry season using groundwater irrigation is an option to produce more and meet this increasing demand. When using ground water for irrigation, manual water lifting technologies are more viable technologies as they are easily available and affordable for the farmers. For many important agricultural production areas, groundwater will remain the ultimate source of freshwater when surface water sources are not accessible, especially for irrigation in areas subject to extended dry seasons.

Given the hydro-geological complexity and costs, Ethiopia has barely exploited its groundwater resources, especially for agriculture. Research in this area is relatively new and initial estimates of groundwater potential vary from 2.6 to 13.5 billion m^3 per year. Local experts’ advice and test drillings for new projects suggest that the potential could be much higher (Awulachew, 2010).

Even though livestock plays a very significant role in the livelihood of smallholder farmers in the study area (Robit Kebele), irrigation of fodder is a new intervention that we are testing in order to improve livestock productivity.

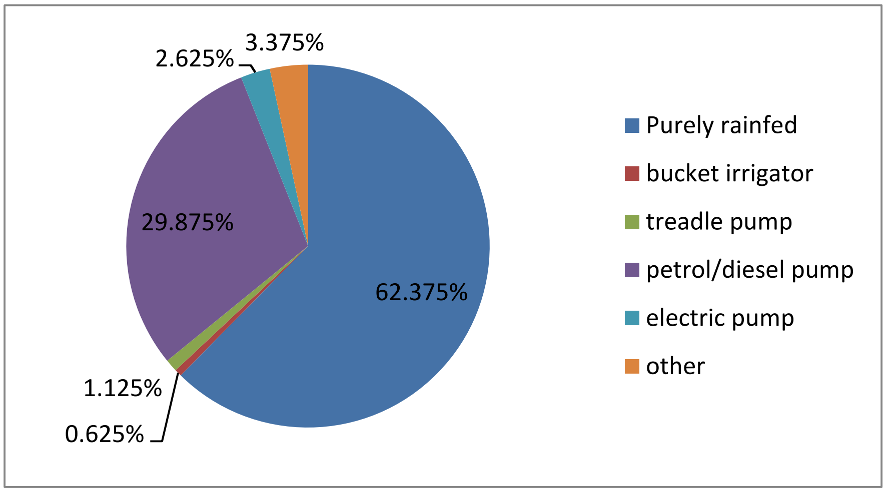

Fig. 1.1. Percentage plot for farmers in Ethiopia using available water-lifting technologies and those depend entirely on rainfall (Gebrehaweria, 2011).

1.2 Statement of Problem

Lack of manual well drilling experience, lack of knowledge and access to appropriate lifting technologies and not knowing when and how much water to apply to plants are the main constraints to agricultural production in areas that have good groundwater potentials. Manual water lifting technologies like pulleys and rope and washers pumps are very important to low income small holder farmers using groundwater as a water source. These technologies have to be studied in detail to evaluate their efficiency, use of energy, simplicity of operation, maintenance and productivity as compared with traditional experiences. Furthermore, due to forage shortages for livestock in the dry season, an assessment is needed to determine whether lifting technologies and overall irrigation of fodder using groundwater are feasible.

Fig 1.1 shows that most of Ethiopian farmers are dependent on rain. However, rain fed agriculture only is not a solution as the demand for food and fodder production is high and technologies such as diesel/petro pumps are expensive and can't be afforded by most farmers. Thus, for the low-income-smallholder farmers, non-motorized pumps which are low cost and easy to operate and maintain are preferable. In order for the use of manual water lifting technologies such as pulleys and rope-washer pumps to be scaled up in rural communities in Ethiopia, understanding their performance is needed. The idea of the rope and washer pump is that it is repairable by trained locals, using materials that are readily available and it is capable of lifting groundwater up to 30m, although the weight of water to be lifted increases as the depth of water increases thus requiring more energy to pump the water. The pump's simple design also makes sealing of the water supply from outside contamination a realistic possibility. The other advantage of the rope-washer pump over other pumps is its cost which ranges from 3775 to 4175 ETB (3775 ETB for the longer rope-washer with slab and 4175 ETB for the shorter R&W with a 60 cm masonry (Fig.2.7)). The other and simple technology that every farmer can access is the pulley which costs only 1250 ETB and has a capability of lifting water from any well depth.

The other challenge in small scale irrigation is knowing when and how much water to apply to plants. Determining when to irrigate requires estimating the water deficit in the soil so that yield reductions will not occur due to excessive soil moisture depletions. One method for irrigation scheduling is to measure or monitor soil moisture content. By over-irrigating or under-irrigating, production problems like yield loss, diseases, nutrient losses through leaching, weed encroachment, power or water costs, water losses, frost injury and other environmental concerns are increased (Orloff et al., 2001).

1.3 Research Questions

✓ What are the crop coefficients for Napier grass at different growing stages?

✓ Which water lifting technology (rope-washer pump or pulley) is most suitable in the area for Napier grass production?

✓ Can yield, water use efficiency and irrigation productivity be improved by irrigation scheduling?

1.4 Objective of the research

The general objective of this research is to assess the potential of manual water lifting technologies for irrigation of Napier grass from groundwater. And the specific objectives are;

✓ To determine water requirement of Napier grass in the study through scientific irrigation scheduling and develop its crop coefficients at the different growth stages.

✓ To evaluate water use and productivity of water lifting technologies (rope-washer pump and pulley) for Napier grass production.

1.5 Significance of the study

This study identified the suitable water lifting technology for Robit farmers and other farmers sharing similar agro-ecology and socio-cultural features with Robit for the irrigation of fodder. The findings also help the farmers to identify better technology in order to increase their productivity, minimize excessive labor use and cost. Also, by developing crop coefficients and improving irrigation scheduling, the farmers will be able to use the available groundwater resources sustainably to produce more crops in the dry season.

1.6 Description of the study area

Ethiopia is situated in the “horn of Africa” and lies between 3°30´ and 14°50´ N latitudes and 32°42´ and 48°12´ E longitudes. The country has a surface area of about 1.127 Million km^2 of which 1,119,683 km^2 is land area and 7,444 km^2 is water area. The country has a land boundary length of 5311km (Awulachew et al., 2001).

Robit is one of the 32 rural kebeles in Bahirdar Zuria Woreda of Amhara Regional State and located 10 Km north of Bahir-dar town, the capital of the Amhara region. Bahir-dar Zuria Woreda is one of the potential areas suitable for manual well drilling. Robit kebele has a total population of 9707 people (5000 male and 4707 female) and area coverage of 44.64 km^2. (Bahirdar Zuria Woreda office of Agriculture, 2013). Because of its close distance to Lake Tana, groundwater potential and experience in smallholder irrigation are relatively high. Shallow groundwater, river diversion and lake pumping are the main sources of irrigation water. 157 small motorized pumps have been reported in the woreda. There are about 4000 individual shallow wells in this kebele. Also traditionally made pulleys and some rope and washers are experienced in the area. Currently, 1824.65 hectares of land are being irrigated in the woreda using different irrigation technologies (BahirDar Zuria Woreda office of Agriculture, 2013). Given its close proximity to the regional capital, dairy is one of the emerging businesses implying that demand for improved livestock feed is growing as demand for livestock products in the area grows. About 53 households in the Woreda are currently producing different types of irrigated fodder like alfalfa and Napier grass which can be developed into business for market (Bahirdar Zuria Woreda office of Agriculture, 2013).

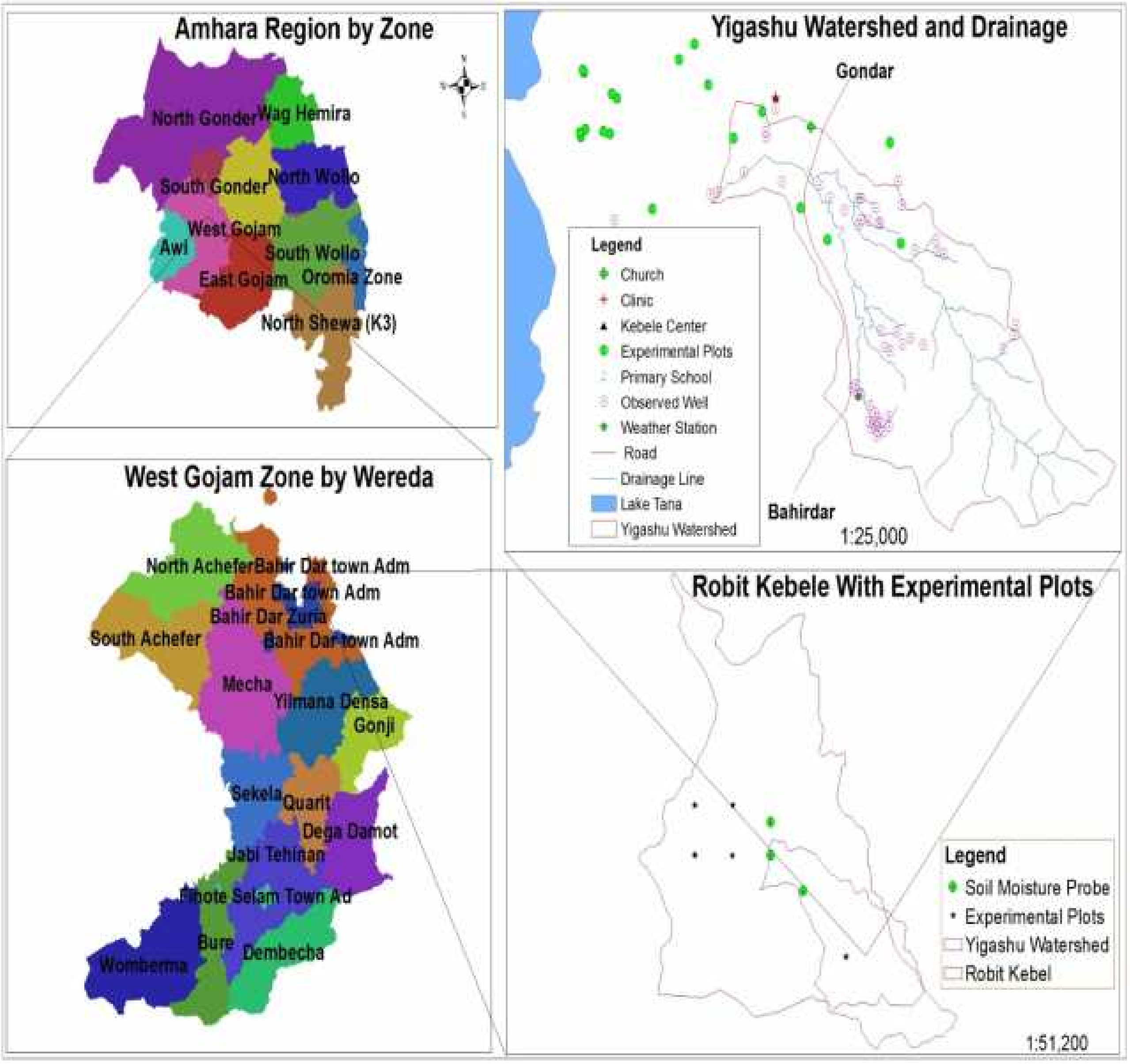

Fig 1.2. Location map of Robit and Yigashu watershed with drainage. Yigashu is the main river in the kebele.

2. LITERATURE REVIEW

2.1 Livestock Feed

The highlands of Ethiopia are characterized by mixed crop livestock farming systems where the crop and livestock sub-systems complement each other (Getachew et al,. 1993). They are inhabited by large human and livestock populations where smallholder farmers cultivate variety of crops and rear different livestock species. The area of land allocated to grazing in the highlands has been progressively declining with time due to expansion of cultivation. As a result, fodder has become one of the major feed sources for livestock, particularly during the dry period (Getachew et al,. 1993). Livestock industry is an important and integral part of the agricultural sector in Ethiopia. Livestock farming is vital for the supply of meat and milk; it also serves as a source of additional income both for smallholder farmers and livestock owners (Ehui et al., 2002). Livestock production constraints can be grouped into socio-economic and technical limitations (Mengistu, 2003). Inadequate feed, widespread diseases, poor breeding stock, and inadequate livestock policies with respect to credit, extension, marketing and infrastructure are the major constraints affecting livestock performance in Ethiopia (Mengistu, 2003). Feed resources as reported by Mengistu (2003) can be classified as natural pasture, crop residue, improved pasture and forage and agro industrial by-products.

In the Highlands of Ethiopia (including major parts of the Blue Nile Basin), livestock feed resources are mainly from natural pasture and crops residues but their contribution from the total feed resource varies in different systems, farm types and seasons of the year (Seyoum et al., 2001). Temporal and spatial variation of the feed resources in terms of access, availability and quality is a major concern. In general, feed resources availability depends on the intensity of crop production and amount and distribution of the rainfall (Mohammed and Abate, 1995). Seyoum et al. (2001) noted that pasture growth is a reflection of the annual rainfall distribution pattern. Despite the good rainfall in major parts of the Blue Nile Basin, decline in the size and productivity of grazing land is a growing concern. Numbers of scholars ascribe this to overgrazing and the expansion of arable cropping. As a coping mechanism, farmers in different mixed-crop livestock production systems are increasingly feeding agricultural by-products to their livestock (Alemu et al., 1991). The potential use of crop residues as livestock feed is greatest in mixed crop-livestock farming systems (Kossila, 1988; Getachew, 2002; Lemma, 2002). Relying purely on crop residues and stubble as livestock feed causes major challenges of poor quality feeds as the only available feeds to livestock, and also removes the option of leaving the stubble or other crop residues as a soil cover for both soil fertility and soil water conservation.

2.2 Irrigation in Ethiopia

It is commonly agreed that irrigation contributes to poverty reduction. Access to water, poverty and people's livelihoods are interlinked. These linkages are both direct and indirect. Direct linkages operate on localized and household-level effects, and indirect linkages operate on national level impacts. At the same time, water is becoming a scarce resource in many countries, particularly in Sub-Saharan Africa (Hussain and Hanjra, 2004).

Irrigation in Ethiopia is becoming improved now a days but the most common irrigation methods for fodder and other crops are the traditional irrigation methods, majorly surface irrigation, that have been practiced for centuries by using seasonal streams in traditional irrigation schemes. Irrigation schemes usually were developed by the farmers themselves without any government involvement. Modern communal irrigation schemes have since been implemented by regional governments. Here, rivers and run-off water, lakes, springs and groundwater are the main sources. Generally, modern communal irrigation schemes are more sophisticated than traditional ones. There are also modern private irrigation schemes that started in the 1950s by Dutch companies that implemented sugar estates. These private irrigation schemes became state farms in the Derg regime. With the adoption of a market based economy, the private schemes reemerged in the 1990s. Their water source is mainly from rivers or lakes by pumps or diversions, although some small farms use water harvesting techniques. Smallholder farmers in Ethiopia mostly practice irrigation through applying water directly by bucket from the source.

2.3 Water Lifting Technologies

Water-lifting devices are used to lift water to a height that allows users easy access to water. Lifting devices can be used to raise groundwater, rainwater stored in an underground reservoir, and river or lake water. Farmers should be able to choose from different water-lifting devices, and each option should be presented with its advantages and disadvantages. For example, water lifting involves additional operation and maintenance activities and potential problems, compared to gravity systems, and the latter are often preferred if they are available and applicable to the situation (Morgan et al., 1990). These water-lifting devices can be used for easy lifting of water for irrigation of different crops including fodder. Here are some of the water lifting technologies which can be used for irrigation of crops and fodder:

2.3.1 Rope and bucket (and pulley) system

This device is mainly used with hand-dug wells. A bucket on a rope is lowered into the water. When the bucket hits the water it dips and fills, and is pulled up with the rope. The rope may be held by hand, run through a pulley. Sometimes, animals can pull it. Improved systems use a rope through a pulley, and two buckets – one on each end of the rope. When a pulley is used (Fig.2.2), it becomes easier to draw water when compared to the traditional rope and bucket as the force applied to draw water is in the opposite direction of the water being lifted, thus causing less strain on the back of the user. Pulley is a simple technology that every farmer can access; it costs only 1250 ETB and has a capability of lifting water from any well depth. For water less than 10 m deep, a windlass with a hose running from the bottom of the bucket to a spout at the side of the well can be used. However, the hygiene of this system is poorer, even if the well is protected (Morgan et al., 1990).

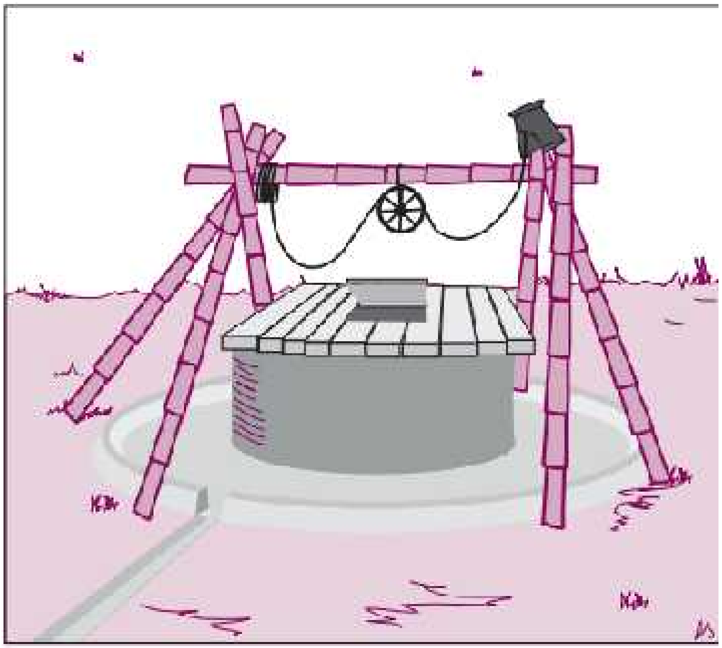

Fig 2.3.1 Rope and bucket (and pulley) system (Source: Morgan et al., 1990)

2.3.2 Bucket pump

The bucket pump is mainly used in drilled wells. It has 125 mm PVC tube, down which a narrow bucket with a valve in the base is lowered into the water on a chain. When the bucket hits the water, the valve opens and the water flows in. When the bucket is raised, the valve closes and the water is retained in the bucket. To release the water, the pump operator rests the bucket on a water discharger, which opens the valve in the base (Morgan et al., 1990).

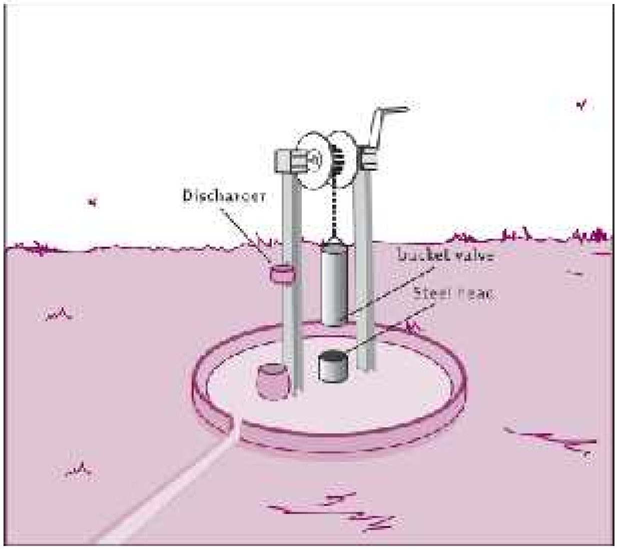

Fig 2.3.2 Bucket pump (Source: Morgan et al., 1990)

2.3.3 Rope and washer pump

The basic parts of a rope and washer pump (Fig. 2.3) are a pulley wheel above the well, a riser pipe from under the water level to an outlet just under the wheel, and a rope with rubber or plastic washers. The rope comes up through the pipe, over the wheel; back down into the well and into the bottom of the pipe, completing the loop. When the wheel is turned, the washers move upwards and lift water into the pipe towards the outflow. Other important parts are an underwater rope guide that directs the rope and washers back into the pipe, and a frame that holds the pulley wheel (Hemert et al., 1992); (Lammerink et al., 1995). The advantage of the rope-washer pump and why it is selected for this study is that it is repairable by trained locals, using materials that are readily available and it is capable of lifting groundwater up to 10m. The pump’s simple design also makes sealing the water supply from outside contamination a realistic possibility.

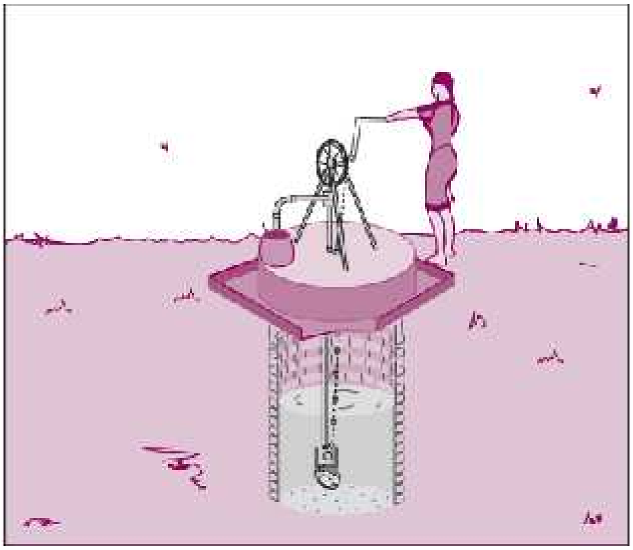

Fig 2.3.3 Rope and washer pump (Source: Hemert et al, .1992; Lammerink et al,. 1995)

2.3.4 Suction plunger hand pump

A suction plunger hand pump has its cylinder and piston located above the water level, usually within the pump stand itself. On the up-stroke of the plunger, the pressure inside the suction pipe is reduced and atmospheric pressure on the water outside pushes the water up into the pipe. On the down-stroke, a check valve at the inlet of the suction pipe closes and water passes the piston through an opened piston valve. With the next upstroke, the piston valve closes and the water is lifted up by the piston and flows out at the top of the pump, while new water flows into the suction pipe. The operational depth of this type of hand pump is limited by barometric pressure and the effectiveness of the piston seals to about 7 m at sea level, less at higher altitudes (Arlosoroff et al, .1987).

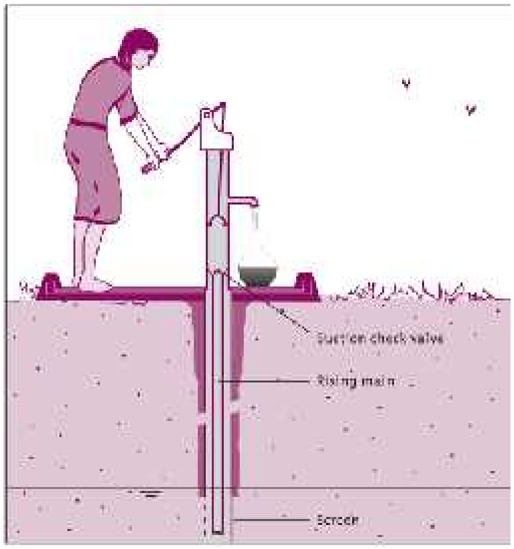

Fig 2.3.4 Suction plunger hand pump (Source: Arlosoroff et al, .1987).

2.3.5 Direct action hand pump

Direct action hand pumps are usually made of PVC and other plastics, and are installed on boreholes of limited depth. A plunger is attached to the lower end of a pump rod, beneath the groundwater level. The user moves the pump rod in an up-and-down motion, using a T-bar handle. On the up-stroke, the plunger lifts water into the rising main, and replacement water is drawn into the cylinder through the foot valve. On the down stroke, the foot valve closes, and water passes through a one-way valve in the plunger and is listed on the next up-stroke. Because direct action hand pumps have no mechanical advantage, such as the lever or fly-wheel of a deep-well hand pump, direct action pumps can only be used to depths from which an individual can physically lift the column of water (about 12 m). However, the mechanical simplicity, low cost and lightweight construction makes these pumps well equipped to meet operation and management objectives at the village level (Arlosoroff et al, 1987; Morgan et al., 1990; Reynolds, 1992).

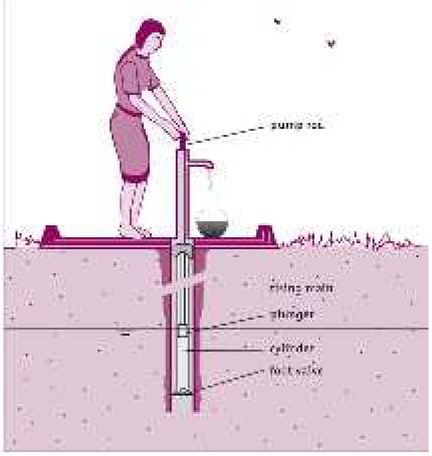

Fig 2.3.5 Direct action hand pump (Source: Arlosoroff et al, .1987; Morgan et al., 1990; Reynolds, 1992).

2.3.6 Deep-well diaphragm pump

Inside a cylindrical pump body at the bottom of the well, a flexible diaphragm shrinks and expands like a tube-shaped balloon, taking the water in through an inlet valve and forcing it out through an outlet valve. The cylindrical pump is connected to a flexible hose which leads the water to the surface. Movement of the diaphragm is effected by a separate hydraulic circuit that consists of a cylinder and piston in the pump stand, and a water-filled pilot pipe, which is also a flexible hose. The piston is moved, usually by pushing down on a foot pedal, although conventional lever handles may also be used. When foot pressure is removed, the elasticity of the diaphragm forces water out of it, back up the pilot pipe, and lifts the foot pedal. It is possible to install several pumps in a single well or borehole (Arlosoroff et al, .1987; Fonseka & Baumann, 1994).

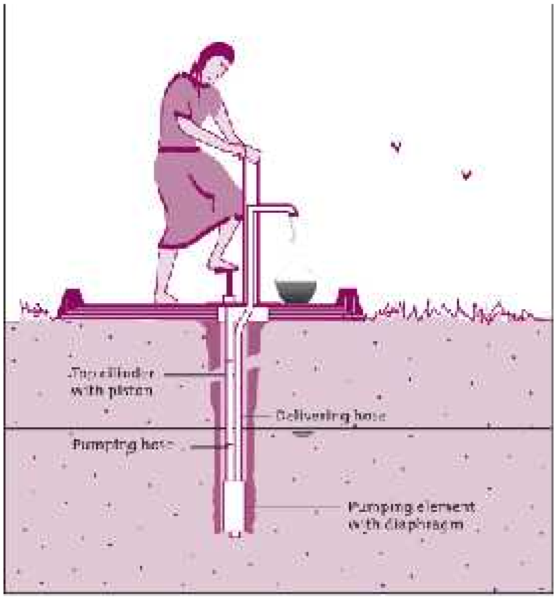

Fig 2.3.6 Deep-well diaphragm pump (Source; (Arlosoroff et al, .1987); Fonseka & Baumann, 1994).

2.3.7 Motorized pumps

Small motorized pumps are the most commonly used engine-powered pumps for small-scale irrigation. They are relatively expensive and this the disadvantage for most farmers in Ethiopia since they can’t afford it. The centrifugal pump has an impeller with blades, which spins at high speed inside the pump casing. Water is drawn into the pump from the source through a short inlet pipe or suction pipe. As the impeller spins, the water is thrown outwards and is guided towards the outlet or delivery pipe. Centrifugal pumps are described by the diameter (in mm) of the delivery connection pipe where the hose is connected. (Taffa Tulu et al., 2009).

2.3.8 Treadle pumps

A treadle is a lever device pressed by the foot to drive a machine, in this case a pump. The treadle pump can do most of the work of a motorized pump, but costs considerably less to purchase because it needs no fossil fuel (it is driven by the operator's body weight and leg muscles) and this is very advantageous for Ethiopian farmers who cannot afford the motorized pumps. It also costs less to operate than a motorized pump because leg muscles tire less than arm muscles, thus it can also be used by the farmers for longer. The treadle pump can greatly increase the income that farmers generate from their land, both by extending the traditional growing season and by expanding the types of crops that can be cultivated. The treadle pump can draw water from up to 7.5m below the surface and has a maximum flow rate of 18m per hour. As the lift height increases, flow rate falls so at a maximum lift, the actual flow rate will be much less that the maximum flow rate (Sadak and Maharajgunj, 2010).

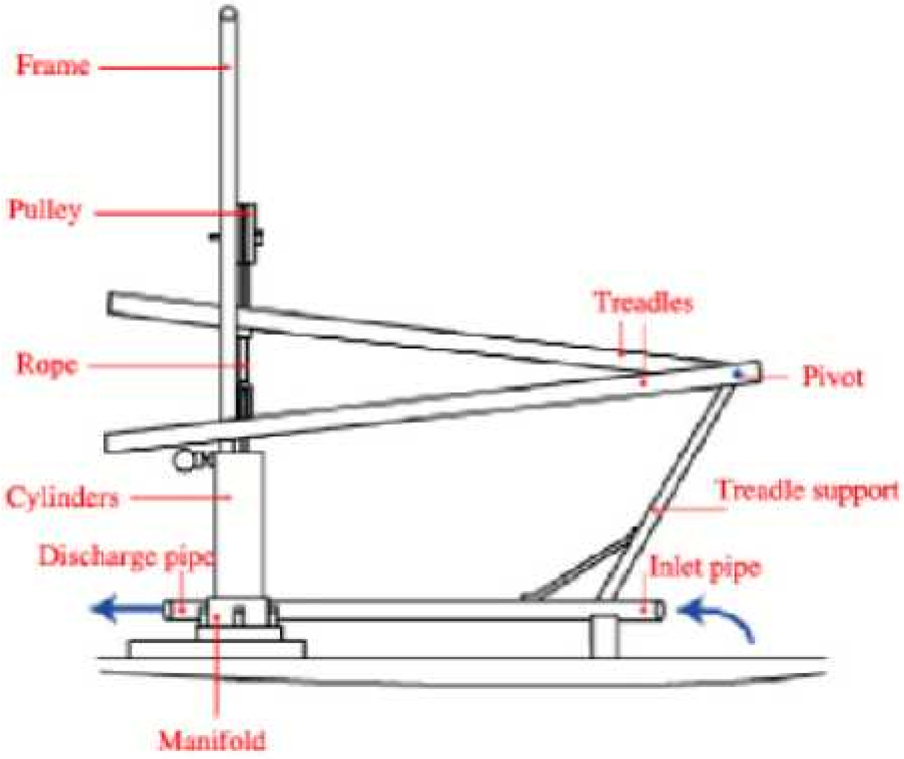

Fig 2.3.8 Treadle pump (Source; Sadak and Maharajgunj, 2010)

For this study, the selected water lifting technologies for the irrigation of fodder were rope and washer pump (Fig 2.3.9 and Fig 2.3.10) and pulley. For the rope and washer pumps, water was drawn into buckets and these buckets carried to the plots for irrigation. For the pulley, in addition to the pulley, a tank with a tap and hose (Fig 2.3.11) were added to improve water storage, conveyance to the field and reduce drudgery in irrigation activities. The volume of tank was 150 liters and also depending on the elevation of the field to the well location, sometimes the tank had to be elevated to about 0.5 m - 0.6 m to ensure adequate flow of water through the hose to irrigate the fodder plants. The hose had an internal diameter of 1.27 cm and average length of 25m.

Table 2.1 Rope and washer

Longer rope and washer:	**Shorter rope and washer:**
Height of rope and washer: normal height ~ 120 cm	Height of the rope and washer ~ 60 cm. The shorter R&W was more stable when pumping.
Normal cement base plate installed on top of the well. When properly installed, the slab prevents runoff from flowing into the well	Masonry 60 cm high to prevent runoff from flowing into the well
Total cost price (including VAT, excluding transportation 3775Birr)	Total cost price (including VAT, excluding transportation 4175Birr)

Fig. 2.3.9. Longer R&W pump

Fig. 2.3.10 Shorter R&W with masonry

Fig. 2.3.11. Pulley/tank/hose system

2.4 Monitoring soil moisture content

Efficient irrigation requires systematic water management program. A key component of good on-farm irrigation water management is the routine monitoring and measurement of soil water. Soil water must be maintained between desirable upper and lower limits of availability to the plant. This requires accounting for soil evaporation, crop water use, drainage and rainfall. Accurate assessment of the soil water-holding characteristics along with periodic soil water monitoring and measurement are required. Monitoring and measuring soil water available to irrigated crops is part of an integrated management package and helps avoid: 1) the economic losses due to effects of both under irrigation and over irrigation on crop yields and crop quality, and 2) the environmentally costly effects of over irrigation: wasted water and energy, the leaching of nutrients or agricultural chemicals into groundwater supplies and degradation of surface water supplies by sediment-laden irrigation water runoff.

Soil moisture is a key state variable of the land surface controlling the partition of rainfall to subsoil drainage, surface runoff or evaporation from the land surface. Understanding the dynamics of soil moisture is important for understanding the hydrological cycle in the climate system.

Soil moisture levels can be expressed in different ways, depending largely on the instrument used. Soil moisture content is often expressed as a percent (the weight of the water in the soil divided by the weight of oven-dry soil x 100). Other soil moisture monitoring devices use soil moisture tension to indicate soil moisture levels. Soil moisture tension refers to how strongly water is held on soil particles the higher the tension the more difficult it is for plant roots to extract water from the soil. Therefore, low soil moisture tension indicates moist soil and high soil moisture tension indicates dry soil. Soil moisture tension data can help train the person irrigating to make wise irrigation decisions combined with observations of the crop and other irrigation scheduling techniques, soil moisture checks can help to know what is happening in the soil, and to ground truth irrigation decisions.

It can help answer questions such as: is there enough deep moisture, when do I Start irrigating, am I applying enough water, am I watering at the wrong time and am I watering too much? (Orloff et al., 2001). By answering these questions, the crop will get adequate amount of water not less or excess. This leads to good production with sustainable use of water. Thus, scientific irrigation scheduling prevents water losses and leads to more sustainable use of scarce water resources. Water resources become scarcer as the dry season progresses and this may limit the plant growth at certain times during the growing season if water resources are not used sustainably.

Among the most common soil moisture monitoring approaches are:

2.4.1 Soil feel and appearance

Soil feel and appearance is easy to implement but requires some skill. The procedure involves the use of a soil auger or core sampler to obtain soil samples at various depths of the rooting zone to assess soil water status. Samples taken are compared to tables and charts which give the characteristics of different soil textures in terms of feel and appearance at different water contents (Ley et al., 1994).

2.4.2 Gravimetric sampling

Soil sampling is the only direct method for measuring soil water content. When done carefully and with enough samples, it is one of the most accurate methods, and is often used for calibration of other techniques. This approach requires careful sample collection and handling to minimize water loss between the times a sample is collected and processed. First weigh an aluminum tin, and record the weight then Place a soil sample of about 10g in the tin and record this weight, place the sample in the oven 105 ^{o}C, and dry for 24 hours or overnight, then Weigh the sample, and record this weight as weight of dry soil and tare, return the sample to the oven and dry for several hours, and determine the weight of dry soil and tare. Finally repeat this until there is no difference between any two consecutive measurements of the weight of dry soil and tare. Replicated samples should be taken to reduce the inherent sampling variability that results from small volumes of soil (Ley et al., 1994).

2.4.3 Tensiometer

Soil water tension, soil water suction, or soil water potential are all terms describing the energy status of soil water. Soil water potential is a measure of the amount of energy with which water is held in the soil. Careful installation and maintenance of a tensiometer is required for reliable results. The ceramic tip must be in intimate and complete contact with the soil. This is done by auguring a pilot hole out to the proper depth, making a soil water slurry mix with the soil removed and re-introducing this into the hole. Finally the tensiometer tip is pushed into this slurry. Soil is banked up around the tube at the soil surface to prevent water from standing around the tube itself. A few hours to a few days are required for the tensiometer to come to equilibrium with the surrounding soil. The tensiometer should be pumped with a hand vacuum pump to remove air bubbles. The tensiometer establishes a quasi-equilibrium condition with the soil water system. The porous ceramic cup acts as a membrane through which water flows, and therefore must remain saturated if it is to function properly. Consequently, all the pores in the ceramic cup and the cylindrical tube are initially filled with de-aerated water. Once in place, the tensiometer will be subject to negative soil water potentials, causing water to move from the tensiometer into the surrounding soil matrix. The water movement from the tensiometer will create a negative potential or suction in the tensiometer cylinder which will register on the recording device (Ley et al,. 1994).

2.4.4 Porous blocks

Porous blocks are made of materials such as gypsum, ceramic, nylon, and fiberglass. Similar to tensiometer, the blocks are buried in intimate contact with the soil at some desired depth and allowed to come to water tension equilibrium with the surrounding soil. Once equilibrium is reached, different properties of the block which are affected by its water tension may be measured (Ley et al, .1994).

2.4.5 Neutron scattering

Neutron scattering is a time-tested technique for measuring total soil water content by volume. This method estimates the amount of water in a volume of soil by measuring the amount of hydrogen present. A neutron probe consists of a source of fast or high energy neutrons and a detector, both housed in a unit which is lowered into an access tube installed in the soil this fast neutrons spread from the source are slowed by collisions with atoms of the surrounding medium, particularly by the hydrogen atoms in water. Some of the slow neutrons produced in this manner return to the detector where they produce pulses which are recorded during a pre-set time interval. The probe is connected by cable to a control unit which remains on the surface. Clips on the cable allow the probe to be set at pre-selected depths in the soil profile. Access tubes should be installed at least to the depth of the expected rooting zone (Ley et al, .1994).

2.4.6 Time domain reflectometry (TDR)

Newer methods which measure the dielectric constant of the soil water medium and then estimate soil water content have recently become commercially available. These methods include time domain reflectometry, frequency domain reflectometry and soil capacitance measurements.

The main advantages of TDR over other soil water content measurement methods are: superior accuracy to within 1 or 2% volumetric water content; calibration requirements are minimal, in many cases soil-specific calibration is not needed; lack of radiation hazard associated with neutron probe or gamma-attenuation techniques; TDR has excellent spatial and temporal resolution, also measurements are simple to obtain and it gives continuous measurements through automation and multiplexing.

When a high-frequency radio pulse is injected into two parallel conductors in a vacuum, it travels along them at the speed of light (3 x 10^8 m sec^{-1}). When it reaches the end, it is reflected and travels back to the source. Any matter (air, plastic insulation, wet soil) between or surrounding the conductors slow the pulse velocity and hence increases travel time. The travel time of the pulse varies with the amount of moisture in the soil. The TDR measures the round trip travel time of the pulse and translates into soil moisture content.

2.4.7 Soil moisture probe (soil moisture profiler)

The soil moisture probe is built around newly patented sensing technology which provides a good performance in all soil types, with minimal influence from either salinity or temperature. First, an access tubes is installed into the soil. The access tube is manufactured to strict tolerances and is exceptionally strong and durable in the soil but correct installation is essential, thus it is recommended to use an auger for digging, allowing easy installation and minimal soil disturbance. After installing the access tube and inserting the Profile Probe, by simply press the Read button to display an instantaneous reading of soil moisture at 6 depths 10 cm, 20 cm, 30 cm, 40 cm, 60 cm and 100 cm, which is longer than the maximum root depth of Napier grass at maturity stage.

When power is applied to the Profile Probe it creates a 100MHz signal (similar to FM radio). The signal is applied to pairs of stainless steel rings which transmit an electromagnetic field extending about 100mm into the soil. The field passes easily through the access tube walls, but less easily through any air gaps. The water content of the soil surrounding the rings dominates its permittivity, a measure of a material’s response to polarization in an electromagnetic field. Water has a permittivity ≈ 81, compared to soil ≈ 4 and air ≈ 1. The permittivity of the soil has a strong influence on the applied field resulting in a stable voltage output that soil moisture acts as a simple, sensitive measure of soil moisture content.

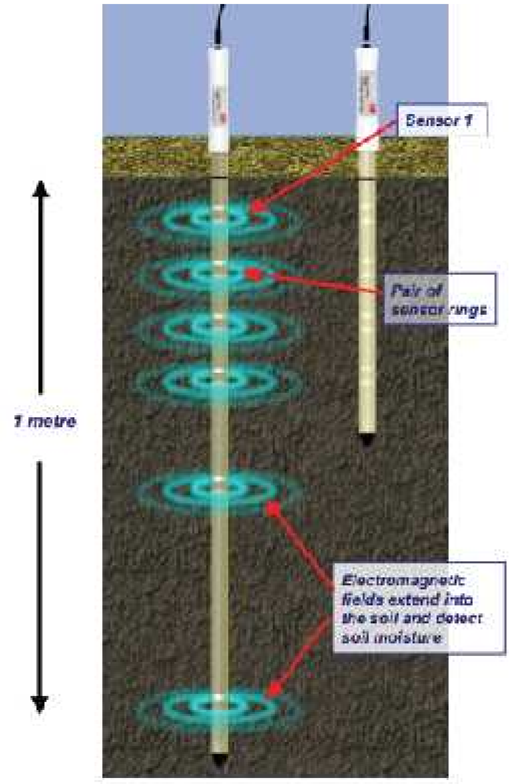

Fig 2.4.7 soil moisture probe

For this study, two types of devices were used. The first one is time domain reflectometry and the other was the soil moisture probe (soil moisture profiler).

2.5 Reference Evapotranspiration estimation methods

Although several variations of the definition exist, potential evapotranspiration (PET or ETo) can be generally defined as the amount of water that could evaporate and transpire from a vegetated landscape without restrictions other than the atmospheric demand (Currie, 1991). The concept of PET provides a convenient index to represent or estimate the maximum water loss to the atmosphere. Potential evapotranspiration is also used as an index to represent the available environmental energies and ecosystem productivity (Currie, 1991).

Many methods have been proposed for estimating ETo based on weather data. These methods range from locally developed, empirical relationships to physically based energy- and mass-transfer models. To allow for greater understanding, sharing, and inter-comparison of evapotranspiration information worldwide, under varying climatic and agronomic conditions, a standardized method of estimating ETo was developed, it's referred to as the FAO-56 Penman-Monteith method. The FAO-56 method has become the standard worldwide for estimating ETo but it is a complex method requiring several weather parameters, including air temperature, humidity, solar radiation, and wind speed, to be measured under strict instrumentation, setting, and maintenance conditions. Often times, limitations including financial, personnel, instrumentation, and maintenance, make the weather data required for using the FAO-56 method unavailable, and alternative reference ET methods must be used.

The following six methods are commonly used and require relatively fewer input requirements than the Penman-Monteith method. The six PET methods include three temperature based methods; Thornth Waite, Hamon, and Hargreaves-Samani; and three radiation based methods; Turc, Makkink, and Priestley-Taylor (Ge Sun et al., 2005).

Table 2.2 Monthly variables and parameters required by the six PET methods.

Method	Temperature	Radiation	Humidit	Others
Thornth	Mean Daily			Daytime Length
Hamon (1963)	Mean Daily			Daytime Length, Calibration Coefficient (1.2)
Hargreaves-Samani (1985)	Daily Maximum and Minimum Temperatures	Extraterrestrial Radiation		

Priestley-Taylor (1972)	Mean Daily	Net Radiation Derived From Solar Radiation and Extraterrestrial Radiation		Calibration Constant (1.26)
Turc (1961)	Mean Daily	Solar Radiation	Mean Daily	
Makkink (1957)	Mean Daily	Solar Radiation		

For this study, since all the climatic parameters that the Penman Monteith equation requires were available, the equation was used.

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

……………….……..Eq. 2.1

Where:

ETo = reference evapotranspiration [mm day-1],

R_n = net radiation at the crop surface [MJ $m^{-2}day^{-1}$],

G = soil heat flux density [MJ $m^{-2}day^{-1}$],

T = mean daily air temperature at 2 m height [°C],

u_2 = wind speed at 2 m height [m s^{-1}],

e_s = saturation vapor pressure [kPa],

e_a = actual vapor pressure [kPa],

$e_s - e_a$ = saturation vapor pressure deficit [kPa],

Δ = is slope vapor pressure curve [kPa °C^{-1}],

γ = psychometric constant [kPa °C^{-1}]

e^0 = saturation vapor function and

T_{Max} and T_{min} are the daily maximum and minimum air temperature.

2.6 Crop evapotranspiration (ETc)

The actual evapotranspiration is the amount of water transpired from plants and evaporated from soil surface under actual meteorological conditions and under non-optimal soil, biological management and environmental conditions. It differs from the potential evapotranspiration due to soil water shortage or waterlogging, diseases, soil salinity, low soil fertility. According to Allen et al. (1998), the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions defined for the potential evapotranspiration can be called the crop evapotranspiration. For this study, the actual evapotranspiration (crop evapotranspiration) was determined by soil water balance method.

2.6.1 Soil water balance method

Rain or irrigation reaching a unit area of soil surface, may infiltrate into the soil, or leave the area as surface runoff. The infiltrated water may evaporate directly from the soil surface, be taken up by plants for growth or transpiration, drain downward beyond the root zone as deep percolation, or accumulate within the root zone.

The soil water balance method is based on the conservation of mass which states that change in soil water content, ΔS, of a root zone of a crop is equal to the difference between the amount of water in the root zone (Q_o) and the amount of water in the root zone after a given time interval (Q_i) as expressed below.

$$\Delta \mathbf{S} = \mathbf{Q_i} - \mathbf{Q_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Eq. 2.2}$$

Where $Q_i = S_i \times$ root depth

$Q_o = S_o \times$ root depth

Where S_o = the initial volumetric soil moisture content

S_i = volumetric soil moisture content after a given interval i.

This equation can be used to determine evapotranspiration of a given crop as follows:

$$\mathbf{Q_o + P + I + U - R - D - ETc = Q_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Eq. 2.3}$$

Rearranging this equation,

$$\mathbf{ETc = P + I + U - R - D - Q_i + Q_o}$$

Which is the same as:

$$\mathbf{ETc = P + I + U - R - D \pm \Delta S} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Eq. 2.4}$$

Where: ΔS = change in root zone soil moisture storage for a given interval,

P = Precipitation,

I = Irrigation,

U = upward capillary rise into the root zone,

R = Runoff,

D = Deep percolation beyond the root zone,

ETc = crop evapotranspiration.

All quantities are expressed as volume of water per unit land area (depth units).

In order to use equation 2.4 to determine crop evapotranspiration (ETc), the various parameters in the equation must be measured and estimated.

2.7 Crop coefficient (Kc)

The concept of Kc was introduced by Jensen (1968) and further developed by the other researchers. The crop coefficient is the ratio of the actual crop evapotranspiration to reference crop evapotranspiration and it integrates the effects of characteristics that distinguish field crops from the reference grass, like ground cover, canopy properties and aerodynamic resistance, where ETo is determined and ETc is calculated for the same day (Lazzara and Rana, 2010).

The crop coefficient adjusts the calculated reference ETo to obtain the crop evapotranspiration ETc. Different crops will have a different crop coefficients at the various development stages.

$$ETc = ETo \times Kc$$

$$Kc = \frac{ETc}{ETo} \text{...Eq. 2.5}$$

Where ETo = calculated reference ET for grass (mm)

Kc = crop coefficient

ETc = crop evapotranspiration or crop water use (mm)

The crop coefficient will increase from the initial stage to mid stage because of the development of the leaves or leaf area becomes larger. After maturity, when the crop begins to die and the crop coefficient become smaller.

3. MATERIALS AND METHODS

3.1 Experimental work and design

For this experiment, First 36 farmers were selected but finally only 15 households fulfill the criteria (like land, well etc.) for this irrigation season and continued. These farmers have areas of land ranging from 50m^2-100m^2 for Napier grass production and a nearby well as a source of water for irrigation. In addition, there were 2 households selected as control farmers; growing the same variety of Napier grass using their own water lifting technologies (traditional bucket and rope) and doing their own irrigation scheduling based on their experience. The 15 households were divided into two groups; the first group included 6 households using rope and washer pumps and the remaining 9 households used the pulley/tank/hose system to lift water from shallow wells and apply it to the fodder plots.

All 17 households grew the same variety of Napier grass. Also, similar land management practices, and fertilizer application were applied to all the plots. Each household (each plot) has a code name depending on the lifting technology they used. For example: RW1 represents the plot 1 irrigated with rope and washer, thus the 6 R&W plots were denoted RW1 up to RW6. The plots irrigated with pulley/tank/hose system were denoted pulley P1 up to P9. The two control farmers using their own water lifting technology and their traditional ways of irrigation scheduling were denoted C1 and C2.

The installation of water lifting technologies was done from February 8th to 24th 2015 for both Rope and washer and pulley users. The soil moisture probe access tubes were installed on four plots; two from rope and washer (RW1 and RW3) and two from pulley (P5 and P7) using an auger.

Fig.3.1.1 Shorter rope and washer pump during installation

Fig.3.1.2 Soil moisture measurement using soil moisture profiler

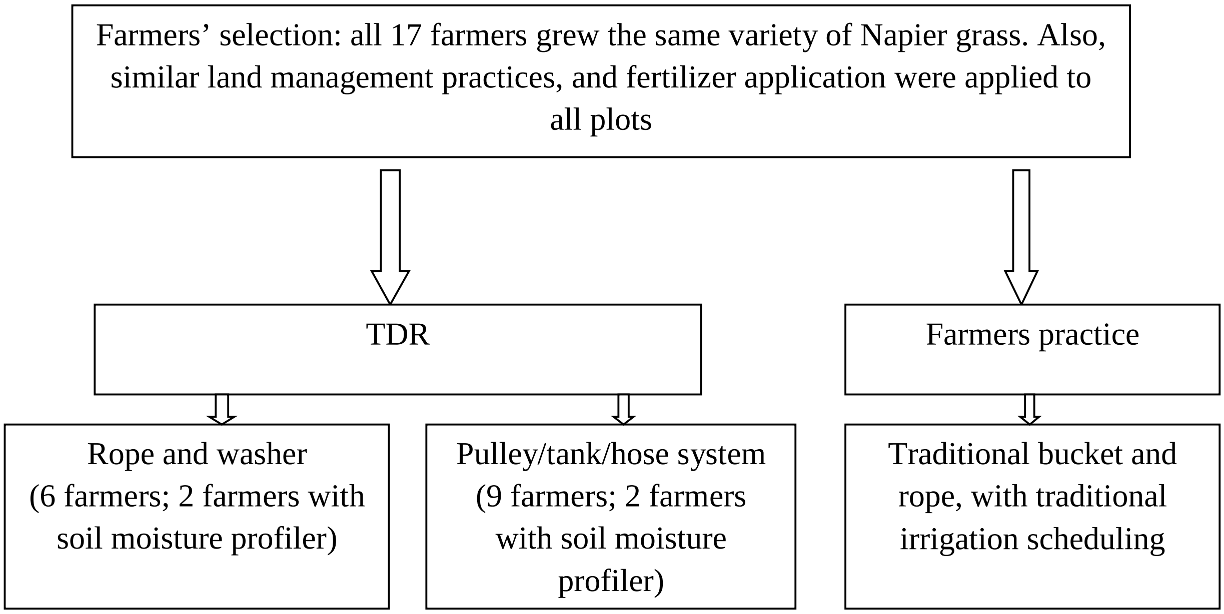

Fig.3.1.3 Summary of experimental design

3.2 Data collection

3.2.1 Beginning of season activities

First, to have basic information about each of the 17 households in the experiment, a baseline survey was conducted to have a better understanding of the target farmers. Information collected prior to the field study included: GPS coordinates on the farmer's home, well and field; well depth and information related to experience in fodder production, experience in irrigation, type and number of livestock the household owns, and current fodder sources for the household. Also, a focus group discussion was conducted with the target farmers to select the fodder type they all should grow and to also orient farmers in a group about the project, the studies and field activities to be carried out.

On technology installation, each of the target farmers was trained on the technology operation and maintenance. A field book complied by IWMI was used to collect various agronomic, management and economic data during the course of the growing period; the target farmers and the data collectors were given training on how to fill in the daily activities on the fodder plot in the field book. To create more awareness on fodder production and irrigation for the target farmers, they were taken to Merawi, 37 km from Robit kebele, for experience sharing. Merawi was chosen because farmers in this area are more experienced in irrigated fodder. The target farmers' knowledge and interest on the fodder irrigation increased. After the trip, all farmers were motivated and started taking good care of the grass.

3.2.2 Soil physiochemical properties

After collecting basic information on each household, and making sure that they fulfill the criteria for this study like willingness to allocate some area of their land to fodder production, and having a well near to the fodder plot, the next step was collect soil samples from each of the plots. By digging up to 20 cm in 10 spots in each farmer's plot, a 1.5-2 kg composite soil sample was collected. The composite sample was analyzed for soil texture, EC, organic matter content, pH, cation exchange capacity, total nitrogen, available P and iron status from the Amhara Design and Supervision Works Enterprise laboratory. Core samples were also collected from each plot and taken to the laboratory to test for soils' field capacity, permanent wilting point and bulk density. Soil texture was determined in the laboratory using the hydrometer method. The water content at field capacity and at permanent wilting point were determined in the laboratory by using a pressure (porous) plate apparatus where the undisturbed soil sample was saturated and subjected to pressures of -0.1 to -0.33 bar for field capacity and -15 bar for permanent wilting point. A soil suspension was stirred for 30 min and before measuring its pH with a pH-meter. Total N was measured with Kjeldahl method. Available phosphorus P (mg P per kg soil) with extraction of acid-soluble. And, finally EC was analyzed by Conductometry method with a soil-water ratio of 1 to 5. The suspension is stirred during 60 min before measurement.

3.2.3 Agronomic management and yield

Planting of Napier grass took place between 4th and 13th of March, 2015. Rhizome cuttings with accession numbers: 16784, 16794 and 16543 were brought from Andasa research center and planted with a spacing of 0.5 m × 0.5 m. Fertilizer amounts and timings were same for all the plots. From 23 to 25th of April, 2000g of UREA fertilizer was applied per a 100 m^2 area (2Ql/ha). In order to monitor the grass and identify the development stages (initial stage, mid stage and maturity stage) during the growing season, on each plot, the plant height, leaf width, length and leaf amount were recorded by dividing each plot in 5 subplots and measuring for 3 plants from each subplot. Napier grass is a perennial grass that can be harvested 4 to 6 times a year. The first harvest (or cutting) was done between 6th May and 29th June, 2015 for all the plots. Some plots were grazed in the first 30 days and the growing process was interrupted, thus the grass has to re-grow and therefore harvesting was done later. All the harvested wet biomass from each plot for the first cutting was weighed and recorded. If harvesting in the whole plot exceeded a single day, for each day of harvest, the harvested wet biomass and harvested plot area were measured and recorded. The total harvested wet biomass and total harvested area were then computed. Weighed wet biomass samples were dried outside in the air (sundry) for a week, after which, the dry matter weight was recorded. On average, 1Kg of wet grass resulted into 0.1838 kg of dry matter. For this study only, the first cutting was considered.

3.2.4 Irrigation

Each time water was applied to the Napier grass, the irrigation amount was recorded in the field books. This was done throughout the growing period. All 6 farmers using a rope and washer pump used a different size tank to store the water and the tanks’ volume was measured for each rope and washer household at the beginning of the experiment. The 9 farmers having pulley used plastic tanks of 150-liter capacity to store the water lifted from the well using the pulley, rope and bucket. After which they applied water to the plants through a plastic hose connected at the bottom of the tank. The average water flow rate through the hose for a whole tank of water measured at three levels: 1) at full tank, 2) at half a tank, and 3) at a quarter a tank, was determined at the beginning of the season for each pulley farmer. The flow rate were measured by filling a bucket of known volume, and measuring the amount of time taken to fill that bucket. This was done 3 times at each water level in the tank. Both rope and washer farmers and pulley farmers irrigated their plots on a 3-day interval. For each irrigation event, the number of buckets applied by the rope and washer farmers to the whole plot were recorded. The number of 150-liter tanks applied to the whole plot for each irrigation event was recorded for the pulley farmers. Also, the time taken to apply water to the whole plot was recorded for the pulley farmers. This time was multiplied by the water flow rate through the hose in order to double check the volume of water applied to the plot. One of the control farmers used a 10 liters bucket to draw and irrigate the field since the water source was a pond near the farm. The number of buckets applied to the experimental plot were recorded for each irrigation event. The second control farmer used an 80-liter tank to store water lifted from the well by pulley (pulley made from wood). The number of tanks for each irrigation event were recorded.

For the rope and washer farmers and the pulley farmers, irrigation were scheduled every after 3 days. Before each day of irrigation, soil moisture readings were taken in 5 spots across each plot using the TDR. The average of the readings was then calculated. The farmers were advised on how the amount of water they should apply depending on the determined deficit in their plots i.e. FC of that field - the average soil moisture reading as calculated from the TDR readings.

Volume Amount of water to be applied (m3) = (FC – Ave. TDR reading) (% vol)/100 × Root depth (m) ×Area (m2)…………Eq. 3.1

The effective rooting depth for Napier grass was taken to be 40 cm. The volume of water to be applied for each farmer's plot was converted to liters and each farmer advised on many liters and thus buckets or tanks to apply to the whole plot. Even though the farmers were advised on how much water to apply, they usually did not apply enough water to meet the crop water demand. Several farmers faced water shortages during the growing period, as this period was also the driest time of the year and the well yields were not sufficient to meet the crop water demand and some other water uses the farmers used the wells for. Moreover, two of the farmers ended up over irrigating as their wells' yields were sufficient and the plot areas they allocated for Napier production were smaller when compared to the rest of the farmers i.e. 50 and 70 m^2 compared the 100 m^2 most farmers grew.

3.2.5 Soil moisture monitoring

3.2.5.1 Using TDR

The TDR measured soil moisture up to a depth of 20 cm. The initial readings i.e. beginning of season readings were taken before the planting. After planting, with a 3-day interval, the readings was taken in each of the farmer's plot in 5 spots per plot and averaged to get on representative reading per plot. This average TDR reading per plot was sued to schedule irrigations as mentioned above. On the first cutting (or harvest) date of each farmer's plot, the final TDR readings i.e. end of season readings were taken and recorded in order to be able to close the soil moisture balance for the first cutting.

3.2.5.2 Using soil moisture probe (soil profiler)

For this study, four access tubes were installed, one in each plot, in two rope and washer plots (RW1 and RW3) and two pulley plots (P5 and P7). Soil profiler readings were taken weekly and soil moisture was monitored up to 1m in order to be able to detect for deep percolation below the Napier grass effective root zone (40cm).

3.3 Crop coefficient development

Crop coefficients for the various development stages were determined by first calculating the actual crop evapotranspiration and reference evapotranspiration for each three days interval. Next was to identify the length of the grass' various development stages. Development stages' durations were identified by manually observing the plants. For each identified development stage, crop coefficients were calculated for each 3-day interval and then average for the duration of the development stage in order to obtain a single Kc for each development stage.

3.4 Reference evapotranspiration (ETo)

To calculate the reference evapotranspiration (ETO), Penman- Monteith equation was used. This is because it uses different climatic parameters and thus, it gives more accurate result than the other methods. The various climatic parameters were available from Bahirdar metrological station located only 12 km from the study kebele. Daily climatic data including minimum and maximum temperature, rainfall, relative humidity, wind speed, and sunshine hours for the period of March to June was obtained from the metrological station and used to calculate reference evapotranspiration. The climatic parameters used to calculate ETo are shown in Appendix A. Other parameters used to calculate for ETo are shown below:

Table 3.1. Other parameters used to calculate ETo

Latitude	11.590
solar constant (Gsc) (MJ m-2 min-1)	0.082
latitude expressed in radians(Ψ)	0.202
Elevation (m)	1800

3.5 Crop evapotranspiration

Crop evapotranspiration was determined using the soil water balance method for each three day interval. That is, all soil water inputs and outputs within the 3-day interval were quantified as shown below and ETc calculated using equation 2.4.

3.5.1 Precipitation (P)

During the growing season (March-June), 377.1 mm of rainfall were received in the study area. The distribution of rainfall as recorded by the Bahirdar metrological station during the experimental period is shown in Fig 3.5.

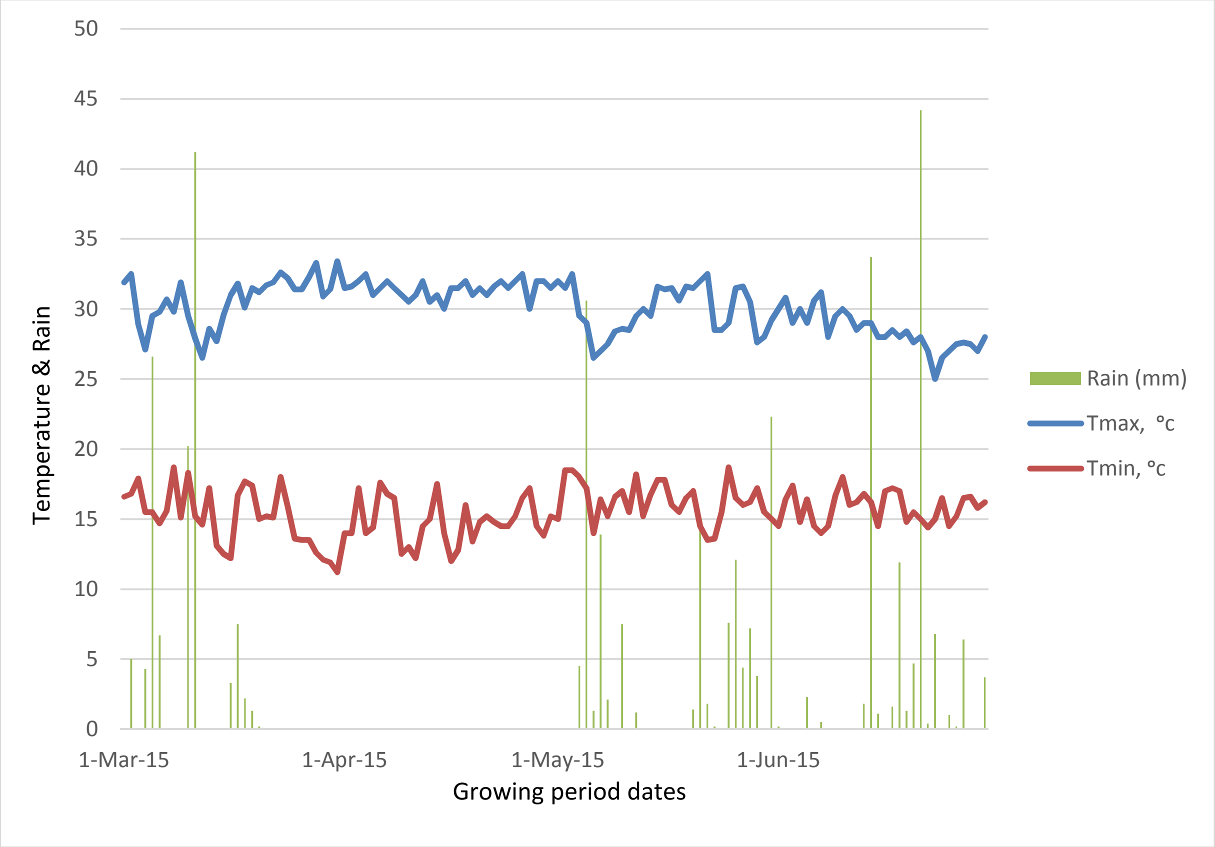

Fig 3.5 Rainfall data and average temperature during the growing period

3.5.2 Irrigation (I)

As mentioned before, for all farmers' plots and on each day of irrigation, the number of buckets or tanks applied were recorded. The number of buckets or tanks were then converted to volume of water applied per plot per irrigation event. After harvest, total volume applied throughout the growing period for each plot was then deduced (Table 4.5).

3.5.3 Runoff (R)

The water applied to the Napier grass plots never ran off the plots, thus the runoff component of the soil water balance is negligible.

3.5.4 Upward capillary rise into the root zone (U)

When the groundwater table is deep, capillary rise is negligible. This depends on the topographic location and how far the plot is from Lake Tana. For plots close to Lake Tana, there will be interaction between the groundwater and the lake water level in the lake and capillary rise in this case it may not be negligible. For the target farmers' wells, the average depth measured from the ground surface to the water level in the well was 7.383 m. Thus, considering the maximum root depth of Napier grass at maturity to be 40cm, the water could not have reached the root zone, so the upward capillary rise into the root zone was considered negligible for all plots.

3.5.5 Deep percolation beyond the root zone (D)

The growing period was also the driest season of the year in Ethiopia where water level in the wells was at its lowest and the well yields significantly decreased. Owing to this, water was scarce and some farmers could hardly get enough water to irrigate their plots adequately and also save some water for other uses like domestic use and feeding livestock. Nevertheless, two representative plots per lifting technology were monitored within the root zone of the Napier grass (up to 40 cm) and below the root zone (40cm to 1m) to see changes in soil moisture content throughout the growing season and determine whether the soil moisture content ever exceeded field capacity of that soil using the soil moisture probe. Water will percolate below the root zone when the water in the root zone exceeds field capacity.

3.5.6 Change in root zone soil moisture storage (ΔS)

The difference between the amount of water in the root zone (Q_o) and the amount of water in the root zone after a given time interval (Q_i) which was 3 days in this case because the TDR readings were taken after every 3 days is the change in soil moisture storage in the root zone. By multiplying the percentage volumetric water content with the effective root depth of Napier (400 mm), the change in the root zone's soil moisture storage was calculated in mm before each irrigation event.

3.6 Dry matter yield (kg/ha) of Napier grass

All farmers harvest data (both wet and dry yield) per plot area was recorded. Dry matter weight (kg/ha) is shown in Table 4.5.

3.7 Water use efficiency

Water use efficiency (WUE) was calculated as the ratio of dry matter yield (kg/ha) to crop evapotranspiration (m^3/ha). WUE is used as an index to compare the two lifting technologies. A lifting technology with a higher WUE would imply better performance.

3.8 Irrigation productivity

Irrigation Productivity was calculated as the ratio of dry matter yield (kg/ha) to the volume of amount of water applied (m3/ha).

3.9 How much of the crop water demand is actually applied using the two technologies?

One of the parameters used to compare the two water lifting technologies is comparing how much of the crop water demand is actually applied by the farmers using the different lifting technologies. Both technologies are manual technologies, and manual technologies are often limited by ease of use and breakdowns. Quantifying this helps to know which technology farmers in the site would prefer to use.

3.10 Data analysis

Statistical analysis of the data included analysis of variance (ANOVA) using Microsoft Excel. The analysis used was a one way ANOVA i.e. one factor (lifting technology) ANOVA. *F* tests and p-values were obtained and normality test were done for amount of water applied, dry matter yield, WUE, and irrigation productivity.

4. RESULT AND DISCUSSION

4.1 Baseline survey and FGD

From the baseline survey and FGD, target farmers' basic information like gender of the household heads, well depth, experience in fodder growing, number of livestock and sources of feeds was collected and is summarized in table 4.1.

Table 4.1 Summary of results on baseline survey and FGD

Plot code	**Gender**	**Well depth (m)**	**No of livestock (Dairy cows, heifers, calves, sheep, oxen and bulls)**	**Sources of feeds before the study**	**Experience in fodder growing**
RW1	Male	8	9	crop residues	No
RW2	Female	11.25	4	grazing and green fodder	Yes
RW3	Male	8.97	8	crop residues and green fodder	Yes
RW4	Male	10	14	factory supplements and grazing	No
RW5	Male	12	24	hay and factory supplements	No
RW6	Male	10.8	11	crop residues and factory supplements	No
P1	Female	13	2	grazing	No
P2	Female	11.7	3	grazing	No
P3	Male	10	9	crop residues and hay	No
P4	Male	17.2	5	hay and factory supplements	No

P5	Male	10.4	17	crop residues	No
P6	Female	7.2	2	grazing	No
P7	Male	13	30	crop residue and green fodder	Yes
P8	Male	6.2	20	Factory supplements	No
P9	Female	13	4	crop residues and grazing	No

- Factory supplements include oil cake and wood shaving and crop residues of teff, millet, maize. Crop residues include both straw and stubble.

4.2 Soil physiochemical properties

Soil sampling and analysis was done before planting of the Napier grass and there is no significant difference in parameters between the two groups (Table 4.8). Results are shown in Table 4.2. The soils in Robit kebele are Alfisols. The soils' texture ranges from clay to clay loam to loam. The soils are acidic; pH ranged from 5.1 to 6.8.

Table 4.2 Laboratory Result of soil physiochemical properties

Plot code	**pH**	**EC (ds/m)**	**Soil class**	**CEC**	**OM (%)**	**TN (%)**	**Av. P (ppm)**	**Fe (ppm)**	**FC (%)**	**PWP (%)**
RW1	5.13	0.105	Clay	29	5.24	0.26	0.48	8.261	34.89	20.11
RW2	6.72	0.285	Loam	32	5.85	0.29	3.56	5.638	26.82	14.62
RW3	6.15	0.284	Loam	42.2	7.06	0.35	6.14	10.29	40.13	22.48
RW4	5.63	0.074	Clay	37.8	3.5	0.17	0.58	6.747	35.25	20.86
RW5	5.47	0.109	Clay	43	4.17	0.21	1.13	7.656	26.87	14.46

RW6	5.68	0.178	Clay loam	34.6	5.11	0.26	1.96	9.962	26.08	14.7
P1	5.86	0.35	Loam	40.6	6.39	0.32	5.45	10.33	41.23	23.65
P2	5.24	0.105	Clay	29.4	4.1	0.21	0.68	9.472	38.9	21.78
P3	5.58	0.202	Clay loam	41	5.04	0.25	1.62	9.845	27.54	14.76
P4	5.76	0.071	Clay loam	30.6	3.83	0.19	0.39	8.649	31.71	18.13
P5	5.82	0.099	Clay loam	22.2	3.83	0.19	1.77	9.566	37.86	20.36
P6	5.6	0.121	Clay loam	36.2	5.65	0.28	1.17	9.982	40.3	23.46
P7	5.65	0.179	Clay	36	4.84	0.24	0.4	7.065	26.41	15.8
P8	5.7	0.239	Clay loam	43	5.98	0.3	6.67	9.362	28.95	14.52
P9	6.21	0.224	Loam	37	5.85	0.29	3.92	9.21	38.71	22.03

4.3 Technology calibration and discharge measurement

The discharge for the rope and washer and pulley was measured by using a 10 liter jar and recording the time to fill the jar by a stopwatch. 3 trials were recorded and averaged for each technology to get a representative value because one person cannot lift the water with equal force and time as the first trial also different persons cannot lift with equal time. In the result the pulley technology has a higher average discharge of 0.346 l/s while the rope and washer has 0.207 l/s.

Table 4.3 Discharge of both technologies

plot code	**Technology**	**Discharge (l/s)**
RW1	R&W	0.205
RW2		0.2
RW3		0.202
RW4		0.231
RW5		0.22
RW6		0.182
Average		**0.207**
Standard deviation		**0.017**
P1	Pulley	0.31
P2		0.438
P3		0.302
P4		0.337
P5		0.283
P6		0.297
P7		0.362
P8		0.393
P9		0.395
Average		**0.346**
Standard deviation		**0.054**

4.4 Crop coefficient development

4.4.1 Reference evapotranspiration (ETO)

As indicated in the methodology, ETo was determined using Penman-Monteith equation, using climatic data from the Bahirdar metrological station from March to June, 2015 (Appendix A). The computed daily ETo for the growing season is also given in Appendix A and Fig 4.1. Table 4.3 shows a summary of the average daily ETo for the growing season months. ETo values vary across farmers' plots because of differences in length of the growing period.

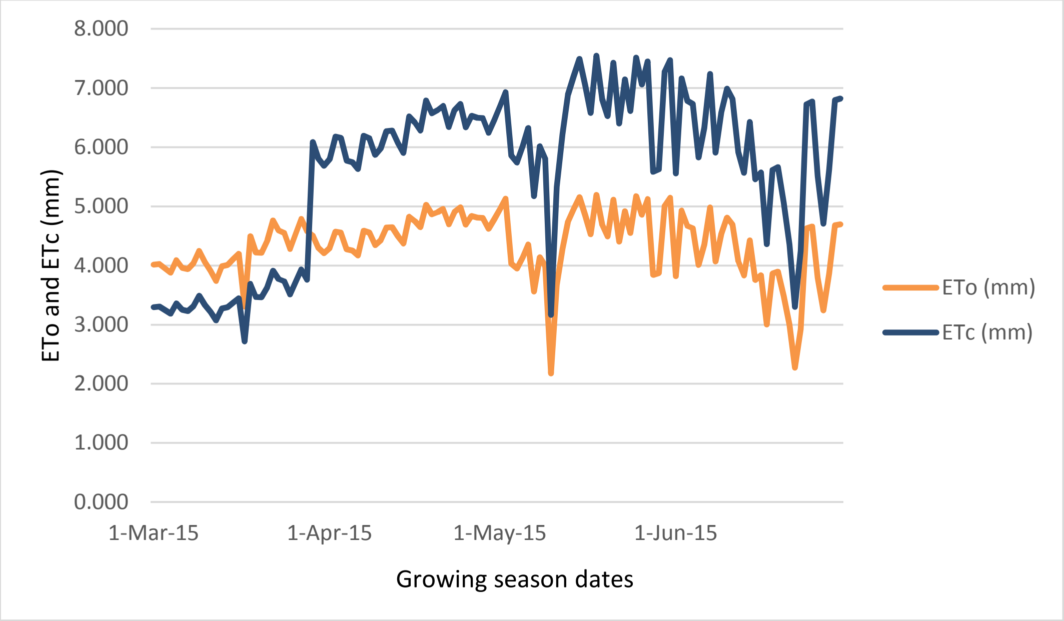

Fig 4.1 Daily ETo for the Napier growing period

Table 4.4 Average daily ETo for the growing season months

Year	**Month**	**ETo (mm)**		
		Min.	**Max.**	**Average**
2015	*MAR*	3.308	4.791	4.191
	APR	4.169	5.027	4.643
	MAY	2.178	5.196	4.484

	JUN	2.273	4.982	4.048

4.4.2 Crop evapotranspiration (ETc)

ETc was determined using the soil water balance equation 2.4. Runoff and the upward capillary rise were considered negligible parameters in the soil water balance equation as explained earlier. For deep percolation, soil moisture was monitored using a soil profiler up to a depth of 1m below the soil surface as shown in Figs. 4.2, 4.3, 4.4, and 4.5 for two plots irrigated using R&W (RW1 and RW3) and another two plots irrigated using pulley (P5 and P7). The figures show that below 40 cm, the effective rooting depth of Napier grass, the average changes in soil moisture were smaller throughout the growing season when compared to soil moisture changes above 40 cm. Also, except towards the soil surface, the soil moisture levels down the 1 m profile were always lower than the field capacity, thus suggesting that deep percolation was negligible. During soil water redistribution, it is expected that when it rains or under irrigation, a soil layer's water content will increase until it reaches the field capacity. Any other water that is added after the soil has reached field capacity will drain to the soil layer below the former layer. When the moisture content of the soil layer is below field capacity, deep percolation is assumed negligible. In this case deep percolation is when irrigated water seeps below the root zone (40cm). But the moisture increases at depth 100cm than 60cm this might be caused from ground water interaction.

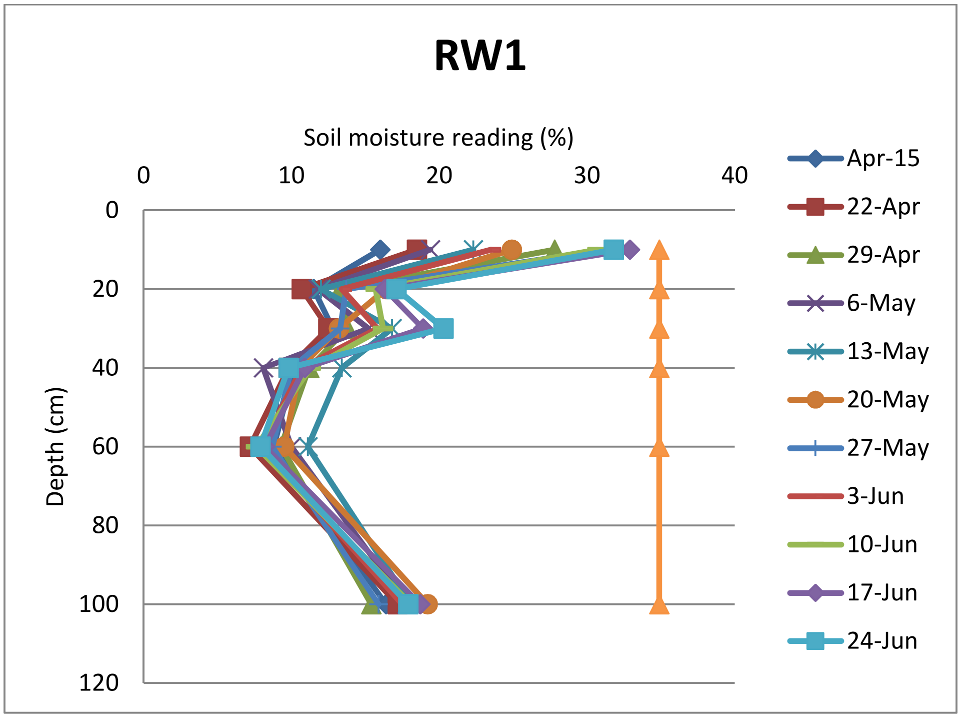

Fig 4.2 Soil moisture readings using soil profiler on plot RW1

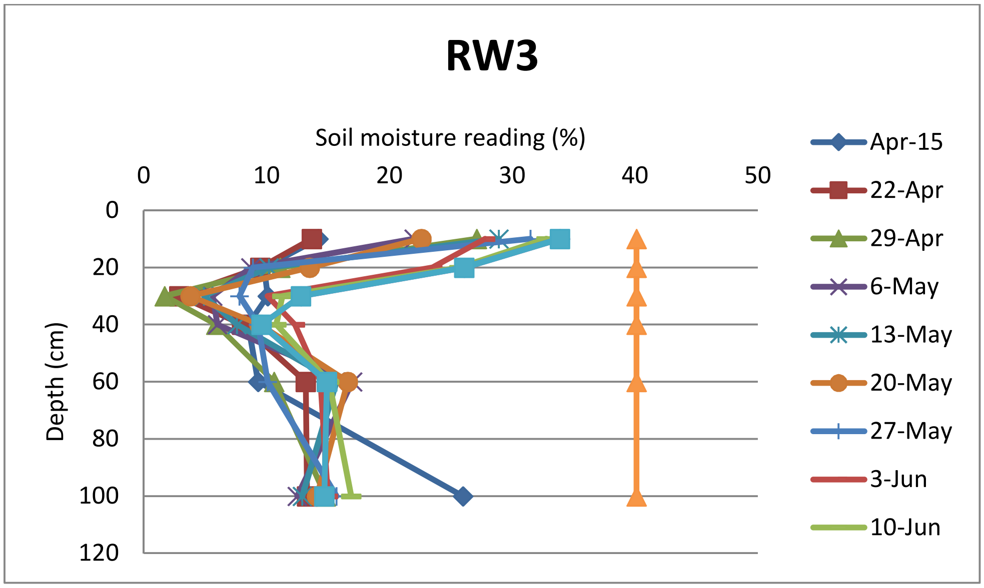

Fig 4.3 Soil moisture readings using soil profiler on plot RW3

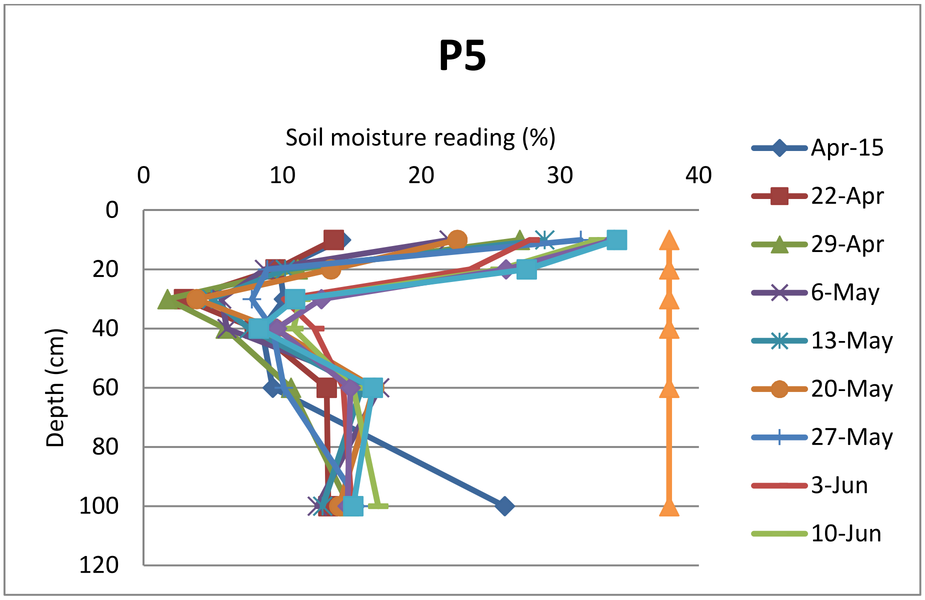

Fig 4.4 Soil moisture readings using soil profiler on plot P5

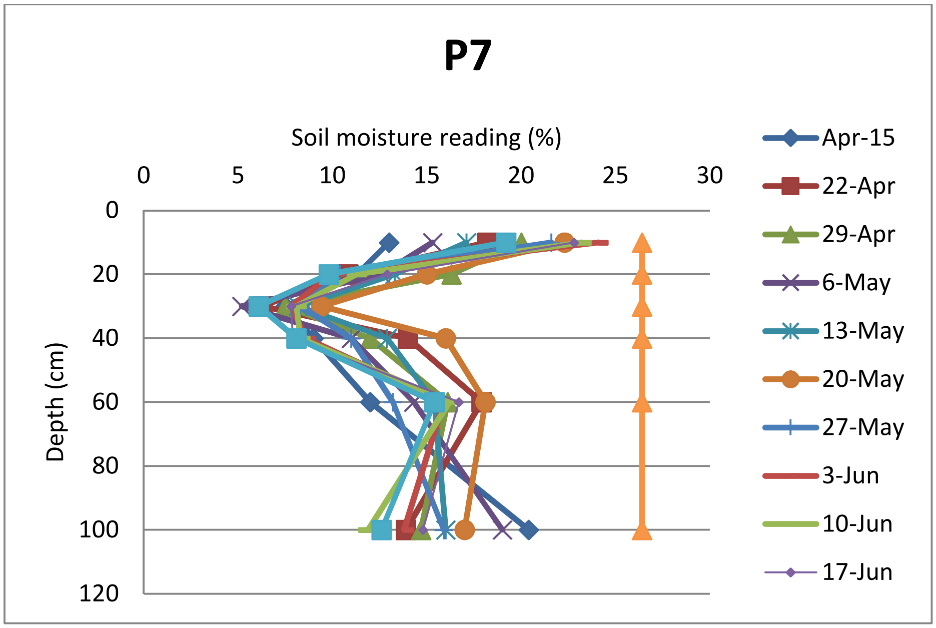

Fig 4.5 Soil moisture readings using soil profiler on plot P7

Adjusting for runoff, upward capillary rise and deep percolation in the root zone, soil water balance equation 2.4 becomes ETc = P + I ± ΔS. The soil moisture readings were taken with 3 days. ETc therefore was calculated every 3 days throughout the growing season for the irrigation applied, rain received and changes in soil storage for that interval. Table 4.5 shows the ETc values for the various plots,

Table 4.5. Plot area, irrigation applied, ETc, dry matter yield, WUE, irrigation productivity and seasonal Kc for the experimental plots.

Plot code	Plot area (m2)	Amount of water applied (mm)	Volume of water applied (m3/ha)	ETo (mm)	ETc (mm)	ETc (m3/ha)	Dry matter yield (kg/ha)	WUE (kg/m3)	Irrigation productivity (kg/m3)	Seasonal Kc
RW1	100	383.5	3835	488	601	6010	501*	0.083	0.131	1.23
RW2	50	756	7560	453	803	8030	3711	0.462	0.491	1.773
RW3	100	211.5	2115	488	465	4650	331*	0.071	0.157	0.951
RW4	60	525	5250	488	734	7340	1326*	0.181	0.253	1.503
RW5	70	497.1	4971	488	767	7670	461*	0.06	0.093	1.571
RW6	100	344	3440	488	603	6030	331*	0.055	0.096	1.235
Average	**80**	**453**	**4529**	**482**	**662**	**6622**	**1110**	**0.152**	**0.203**	**1.377**
Standard deviation	**22.80**	**186.53**	**1865.32**	**14.29**	**128.1**	**1281.41**	**1515.0**	**0.16**	**0.15**	**0.29**
P1	60	445	4450	371	616	6160	3043	0.494	0.684	1.662
P2	100	408	4080	453	554	5540	1224	0.221	0.3	1.223

P3	100	193.5	1935	291	315	3150	1592	0.505	0.823	1.08
P4	100	321	3210	520	677	6770	1481	0.219	0.461	1.301
P5	100	346.5	3465	453	513	5130	901*	0.176	0.26	1.131
P6	140	305.4	3054	371	366	3660	2679	0.732	0.877	0.988
P7	100	354	3540	488	625	6250	542*	0.087	0.153	1.28
P8	100	376.5	3765	371	400	4000	1084	0.271	0.288	1.08
P9	100	244.5	2445	371	400	4000	1832	0.458	0.749	1.078
Average	**100**	**333**	**3327**	**410**	**496**	**4962**	**1598**	**0.351**	**0.511**	**1.203**
Standard deviation	**20.00**	**78.17**	**781.68**	**72.57**	**130.1**	**1301.67**	**1037.0**	**0.21**	**0.28**	**0.20**
C1	100	236.8	2368				1250*		0.528	
C2	100	164	1640				1470*		0.897	
Average	**100**	**200.4**	**2004**				**1360**		**0.713**	
Standard deviation	**0.00**	**51.48**	**514.77**				**155.5**		**0.26**	

* Grass in these plots was eaten a number of times by livestock during the growing season.

4.4.3 Crop coefficient (Kc)

The crop coefficients were developed for three stages: initial, mid- and maturity stages. The crop coefficients for each development stage were obtained by dividing the total crop evapotranspiration by the total reference evapotranspiration for the 3-day irrigation scheduling intervals and averaging the quotients over each development's stage growth period. The crop coefficients obtained for each development stage (Table 4.6) and the overall season (Table 4.5) for the target farmers are in accordance to the single crop coefficient approach. This approach's purpose of calculation is for irrigation planning and design, and irrigation management.

4.4.3.1 Initial stage

The length of this stage ranged from 25 to 30 days. During the initial stage, the leaf area was small, and evapotranspiration was mainly in the form of soil evaporation. The Kc during the initial period is therefore large when the soil is wet from irrigation and/or rainfall and is low when the soil surface is dry. The crop coefficients obtained in this analysis on the 15 experiment plots as shown in Table 4.6 varied between 0.43 and 1.40; giving an average of 0.82.

4.4.3.2 Mid-stage

Shortly after initiation of new leaves, the value for Kc (initial Kc) is low as seen above. The Kc then begins to increase from the initial Kc value to a time of maximum or near maximum plant development, the mid-development stage. The length of this stage varied from 20 to 50 days among the 15 farmers. Crop coefficients obtained for this development stage varied between 0.56 and 2.32; with an average of 1.35.

4.4.3.3 Maturity-stage

The late season stage runs from the start of maturity to harvest. The calculation for ETc and Kc ends when the crop is harvested. The Kc value at the end of the late season stage (Kc end) reflects crop and water management practices. The Kc end value is high if the crop is frequently irrigated until harvested fresh. If the crop is allowed to senesce and to dry out in the field before harvest, the Kc end value will be small (FAO, 2006). The maturity stage lasted from 40 to 45 days. In this study, Kc for the maturity stage varied between 0.76 and 2.16; with an average of 1.45. The Napier grass was harvested fresh, and was being irrigated regularly until harvest and thus the high Kc value at the maturity stage.

The crop coefficients for the various stages varied significantly among the target farmers. This is because crop coefficients are dependent on the actual evapotranspiration which is also depends on crop management which varied from farmer to farmer. Figure shows the overall trend of the average crop coefficients for the three growing stages.

Table 4.6. Average crop coefficients for each the development stages for each plot.

No	**Plot code**	**Water lifting technology used**	**Average Kc for different development stages**		
			initial	**mid**	**maturity**
1	RW1	R&W	0.504	1.417	1.545
2	RW2		1.124	2.321	2.163
3	RW3		0.425	0.654	1.221
4	RW4		0.963	1.438	1.855
5	RW5		0.681	2.012	1.926

6	RW6		0.607	1.425	1.499
7	P1	pulley	1.404	1.781	1.894
8	P2		1.124	1.27	1.316
9	P3		1.078	0.563	1.174
10	P4		0.638	1.101	1.58
11	P5		0.666	1.356	1.162
12	P6		0.832	0.913	1.153
13	P7		0.856	1.123	1.623
14	P8		0.639	1.647	0.763
15	P9		0.78	1.248	0.927
Average			**0.821**	**1.351**	**1.453**
Standard deviation			**0.271**	**0.470**	**0.398**

Table 4.7 Average Kc for the development stages for each lifting technology

Water lifting technology	Development stages with average number of days		
	Initial stage (28 days)	Mid stage (35 days)	Maturity stage (42 days)
	Average Kc		
R&W	0.717	1.545	1.702
pulley	0.891	1.222	1.288

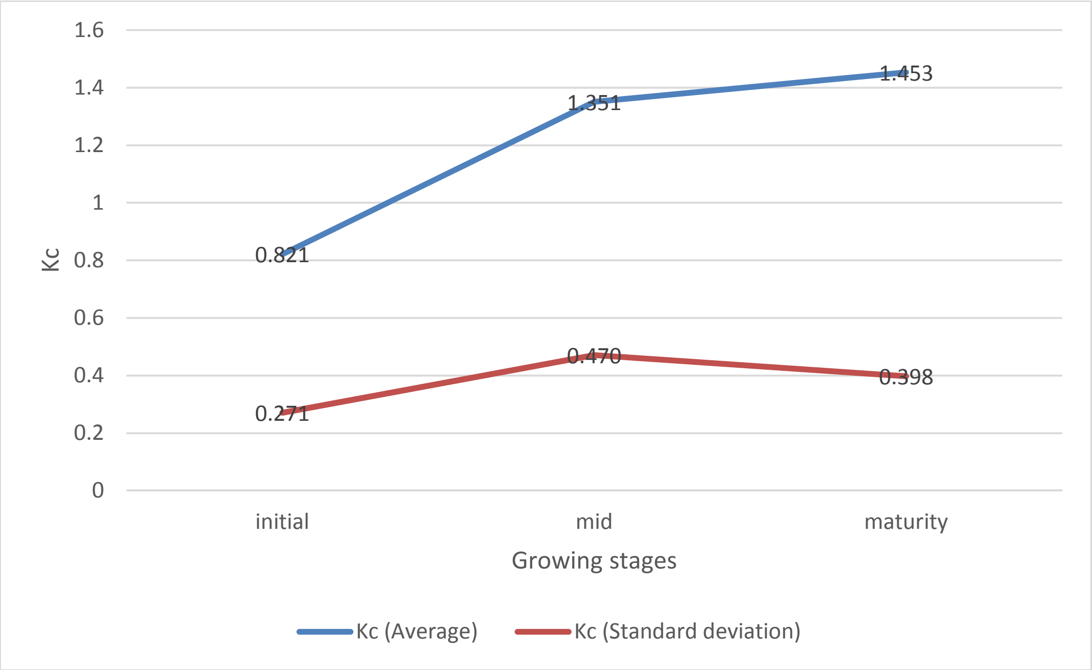

Fig 4.6 Trend of the crop coefficient developed for Napier grass.

4.5 Technology comparison

Table 4.8. Comparing means of irrigation water applied, ETc, dry matter yield, WUE and irrigation productivity for the two lifting technologies and soil physiochemical properties.

Lifting technology	Plot area (m2)	Irrigation water applied (m3/ha)	ETc (m3/ha)	Dry matter yield (kg/ha)	WUE (kg/m3)	Irrigation productivity	Soil physiochemical Properties								
							pH	EC (ds/m)	CEC	OM (%)	TN (%)	Av. P (ppm)	Fe (ppm)	FC (%)	PWP (%)
R&W	80	4529 a[1]	6622 a	1110 a[1]	0.1 a[1]	0.2 a	5.7 a[1]	0.1 a[1]	36.4 a[1]	5.1 a[1]	0.2 a[1]	2.3 a[1]	8.0 a[1]	31.6 a[1]	17.8 a[1]
Pulley	100	3327 a	4962 b	1598 a	0.3 a	0.5 b	5.7 a	0.1 a	35.1 a	5.0 a	0.2 a	2.4 a	9.2a	34.6 a	19.38 a
p-value		0.1	0.03	0.3	0.06	0.02	0.7	0.9	0.6	0.8	0.8	0.9	0.1	0.3	0.4

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[1] Means that share a letter down the column are not significantly different at a significance level of 5%.

4.5.1 Irrigation water applied and crop water use

The average irrigation water applied using the R&W was 4529 m^3/ha whereas 3327 m^3/ha were applied using pulley (Table 4.5). Although the amount of water applied using R&W was higher than that of pulleys, both average irrigation amounts were not significantly different ($p = 0.105$). The average ETc for the Napier grass plots irrigated with R&W, 6622 m^3/ha, was significantly higher than that of the pulley plots, 4962 m^3/ha (p-value = 0.03).

4.5.1.1 How much of the crop water demand was actually applied Using the two technologies

The study period was also the driest period of the year, thus several farmers faced water shortages as their wells' yields were significantly low. The water shortages led to most farmers not being able to meet the crop water demand (CWD) of the Napier grass plots, considering that the water from these wells also had other uses like domestic use, feeding livestock and irrigation of other crops especially Kchat. Even though the farmers were always advised on how much water to apply depending of the measured soil moisture, there were sometimes when the water in the wells was not enough for the farmers to irrigate adequately. The rope and washer users seemed to fair better than the pulley users; two R&W farmers (RW2 and RW5 with plots areas 50 and 70 m^2 respectively) even applied more water than was required (Figs. 4.7 and 4.8). The average ratio of total water applied to the crop water demand was 88% for R&W users and 57% for pulley users (Table 4.9). The reason for the R&W farmers faring better than pulley farmers was because the R&W farmers generally allocated smaller experimental plots (80 m^2 on average) to Napier grass irrigation compared to the average 100 m^2 that the pulley farmers allocated.

While using manual lifting technologies, both energy and time are required in order to meet the crop water demand. Thus, the effort each technology requires and the water availability (as seen above) would determine whether farmers are able to irrigate adequately. When the amount of water of water actually applied was compared to the crop water demand for the two lifting technologies for the same plot area irrigated (Table 4.10), it was found that the pulley farmers performed better at meeting the crop water demand than the rope and washer farmers. For the two farmers that irrigated 60 m^2 of Napier grass; one for each technology, the pulley farmers was able to apply 78% of the crop water demand while the rope and washer farmers applied 74% of the crop water demand. As the area of land increased to 100 m^2, the ability for both the pulley and rope and washer farmers to meet the crop water demand decreased. On average, pulley farmers that irrigated 100 m^2 were able to apply 52% of the crop water demand, while the rope and washer farmers applied 51% of the crop water demand. On average, pulley farmers performed better than rope and washer farmers.

This results suggests that even though water may be readily available, the manual water lifting technologies would limit farmers on how much area they can irrigate because of the effort farmers have to put in to pump or lift water and the time it requires to irrigate. The pulley users liked the technology whereas rope and washer users reported a number of issues with the technology including high investment cost, a lot of effort required to pump water, low flow rate from the pumps, and frequent maintenance and operational issues like the rope breaking.

Table 4.9 Percentage of total applied water to CWD.

Water lifting technology									
R&W					Pulley				
Plot code	Plot area (m2)	Total Crop Water Demand (m3)	Total amount of water applied (m3)	Percentage of total applied water to CWD (%)	Plot code	Plot area (m2)	Total Crop Water Demand (m3)	Total amount of water applied (m3)	Percentage of total applied water to CWD (%)
RW1	100	59	38	66	P1	60	51	40	78

RW2	50	23	38	161	P2	100	98	41	42
RW3	100	86	21	25	P3	100	38	40	104
RW4	60	43	32	72	P4	100	73	32	44
RW5	70	29	35	119	P5	100	87	35	40
RW6	100	39	34	87	P6	140	119	43	36
					P7	100	55	35	64
					P8	100	63	38	59
					P9	100	91	42	47
Average	**80**	**47**	**33**	**88**	**Average**	**100**	**75**	**38**	**57**
Standard deviation	**22.80**	**22.99**	**6.32**	**46.90**	**Standard deviation**	**20.00**	**25.88**	**3.71**	**22.16**

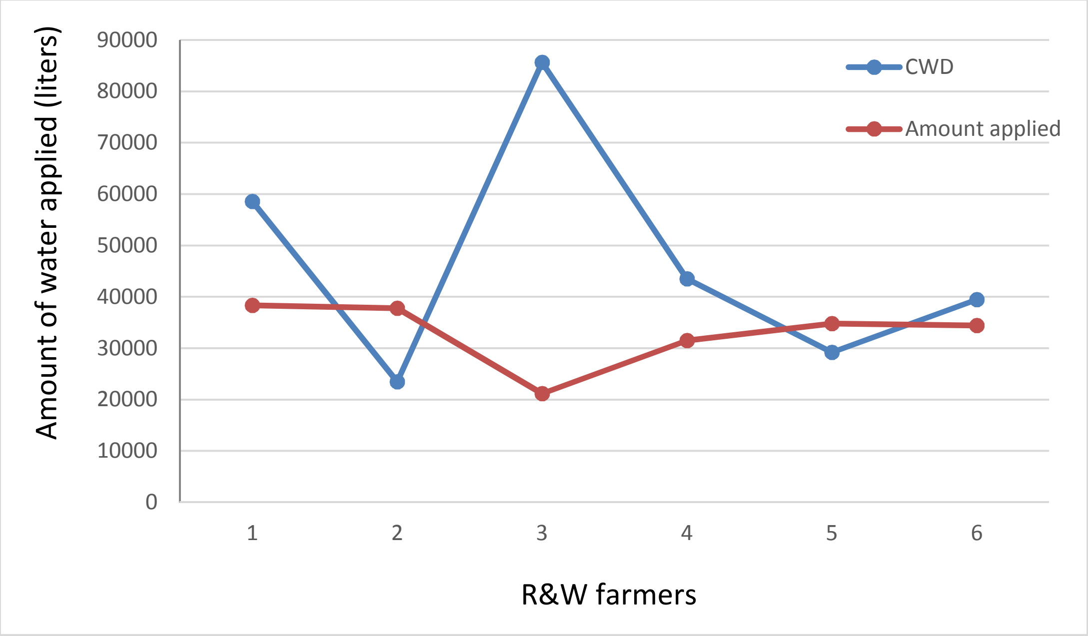


Fig 4.7 Percentage of total applied water to CWD for Rope and washer users

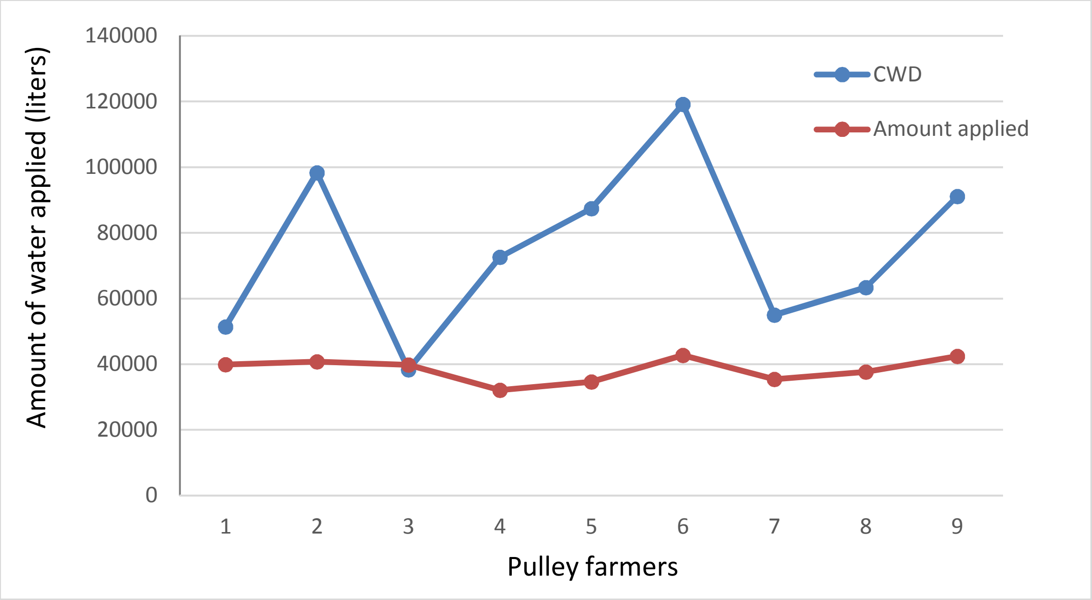


Fig 4.8 Percentage of total applied water to CWD for pulley users

Table 4.10 Percentage of total applied water to CWD for the same plot area irrigated

	Rope and washer users			Pulley users		
Plot area (m^2)	Total Crop Water Demand (m^3)	Total amount of water applied (m^3)	Percentage of total applied water to CWD (%)	Total Crop Water Demand (m^3)	Total amount of water applied (m^3)	Percentage of total applied water to CWD (%)
60	43	32	74	51	40	78
100	61	31	51	72	38	52

4.5.2 Dry matter yield

Pulley plots yielded more than rope and washer plots. The average dry matter yield for rope and washer farmers was 1110 kg/ha whereas for the pulley, the average dry matter yield was 1598 kg/ha. Statistically, there was no significant difference in yield between plots irrigated with rope and washer and those irrigated with pulleys (*p*-value = 0.391). As indicated in the remarks in table 4.5, the study faced a challenge of keeping livestock away from the experimental plots. Several farmers had challenges in fencing the plots adequately. Consequently, livestock got into the plots and grazed on the grass a number of times before harvest. 2 out of the 9 pulley plots were fed on by livestock a number of times during the growing season, whereas, 5 out of the 6 R&W plots were affected. Thus, the yield values in those plots do not represent the actual yield of those plots, and this affects the comparison of productivity for the two lifting technologies.

For both the plots irrigated with R&W and those irrigated with pulley, dry matter yield increased with increase in the amount of water applied (Fig. 4.9).

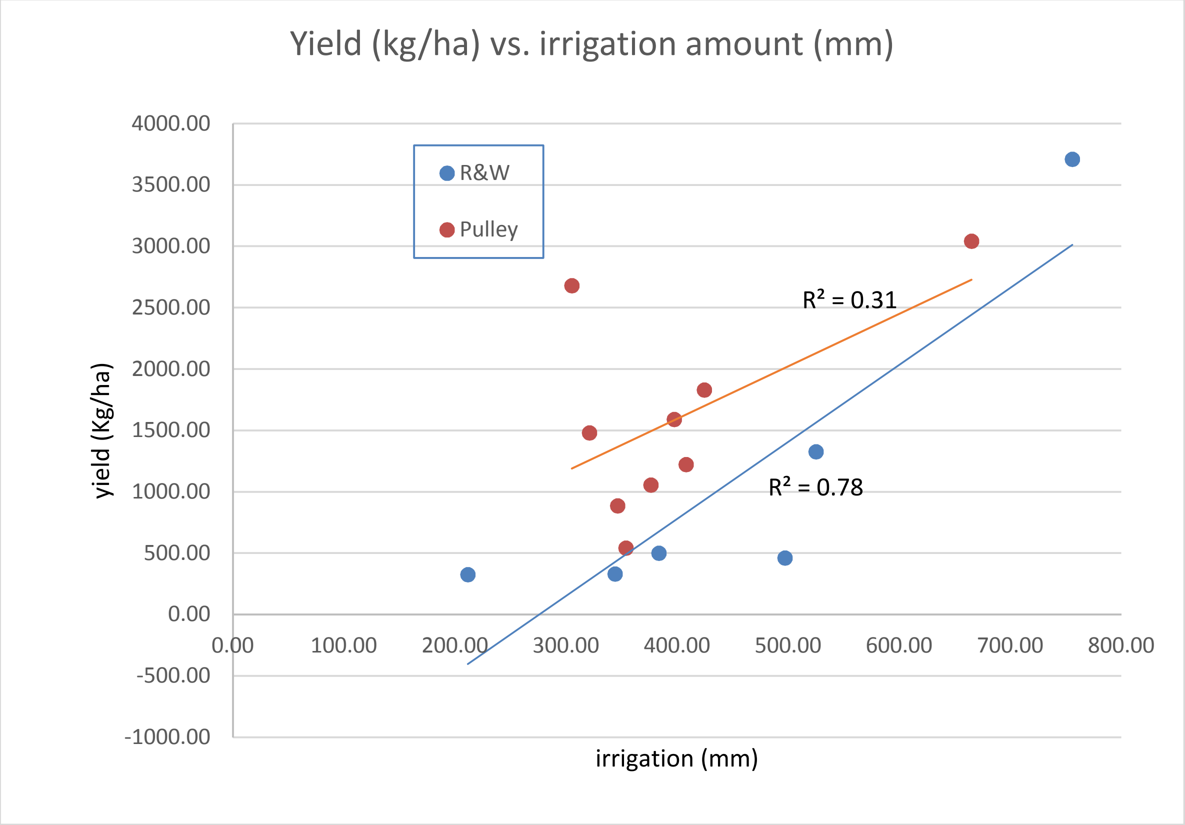


Fig 4.9 Relation of amount of water applied to yield.

4.5.3 Yield characteristics

4.5.3.1 Plant height

For both technologies, the plant height throughout the days of the growing season was almost the same i.e. did not show significant differences (Fig. 4.10). Appendix B shows the plant height values are averaged for each plot for intervals after the days of planting (30th, 60th and 120th).

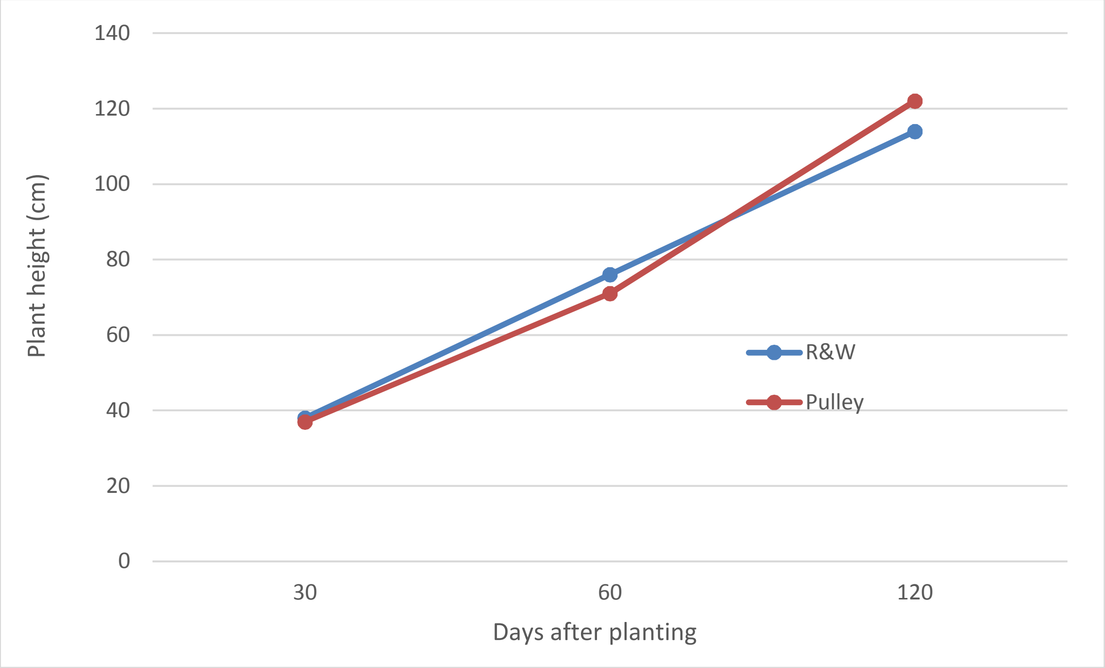


Fig. 4.10 Plant height in days after planting

4.5.3.2 Leaf area

The average leaf area increases with increase in the days after plantation. The leaf area is calculated by multiplying leaf length by the width and the total leaf area for a plant is calculated by multiply leaf area by the number of leaves. For both technologies, the leaf area increased with time, although for rope and washer users the leaf area increase was more after the 60th day since the crop was grazed in the first 30 days and had to re-grow. For the pulley users, the area increased more uniformly in the whole season (Fig 4.11).

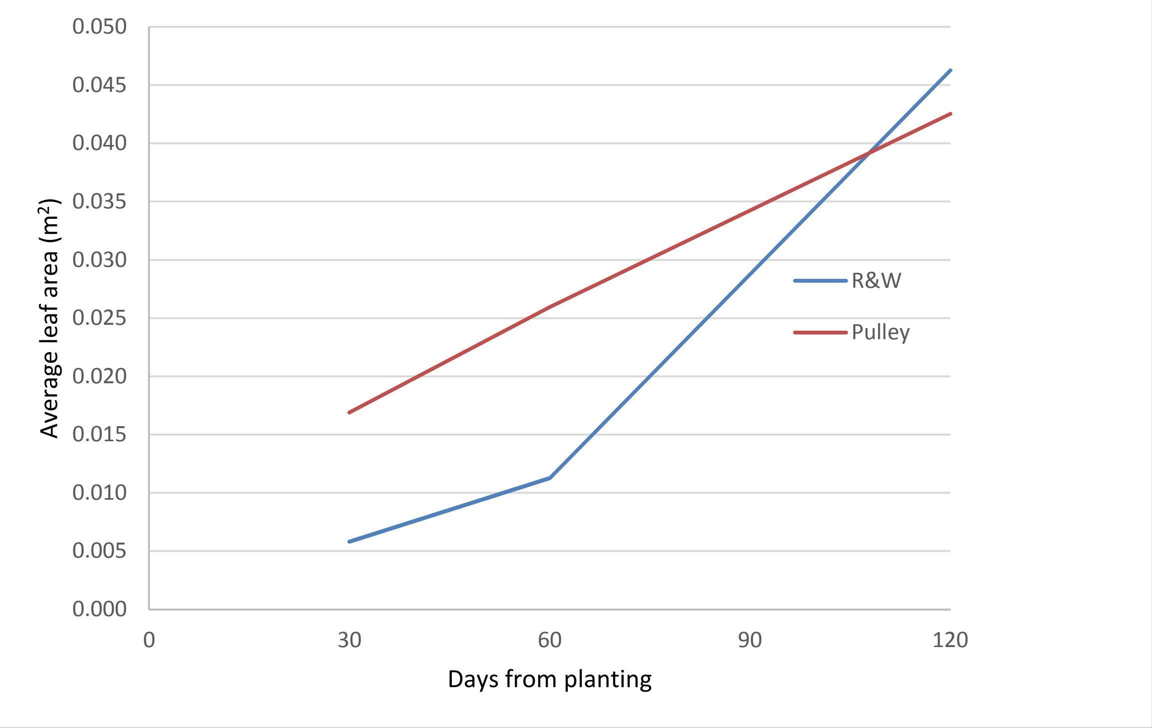


Fig 4.11 Leaf area index

4.5.4 Water use efficiency

The water use efficiency was calculated as the ratio of dry matter yield to crop evapotranspiration which are both highly dependent on the management of the crop. The well managed crops will have a higher water use efficiency. Plots watered by pulley technology had a higher average water use efficiency of 0.351 kg/m^3 and plots watered using rope and washer had an average water use efficiency of 0.152 kg/m^3. Statistically, there was no significant in water use efficiency among the two technologies (*p*-value = 0.067). As mentioned earlier, livestock grazed in several plots during the study period that the reported yield results for some of the plots were not the actual. This also affected the calculated values of the water use efficiencies.

For the pulley users, water use efficiency decreased with increasing amount of water applied (Fig. 4.12). The opposite happened for rope and washer farmers. If water losses are limited, it is expected that increasing the amount of water applied would increase biomass production and thus dry matter yields. The water use efficiency would thus increase with increasing amount of water applied.

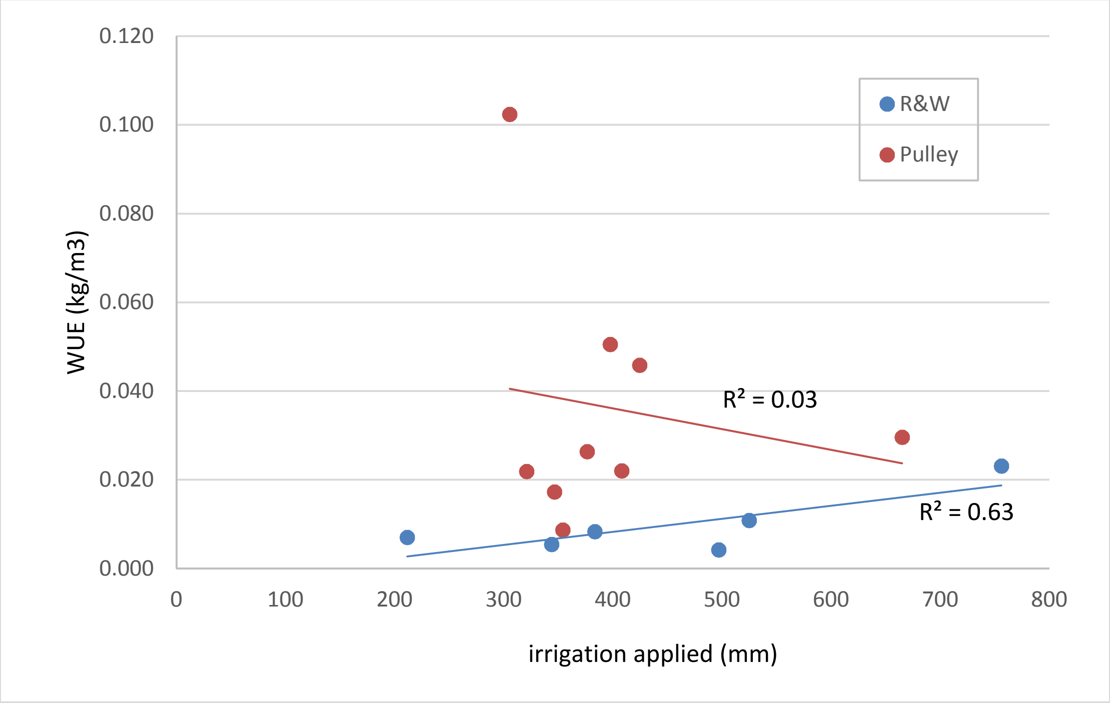


Fig 4.12 Relation of amount of water applied to Water use efficiency.

4.5.5 Irrigation productivity

The irrigation productivity was calculated at a ratio of dry matter yield to the total irrigation water applied. The pulley users had higher average irrigation productivity (0.511 kg/m^3) than the rope and washer users (0.203 kg/m^3). The difference in irrigation productivity for the two technologies has a significant difference (*p*-value = 0.028). Since also irrigation productivity is as result of yield, these results are also affected by yield discrepancies caused due to livestock feeding on the grass during the experimental period.

Figure 4.13 shows the variation of irrigation productivity with the amount of irrigation water applied for the two technologies. Irrigation productivity increased with increase in amount of water applied for rope and washer plots as expected, whereas, for pulley plots, irrigation productivity decreased slightly with increase in the amount of irrigation applied.

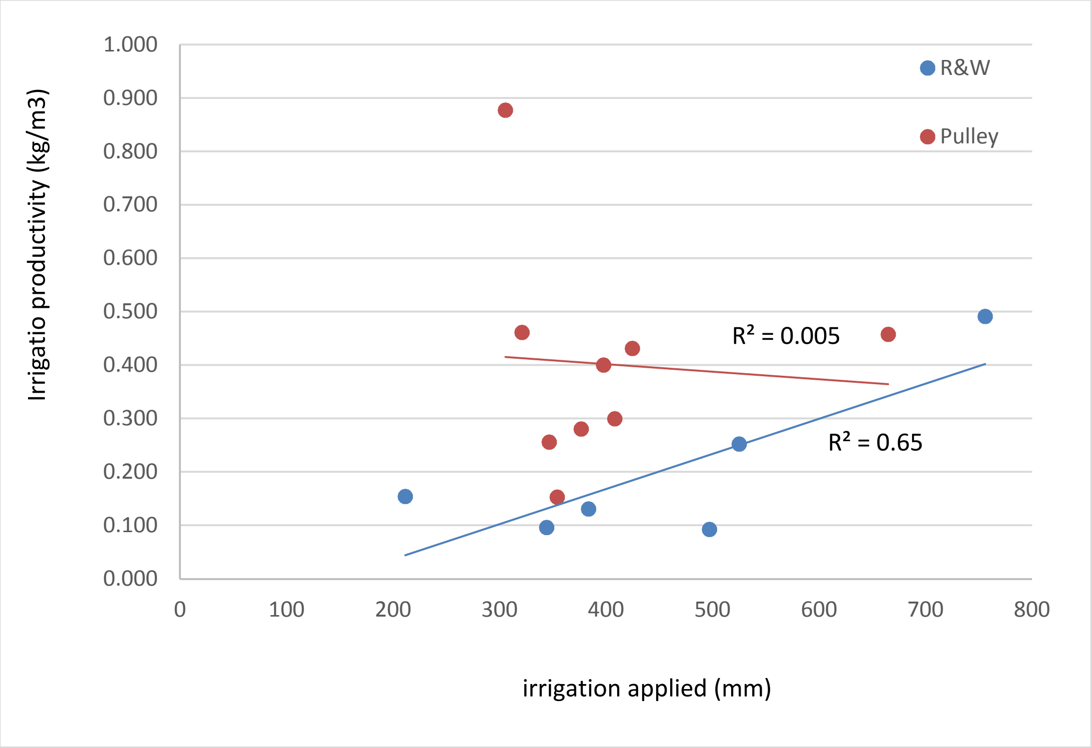


Fig 4.13 Relation of amount of water applied to irrigation productivity

4.5.6 Operation of the technologies

As mentioned earlier, the ability for users of manual water lifting technologies to meet the crop water demand of the crop they are irrigating does not only depend on water availability, but also the ease of use of the technology. Also, technology breakdowns affect irrigation activities. Farmers in Robit kebele preferred the pulley/tank/hose system to the rope and washer pumps. The reasons given include: high investment cost, a lot of effort required to pump water, low flow rate from the pumps, and frequent maintenance and operational issues like the rope breaking. Table 4.11 shows the failure history of both technologies for all the farmers. The farmers reported each time they had issues with the technology. Maintenance or repair measures that were taken are also reported.

Table 4.11 Record of failure of technologies

plot code	Technology	Detail of failure and taken measures
RW1	R&W	no issues
RW2		no issues
RW3		wheel hard to rotate; improved by cleaning the joints and applying oil
RW4		no issues
RW5		the rope was broken and was replaced
RW6		wheel hard to rotate; improved by cleaning the joints and applying oil
		wheel hard to rotate; improved by cleaning the joints and applying oil
P1	Pulley	no issues
P2		no issues
P3		no issues
P4		no issues
P5		no issues
P6		no issues
P7		no issues
P8		no issues

P9		no issues

4.6 Traditional irrigation methods vs. improved ones

The two control farmers that accepted to grow and irrigate Napier grass used buckets to apply water. One of them (C1) has a well near the plot like the other farmers in the experiment and used a circular shaped wood that served as pulley to lift the water and store in a tank. The other farmer (C2) does not have a well but a pond very close to the plot. He lifts water from the pond using a bucket which he also uses to apply water to his fields. Also they used their own experience to schedule for irrigations. Both control farmers managed 100 m^2 plot of Napier grass. On average, the control farmers applied less water than both the pulley and rope and washer users; 2004 m^3/ha compared to 3120 and 3206 m^3/ha applied on average by the rope and washer and pulley users respectively who managed the same plot areas. On average also, the control farmers had better yield than both the rope and washer users and the pulley users (Table 4.12), altogether giving better irrigation productivity for the control farmers than the farmers with the two lifting technologies. Again, yield values especially for the rope and washer farmers and two pulley farmers do not show the actual yield from the plots which limits drawing conclusions from these results. The grass in the control farmers' plots was also eaten by livestock on a number of occasions due to poor fencing.

Table 4.12: Comparisons of control farmers with farmers that received technologies

	Rope and washer users			Pulley users			Control		
Plot area (m2)	Amount of water applied	Dry matter yield	Irrigation productivity (kg/m3)	Amount of water applied	Dry matter yield	Irrigation productivity (kg/m3)	Amount of water applied	Dry matter yield	Irrigation productivity (kg/m3)

	(m^3/ha)	(kg/ha)		(m3/ha)	(kg/ha)		(m3/ha)	(kg/ha)	
100	3130	388	0.128	3206	1237	0.433	2004	1360	0.679

5 Limitations of the study

The coefficients obtained from this study varied from field to field, due to differences in crop management among the various farmers, and were also constrained by water shortages faced by several of the farmers in the experiment. The amount of water applied by most farmers was less than the crop water demand and hence this causes limitations in developing accurate coefficients as the crop must be in a good management and should not be subjected to water stress. In some plots, the Napier grass was eaten by livestock a number of times during the growing season, so the continuity of the growing stage as well as the actual evapotranspiration was interrupted, and thus the crop coefficient should be used with limitations. The developed crop coefficients though can be used as basis for further studies in the area.

The results presented in this study represent only one irrigation season and one cutting for Napier grass. Effects of season to season variability and year to year variability are not represented in the results of this study. Thus, these results should be a starting point for the next study which should try to overcome the various limitations mentioned here in order to obtain better results.

6 CONCLUSIONS

The crop coefficients developed for the development stages are: 0.821 at the initial stage and the average length of this stage is 28 days, at mid stage 1.351 and the average number of days increased to 35 days, and finally for maturity stage, Kc is 1.453 for an average duration of 42 days. The water demand for Napier grass was found to be 562 mm on average. In comparing the technologies, the results show that the pulley technology had a better performance, giving the higher average yield of 1598 kg/ha while the rope and washer gave 1110 kg/ha. The pulley also had higher average water use efficiency of 0.351 kg/m^3 whereas the rope and washer had 0.152 kg/m^3. For irrigation productivity, pulley had 0.511 kg/m^3 compared to 0.203 kg/m^3 for the rope and washer. The pulley has a better potential for irrigation of Napier grass and even a better discharge; it can discharge 3.46 l/s on average while the rope and washer's average discharges was 2.07 l/s. In addition, the pulley did not fail during the growing season whereas four rope and washers experienced problems with the technology including the wheel being hard to rotate and the rope breaking.

Farmers who used improved lifting technologies and whose soil moisture was monitored throughout the growing season, applied more adequate water (closer to meeting the crop water demand) compared to the traditional ones although during the growing season all farmers faced shortages of water. On average, the control farmers had better yield than both the rope and washer users and the pulley users and giving better irrigation productivity for the control farmers than the farmers with the two lifting technologies. But yield values especially for the rope and washer farmers and two pulley farmers do not show the actual yield from the plots which limits drawing conclusions from these results.

One of the constraints of the study was farmers' low interest on the R&W technology because of the bad back history of the technology in the area. In the area, there were some farmers using this technology before and because of the poor quality of the pumps, breaks down were frequent. Farmer were trained on maintenance and repair, hence when the technology got problems, it was just abandoned. In this study, although some technologies had a few issues, farmers were trained on use and maintenance so they would handle some of the maintenance issues. Also, a trained technician was readily available to handle issues that the farmers wouldn’t handle.

7 RECOMMENDATIONS

At the end of this study the farmers in Robit kebele were very happy with what they experienced and would like to continue planting the fodder because livestock feed source is becoming scarce each year, land for grazing is limited and industrial byproducts become expensive as demand for them rises. Irrigated fodder comes in handy in solving the feed shortage issues of this site. The grass grows fast in any weather condition and in countries with high population of livestock like Ethiopia, irrigated Napier grass would be a good option of livestock feed. In my experience in the area, with the farmers using different water lifting technologies, they can easily identify the better technology themselves but only after they have experienced using these technologies. Once the technology meets their needs, they are highly motivated to adopt a better technology especially in the dry season as the only water source is the well. Thus, to ensure good technology adoption in the kebele, different types of technologies should be tested like this study tried to do, such that farmers can make an informed decision of which technology better suits the conditions of their site.

References

Alemayehu Mengistu, 2003, Country Pasture/Forage Resource Profiles, information product, Ethiopia.

Bahirdar Zuria, Woreda office of Agriculture, 2013 Yearly report.

Belay Duguma, Azage Tegegne and B.P. Hegde, 2012, Smallholder Livestock Production System in Dandi District, Oromia Regional State, Central Ethiopia, IDOSI Publications.

Currie David, 1991, Energy and large-scale patterns of animal and plants, The University of Chicago Press for The American Society of Naturalists Vol. 137, No. 1.

Duncan A., Teufel N., Ravichandran T., Hendrickx S. and Ballantyne P, 2015, Innovation platforms to improve smallholder dairying at scale: Experiences from the Milk IT project in India and Tanzania. ILRI project report. Nairobi, Kenya: ILRI.

Daniel k. fisher, H. c. Pringle iii, 2013, Evaluation of alternative methods for estimating reference evapotranspiration, Vol.4, No.8A, 51-60, USA.

David Molden, Bharat Sharma and Simon Cook, 2013, Water use efficiency in agriculture: Measurement, current situation and trends, Managing water and fertilizer for sustainable agricultural intensification, publications@fertilizer.org.

Delta-T Devices Ltd, 2008, User Manual for the Profile Probe, User Manual Version: PR2-UM-3.0.

Gebrehaweria Gebregziabher (IWMI), 2011, Case study water lifting irrigation technology adoption in Ethiopia: challenges and opportunities, Ethiopia, 2012.

Getachew Terefe, Gizat Almaw and Daniel Getachew, 1993, Occurrence and fertility rates of hydrated cysts in sheep and goats, Vol. 16 (1), 83-91, Ethiopia.

ILRI, 2012, Fodder and feed in livestock value chains in Ethiopia, trends and prospects, project report, Ethiopia.

Intizar Hussain and Munir A. Hanjra, 2004, Irrigation and poverty alleviation: review of the empirical evidence, Published online in Wiley Inter Science (www.interscience.wiley.com), Irrig. and Drain. 53: 1–15.

Jianbiao Lu, Ge Sun, Steven G. McNulty, and Devendra M. Amatya, 2005, a comparison of six potential evapotranspiration methods for regional use in the southeastern United States, Journal of the American water resources association.

Magayane Machibya, Makarius Mdemu and Bruce lankford, 2004, Tools for irrigation professionals and PR actioners, Draft irrigation efficiency and productivity manual, Department for international development.

Mengistu Seyoum, Eskedar Tariku and Dagne Tussa, 2001, Study of smallholder farms livestock feed, 16th_Proceeding Technical paper.

Michel Jensen, 1968, Determination of growth-stage-specific crop coefficients, the journal vol. 23, issue 2.

Morgan Jean, Van Hemert, Lammerink, Arlosoroff, Reynolds, Fonseka & Baumann, 1990, Linking technology choice with operation and maintenance, technical brief on water-lifting devices.

Narayan Gopal Sadak and Maharajgunj, 2010, Practical Action technology challenging poverty, technical brief, Nepal.

Paola Lazzara, Gianfranco Rana, 2010. The crop coefficient (*K*c values of the major crops grown) a case study under Mediterranean climate.

Richard G. Allen, Luis S. Pereira, Dirk Rees, Martin smith, 2006, Crop Evapotranspiration, guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper No. 56.

Seleshi Bekele Awulachew and Douglas J. Merrey, 2011. Assessment of small scale irrigation and water harvesting in Ethiopian agricultural development. International Water Management Institute.

Seleshi Bekele Awulachew, 2010. Irrigation potential in Ethiopia constraints and opportunities for enhancing the system. International Water Management Institute.

Simeon Ehui, Samuel Benin and Zelekawork Paulos, 2002, Policy options for improving market participation and sales of smallholder livestock producers: A case study of Ethiopia, Contemporary Development issues in Ethiopia, Addis Ababa, Ethiopia.

S. Orloff, 2001. A simple method to improve alfalfa and pasture irrigation management. Publication of University of California, Davis.

Thomas w. ley, Robert g. Stevens, Richard r. Topielec and w. Howard Neibling, 1994, soil water monitoring and measurement, a pacific northwest publication, Washington ,Oregon ,Idaho.

W. Loiskandl, D. Ruffeis, M. Schönerklee, R. Spendlingwimmer, S. B. Awulachew and E. Boelee, 2011, Case study review of investigated irrigation projects in Ethiopia, International Water Management Institute IWMI, Addis Ababa, Ethiopia.

Yami Alemu, Bogale Solomon and Melaku Solomon, 1991, Potential use of crop residues as livestock feed resources under smallholder farmer's conditions in bale highlands of Ethiopia, Tropical and Subtropical Agro ecosystems.

Appendix A: Metrological data of the dry season and ETo.

Year	month	date	Tmax, oC	Tmin, oC	sunshine (hour)	Humidity, %	Wind speed, m/s	Rainfall (mm)	ETo (mm)
2015	*MAR*	1	31.9	16.6	10	28	0.86	0	4.014
		2	32.5	16.8	9.8	44	0.78	5	4.025
		3	28.9	17.9	10.2	35	0.78	0	3.926
		4	27.1	15.5	10.5	29	0.91	4.3	3.882
		5	29.5	15.5	10	30	1.05	26.6	4.091
		6	29.8	14.7	10	37	0.92	6.7	3.962
		7	30.7	15.6	9	44	1	0	3.938
		8	29.8	18.7	9.2	35	0.99	0	4.036
		9	31.9	15.1	10.7	23	0.97	0	4.250
		10	29.5	18.3	10.9	27	0.81	20.2	4.057
		11	27.9	15.2	10.3	35	0.82	41.2	3.913
		12	26.5	14.6	10.4	20	0.86	0	3.741
		13	28.6	17.2	9.9	30	0.91	0	3.986
		14	27.7	13.1	10.5	28	0.96	0	4.011
		15	29.6	12.5	10.1	30	1.03	0	4.107
		16	31	12.2	10.6	29	1	3.3	4.198

		17	31.8	16.7	2.7	40	1.11	7.5	3.308
		18	30.1	17.7	7	35	1.65	2.2	4.495
		19	31.5	17.4	7	51	1.54	1.3	4.222
		20	31.2	15	9.6	50	1.03	0.2	4.217
		21	31.7	15.2	10.7	50	1.03	0	4.421
		22	31.9	15.1	10.8	48	1.46	0	4.764
		23	32.6	18	10.6	48	1.05	0	4.595
		24	32.2	15.9	10.7	43	0.98	0	4.550
		25	31.4	13.6	10.9	38	0.8	0	4.280
		26	31.4	13.5	10.9	35	1.07	0	4.531
		27	32.3	13.5	10.8	38	1.28	0	4.791
		28	33.3	12.6	8.9	37	1.22	0	4.584
		29	30.9	12.1	10.2	39	1.16	0	4.505
		30	31.4	11.9	10	44	0.99	0	4.303
		31	33.4	11.2	10	51	0.73	0	4.209
	APR	1	31.5	14	10	50	0.89	0	4.294
		2	31.6	14	10.4	42	1.13	0	4.573
		3	32	17.2	10.5	32	0.94	0	4.557
		4	32.5	14	9.3	27	0.83	0	4.273
		5	31	14.4	9.1	40	0.97	0	4.254

		6	31.5	17.6	7.6	45	1.06	0	4.169
		7	32	16.8	8.9	45	1.21	0	4.587
		8	31.5	16.5	10.4	40	0.85	0	4.556
		9	31	12.5	10.6	29	0.77	0	4.345
		10	30.5	13	10.4	32	0.9	0	4.425
		11	31	12.2	10.4	33	1.1	0	4.642
		12	32	14.5	9.5	30	1.1	0	4.650
		13	30.5	15	8.9	35	1.14	0	4.495
		14	31	17.5	7.6	38	1.09	0	4.370
		15	30	14	10.7	36	1.16	0	4.825
		16	31.5	12	10.8	34	1.03	0	4.751
		17	31.5	12.8	10	35	1.06	0	4.649
		18	32	16	10.7	35	1.16	0	5.027
		19	31	13.4	10.6	38	1.13	0	4.864
		20	31.5	14.8	10.8	36	1.08	0	4.905
		21	31	15.2	11	31	1.09	0	4.956
		22	31.6	14.8	8.7	36	1.16	0	4.694
		23	32	14.5	11.2	35	0.92	0	4.907
		24	31.5	14.5	11.2	32	1.03	0	4.983
		25	32	15.2	9.5	30	0.97	0	4.689

		26	32.5	16.5	9.1	35	1.08	0	4.835
		27	30	17.2	10.4	29	0.96	0	4.809
		28	32	14.5	9.9	32	0.96	0	4.804
		29	32	13.8	9.4	29	0.89	0	4.622
		30	31.5	15.2	10.1	34	0.92	0	4.783
	MAY	1	32	15	9.7	35	1.14	0	4.957
		2	31.5	18.5	10.3	41	1.17	0	5.131
		3	32.5	18.5	4.7	57	1.26	TR	4.034
		4	29.5	18	5.6	59	1.12	4.5	3.953
		5	29	17.2	6.3	59	1.25	30.6	4.140
		6	26.5	14	9.7	65	1.01	1.3	4.354
		7	27	16.4	5.6	64	0.88	13.9	3.558
		8	27.5	15.2	7.9	62	1.1	2.1	4.142
		9	28.4	16.6	7.6	68	0.74	0	3.994
		10	28.6	17	0	73	0.42	7.5	2.178
		11	28.5	15.5	5.6	64	0.94	0	3.668
		12	29.5	18.2	8.2	62	0.66	1.2	4.282
		13	30	15.2	9.7	64	1.08	0	4.740
		14	29.5	16.7	11.3	55	0.79	0	4.955
		15	31.6	17.8	10.8	52	0.94	0	5.156

		16	31.4	17.8	9	49	0.97	0	4.850
		17	31.5	16	8	55	0.9	0	4.527
		18	30.6	15.5	10.2	49	1.32	0	5.196
		19	31.6	16.5	8.8	53	0.89	0	4.689
		20	31.5	17	7.8	53	0.84	1.4	4.490
		21	32	14.5	9.9	51	1.13	14.9	5.114
		22	32.5	13.5	7.6	68	0.99	1.8	4.405
		23	28.5	13.6	11	61	1.03	0.2	4.921
		24	28.5	15.5	9.3	63	1.03	0	4.552
		25	29	18.7	10.5	52	1.22	7.6	5.173
		26	31.5	16.5	9.3	65	1.03	12.1	4.858
		27	31.6	16	10.7	74	1.06	4.4	5.126
		28	30.5	16.2	5.7	76	1.04	7.2	3.844
		29	27.6	17.2	6.1	66	0.84	3.8	3.874
		30	28	15.5	11.6	66	0.76	0	5.009
		31	29.2	15	11.2	61	1.17	22.3	5.143
	JUN	1	30	14.5	6.3	75	0.8	0.2	3.823
		2	30.8	16.4	9.9	65	0.98	0	4.931
		3	29	17.4	9.1	62	0.84	0	4.671
		4	30	14.8	9	59	0.86	0	4.631

		5	29	16.4	6.9	54	0.58	2.3	4.011
		6	30.6	14.5	7.4	60	0.97	0	4.356
		7	31.2	14	10	60	0.98	0.5	4.982
		8	28	14.5	7.2	63	0.87	0	4.068
		9	29.5	16.7	8.2	63	1.16	0	4.536
		10	30	18	8.7	57	1.07	0	4.811
		11	29.5	16	8.6	57	1.04	0	4.692
		12	28.5	16.2	6.3	60	1.03	0	4.075
		13	29	16.8	4.6	61	1.23	1.8	3.832
		14	29	16.2	8.1	70	1.01	33.7	4.425
		15	28	14.5	5.7	67	0.95	1.1	3.756
		16	28	17	6.4	73	0.71	0	3.837
		17	28.5	17.2	2.6	72	0.69	1.6	3.002
		18	28	17	6	74	1.03	11.9	3.866
		19	28.4	14.8	6.7	74	0.71	1.3	3.898
		20	27.6	15.5	4.8	72	0.87	4.7	3.485
		21	28	15	2.7	75	0.91	44.2	2.999
		22	27	14.4	0.4	80	0.45	0.4	2.273
		23	25	15	3.5	79	0.56	6.8	2.922
		24	26.5	16.5	10	69	0.91	0	4.629

		25	27	14.5	10.1	69	1.14	1	4.661
		26	27.5	15.2	6.5	70	0.73	0.2	3.795
		27	27.6	16.5	4.4	82	0.4	6.4	3.241
		28	27.5	16.6	6.5	75	0.85	0	3.871
		29	27	15.8	10.2	67	0.87	0	4.678
		30	28	16.2	8	67	0.85	3.7	4.694

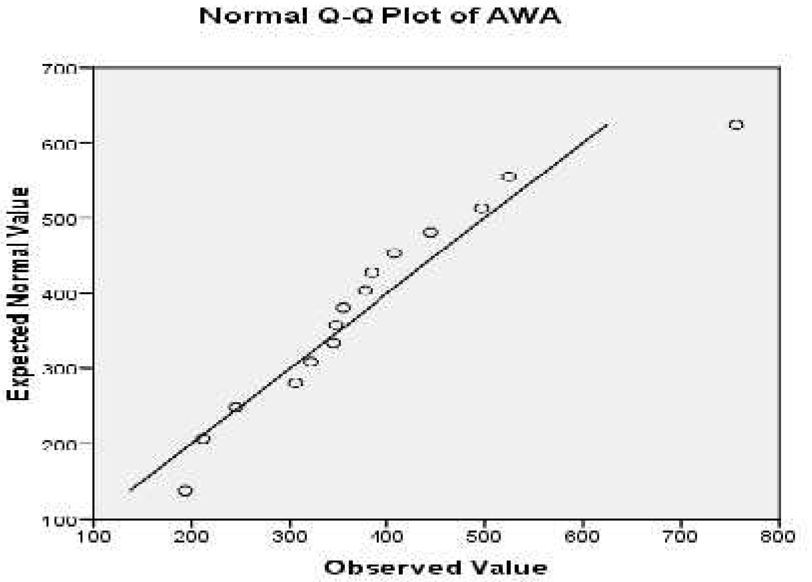
Appendix B: Average crop height in days after planting for both technologies

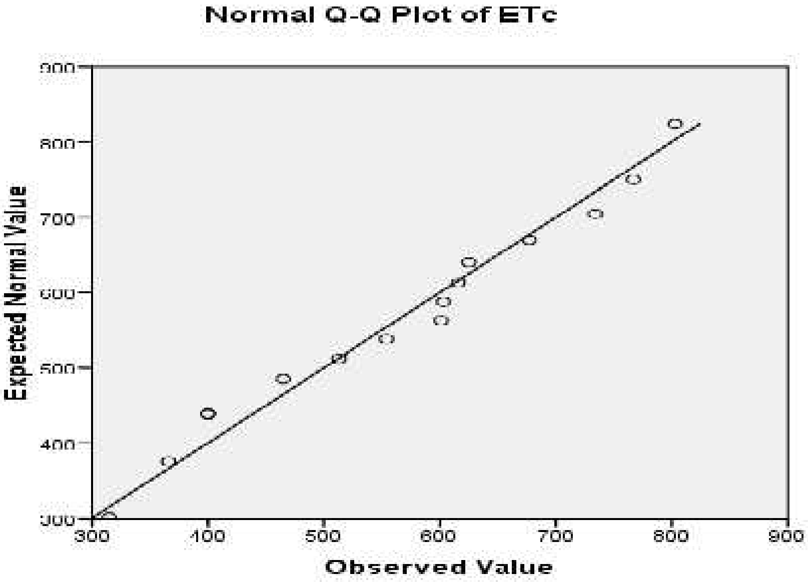
Plot code	**Technology**	**Average crop height (cm)**		
		Days from planting		
		30	**60**	**120**
RW1	R&W	49	85	110
RW2		54	93	130
RW3		29	77	118
RW4		28	80	110
RW5		34	50	108
RW6		31	72	105
Average		**38**	**76**	**114**
Standard deviation		**11**	**15**	**9**
P1	Pulley	38	83	132
P2		39	85	105
P3		40	85	160
P4		25	48	122
P5		46	68	112
P6		28	62	107
P7		30	50	103
P8		44	76	123
P9		46	79	130
Average		**37**	**71**	**122**
Standard deviation		**8**	**15**	**18**

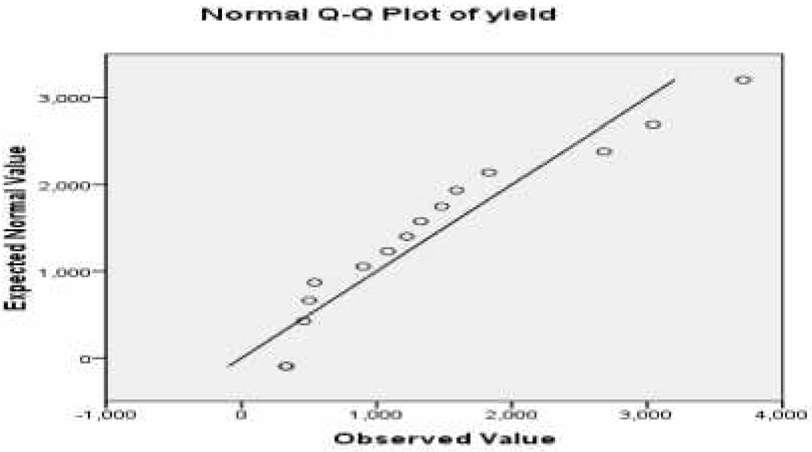
Appendix C: Average Napier grass leaf area

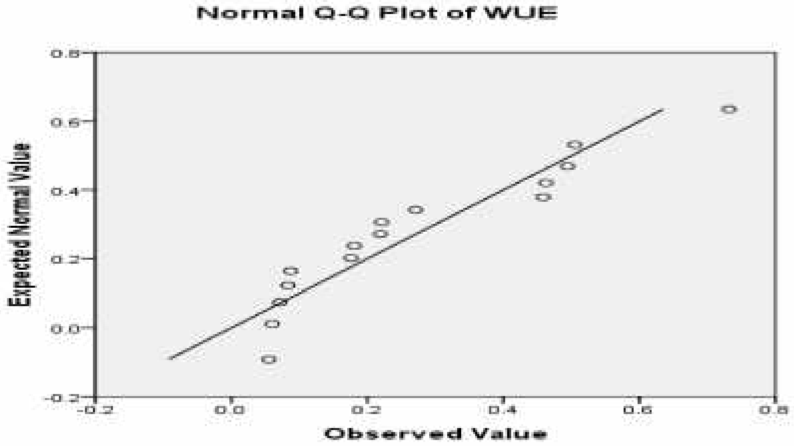
Plot code	**Technology**	**Average leaf area**		
		Days from planting		
		30	**60**	**120**
RW1	R&W	0.003	0.003	0.016
RW2		0.004	0.011	0.086
RW3		0.005	0.013	0.037
RW4		0.006	0.017	0.079
RW5		0.001	0.003	0.029
RW6		0.016	0.022	0.031
Average		**0.006**	**0.011**	**0.046**
Standard deviation		**0.005**	**0.008**	**0.029**
P1	Pulley	0.025	0.046	0.069
P2		0.01	0.013	0.039
P3		0.031	0.047	0.045
P4		0.002	0.003	0.035
P5		0.002	0.003	0.025
P6		0.057	0.07	0.049
P7		0.002	0.007	0.029
P8		0.008	0.024	0.041
P9		0.016	0.022	0.05
Average		**0.017**	**0.026**	**0.043**
Standard deviation		**0.018**	**0.023**	**0.013**

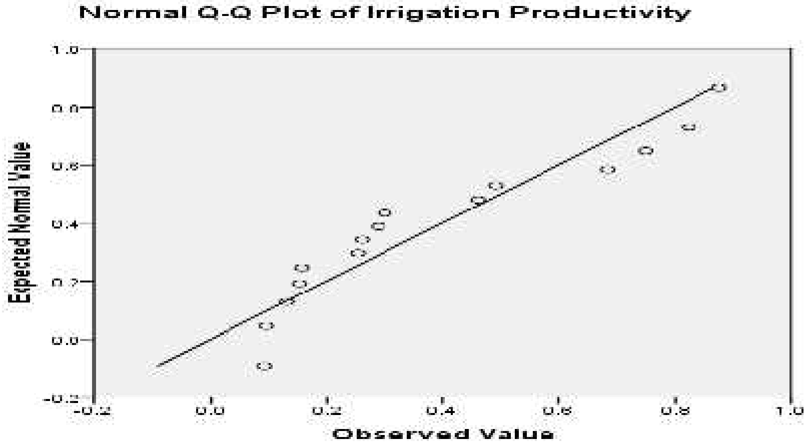
Appendix D: Normality test






Normal Q-Q Plot of yield
Expected Normal Value
3,000
2,000
1,000
0
-1,000
0
1,000
2,000
3,000
4,000
Observed Value


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


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